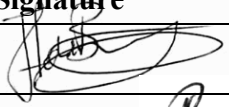
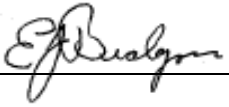


NGNP and Hydrogen Production Conceptual Design Study

NGNP CTF Test Loop Preconceptual Design Report

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NGNP-CTF MTECH-TLDR-004	0	Section 4: System Requirement Manual
NGNP-CTF MTECH-TLDR-005	0	Section 5: Small Scale Development Test (SSDT)
NGNP-CTF MTECH-TLDR-006	0	Section 6: Technology Development Loop (TDL)
NGNP-CTF MTECH-TLDR-007	0	Section 7: Component Qualification Loop 1 (CQL1)
NGNP-CTF MTECH-TLDR-008	0	Section 8: Component Qualification Loop 2 (CQL2)
NGNP-CTF MTECH-TLDR-009	0	Section 9: Circulator Test Loop (CTL)

**NGNP and Hydrogen Production
Conceptual Design Study
NGNP CTF Test Loop Preconceptual Design
Report**

Section 1: Introduction

APPROVALS

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1. INTRODUCTION

This document describes the overall NGNP Component Test Facility (CTF) Preconceptual Design (PCD) Package as per the BEA Statement of Work (SOW) in Reference [1-1]. The CTF PCD package consists of nine sections that will be briefly described in the next paragraphs.

1.1 Section 2: Strategies and Philosophies

This section of the report provides the overall strategies and philosophies that are applicable to the technology development systems (i.e. test loops) that are being presented for the Component Test Facility (CTF). The strategies are intended to aid the engineering process based on the NGNP Preconceptual design study together with the additional complementation work. These typically include the CTF Preconceptual design; conceptual design/special studies as well recently completed Technology Development Roadmaps (TDRM) and associated test plans. The section provides an overview of proposed strategies that need to be considered during the lifecycle phases of the CTF. These strategies have the intent to serve as guidelines in order to aid the appropriate process and are divided into the design and engineering, and the construction and commissioning strategies.

1.2 Section 3: Design Criteria Document (DCD)

The purpose of this section of the report is to identify and describe the design criteria, standards, performance measures, classifications, quality indices, and limits for the design of the Next Generation Nuclear Plant (NGNP) CTF Test Loops, and the Test Loops design requirements imposed on the Facility Design.

The CTF design criteria are primarily based on the requirements found in the INL Engineering Standards document, STD-139 (Reference [1-1]). The requirements and recommendations of this section were compiled to act as the criteria for both the preconceptual and follow on design phases and also contain the applicable additional codes and standards listed throughout STD-139.

1.3 Section 4: System Requirement Manual (SRM)

The Facility Design Description (FDD) section outlines the functions and requirements that the facility must fulfil based on interface requirements driven by the various test loops described in the following sections. The Facility Designer will be responsible to take these requirements as input and develop the overall detailed SRM containing functions and requirements for the facility as well as detailed overall FDD.

In an FDD, all the systems in a facility or building are addressed with respect to their top-level functions and requirements. The FDD also contains the design basis and design criteria information that is pertinent to interfaces with the design requirements for the Test Loop systems.

1.4 Section 5: Small Scale Development Tests (SSDT)

In this section the Small-Scale Development Tests (SSDTs) are described. The SSDTs are a collection of tests that do not require significant volume flow rates or large amounts of heat transfer. Most of the SSDTs have a common requirement for a high-temperature (950°C) high-pressure (9MPa) Helium environment. For the tests that require a high-temperature high-pressure Helium environment, a generic setup is proposed that comprises a low-temperature pressure vessel, internally insulated high-temperature test vessel, heater and small flow line water coolers. Specifically for the Intermediate Heat Exchanger (IHx) unit cell fatigue tests, a specialized system is designed that comprises heaters, coolers, a pressure vessel and hydraulic gas compression systems.

1.5 Section 6: Technology development loop (TDL)

The Technology Development Loop (TDL) is described in more detail in this section. The TDL is a high temperature high pressure helium test system. The TDL is capable of providing helium at a temperature of up to 950 °C, pressure of up to 9.6 MPa(g) and a mass flow rate of up to 3.65 kg/s. The objective of the TDL is to provide a system capable of supplying helium at the desired temperature, pressure and mass flow to components under test and to provide a means of measuring the performance of the component under test. The TDL design is based on the test specifications of various components as listed in the Technology Development Road Maps (TDRM) reference [1-3]. The TDL's design is modular, therefore allowing sections of a TDL or complete TDLs to be installed as the need arises. The TDL's design also allows for interfacing with other facilities such as the Component Qualification Loop1 (CQL1) (described in the next section). In the TDL's design, the focus was placed on designing the TDL, where possible, with proven robust technology and components of the shelf. This was done to give the TDL conditioning loop a high reliability as well as robustness.

1.6 Section 7: Component Qualification Loop 1 (CQL1)

In this section the Component Qualification Loop 1 (CQL1) is described. The initial concept to include a Component Qualification Loop (CQL1) within the Component Test Facility (CTF) arose from the idea of using the combined helium mass flows of possible carbon copy Technology Development Loop (TDL) building blocks. Utilizing such an approach permits for larger component testing capabilities than those tested within the TDLs alone. At present only two TDLs are incorporated into the thermal hydraulic calculations used for the anticipated operation of CQL1. CQL1 can be seen as a larger component testing area using the mass flow of combined TDLs.

At present, two component tests are anticipated for CQL1 operation. These are a Steam Generator (SG) and the Sulfuric Acid (H₂SO₄) Decomposition Reactor.

1.7 Section 8: Component Qualification Loop 2 (CQL2)

In this section the Component Qualification Loop 2 (CQL2) is described. The needs for testing of high temperature nuclear reactor process heat components were defined in previous studies through an evaluation, selecting and grouping process as defined in the CTF Feasibility and Recommendation (Reference [1-4]). The CQL2 is a large scale high temperature high pressure helium test facility. The CQL2 Test Loop, which can be configured in seven different configurations, has a flow capability simulating about 14 percent of the proposed NGNP flow rate. The seven different configurations provide the necessary flexibility for testing the different main components under the maximum attainable process conditions and provide for flexibility in the readiness levels of components under test. Examples include: the use of the Main Loop without the Secondary Loop or using the developed highly efficient compact intermediate heat exchangers as recuperators in the Main Loop to perform the tests more economically.

1.8 Section 9: Circulator Test Loop (CTL)

The Circulator Test Loop (CTL) described in this section, comprises a Test Station for a full-scale circulator for the NGNP, which operates at 160kg/s helium flow rate, at a maximum temperature of 350°C and a pressure of 9MPa. Due to the availability of a high flow rate of helium at a high pressure drop (450kPa total), several other tests can be conducted in the CTL. These include: the calibration of flow meters for the full-scale NGNP, testing of flow-induced vibrations in the full-scale Heat Transport System piping (hot gas ducts), testing of vibration damping devices in the mixing chamber and determination of the pressure drop coefficient of a full-scale check valve.

1.9 References

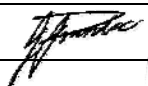
- [1-1] “Statement of Work Westinghouse Electric Company Component Test Facility Conceptual Design Studies,” SOW – 6391.
- [1-2] “INL Engineering Standards” STD-139
- [1-3] “NGNP Technology Development Road Mapping Report,” NGNP-CTF MTECH-TDRM
- [1-4] “HTGR Component Test Facility (CTF) Feasibility and Recommendations,” NGNP-CTF, dated February 2008

NGNP and Hydrogen Production Conceptual Design Study

NGNP CTF Test Loop Preconceptual Design Report

Section 2: Strategies and Philosophies

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ACRONYMS

Abbreviation or Acronym	Definition
A	Accelerometer
A-E-C	Architecture – Engineering -Construction
AGR	Advanced Gas-cooled Reactor
AHJ	Authority Having Jurisdiction
AICE	American Institute of Chemical Engineers
AISC	American Institute of Steel Construction
AISI	American Iron and Steel Institute
ALARA	As Low As Reasonable Achievable
AMB	Active Magnetic Bearing
ANSI	American National Standards Institute
API	American Petroleum Institute
ASHRAE	American Society of Heating Refrigeration and Air Conditioning Engineers
ASME	American Society of Mechanical Engineers
AWS	American Welding Society
BEA	Battelle Energy Alliance
BIL	Basic Impulse Insulation Level
BIM	Building Information Management
BS	British Standard
Btu/hr	British thermal unit per hour
CAD	Computer Aided Design
CAE	Computer Aided Engineering
CBCS	Core Barrel Conditioning System
CCS	Core Conditioning System
CFR	Code of Federal Regulations
CH	Cold Header
CMAA	Crane Manufacturers Association of America
COR	Client Observation Room
COTS	Commercial Off-The-Shelf (Commercial Grade Items)
CQL	Component Qualification Loop
CQL1	Component Qualification Loop 1
CQL2	Component Qualification Loop 2
CTF	Component Test Facility
CTL	Circulator Test Loop
CV	Valve Flow Coefficient
DAQ	Data Acquisition
db	Dry Bulb
DB	Distribution Board

Abbreviation or Acronym	Definition
DC	Direct Current
DCD	Design Criteria Document
DCS	Distributed Control System
DDN	Design Data Need
DOE	Department of Energy
dP	Differential Pressure
DPP	Demonstration Power Plant
EDMS	Engineering Data Management System
EHR	Essener Hochdruck Rohrleitung
EIA	Electronic Industry Alliance
EMB	Electro-magnetic Bearing
ENS	Emergency Notification System
EPACT	Energy Policy Act (of 2005)
EPC	Engineering Procurement and Construction
ER	Environmental Requirement
ES&H	Environmental, Safety and Health
ESD	Emergency Shutdown
F	Flow Rate
FDD	Facility Design Description
FHA	Fire Hazard Analysis
FIPS	Federal Information Processing Standards
FM	Factory Mutual
FMS	Facility Monitoring System
FS	Flow rate (switch)
GA	Gas analyzer (composition)
GHEP	Guidelines for Hazard Evaluation Procedures
gpm	Gallon per minute (US)
GR	General Requirements
H ₂	Hydrogen Production Test (Specifically referring to H ₂ SO ₄ Decomposition Reactor Test)
H ₂ SO ₄	Sulfuric Acid
HAZOP	Hazard and Operational Study
HDBK	Handbook
HGD	Hot Gas Duct
HGDs	Hot Gas Ducts
HH	Hot Header
HICS	Helium Inventory Control System
HIPCS	Helium Inventory and Pressure Control System
HIRA	Hazard and Risk Identification Analysis
HLR	High Level Requirement
HMI	Human Machine Interface

Abbreviation or Acronym	Definition
HPS	Helium Purification System
HT	Heat Transfer
HTF	Helium Test Facility
HTGR	High Temperature Gas -Cooled Reactor
HTS	Heat Transport System
HTSE	High Temperature Steam Electrolysis
HTTR	High Temperature Test Reactor
HTTU	High Temperature Test Unit
HV	High Voltage (>132 000V)
HVAC	Heating, Ventilation, & Air Conditioning
HX	Heat Exchanger
HyS	Hybrid Sulfur
I&C	Instrumentation and Control
I/O	Input/Output
IBC	International Building Code
ICC	International Code Council
ICD	Initial Conceptual Design
ICEA	Insulated Cable Engineers Association
IDAPA	Idaho Administrative Procedure Act
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IFC	International Fire Code
IFGC	International Fuel Gas Code
IHX	Intermediate Heat Exchanger
IHXA	Intermediate Heat Exchanger A
IHXB	Intermediate Heat Exchanger B
IMC	International Mechanical Code
IMS	Information Management Systems
INL	Idaho National Laboratory
IPMC	International Property Maintenance Code
ISA	International Society of Automation
ISO	International Organization for Standardization
JB	Junction Box
kg/s	Kilogram per second
kV	Kilovolt (1000 Volts)
kl/h	Kilolitre per hour
kPa	Kilopascal (1000 Pascal)
kW	Kilowatt (1000 Watts)
LCD	Liquid Crystal Display
LCP	Local Control Panel
LRFDS	Load and Resistance Factor Design Specification

Abbreviation or Acronym	Definition
LV	Low Voltage (<1000 V)
MBMA	Metal Building Manufacturers Association
MCC	Motor Control Center
MCR	Mission Critical Requirement
MDB	Main Distribution Board
MES	Manufacturing Execution System
MPa	Megapascal = million Pascal
MTI	M-Tech Industrial (Pty) Ltd.
MV	Medium Voltage (>1000V< 132 000V)
MW	Megawatt (Million Watts)
N	Rotational Speed
NBIMS	National BIM Standards Project Committee
NEC	National Electrical Code
NEMA	National Electrical Manufacturers Association
NEPA	National Environmental Policy Act
NESC	National Electrical Safety Code
NFPA	National Fire Protection Association
NGNP	Next Generation Nuclear Plant
NHI	Nuclear Hydrogen Initiative
NIST	National Institute of Standards and Technology
NQA-1	ASME NQA-1 2000, Quality Assurance for Nuclear Facilities
OPC	Operating Procedure Checklist
OSHA	Occupational Safety and Health Administration
P	Pressure
P&ID	Piping and Instrument Diagram
PBMR	Pebble Bed Modular Reactor (RSA)
PCDR	Preconceptual Design Report
PCFC	Preconceptual Facility Configurations
PCHX	Printed Circuit Heat Exchanger
PCS	Process Control System
PDA	Potential Deviation Analysis
PDMS	Project Data Management System
PDS	Plant Design System
PFD	Process Flow Diagram
PHA	Preliminary Hazard Analysis
PHTS	Primary Heat Transport System
PLC	Programmable Logic Controller
PLCs	Programmable Logic Controllers
PMN	Support Manager
PRV	Pressure Relief Valve
psig	Pound per square inch gauge

Abbreviation or Acronym	Definition
PSM	Support Modeler
QC	Quality Control
QCP	Quality Control Plan
RCS	Reactivity Control System
RIS	Relational Interface System
RPV	Reactor Pressure Vessel
RSA	Republic of South Africa
SBS	System Breakdown Structure
SCADA	Supervisory Control and Data Acquisition System
scfm	Standard cubic feet per minute
SDD	System Design Description
SDI	Steel Door Institute or Steel Deck Institute
SG	Steam Generator
SHEQ	Safety, Health, Environmental and Quality
SHTS	Secondary Heat Transport System
SI	Sulfur Iodine
SIL	Safety Integrity Level
SIS	Safety Instrument System
SJI	Steel Joist Institute
SNM	Special Nuclear Materials
SPEL	SmartPlant Electrical
SPF	SmartPlant Foundation
SPMat	SmartPlant Material
SPR	SmartPlant Review
SPS	Standby Power System
SR	Safety Requirement
SRM	System Requirement Manual
SSC	Systems Structures and Components
SSDT	Small Scale Development Test
SSS	Site Selection Study
SSSB	Specification for Structural Steel Buildings
STD	Standard
T	Temperature
T&FR	Technical and Functional Requirement
TBC	To Be Confirmed
TBD	To Be Determined
TDL	Technology Development Loop
TDRM	Technology Development Road Map
TEDS	Transducer Electronic Data Sheet
TEMA	Tubular Exchanger Manufacturers Association
THTR	Thorium High Temperature Reactor

Abbreviation or Acronym	Definition
TIA	Telecommunications Industry Association
TRL	Technology Readiness Level
TSR	Technical Safety Requirement
UL	Underwriters Laboratories
UPC	Uniform Plumbing Code
UPS	Uninterruptable Power Supply
UUT	Unit Under Test
V&V	Verification and Validation
VHTGR	Very High Temperature Gas-Cooled Reactor
VL	Valve
VSD	Variable Speed Drive
wb	Wet Bulb
WBS	Work Breakdown Structure
WEC	Westinghouse Electric Company
WE-SA	Westinghouse Electric - South Africa
ϵ	Strain

SUMMARY AND CONCLUSIONS

This section establishes the basic strategies and philosophies with regards to the engineering, design, construction and commissioning of the proposed Component Test Facility (CTF) systems. The strategies are intended to aid the engineering process based on the Next Generation Nuclear Plant (NGNP) Preconceptual design study together with the additional complementation work. These typically include the HTGR CTF Feasibility and Recommendations study; other Systems Structures and Components (SSC) conceptual designs/special studies as well recently completed Technology Development Road Maps (TDRM) (Reference [2-5]) and associated test plans.

The strategies are divided into *Design and Engineering* as well as *Construction and Commissioning* strategies. Design and Engineering strategies provide general guidelines to support the test loop design process. These guidelines are deemed necessary due to the Preconceptual status of the NGNP design with only limited testing information available on specific components. All of the strategies are presented per engineering discipline and are intended as a very high level design recommendation. The Instrumentation and Control (I&C) strategy is also presented as a philosophy and includes important aspects associated with the data acquisition and related security issues, control loops and development tests' measurements.

The *Construction and Commissioning* strategy section include two separate possibilities, which are supported by the proposed systems for technology development. Both these strategies would need to support the test plans as well as the integrated test schedule that was developed as part of the TDRM process. The two possibilities include a phased approach as opposed to a large scale test facility. The phased approach incorporates numerous independent smaller technology development systems (test loops) which could be constructed progressively, while the large scale approach would result in a single facility with larger testing capacity. Both of these construction and commissioning strategies are only applicable to the technology development test loops and need to be separated from the facility and associated utilities, which does not necessarily allow for a phased approach. A brief description of both of these strategies is presented in this document.

2. STRATEGIES AND PHILOSOPHIES

2.1 Introduction

The following section provides the overall strategies and philosophies that are applicable to the technology development systems (i.e. test loops) that are being presented for the CTF. The strategies are intended to aid the engineering process based on the NGNP Preconceptual design study together with the additional complementation work. These typically include the CTF Preconceptual design; conceptual design/special studies as well recently completed Technology Development Roadmaps (TDRM) and associated test plans. The information in this section is not to be confused with criteria or system requirements, which would be provided respectively in Section 3: Design Criteria Document [2-8] and Section 4: System Requirement Manual [2-9].

2.2 Strategies

The following section provides an overview of proposed strategies that need to be considered during the lifecycle phases of the CTF. These strategies have the intent to serve as guidelines in order to aid the appropriate process and are divided into the *design and engineering* and *construction and commissioning* strategies.

2.2.1 Design and Engineering Strategies

The design and engineering strategies include specific recommendations to assist the design and engineering processes in an initial design phase. These guidelines are deemed necessary, based on the Preconceptual design level of all NGNP related SSC. The intent of these strategies is therefore to create high level requirements for design and engineering which need to flow down as requirements for systems, subsystem, component, parts etc.

- Design input
 - Input to the design would consist of all appropriate requirements as indicated in Reference [2-1]..[2-7]. Preference would be given to the test specifications as developed as part of the technology development road maps.
 - Test specifications with the highest level of detail would be considered as primary design drivers, while provision is made for less specific requirements.
 - Test loops should be designed in such a way to accommodate the failures of a Unit Under Test (UUT), without compromising safety and component integrity.

- The test loops primarily need to be design to support independent parallel testing while occasional serial testing might be required. This strategy is in support of the long term mission of serving multiple vendors at the same time.
 - A phased approach would be recommended which would require systems and their related interfaces to be presented separately.
- Thermal Hydraulic Design
 - The strategy for TH design is such that the initial design will only include steady state calculations with preliminary information on start-up procedures and anticipated modes and states. Transient analyses will only be performed once transients are determined during future phases in the design life cycle of the NNGNP.
 - An engineering simulator for the CTF is also proposed as part of the strategies. This simulator need to be based on fundamental engineering codes and methods and is intended to be used by designers and operators alike. Typical uses would be to model and analyze different configuration and control philosophies before implementation into the actual plant in order to mitigate technical risks. A simulator development specification is presented in Section 11: CTF Simulator Specification (Reference [2-12]).
- Mechanical Design
 - Due to the Preconceptual design stage that the project is currently in, the design deliverables will not be optimized configurations of what the final system would be but it is suitably sufficient.
 - Two different strategies will be followed in this phase; firstly a modular strategy with several phased systems that can be interconnected and secondly a larger singular system with reconfigurable setups.
 - Both strategies/approaches will utilize duplicable components throughout the design with layouts addressing future maintenance, spares inventory and inspection issues.
 - A modular design strategy is needed to accommodate a potential phased approached, in support of NNGNP / HTGR / VHTGR future development plans.
 - A larger singular strategy could be needed for testing of larger NNGNP SSC if the need arises.
 - Availability / manufacturability and transportability should be considered as important aspects due to timescale limitations and avoidance of unnecessary risks.
 - In the modular strategy, separate systems would need to be constructed simultaneously or while another modular system is testing some UUT without major interference or disturbances being caused.

- Electrical Design
 - The electrical designs must be done with the preliminary facility layouts kept in mind while more detailed configurations could result in required future modifications.
 - The electrical design needs to encompass the full range of expected tests to ensure adequate power availability.
- Component Selection / Design
 - A Commercial-Off-the-Shelf (COTS) strategy should be followed as far as possible to avoid additional technology development, possibly leading to many FOAKE systems that could impede the system availability.
 - Together with this strategy, a philosophy must be followed to ensure that the system components must be of a higher reliability than the UUT. This could result in technologically less advanced test loops, but more with greater levels of reliability and availability during the 40 year life cycle of the CTF.
 - The utilization of NNGP specific components as part of the test loop components might be accompanied in future in order to obtain increased operation time. This strategy will however need to be re-evaluated in future design tasks.
- Interfaces
 - All interfaces to be presented per system as far as practically possible. This method of presenting the systems is intended to aid decision making for input to later configurations. Primary drivers in the configuration changes would be the integrated schedules.

2.2.2 Construction and Commissioning Strategies

The construction and commissioning strategies can be divided into two different approaches. The first approach would be to develop numerous smaller systems, with the advantages of supporting a phased approach in terms of flexibility, expandability and configuration changes. The second approach would be to have a single large scale facility which would allow for larger scale components. Both these approaches have been presented in the CTF recommendations and feasibility study - reference [2-4] and will be used as reference designs for the Preconceptual Design Phase (PCD) of the CTF. It should however be noted that these construction and commissioning strategies are only applicable to the test loops and does not include the overall facility which comprise the High Bay building, auxiliaries or other needed site utilities.

Phased Approach

The recommended phased approach is only proposed in terms if the technology development systems (i.e. the test loops) and can be considered as providing a progressive expansion of technology development systems and functionalities. This structured growth pattern would typically need to resemble a development path which would start with small scale development systems such as the Small Scaled Development Tests (SSDT), while being followed by larger more involved test loops such as the Technology Development Loop (TDL) and a possible Component Qualification Loop (CQL). Together with this flexible expansion, duplication would also need to be accommodated to cater for needs such as concurrent testing by different vendors. Figures 2-1 to 2-5 provides a series of diagrams illustrating a typical implementation of the proposed phased approach process. This is for illustrative purposes only and a final recommendation would only be made in Section 10: System Integration [2-10]. Such a recommendation would typically include aspects such as the integrated SSC test schedule, funding and other limitations.

Phase 1:

- Construction and commissioning of complete CTF site and all related site utilities, to provide for anticipated technology systems.

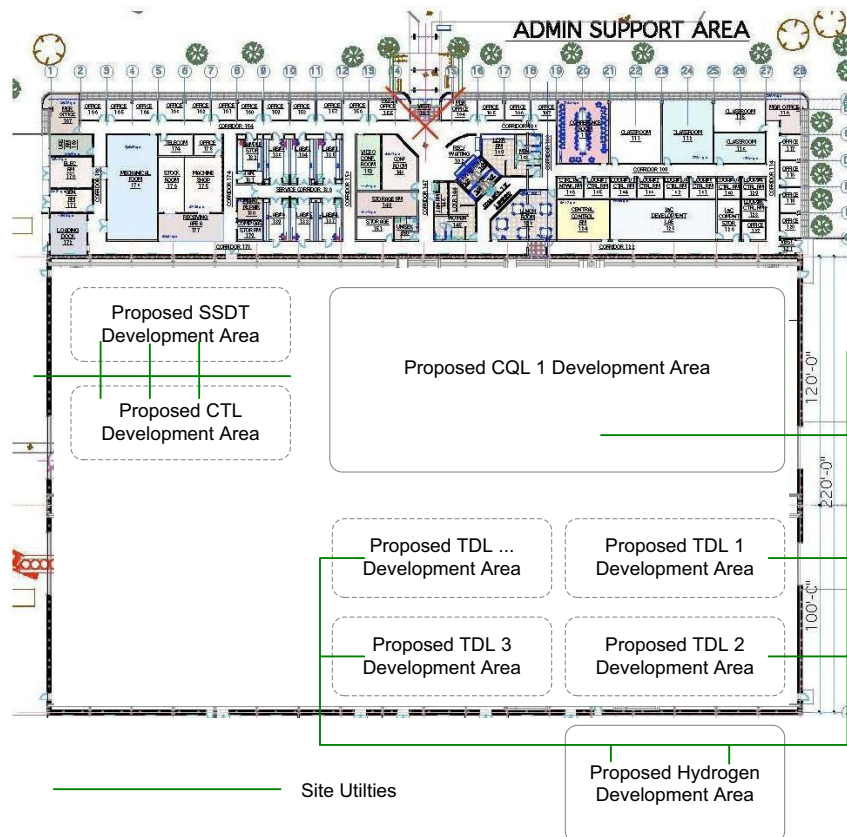


Figure 2-1: Phased approach: Phase 1

Phase 2:

- Construction of SSDT to assist with initial technology maturation plans as well providing a basis for technology development needed for test loop.

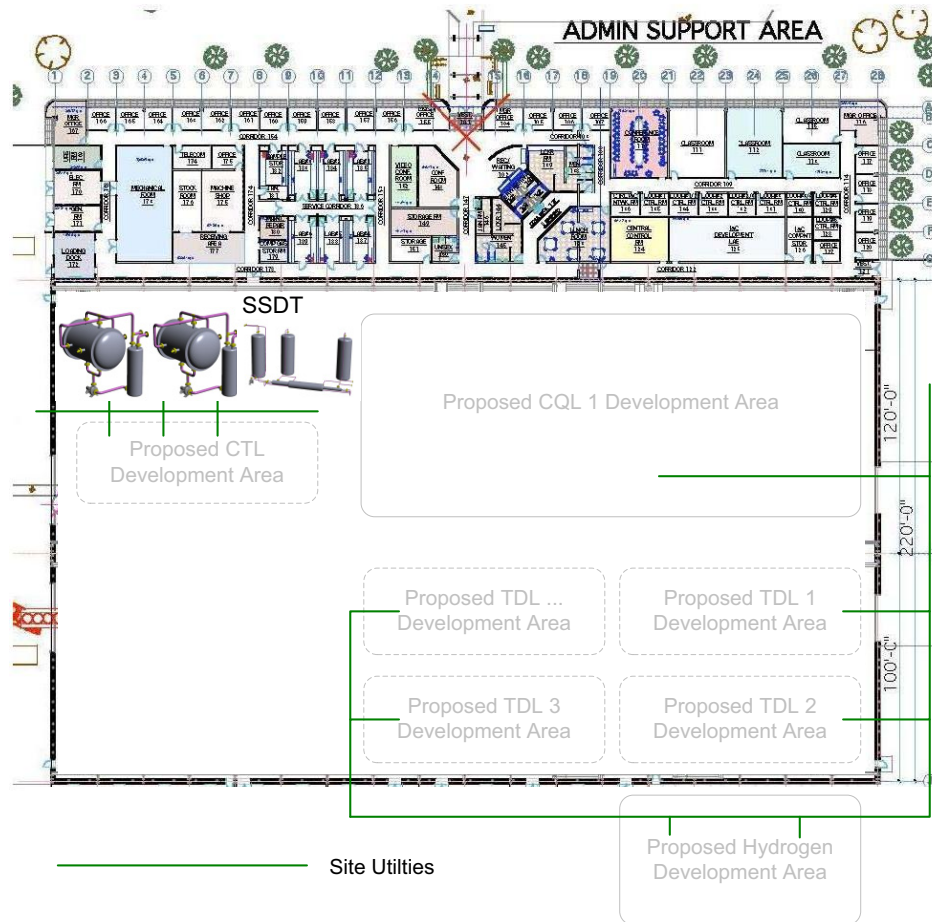


Figure 2-2: Phased approach: Phase 2

Phase 3:

- Construction of first TDL to serve as dedicated steady state, long term testing development loop.
- Lessons learnt from this system could be passed on to successive TDL's

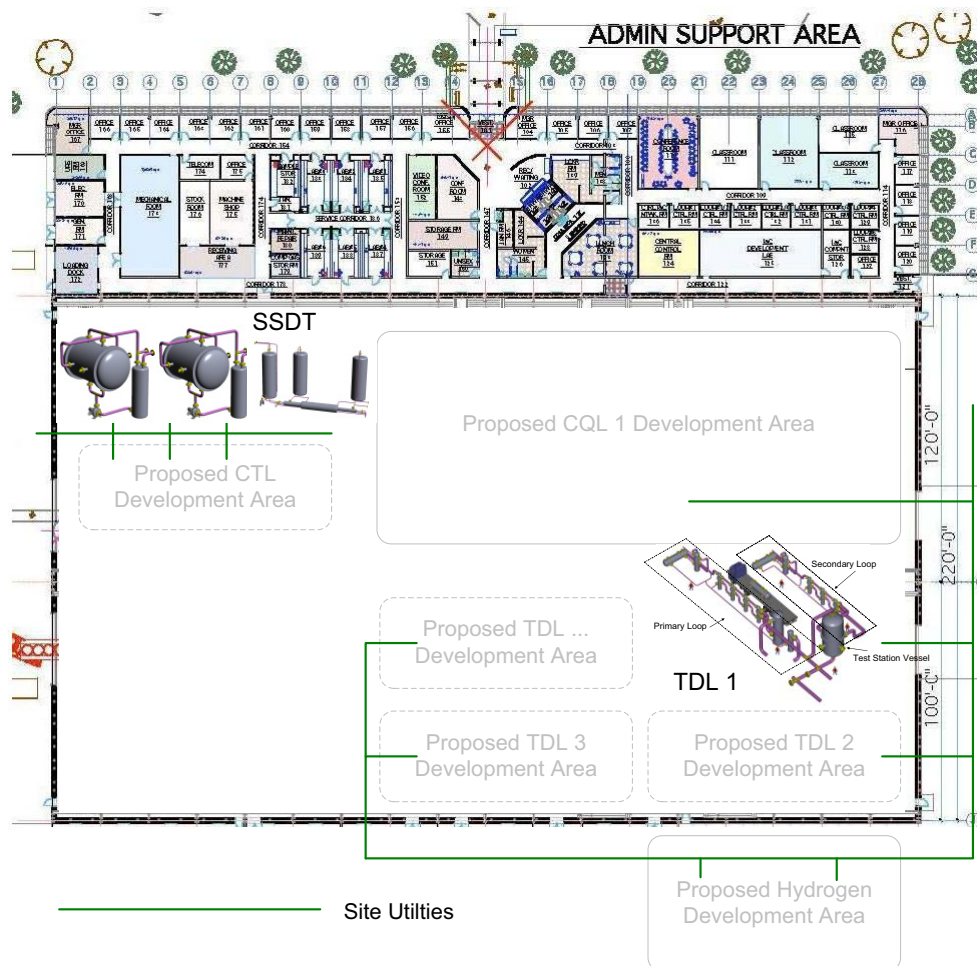


Figure 2-3: Phased approach: Phase 3

Phase 4:

- Additional TDLs could be implemented to either satisfy schedule requirements or to cater for further clients.
- These additional systems would utilize similar components to the first TDL and would benefit from the lessons learnt (successes and failures) of the preceding loops. Similar components would add to improved reliability of the overall facility.
- The Circulator Test Loop (CTL) could also be implemented as part of this phase but a possible just-in-time approach can also be followed here, depending on the time scales and test program of a full scale circulator.

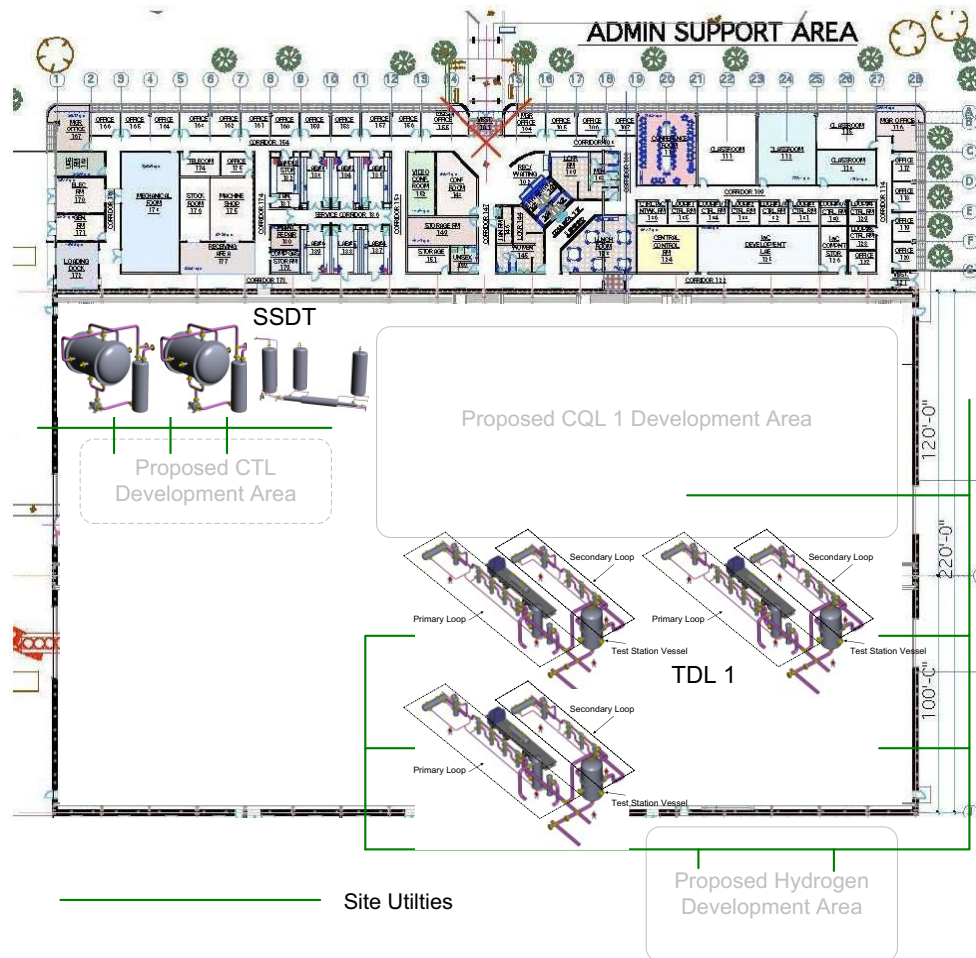


Figure 2-4: Phased approach: Phase 4

Phase 5:

- A follow on phase would probably include expansion for qualification of larger scale components that is anticipated to be tested in the CQL.
- Expansion of the facility to provide testing capabilities for Hydrogen production development could also be done at either this or the previous phase.

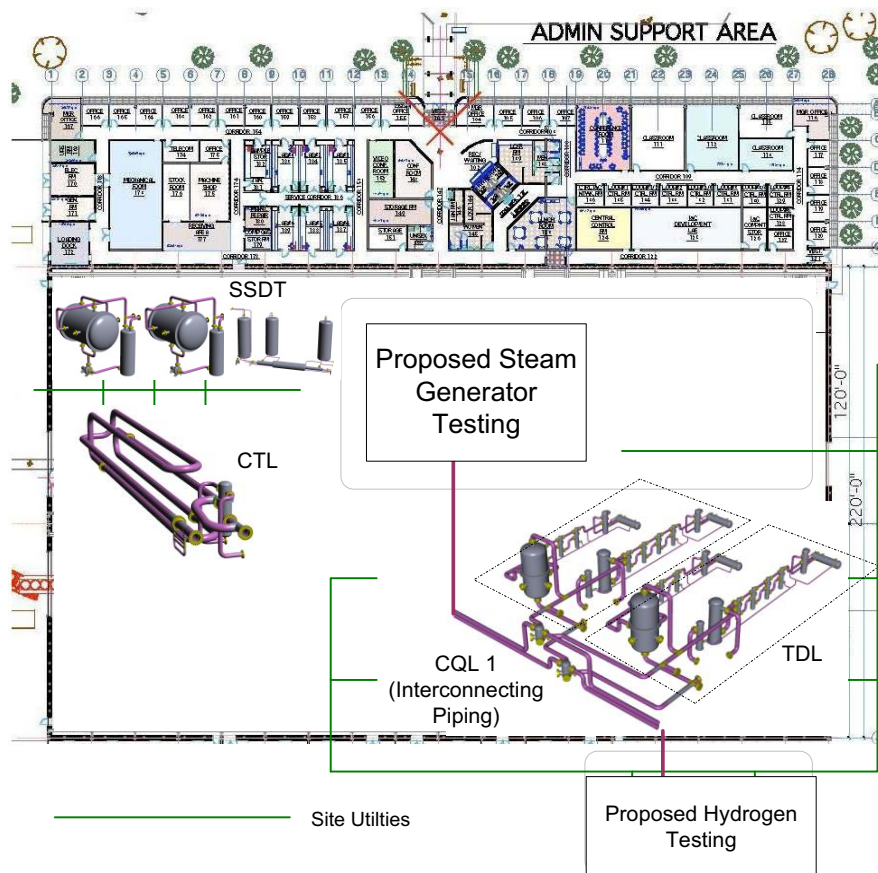


Figure 2-5: Phased approach: Phase 5

The advantages associated with this approach include the following:

- Provide technology development building blocks in support of long term coordinating, consolidating, and leadership in the HTGR heat transfer and transport technologies.
- Such an approach would make it possible to support NGNP relevant technology development, while also providing flexibility and future expandability for development beyond NGNP such as the Very High Temperature Gas-Cooled Reactor (VHTGR)
- Off line trouble shooting could be accomplished by having numerous development loops.
- Dedicated technology development building blocks might be added at later stages in further support of the Nuclear Hydrogen Initiative (NHI).
- It is anticipated that a phased approach would complement the current preconceptual design level of the NGNP, and would be more forgiving to configuration changes should further NGNP component design require it.
- A phased approach would also assist in satisfying the integrated test schedule as generated as part of the TDRM process.

The disadvantages associated with this approach include the following:

- Smaller test facilities would be restricted to lower mass flow capabilities. Although these systems would be designed to fulfill all requirements that are applicable at this stage, future requirements might fall outside the capability of the combination of the number of loops at that specific point in time.
- The phased approach has interconnectivity design challenges associated with it. This interconnectivity relates to possible complex piping and header configurations.

Large Scale Facility Approach

An alternative approach is to provide a single, much larger test facility, with the flexibility of a number of different test configurations. These different configurations should provide testing capabilities for the anticipated SSC as indicated in reference [2-1], and would typically utilize a flow of about 15 percent of the proposed NGNP conditions.

It is envisaged that the construction of such a facility could follow a parallel sequential procedure, with the numerous parallel groups being defined in Section 8: Component Qualification Loop 2 [2-11]. Commissioning is anticipated to follow a functional group logic with a functional group referring to a group of components, parts, or equipment that works together to fulfill a certain function in a plant.

This approach would not necessarily address specific test requirements and would rather act as an umbrella facility to cater over and above the required test specifications. Typical advantages associated with this approach include:

- The ability to test and qualify larger scale components than those applicable to the phased approach.
- This facility might provide conditions closer to NGNP environment and could be slightly more related with regards to plant operation.
- Quality assurance programs (such as NQA-1 2000) on a large facility could be of more relevance to NGNP related programs than from smaller facilities.

In contrast to these advantages, a single large scale facility also incorporates a number of additional disadvantages. These typically include:

- The complexity associated with a large facility increases the risk in terms of non standard components and long manufacturing lead times.
- A COTS philosophy is also more difficult to follow on this larger scale, and could inevitably result in more technology development needed for the proposed system.
- A single facility, although boasting different configurations, would not allow concurrent testing by different vendors. This might result in additional risk due to time schedule requirements.
- A large facility is less flexible to possible and likely changing-client-needs.

2.3 Philosophies

The proposed engineering philosophies can be considered as a more complete strategy with regards to specific engineering disciplines. These philosophies address much of the high level requirements while also generating lower level needs which have to be implemented on a systems, subsystems and component level. The I&C philosophy is presented in more detail due to the importance of data obtained through test at the CTF.

2.3.1 Control and Instrumentation Philosophy

The requirements for the equipment needed for the acquisition of test data is different to that of the control and protection of the CTF for instance with regards to accuracy, security, reliability, calibration and instrumentation. The test measurement issues therefore justify a separate philosophy apart from the loops control philosophy. There are however some issues that apply to the whole of the I&C scope and those will be discussed first in a general philosophy section.

2.3.1.1 General Instrumentation and Control philosophies

Plant life cycle

The CTF has a plant lifetime requirement of 40 years. Due to the rapid renewal of control system technology, it is necessary to be well informed of the latest trends in control and data acquisition (DAQ) equipment to start off and remain competitive. Due to the CTF phased approach that could be followed, expandability and compatibility of the control system and network will have to be assured to accommodate new technology when new phased are built.

Supplier Evaluation and Selection

Well represented vendors and expertise need to be taken into consideration when deciding on a particular control and DAQ system. World leading vendors like ABB and Siemens have state of the art controller hardware and software while National Instruments is a global market leader in PC-based data acquisition (DAQ) systems. These vendors are all well represented in the United States. It is recommended that the same type of software or the same software vendor that is used for the control system be used for the auxiliary systems as well. Additionally, it could be considered to use the same vendor for the CTF control system that is envisioned for the NGNP control system.

Data network

Industry standard protocols will be used while minimizing the number thereof. A high capacity data network should connect the operator control station, control components, and instrument termination points. It should provide sufficient network ports with connections for instrumentation devices, data collection/control systems, and operator system access with substantial (at least double initial) additional bandwidth capacity and network ports.

The location and number of these portals should support the ease of movement of instruments or instrument clusters without network disruptions or major restructuring.

All communication in the network should be protected from external interference and the network should maintain data integrity. As far as possible, all network components should be capable of self-diagnostics, support system diagnostics, perform alternate routing and be located in easily accessible areas that are suitably protected for the environment in which they are used.

Data security

The data storage system will be designed to store data from all of the instruments, control actions, and modeling for project specified time requirements. The size of data storage depends on the number of instruments, data bandwidth, and data granularity. The data management system will be designed to accommodate new technologies in the transmission and storage of data. This may include the ability to add or change data transmission paths or technologies and data storage media or devices.

Data capacity

The data storage system should be designed to store data from all of the instruments, control actions, and modeling for project specified time requirements. The size of data storage depends on the number of instruments, data bandwidth, and data granularity. The data management system should be designed to accommodate new technologies in the transmission and storage of data. This may include the ability to add or change data transmission paths or technologies and data storage media or devices.

System structure

The control, protection and DAQ interfaces should consist of industry standard hierarchal levels as follows:

- Level 0: Field instrumentation
- Level 1: Programmable Logic Controllers (PLC) and local Human Machine Interface (HMIs)
- Level 2: Supervisory Control and Data Acquisition (SCADA)
- Level 3: MES (Manufacturing execution system)

Level 0 consists of the primary sensing elements, transmitters and switches for the relevant process variable signals to be monitored by the control system and final control elements such as actuators and control valves. The field instrumentation is physically installed on and around the process equipment. The interface from the field instrumentation to the control system should generally be via hardwired cabling and junction boxes to classic (0mA~20mA) analogue, (-10v~10v) analogue, (-5v~5v) analogue, digital fieldbus and 24V DC binary I/O.

Level 1 consists of PLCs and where required, local HMIs. The local HMI should be installed where dedicated local operator intervention is required. The control system should perform the following functions as a minimum:

- System fault diagnostics
- Interface to field instruments
- Interface to SCADA system
- Interface to HMI via the SCADA
- General process control functions controlled by the PCS (Process Control System)
- Process sequences controlled by the PCS
- Control algorithms and closed loop control, controlled by the PCS
- Safe Process Shutdown controlled by the ESD (Emergency Shut-down)
- Process control Non-safety related interlocks controlled by the PCS
- Process control Safety related interlocks controlled by the SIS (Safety Instrumented System)
- Calculations controlled by the PCS
- Alarm and switch point generation
- Fault and event logging

Level 2 consists of a real time supervisory system to provide the main human machine interface to the plant via graphic screens displaying plant mimics. All processes and process equipment should be monitored and supervised from the SCADA system.

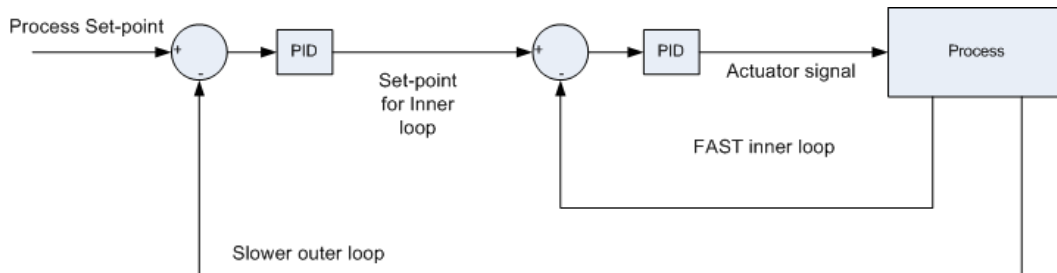
Level 3 consists of analysis and reporting capabilities. This level should have no direct access to the control of the plant but provides access to historical data for analyses and report requirements.

2.3.1.2 Control and Protection Philosophy

Since the requirements for the control and protection of the plant are different from the DAQ or test measurement process, the control and protection system and DAQ system can be separate systems utilizing separate hardware and software.

Closed loop control

The process control system should be capable of providing programmable control to the heaters, motors, and other actuators to implement the steady-state and transient temperature and flow profiles, as specified. The control system should have the capability of responding to synthetic and sensor data, and use classical and intelligent control algorithms. Figure 2-6 shows a typical cascade controller that is typically used where the variable to be controlled has a slow response. The inner loop makes use of another faster responding variable to pre-control the actual variable to be controlled.

**Figure 2-6: Cascade control**

Each System or sub-system should have its own controllers to control variables inside that Each System or sub-system should have its own controllers to control variables inside that relevant system. The TDL loops should be sub-systems for the CQL process for instance. Each system should be able to communicate (send control-set-points and monitor conditions) with its subsystems and auxiliary system to ensure timely standby and operation of sub-systems and auxiliaries.

The CTF loop control systems should provide a means to allow users to establish required loop temperature and flow profiles. UUT placed in the CTF will provide monitor signals to the loop control so that the requested process conditions can be provided. A minimum number of measurement signals should be provided from the UUT to the control system for incorporation of warning and fault conditions.

The parameters of each system (pressure, flow and temperature etc.) must be controlled throughout that system's operating range.

The operation and protection of each system can be subdivided into the following systems:

- Process control system (PCS)
- Safety instrumented system (SIS)
- Emergency shutdown (ESD) system

The PCS should include the mode and state control and ensures that the system progresses safely from one mode or state to another. The interlock system should include warnings and fault conditions. Each system should have a FAULT mode in which diagnostics can be performed to determine if a problem can be resolved and normal plant operation can commence, else the PCS should proceed to a SAFE mode where the necessary remedial actions are activated. The PCS should include a safe shutdown procedure.

The SIS will operate entirely independently from the PCS and is responsible for sensing any unsafe condition and act accordingly to eliminate the specific unsafe scenario automatically. A safety integrity level (SIL) assessment will have to be performed to determine the SIL requirement for each part of the system.

The SIS should have its own separate high integrity SIL sensor and high integrity SIL actuator for each protection scenario. Based on the severity of an unsafe condition, the SIS will mitigate the condition in the appropriate area.

The ESD will sense any condition that requires a high integrity safe shut down of the system. The ESD should also be connected to the process E-Stop system which provides a means to stop a loop or process manually if an operator observes a possible unsafe situation. An E-Stop activation should only affect the observed loop or process while a facility-wide Master E-Stop should affect all loops and processes. The E-Stop system will be designed to ensure ease of maintenance and testing without unduly compromising the functionality of protected process equipment and will avoid single point and common mode failures.

All equipment for the PCS, SIS and ESD should be wired and installed in such a way as to ensure fail safe conditions.

Data collection

All data should be collected, logged and archived to enable the following:

- Real time and historical data trending
- Reporting
- System operating analysis
- Fault finding
- Optimizing of controllers
- Preventative maintenance

SCADA

The SCADA or operator interface system should have sufficient display areas/monitors to convey the necessary information. The SCADA should be designed to be as simple and clear as possible enabling the operators to identify the system status rapidly. Incorrect operator actions should be minimized by implementing a 'log in' security system. Although all systems should be controlled via the control rooms, local HMIs should be placed at strategic locations if necessary.

Control rooms

It is recommended that related systems be controlled from a single control room where the control room design is such that the display information of systems (such as the TDL which could also be referred to as a sub-system in some configurations) will be clearly visible to the control station. This is especially relevant for the larger CQL system. Each sub-system (such as the case mentioned here) should still have the functionality to be controlled separately and independently as illustrated by Figure 2-7. This will avoid duplication and the complexity of sharing control and observation signals/systems.

Each system should however have its own client observation facility to avoid breach of security while the combined control room will only be accessed by CTF personnel only. If needed, the combined control room can be temporarily partitioned. The PLC's server computers and wiring should typically be located in a separate climate controlled room so that no major disruption will occur in the control rooms during physical reconstruction or additions.

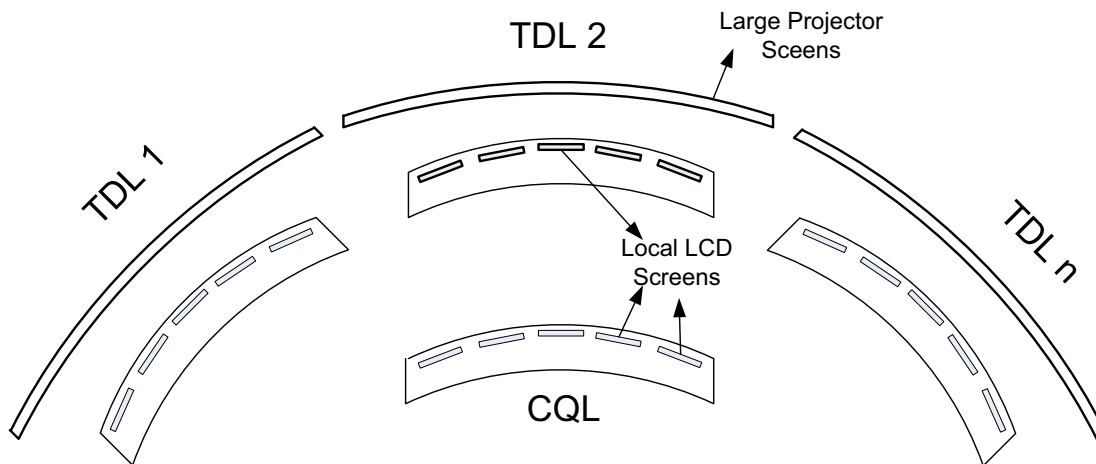


Figure 2-7: Control room layout

Figure 2-8 shows an example of two operating stations that can either be used independently or be combined to form part of a larger operating system.

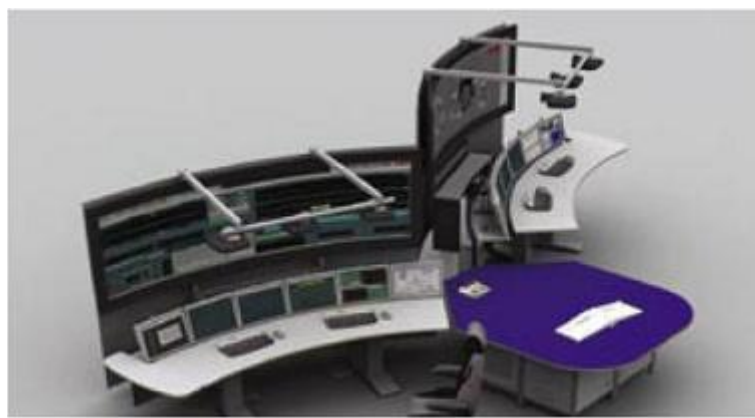


Figure 2-8: Operating stations

Since the control of the conditioning loops that provide the required process conditions for the UTT will be supervised by CTF personnel, it is recommended that separate client observation rooms (COR) with appropriate access security be provided where clients can monitor their own testing process (Figure 2-9). Interfaces should also be provided in the COR for dynamic scheduling of tests. This implies that the original test schedule/sequence provided can be altered in the event of an unforeseen occurrence.

A video collection system should be available in the control rooms and COR to assist in the detection of any detrimental effects on the UUT.

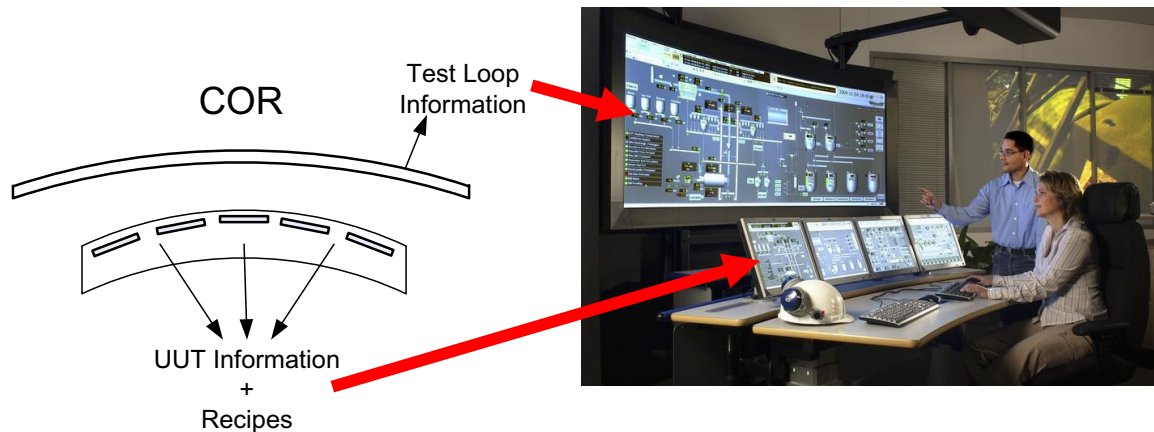


Figure 2-9: Client observation room

Level of automation

The control of each process should have the maximum level of automation requiring the minimum amount of operator action and intervention. The client will need to specify the required order of events for him to be able to perform the required tests on his UUT. Software should be designed such that the specified order of events can be added effortlessly into a recipe. The recipe should be a software sequence that will provide inputs to the control system (PCS) to guide the plant through the required transients or sequence of events. This recipe with the required conditions and transients for the test should be programmed into the system beforehand. The system should however have a pause or manual takeover capability with associated security access codes. The recipe can typically be paused and updated during testing, which might be a requirement of the client.

Different modes of control should exist:

- Automated
- Semi-automated
- Manual
- Maintenance

In the automated mode, the PCS should control all sequences of events. The semi-automated mode should enable the manual initialization and termination of test processes and sequences of events. The manual mode should enable the startup or shutdown of individual systems or sections utilized by the processes and the maintenance mode should enable control over individual equipment/instruments.

The safety and equipment protection systems (ESD & SIS) should be active in all modes except for the maintenance mode where only the safety protection systems should be active.

Redundancy

Redundancy of certain control instruments is proposed because it generally increases plant availability by mitigating the risk of complete system shutdown/failure due to dependence on a single I&C components and resulting hardware failure thereof. Critical components should be identified with the associated level of redundancy. The criticality level instruments can typically be subjected to the following redundancy schemes:

- Voting system – 3 or more measurements are used where one deviation can be voted out
- Hot swap capability – instrument or program can be replaced while testing.

The following control system hardware should be configured in a redundant configuration:

- PLC's
- Input / output modules
- Networking
- SCADA
- Data logging and storing

Additionally, hardware and software that handle critical data should be capable of deterministic or guaranteed data throughput. A hierarchy structure of criticality levels will enable the identification of critical data points and guarantee that the crucial data arrives within a defined amount of time.

Calibration

Instruments should be calibrated according to the class they reside in. The classes determine the frequency and accuracy of calibration and are typically distinguished by function such as:

- Protection
- Safety
- Control
- Data acquisition for units under tests
- Data acquisition for validation and verification

Reference instruments (secondary standards) can be used to calibrate other instruments in its direct vicinity. This is useful for instance when calibrating sleeveless transient temperature sensors which are not easily removable and transportable from the plant.

It is recommended that a certified calibration laboratory be situated onsite. All instruments should have calibration certificates traceable to National Institute of Standards and Technology (NIST) or similar.

The control network, control software and instrumentation should be TEDS (transducer electronic data sheet) compatible. TEDS is a plug and play technology whereby an instrument can be identified, calibrated, its calibration data stored/retrieved, its limits detected and its data sheet info stored/retrieved. The TEDS functionality also allows for early warning on upcoming calibration requirements and online pre-test calibration check-ups.

Diagnostics

Analysis of historical data will enable:

- detection of deviations caused by instrument malfunction
- preventative maintenance
- detection of loss of accuracy

By performing the analysis in real time, warning and fault signals can be generated and sent to the control system.

Instrumentation

Standard industrial instrumentation should be used unless the accuracy or pressure/temperature environment requires a special instrument. If necessary, instrumentation will be tested/developed in the small scale development test (SSDT) loop. For area and large component temperature monitoring, infrared imaging should be used.

Industrial instrumentation installation standards should be adhered to with regard to for instance:

- Upstream and down stream pipe lengths
- Insertion dept
- Impulse line lengths, line sizes, cladding, etc
- Types of sensors
- Diaphragms chemical seals

Valve requirements/considerations may include the following:

- Isolation valves
- Control valves
- Type of valves (globe, gate, ball, plug)
- Seat information (linear, fast open, fast close, equal percentage)
- Actuator type (pneumatic, electrical, mechanical)

All sensors should typically be compatible with standard field-bus technology. Where necessary, safety wiring and shielding will be performed.

2.3.1.3 Test Measurement Philosophy

Data confidentiality

The data management system should be designed to ensure the information contained in the system is not disclosed to unauthorized individuals, processes, or devices. It should provide access control to maintain CTF specific and client experiment data separation. Experimental data and experimental data collection will be kept under access control to ensure that instrument data and control signals associated with proprietary components are protected. This information protection should include assurance that a single failure cannot cause the loss of all data and that stored data cannot be modified. Data shall be classified as lifetime or non-permanent and maintained for as such. Non-permanent data shall be maintained for the identified retention period.

Data integrity

The data management system should be designed to ensure that information has not been modified or deleted in an unauthorized manner. Data should be recorded with accurate time stamps and associated with a unique instrument identifier so that the data can be traced to a specific instrument.

Data availability

The data management system should be designed to ensure that the information stored on the system is accessible and useable upon demand by an authorized user in a timely and reliable manner according to the performance specification for the system. It may contain released experimental data and implement the proper level of access control to this data. It should include an offsite location that duplicates the storage of the streamed data. This storage facility shall be protected from natural disaster, high and low temperatures, humidity, insects, molds or rodents.

The data management system should be designed to provide backup for all information stored on the system. Data should be archived after a set period of time but should be protected. Data storage systems should be reviewed and upgraded on a periodic basis, or as needed, to ensure that the data format and hardware required to retrieve data are still available and functioning. This may require resaving data to different storage media or maintaining hardware that can read and output the stored information.

A data access and reporting system should be provided to allow authorized users to access stored data. Access to data should be provided in project specific or industry standard format.

A provision should be added for remote monitoring of test progress, (e.g., through the Internet with appropriate security).

Data quality

Quality requirements of applicable codes and standards should be applied to data collection and storage. All data should be completely traceable to the source, time, and method it was produced. The sampling and compression of the data should be determined by the requirements for the instrument. Instrumentation hardware and software for the data management system will be under configuration control per applicable codes and standards such as ASME NQA-1-2000, Subpart 2.7.

Instrumentation of UUT's

Instrumentation for UUT should be available onsite. Typical measurements include the following:

- Temperatures
- Pressures
- Flow rate
- Strain/stress
- Vibration (mechanical/acoustic)
- Leak rates
- Noise
- Frequency spectra and sound pressure levels

A leak detection function may make use of ultrasonic detectors to sense sound emitted from a leak. Loop sample ports should be used for general loop gas analysis. Fiber optic sensors may be used for temperature, pressure and flow and strain measurement. This technology type may be necessary in the test facility and in the HTGR for sensors positioned in very high temperature environments. Where necessary, certain types of instrumentation can also be UUT. These instrumentation can be put in-line in the process loop for durability-, life-, fatigue etc testing. The functioning of the main loop must not be dependent on the availability of the UUT.

Different interfacing types should be available like:

- 0 to 20 mA
- -10 to 10 V
- digital protocols (e.g. Profibus, Fieldbus, Modbus)
- Booleans (switches, on/off signals, etc)

2.4 References

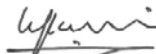
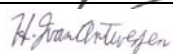
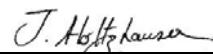
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NGNP and Hydrogen Production Conceptual Design Study

NGNP CTF Test Loop Preconceptual Design Report

Section 3: Design Criteria Document

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DOCUMENT TRACEABILITY

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ACRONYMS

Abbreviation or Acronym	Definition
A	Accelerometer
A-E-C	Architecture – Engineering -Construction
AGR	Advanced Gas-cooled Reactor
AHJ	Authority Having Jurisdiction
AICE	American Institute of Chemical Engineers
AISC	American Institute of Steel Construction
AISI	American Iron and Steel Institute
ALARA	As Low As Reasonable Achievable
AMB	Active Magnetic Bearing
ANSI	American National Standards Institute
API	American Petroleum Institute
ASHRAE	American Society of Heating Refrigeration and Air Conditioning Engineers
ASME	American Society of Mechanical Engineers
AWS	American Welding Society
BEA	Battelle Energy Alliance
BIL	Basic Impulse Insulation Level
BIM	Building Information Management
BS	British Standard
Btu/hr	British thermal unit per hour
CAD	Computer Aided Design
CAE	Computer Aided Engineering
CBCS	Core Barrel Conditioning System
CCS	Core Conditioning System
CFR	Code of Federal Regulations
CH	Cold Header
CMAA	Crane Manufacturers Association of America
COR	Client Observation Room
COTS	Commercial Off-The-Shelf (Commercial Grade Items)
CQL	Component Qualification Loop
CQL1	Component Qualification Loop 1
CQL2	Component Qualification Loop 2
CTF	Component Test Facility
CTL	Circulator Test Loop
CV	Valve Flow Coefficient
DAQ	Data Acquisition
db	Dry Bulb
DB	Distribution Board

Abbreviation or Acronym	Definition
DC	Direct Current
DCD	Design Criteria Document
DCS	Distributed Control System
DDN	Design Data Need
DOE	Department of Energy
dP	Differential Pressure
DPP	Demonstration Power Plant
EDMS	Engineering Data Management System
EHR	Essener Hochdruck Rohrleitung
EIA	Electronic Industry Alliance
EMB	Electro-magnetic Bearing
ENS	Emergency Notification System
EPACT	Energy Policy Act (of 2005)
EPC	Engineering Procurement and Construction
ER	Environmental Requirement
ES&H	Environmental, Safety and Health
ESD	Emergency Shutdown
F	Flow Rate
FDD	Facility Design Description
FHA	Fire Hazard Analysis
FIPS	Federal Information Processing Standards
FM	Factory Mutual
FMS	Facility Monitoring System
FS	Flow rate (switch)
GA	Gas analyzer (composition)
GHEP	Guidelines for Hazard Evaluation Procedures
gpm	Gallon per minute (US)
GR	General Requirements
H ₂	Hydrogen Production Test (Specifically referring to H ₂ SO ₄ Decomposition Reactor Test)
H ₂ SO ₄	Sulfuric Acid
HAZOP	Hazard and Operational Study
HDBK	Handbook
HGD	Hot Gas Duct
HGDs	Hot Gas Ducts
HH	Hot Header
HICS	Helium Inventory Control System
HIPCS	Helium Inventory and Pressure Control System
HIRA	Hazard and Risk Identification Analysis
HLR	High Level Requirement
HMI	Human Machine Interface

Abbreviation or Acronym	Definition
HPS	Helium Purification System
HT	Heat Transfer
HTF	Helium Test Facility
HTGR	High Temperature Gas -Cooled Reactor
HTS	Heat Transport System
HTSE	High Temperature Steam Electrolysis
HTTR	High Temperature Test Reactor
HTTU	High Temperature Test Unit
HV	High Voltage (>132 000V)
HVAC	Heating, Ventilation, & Air Conditioning
HX	Heat Exchanger
HyS	Hybrid Sulfur
I&C	Instrumentation and Control
I/O	Input/Output
IBC	International Building Code
ICC	International Code Council
ICD	Initial Conceptual Design
ICEA	Insulated Cable Engineers Association
IDAPA	Idaho Administrative Procedure Act
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IFC	International Fire Code
IFGC	International Fuel Gas Code
IHX	Intermediate Heat Exchanger
IHXA	Intermediate Heat Exchanger A
IHXB	Intermediate Heat Exchanger B
IMC	International Mechanical Code
IMS	Information Management Systems
INL	Idaho National Laboratory
IPMC	International Property Maintenance Code
ISA	International Society of Automation
ISO	International Organization for Standardization
JB	Junction Box
kg/s	Kilogram per second
kV	Kilovolt (1000 Volts)
kl/h	Kilolitre per hour
kPa	Kilopascal (1000 Pascal)
kW	Kilowatt (1000 Watts)
LCD	Liquid Crystal Display
LCP	Local Control Panel
LRFDS	Load and Resistance Factor Design Specification

Abbreviation or Acronym	Definition
LV	Low Voltage (<1000 V)
MBMA	Metal Building Manufacturers Association
MCC	Motor Control Center
MCR	Mission Critical Requirement
MDB	Main Distribution Board
MES	Manufacturing Execution System
MPa	Megapascal = million Pascal
MTI	M-Tech Industrial (Pty) Ltd.
MV	Medium Voltage (>1000V< 132 000V)
MW	Megawatt (Million Watts)
N	Rotational Speed
NBIMS	National BIM Standards Project Committee
NEC	National Electrical Code
NEMA	National Electrical Manufacturers Association
NEPA	National Environmental Policy Act
NESC	National Electrical Safety Code
NFPA	National Fire Protection Association
NGNP	Next Generation Nuclear Plant
NHI	Nuclear Hydrogen Initiative
NIST	National Institute of Standards and Technology
NQA-1	ASME NQA-1 2000, Quality Assurance for Nuclear Facilities
OPC	Operating Procedure Checklist
OSHA	Occupational Safety and Health Administration
P	Pressure
P&ID	Piping and Instrument Diagram
PBMR	Pebble Bed Modular Reactor
PCDR	Preconceptual Design Report
PCFC	Preconceptual Facility Configurations
PCHX	Printed Circuit Heat Exchanger
PCS	Process Control System
PDA	Potential Deviation Analysis
PDMS	Project Data Management System
PDS	Plant Design System
PFD	Process Flow Diagram
PHA	Preliminary Hazard Analysis
PHTS	Primary Heat Transport System
PLC	Programmable Logic Controller
PLCs	Programmable Logic Controllers
PMN	Support Manager
PRV	Pressure Relief Valve
psig	Pound per square inch gauge

Abbreviation or Acronym	Definition
PSM	Support Modeler
QC	Quality Control
QCP	Quality Control Plan
RCS	Reactivity Control System
RIS	Relational Interface System
RPV	Reactor Pressure Vessel
RSA	Republic of South Africa
SBS	System Breakdown Structure
SCADA	Supervisory Control and Data Acquisition System
scfm	Standard cubic feet per minute
SDD	System Design Description
SDI	Steel Door Institute or Steel Deck Institute
SG	Steam Generator
SHEQ	Safety, Health, Environmental and Quality
SHTS	Secondary Heat Transport System
SI	Sulfur Iodine
SIL	Safety Integrity Level
SIS	Safety Instrument System
SJI	Steel Joist Institute
SNM	Special Nuclear Materials
SPEL	SmartPlant Electrical
SPF	SmartPlant Foundation
SPMat	SmartPlant Material
SPR	SmartPlant Review
SPS	Standby Power System
SR	Safety Requirement
SRM	System Requirement Manual
SSC	Systems Structures and Components
SSDT	Small Scale Development Test
SSS	Site Selection Study
SSSB	Specification for Structural Steel Buildings
STD	Standard
T	Temperature
T&FR	Technical and Functional Requirement
TBC	To Be Confirmed
TBD	To Be Determined
TDL	Technology Development Loop
TDRM	Technology Development Road Map
TEDS	Transducer Electronic Data Sheet
TEMA	Tubular Exchanger Manufacturers Association
THTR	Thorium High Temperature Reactor

Abbreviation or Acronym	Definition
TIA	Telecommunications Industry Association
TRL	Technology Readiness Level
TSR	Technical Safety Requirement
UL	Underwriters Laboratories
UPC	Uniform Plumbing Code
UPS	Uninterruptable Power Supply
UUT	Unit Under Test
V&V	Verification and Validation
VHTGR	Very High Temperature Gas-Cooled Reactor
VL	Valve
VSD	Variable Speed Drive
wb	Wet Bulb
WBS	Work Breakdown Structure
WEC	Westinghouse Electric Company
WE-SA	Westinghouse Electric - South Africa
ϵ	Strain

SUMMARY AND CONCLUSIONS

The Design Criteria Document (DCD) is divided into two sections, the Facility Design requirements, and the Test Loop requirements. The facility design will be the responsibility of the facility designer, who will develop the overall project Facilities Design Criteria.

The facility requirements and criteria identified in this report relate to those required attributes of the facility design that furnish a direct interface with, and support to the Test Loop equipment and operations. The facility designer will take the requirements and criteria as in put to the overall facility DCD.

The overall facility requirements and criteria are found in the Idaho National Laboratory (INL) Engineering Standards document STD-139. Use of this standard ensures compliance to DOE-, Idaho state-, and local building regulations. Details for implementing these criteria will be finalized by the facility designer.

The Plant Design Requirements are those codes, standards and regulations that relate directly to the fabrication, installation, and operation of the CTF Test Loops. These requirements will be augmented as the project development continues.

PURPOSE

The purpose of this document is to identify and describe the design criteria, standards, performance measures, classifications, quality indices, and limits for the design of the Next Generation Nuclear Plant (NGNP) Component Test Facility (CTF) Test Loops, and the Test Loops design requirements imposed on the Facility Design.

3. DESIGN CRITERIA DOCUMENT

3.1 Facility Requirements

The CTF design criteria is primarily based on the requirements found in the INL Engineering Standards document, STD-139 (Reference [3-1]). The requirements and recommendations of this document were compiled to act as the criteria for both the preconceptual and follow on design phases and also contain the applicable additional codes and standards listed throughout STD-139.

This DCD will list applicable and additional codes and standards as part of the section-by-section review of STD-139. Sections of STD-139 are listed in Table 3-1 and more specifically those pertaining to the Test Loop design and interfaces thereof with the facility.

It is important to note that the CTF is not a nuclear facility, thus the regulatory requirements mentioned in STD-139 which are pertinent to nuclear related construction work e.g. ASME III and 10 CFR (Code of Federal Regulation) among others do not apply to the facility design.

Table 3-1: Facility Design Criteria Review Table.

Division Section	Title
DIVISION 1	General requirements
01 1000	General design requirements
01 1010	Architectural
01 1012	Structural
01 1014	Fire protection
DIVISION 2	Existing conditions
DIVISION 5	Metals
05 0000	Welding
05 1000	Structural steel
DIVISION 21	Fire suppression
21 1000	Fire protection systems
21 4000	Fire water storage and distribution
DIVISION 23	Heating, ventilation & air conditioning
23 3000	Comfort heating, ventilation & air conditioning
DIVISION 26	Electrical
26 0000	Electrical design
26 0001	Electrical component markings
26 0500	Raceways
26 0501	Wiring methods and materials
26 0900	Instrumentation
DIVISION 28	Electronic safety & security
28 2600	Emergency notification systems

Division Section	Title
28 3000	Fire alarm systems
DIVISION 33	Utilities
33 7100	Service and distribution Equipment
DIVISION 41	Material processing & handling equipment
41 2200	Cranes and hoists
DIVISION 43	Process gas and liquid handling, purification, and Storage equipment
43 4110	Pressure safety

3.1.1 Division 1– General Requirements

3.1.1.1 General Design Requirements

Table 3-2 lists the identified general codes and standards that need to be adhered to for the general design of the facility.

Table 3-2: General Design Requirements Codes and Standards

Section	Source / subsection	Document number and description
		29 CFR 1910, Occupational Safety and Health Standards
		29 CFR 1926, Safety and Health Regulations for Construction
	DOE Orders	DOE O 420.1B, Facility Safety
		DOE O 430.2A, Departmental Energy and Utilities
	State of Idaho	IDAPA 07.02.06 “Rules Concerning Uniform Plumbing Code” Division of Building Safety
		IDAPA 58.01.16 “Wastewater Rules” State of Idaho Department of Environmental Quality
		IDAPA 58.01.08 “Idaho Rules For Public Drinking Water Systems” State of Idaho Department of Environmental Quality
		IDAPA 07.07.01 “Rules Governing Installation Of Heating, Ventilation, And Air Conditioning Systems” State of Idaho Division Of Building Safety
	INTERNATIONAL BUILDING CODE AMENDMENTS AND ADDITIONS	IBC Section 101 GENERAL
		NEC Substitute NFPA 70, National Electric Code (2005) as specified in ES Division 26 for ICC Electrical Code NFPA 101 Substitute NFPA 101, National Life

Section	Source / subsection	Document number and description
		Safety Code as specified in ES Division 01 for IBC Chapter 10, Egress
INTERNATIONAL BUILDING CODE AMENDMENTS AND ADDITIONS	IBC Section 101 GENERAL	NFPA 54 Substitute NFPA 54, National Fuel Gas Code as specified in ES Division 21 for International Fuel Gas Code
		UPC Substitute Uniform Plumbing Code (2003) as specified in ES Division 33 for International Plumbing Code.
		IPMC For International Property Maintenance Code (IPMC), substitute INL policies and procedures affecting facility maintenance
		IFC For facilities not within the municipal jurisdictions (City of Idaho Falls) substitute applicable NFPA codes and standards for the International Fire Code as follows: NFPA 13 and NFPA 230, in lieu of IFC Chapter 23 NFPA 30, Flammable and Combustible Liquids Code, in lieu of IFC, Chapter 34 NFPA 55, Compressed Gases and Cryogenic Fluids, in lieu of IFC, Chapters 30 and 32. NFPA 58, Liquefied Petroleum Gas Code, in lieu of IFC Chapter 38 NFPA 432, Storage of Organic Peroxide Formulations, in lieu of IFC, Chapter 39 DOE M 440.1-1, Explosives Safety Manual and NFPA 495, Explosives Materials Code, in lieu of IFC, Chapter 33 NFPA 430, Liquid and solid Oxidizers, in lieu of IFC, Chapter 40 NFPA 484, Combustible metals, in lieu of IFC, Chapters 36 and 41
INTERNATIONAL BUILDING CODE AMENDMENTS AND ADDITIONS	IBC Section 103 DEPARTMENT OF BUILDING SAFETY	Creation of enforcement agency. Substitute: the department of building safety (a virtual department) is hereby created and the official in charge shall be known as the INL Engineering Board.
		Deputies. Add the following: At INL the Fire

Section	Source / subsection	Document number and description
		Marshal is appointed for fire protection and life safety matters, the Electrical Authority Having Jurisdiction) AHJ is appointed for NEC related matters, and the Pressure AHJ is appointed for pressure system related matters.
INTERNATIONAL BUILDING CODE AMENDMENTS AND ADDITIONS	IBC Section 104 DUTIES AND POWERS OF BUILDING OFFICIAL	IBC Section 104.2 Applications and Permits Traditional applications and permits are not used at INL. Therefore, instead of the INL Engineering Board receiving applications and issuing permits for the erection and alteration, demolition and moving of buildings and structures, INL shall control building activities through the internal design control process (LWP-10400).
		IBC Section 104.5 Identification Delete section; does not apply to the INL.

3.1.2 Division 5 – Metals

3.1.2.1 Welding Requirements

Table 3-3 lists the reference codes and standards identified in the reference [3-1] that needs to be adhere to.

Table 3-3: Welding Codes and Standards

Document number	Description
TBD	American Welding Society Welding Codes
TBD	Welding Manual

All the other points of welding as highlighted in reference **Error! Reference source not found.** are applicable. These include:

- General
- On-site welding
- Off-site welding
- Execution
- Non-destructive examination requirements

3.1.2.2 Structural Steel

The structural design must be based on the following provisions for structural support, reliable operation, and hazard protection for the Test Loops:

- The superstructure must provide adequate support for the overhead cranes, and other material handling equipment needed to support installation, operating, and maintenance activities.
- Preliminary evaluation of the building and its function indicate that a DOE STD-1020 performance category of PC-2 is appropriate for the seismic design and other hazards associated with natural phenomena. The ultimate classification is subject to the results of a hazard analysis that will be performed during the follow on design phase.
- The building equipment layouts and loads are shown in the System Requirement Manual (SRM) - Section 4 (reference [3-2]).

Table 3-4 lists the specific codes applicable to the structural design over and above the requirements of STD-139. This list may expand as the design progresses.

Table 3-4: Structural Steel Codes and Standards

Document number	Description
DOE STD-1020	Natural Phenomena Hazards Design and Evaluation Criteria for Department of Energy Facilities
DOE STD-1021	Natural Phenomena Hazards Performance Categorization Guidelines for Structures Systems and Components
AISC – SSSB	American Institute for Steel Construction - Specification for Structural Steel Buildings, Allowable Stress Design, Plastic Design
AISC - LRBFDS	American Institute for Steel Construction - Load and Resistance Factor Design Specification for Structural Steel Buildings
AISI	American Iron and Steel Institute - Specification for the Design of Cold-Formed Steel Structural Members
MBMA	Metal Building Systems Manual
SDI – DDMO3	Steel Deck Institute (SDI) - Diaphragm Design Manual
SDI - No. 31	Steel Deck Institute (SDI) - Design Manual for Composite Decks, Form Decks and Roof Decks
DOE Order 420.1B	Facility Safety
SJI	Standard Specification for Open Web Steel Joists

3.1.3 Division 21 – Fire Suppression

3.1.3.1 Fire Protection Systems

The following describes the interface between the Test Loops and the Fire Protection system:

- The Test Loop equipment and activities will result in a building occupancy rating of F2.
- The Test Loops do not introduce any fire hazards to the building that would not be found in a typical, heavy machine assembly area; such as welding and grinding activities, or transient combustible materials required for maintenance activities.
- A detailed fire hazard analysis shall be conducted in follow on design to quantify flammable and combustible materials, potential ignition sources, and overall fire hazards.

Table 3-5 lists the specific codes applicable to the Fire Protection design. This list may expand as the conceptual design progresses.

Table 3-5: Fire Protection Codes and Standards

Document number	Description
NFPA 1	Fire Prevention Code 2006 Edition
NFPA 10	Portable Fire Extinguishers
NFPA 13	Installation of Sprinkler Systems
NFPA 14	Standard for the Installation of Standpipe and Hose Systems
NFPA 30	Flammable and Combustible Liquids Code 2008 Edition
NFPA 45	Standard on Fire Protection for Laboratories Using Chemicals 2004 Edition
NFPA 55	Standard for the Storage, Use, and Handling of Compressed Gases and Cryogenic Fluids in Portable and Stationary Containers,
NFPA 70	National Electrical Code 2008 Edition
NFPA 70E	Standard for Electrical Safety Requirements for Employee Workplaces 2004 Edition
NFPA 72	National Fire Alarm Code 2007 Edition
NFPA 75	Standard for the Protection of Electronic Computer/Data Processing Equipment 2003 Edition
NFPA 80	Standard for Fire Doors and Fire Windows 2007 Edition
NFPA 99C	Standard on Gas and Vacuum Systems 2005 Edition
NFPA 101	Life Safety Code 2006 Editions
NFPA 110	Standard for Emergency and Standby Power Systems 2005 Edition
NFPA 111	Standard on Stored Electrical Energy Emergency and Standby Power Systems 2005 Edition
NFPA 220	Standard on Types of Building Construction 2006 Edition
NFPA 221	Standard for Fire Walls and Fire Barrier Walls 2006 Edition
NFPA 780	Standard for the Installation of Lightning Protection Systems 2008 Edition

3.1.4 Division 23 – Heating, Ventilation & Air Conditioning

3.1.4.1 Comfort Heating, Ventilation And Air Conditioning

The safe and reliable operation and maintenance of the Test Loops require that the HVAC system provide the following:

- Ambient design temperatures per reference [3-1] are: Winter -28°C (-19°F), Summer 35°C (95 °F) db and 16 °C (61° F) wb. Periods during which these values are to be exceeded make up a small percentage of the total life of the facility and will therefore have minimal impact on test loop operations and maintenance activities.
- The HVAC systems must maintain temperatures in the high-bay area at a minimum temperature of 18°C (65°F) during winter operations and a maximum temperature of 6°C (10°F) above ambient in the working spaces during summer. The heat releases from the process equipment can be found in reference [3-2]. Supply air shall be delivered to those areas of the building where people are expected to be working and exhausted be exhausted high in the space.
- Additional strategically located or portable spot mechanical cooling may be required in certain work spaces to support maintenance activities and phased test loop equipment installation and commissioning. Details of this requirement shall be determined during the design process.
- Electric rooms shall be air conditioned to maintain maximum temperatures below 30°C (85°F) to ensure equipment reliability.
- Control rooms and administrative support areas shall be conditioned spaces per reference [3-1].

Table 3-6 lists the specific codes applicable to the HVAC design. This list may expand as the conceptual design progresses.

Table 3-6: HVAC Design Codes and Standards

Document number	Description
IMC	International Mechanical Code.
IFGC	International Fuel Gas Code.
NFPA 90A and 90B	National Fire Protection Agency standards
DOE 420.1B	Facility Safety
ASHRAE 90.1	Energy Standard for Buildings Except Low-Rise Residential
ASHRAE 62	Ventilation for Acceptable Indoor Air Quality.
IDAPA 07.07.01	Rules Governing Installation Of Heating, Ventilation, And Air Conditioning Systems, Division Of Building Safety

3.1.5 Division 26 – Electrical

3.1.5.1 Electrical Design

The Test Loops require the following from the Electrical system:

- Provide electric power to the process at the voltages and amperages required by the process equipment. See the one-line diagram in reference [3-2] .
- Provide appropriate protection for electrical components including wiring and cabling based on the expected typical ambient conditions during test runs and during failure scenarios.
- For motors up to ½ hp, provide 120 volt power. For motors ½ to 250 hp, provide 480 V, 3hp power. Motors over 250 hp will require 4160V or 13.8 kV, 3 phase power.
- Provide Standby or UPS power for safe shut-down of designated systems and components during loss of off-site power or from a single point failure within the electrical system.

Table 3-7 lists the specific codes applicable to the Electric design. This list may expand as the conceptual design progresses

Table 3-7: Electrical Design Codes and Standards

Document number	Description
ANSI/NFPA 70	National Electrical Code (NEC)
ANSI-C2,	National Electrical Safety Code (NESC)
NEMA Standards	National Electrical Manufacturers Association standards
UL	UL Standards and Product Directories
FM	FM Approval Guide, and FM Loss Prevention Data Sheets
ANSI/IEEE 242	Recommended Practice for Protection and Coordination of Industrial and Commercial Power Systems
ANSI/IEEE 493	Recommended Practice for Design of Reliable Industrial and Commercial Power Systems
DOE-HDBK-1092	Electrical Safety
DOE-HDBK-1132	Design Considerations
DOE O 420.1	Facility Safety Implementation Guide for Non-reactor Nuclear Safety Design Criteria and Explosives Safety Criteria
NFPA 780	Lightning Protection Code
IEEE-STD 446	IEEE Recommended Practice for Emergency and standby Power Systems for Industrial and Commercial Applications, Orange Book
IEEE-STD 519	IEEE Recommended Practice and Requirements for the Harmonic Control in Electrical Power Systems
IEEE-STD 141	IEEE Recommended Practice for Electric Power Distribution

Document number	Description
	for Industrial Plants, Red Book
IEEE-STD 242	IEEE Recommended Practice for Protection and Coordination of Industrial and Commercial Power, Buff Book
NFPA 110	Emergency and Standby Power Systems
NFPA 111	Stored Electrical Energy Emergency and Standby Power Systems

3.1.5.2 Electrical Component Marking

Comply directly with the requirements found in reference [3-1].

3.1.5.3 Raceways

Comply directly with the requirements found in reference 3.

3.1.5.4 Wiring Methods and Materials

Comply directly with the requirements found in reference [3-1].

3.1.5.5 Instrumentation

Table 3-8 lists the instrumentation codes and standards identified in the INL standard that need to be adhere to.

Table 3-8: Instrumentation Codes and Standards

Document number	Description
STD-139-011000	General Design Requirements
STD-139-26000	Electrical Design
STD-139-26 0900	Instrumentation
IEEE 315-75 & 315A-86	Graphic Symbols for Electrical and Electronics Diagrams
ISA	Standards and Practices for Instrumentation

Additional requirements are listed in INL STD-139 (reference [3-1]) to which the contractor needs to comply.

3.1.5.6 Emergency Notification Systems

Table 3-9 lists the emergency codes and standards identified in reference [3-1] that need to be adhere to.

Table 3-9: Emergency Codes and Standards

Document number	Description
STD-139-28 2600	Emergency Notification Systems
NFPA-101	Life Safety Code
NFPA-72	National Fire Alarm Code
IBC	ICC International Building Code

3.1.6 Division 33 – Utilities

The Facility design, which refer to the high bay and associated utilities, shall cater for the following Test Loops requirements. The quantities and pressures shown are based on information developed during the preconception design and are subject to change as the design matures during follow-on phases. It is proposed that the facility designer adds a 20% margin to the values in the final tabulation to allow for uncertainties.

- **Cooling water:**
Provide 20°C (68°F) cooling water to the equipment residing in the table shown in reference [3-2]. The water will be returned at 45°C (113°F)
- **Service air**
Provide 0.27 kg/s (500 scfm) of compressed air at 1035 kPa (150 psig) for general industrial use. Quantities for service air to be confirmed in follow-on design.
- **Instrument air**
Provide 0.10 kg/s (200 scfm) of instrument quality [-40°C (-40°F) dew point, particulate free, low hydrocarbon] compressed air at 1034 kPa (150 psig). Quantities for instrument air to be confirmed in follow-on design.
- **Process air**
Provide 0.76 kg/s (1400 scfm) of 5600 kPa (812 psig) of compressed air at 1760 °C (3500 °F) to the HTSE test station heat exchanger. The process Air quality will be similar to the instrument air. The quality will be -40°C (-40°F) dew point, particulate free, hydrocarbon free. This needs to be confirmed in follow on design.
- **De-ionized water**
Provide 38 l/min (10 gpm) (maximum flow) of demineralized or de-ionized water for steam system make-up to the Component Qualification Loop 1 (CQL1) skid, and other specific tests. Exact water chemistry requirements to be determined during follow-on design.
- **Process water**

Provide 95 l/m (25 gpm) make-up from potable grade water at 420 kPa (60 psig) for general industrial use. Temperature range shall be from ground water temperature to ambient temperature.

- **Process Steam and Condensate**
Provide steam at 5600 kPa and 396°C (810 psig and 755°F) for use by the HTSE test station heat exchanger. Approximately 0.62 kg/s (4900 lb/hr) will be required. The precise temperature requirement is not clearly defined and should be clarified in the follow-on design phases. This steam should be returned to the facility after use.

3.1.6.1 Service and Distribution Equipment

Comply directly with the requirements found in reference [3-1].

3.1.7 Division 41 – Material Processing and Handling Equipment

The facility design will include provisions for the following:

- Provide adequate area in the building for lay-down of systems, structures and components during construction and installation activities. Coordinate efforts with the equipment designers during the planning stage of final design.
- Provide portable material handling equipment such as fork lifts and portable cranes identified and sized during conceptual design. Provide storage and battery charging facilities for this equipment.
- Provide cranes and hoists as described below

3.1.7.1 Cranes and Hoists

Provide bridge cranes in both bays of the high-bay area along with jib cranes at locations specified by the equipment designers during conceptual design development.

The weight and sizes of the components to be lifted and moved will be determined during the detail design phase. Initial weights are estimated in reference [3-2].

Table 3-10 lists the Crane and Hoist codes and standards as identified in the INL standard that need to be adhered to.

Table 3-10: Cranes and Hoist Codes and Standards

Document number	Description
ASME B30.2	Overhead and Gantry Cranes
ASME B30.16	Overhead Hoists (Underhung)

Document number	Description
ASME B30.17	Overhead and Gantry Cranes (Top Running Bridge, Single Girder, Underhung Hoist)
ASME B30.20	Below-The-Hook lifting Devices
CMAA 70	Specification for Electric Overhead Travelling Cranes
CMAA 74	Specification for Top Running and Under Running Single Girder Electric Overhead Travelling Cranes

3.1.8 Process Gas and Liquid Handling, Purification, And Storage Equipment

3.1.8.1 Helium Inventory and Control System

The Helium Inventory and Control System (HICS) including the helium purification system will be developed as a part of the follow-on design effort, so no specific interface requirements are identified at this time.

3.1.8.2 Hydrogen

The hydrogen process equipment and storage areas are located in a separate building and are not included in the CTF building.

3.1.8.3 Process Safety

Process safety will include protection against the effects leaks in the high temperature, high pressure helium, steam, high point vents, low point drains and air systems piping and components. A Preliminary Hazard Analysis has been conducted in accordance with reference [3-4] as shown in reference [3-2]. Additional hazard analyses and mitigations shall be conducted in follow-on design.

3.2 Test Loop Requirements

3.2.1 Electrical

3.2.1.1 Electrical Design

This section adds additional codes and standards that are applicable including the codes and standards as applicable in 3.1.5 Division 26 – Electrical.

3.2.1.2 General Facility Electrical Codes and Standards

Table 3-11 lists the general facility codes and standards that need to be adhered to.

Table 3-11: General Facility codes and standards

Document number	Description
NFPA 70	National Electric Code (NEC)
NFPA 70E	Electrical Safety Requirements for Employee Workplaces
IEEE-C2	National Electrical Safety Code
DOE-HDBK-1092 DOE HDBK	Electrical Safety
IEEE-803	IEEE Recommended Practice for Unique Identification in Power Plants and Related Facilities

3.2.1.3 Standby Power System Codes and Standards

Table 3-12 lists the standby power system codes and standards that need to be adhered to.

Table 3-12: Standby power systems codes and standards

Document number	Description
IEEE-STD 446	IEEE Recommended Practice for Emergency and Standby Power Systems for Industrial and Commercial Applications, Orange Book
IEEE-STD 519	IEEE Recommended Practice and Requirements for the Harmonic Control in Electrical Power Systems
IEEE-STD 141	IEEE Recommended Practice for Electric Power Distribution for Industrial Plants, Red Book
IEEE-STD 242	IEEE Recommended Practice for Protection and Coordination of Industrial and Commercial Power, Buff Book
IEEE-336	IEEE Standard Installation, Inspection and Testing Requirements for Power, Instrumentation, and Control Equipment at Nuclear Facilities
NFPA 110	Emergency and Standby Power Systems

Document number	Description
NFPA 111	Stored Electrical Energy Emergency and Standby Power Systems
Article 701 of the NEC	Legally Required Standby Systems
DOE Standard 3003	Backup Power Systems for DOE Facilities

3.2.1.4 Uninterruptible Power Supply System Codes and Standards

Table 3-13 lists the uninterruptible codes and standards that need to be adhered to.

Table 3-13: Uninterruptible power supply system codes and standards

Document number	Description
DOE-SPEC-3021	Uninterruptible Power Supply (UPS) Systems
DOE standard 3003	Backup Power Systems for DOE Facilities
IEEE-519	Recommended Practices for Harmonic Control in Power Systems
IEEE-944	IEEE recommended practice for the application and testing of Uninterruptible Power Supplies for Power Generating Stations
NEMA PE-1	Uninterruptible Power Systems (UPS) - Specification and Performance Verification
NFPA 79	Electrical Standard for Industrial Machinery 2007 Edition
NFPA 111	Standard on Stored Electrical Energy Emergency and Standby Power Systems
NFPA 496	Standard for Purged and Pressurized Enclosures for Electrical Equipment 2008 Edition
Article 700.12(A) of the NEC	Emergency Systems

The UPS shall be designed to maintain independence from the normal power system (after the overcurrent protective device feeding the UPS) and avoid single-point and common mode failures, particularly from maintenance outages, earthquakes, fires, flooding, or spraying by fire sprinklers.

The UPS wiring, including the normal power feeder circuit, will occupy separate conduit from other power systems and general wiring or provide at least a 25 mm (1 inch) physical separation when within the same enclosure (see IEEE-603, Section 5.6).

3.2.1.5 Electric Motors

Table 3-14 lists the electric motor codes and standards that need to be adhered to.

Table 3-14: Electric motor codes and standards

Document number	Description
NEMA MG-2	Safety Standard for Construction and Guide for Selection, Installation, and Use of Electric Motors

Document number	Description
IEEE-C37.96	IEEE Guide for AC Motor Protection

3.2.1.6 Grounding and Lightening Protection

All gas and air handling equipment, filter housings, gas supply, and handling piping will be solidly grounded (Refer to NFPA 77).

The utility will provide a substation grounding system as per IEEE-80.

The lightning protection system will be designed to the requirements of NFPA 780.

Grounding shall follow the requirements of the NEC and should follow the recommendations of IEEE-142.

Table 3-15 lists the electric grounding codes and standards that need to be adhered to.

Table 3-15: Electric grounding codes and standards

Document number	Description
IEEE-80	Guide for Safety in AC Substation Grounding
IEEE-Std-142	Recommended Practice. for Grounding of Industrial and. Commercial Power Systems
IEEE-Std-1100	Recommended Practice for Powering and Grounding Electronic Equipment. Status
IEEE-Std-399	Recommended Practice for Industrial and Commercial Power Systems Analysis
NFPA 77	Recommended Practices on Static Electricity
NFPA 780	Standard for Installation of Lightning Protection

A ground mat safety study shall be provided following the recommendations of IEEE-399 chapter 14.

3.2.1.7 Electrical Distribution

Conduits shall used for distribution in the test loop areas to protect the electric cables from potential high pressure gas and steam leaks. All electrical cable in closed environments shall be of the non-toxic kind.

Provide appropriate protection for electrical components including wiring and cabling based the expected typical ambient conditions during test runs and during failure scenarios.

The electrical system shall be sized to give 25% spare capacity for future load.

Energy conservation shall be coordinated with the other engineering design activities.

3.2.1.8 Electrical Classification

If hazardous gasses and dust are introduced into the facility, the electric classification of those affected areas of the plant or building must be governed by local legislation, standards or specifications. The decisions about using these hazardous gasses and dust will be made during conceptual design development phase.

3.2.2 Steel Structures

The structural steel of the test loops will adhere to the requirements as set out in section 3.1.2.2 Structural Steel

3.2.3 Process Equipment Specifications

3.2.3.1 Vessels

Table 3-16 lists the Vessel design codes and standards that need to be adhered to.

Table 3-16: Vessel design codes and standards

Document number	Description
ASME VIII div 1	ASME Boiler and Pressure Vessel Code, Section VIII, Division 1: Rules for Construction of Pressure Vessels
ASME VIII div 2	ASME Boiler and Pressure Vessel Code, Section VIII, Division 2: Alternative Rules
NFPA 86	Standard for Ovens and Furnaces 2007 Edition
IDAPA 17.06	Boiler and Pressure Vessel Safety Rules

3.2.3.2 Piping

Table 3-17 lists the Piping design codes and standards that need to be adhered to.

Table 3-17: Piping design codes and standards

Document number	Description
Division 40 ASME B31.1	Power Piping Design & Fabrication
Division 40 ASME B31.3,	Process Piping Guide
IDAPA 17.06	Boiler and Pressure Vessel Safety Rules

3.2.3.3 Coolers

Table 3-18 lists cooler codes and standards that need to be adhered to.

Table 3-18: Cooler codes and standards

Document number	Description
TEMA	Standards of the Tubular Exchanger Manufacturers Association - 9th edition

3.2.3.4 Heat Exchanger

Table 3-19Error! Reference source not found. lists heat exchanger codes and standards that need to be adhered to.

Table 3-19: Heat exchanger standards

Document number	Description
TEMA	Standards of the Tubular Exchanger Manufacturers Association - 9th edition

3.2.3.5 Cooling Towers

Table 3-20 lists the cooling tower codes and standards that need to be adhered to.

Table 3-20: Cooling tower codes and standards

Document number	Description
NFPA 214	Standard on Water-Cooling Towers 2005 Edition

3.2.3.6 Pumps

Table 3-21 lists the pump codes and standards that need to be adhered to.

Table 3-21: Pump codes and standards

Document number	Description
ASME B73.1, 73.2, 73.3	Centrifugal pumps for chemical service
API 610	Centrifugal Pumps
ISO 5199:2002	Technical specifications for centrifugal pumps - Class II
BS 5257:1975	Specification for horizontal end-suction centrifugal pumps (16 bar)

3.2.3.7 Compressors

Table 3-22 lists the compressor codes and standards that need to be adhered to.

Table 3-22: Compressor codes and standards

Document number	Description
API 672	Air Compressors

3.2.3.8 Valves

Table 3-23 lists the valve codes and standards that need to be adhered to.

Table 3-23: Valve codes and standards

Document number	Description
ASME/ANSI B16.5	Pipe Flanges and Flanged Fittings
ASME B16.34	Valves - Flanged, Threaded, and Welding End
ASME/ANSI B16.38	Large Metallic Valves for Gas Distribution
ISA-75.01.01-2002 (IEC 60534-2-1 Mod)	Flow Equations for Sizing Control Valves.

3.2.3.9 Flanges

Table 3-24 lists the flange codes and standards that need to be adhered to.

Table 3-24: Flange codes and standards

Document number	Description
ASME/ANSI B16.5	Pipe Flanges and Flanged Fittings
ASME/ANSI B16.36	Orifice Flanges
ASME/ANSI B16.42	Ductile Iron Pipe Flanges and Flanged Fittings, Classes 150 and 300
ASME/ANSI B16.47 - 1996 -	Large Diameter Steel Flanges: NPS 26 through NPS 60

3.2.4 Orifices and Venturi

Table 3-25 lists the orifice and venturi codes and standards that need to be adhered to.

Table 3-25: Orifice and Venturi codes and standards

Document number	Description
ISO 5167-1: Part 1	Measurement of fluid flow by means of pressure differential devices inserted in circular-cross section conduits running full - General principles and requirements
ISO 5167-2: Part 2	Orifice plates
ISO 5167-3: Part 3	Nozzles and Venturi nozzles
ISO 5167-4: Part 4	Venturi tubes

3.2.5 Control

3.2.5.1 Control

Table 3-26 lists the control codes and standards that need to be adhered to.

Table 3-26: Control codes and standards

Document number	Description
IEEE-1046	Application Guide for Safety for Software in Programmable Components
DOE STD 1039	Guide to Good Practices for Control of Equipment and System Status
IEEE-1050	IEEE Guide for Instrumentation Control Equipment Grounding in Generating Stations

3.2.5.2 Function Blocks

Function blocks in the control software shall adhere to IEC 61499.

3.2.5.3 Programmable Logic Controller

The control system architecture shall be determined in follow-on design phases. If PLCs are selected the following shall apply.

PLC's shall conform to the IEC 61131 standard which is divided into several parts:

- Part 1: General information
- Part 2: Equipment requirements and tests
- Part 3: Programming languages
- Part 4: User guidelines
- Part 5: Messaging service specification
- Part 6: Communications via field bus (Awaiting completion of field bus standards.)
- Part 7: Fuzzy control programming
- Part 8: Guidelines for the application and implementation of programming languages

3.2.5.4 Safety

Functional safety of electrical / electronic / programmable electronic safety-related systems (E/E/PES) shall adhere to IEC 61508

Safety Instrumented Systems shall adhere to IEC 61511.

The E-Stop system shall meet the requirements of NFPA 79, Section 7-6 and ANSI B11.19, Section 5.2 and 5.5.

3.2.5.5 Data Security

Experimental data and experimental data collection shall be kept under access control to assure that instrument data and control signals associated with proprietary components are protected. This data protection shall include assurance that a single failure cannot cause the loss of all data and that stored data cannot be modified (FIPS 113, 191, 200; IEEE 1619)

Information shall be secured in accordance with the applicable requirements of the Federal Information Security Management Act, Publications 199 and 200 and supporting NIST guidelines: SP 800-18, -30, -37, -53, -53A, -59, and -60.

3.2.5.6 Quality

The quality requirements of ASME-NQA-1 2000 “Quality Assurance for Nuclear Facilities” will be applied to data collection and storage. All data will be completely traceable to the source, time, and method it was produced. Instrumentation hardware and software for the data management system will be under configuration control per NQA-1 2000.

3.2.5.7 Reliability

IEEE-379 - Standard Application of the Single-Failure Criterion to Nuclear Power Generating Station Safety Systems.

3.2.5.8 Actuators

To be determined in follow on design phases.

3.2.6 Instrumentation

3.2.6.1 General

Instrumentation will be designed and specified in accordance with a number of IEEE (Institute of Electrical and Electronic Engineers), and ISA (Instrument Society of America) standards

All instruments shall be highly accurate, reliable and procured to meet the intent of ASME NQA-1 2000, “Quality Assurance for Nuclear Facilities” and the vendor will provide verification that the instruments meets the intent of ASME NQA-1 2000. The requirements for numerical values for accuracy, error, and reliability of instrumentation shall be developed in follow-on design phases.

3.2.6.2 Calibration

Instruments will have calibrations traceable to National Institute of Standards and Technology (NIST) and shall be in accordance with NQA-1 2000.

3.2.7 Safety Requirement

3.2.7.1 Health And Safety

Table 3-27 lists the health and safety codes and standards that need to be adhered to.

Table 3-27: Health and safety codes and standards

Document number	Description
DOE order DOE-O-420.1B	Facility safety
OSHA standards	Life Safety Code
NFPA 101	Life Safety Code 2006 Editions
ANSI B11-19	American National Standard for Machine Tools - Safeguarding when referenced by the other B11 Machine Tool Safety Standards - Performance Criteria for design, construction, care, and operation
IEC 61508	Functional Safety - Safety Related Systems
UL-1998	UL Standard for Safety for Software in Programmable Components
AICHE GHEP	Guidelines for Hazard Evaluation Procedures , Center for Chemical Process Safety, Third Edition

3.2.7.2 Environmental Requirements

Table 3-28 lists the environmental requirements codes and standards that need to be adhered to.

Table 3-28: Environmental requirements codes and standards

Document number	Description
Doe Order DOE O 450.1	Environmental protection program

3.3 Other Requirements

3.3.1 Standard Design Requirements

Table 3-29 lists the standard design requirements that need to be adhered to.

Table 3-29: Standard design requirements.

Document number	Description
DOE O 414.1C	Quality assurance

3.3.2 Drawing Standards

3.3.2.1 International Society of Automation Symbols

Table 3-30 lists the identified ISA symbols that need to be adhere to.

Table 3-30: ISA Symbols.

Document number	Description
ISA S5.1	Instrumentation Symbols and Identification
ISA S5.3	Graphic Symbols for Distributed Control/Shared Display Instrumentation, Logic and Computer Systems
ISA S5.4	Instrument Loop Diagrams
ISA S5.5	Graphic Symbols for Process Displays

3.3.2.2 Technical Drawing Standard

Table 3-31 list the identified technical drawing standards that need to be adhere to.

Table 3-31: Technical drawing standards

Document number	Description
STD-10011	Drawing requirements standard

3.3.3 CTF Project Data Management Requirements

This portion of the report discusses the design code of record document, software design code of record and coordination with the electronic design data management system (industry references such as Building Information Management (BIM) or Project Data Management System (PDMS) etc.) as indicated in section 3.3 of the task Statement Of Work, reference [3-3]. This subject is commonly referred to as Information Management Systems (IMS) or Computer Aided Engineering (CAE) and usually comprises Engineering Data Management System (EDMS) for project records management, intelligent 3D and 2D Computer Aided Design (CAD), engineering applications software, Equipment Purchasing and Material tracking software, etc.

This section will discuss data management and engineering application software usage during the conceptual design phase leading up to the issue of this report. It will also address recommendations and expectations to be passed on the Engineering Procurement and Construction (EPC) contractor performing services in the conceptual and follow-on design phases to be integrated with procurement and construction activities leading to startup and operations of the facility.

3.3.3.1 CTF Preconcept Design Phase Systems Engineering Software and Applications

During the course of the project, various types of engineering analyses will be performed. There is an extensive market of engineering and other required software available to aid in analysis and project administrative efforts. The WEC team has chosen to use applications for which the team participants already maintain required licenses for use on other ongoing projects including those supporting the PBMR Demonstration Power Plant (DPP) program in RSA.

Application software used during the CTF Preconcept Design (PCD) phase is listed in Table 3-32. It is anticipated that the final suite of software applications that will comprise the design code of record will be selected by the EPC project team that is selected for the ongoing phases of the CTF project.

Table 3-32: CTF PCD Phase software usage

Engineering/ Design Product	Tool	Final document format
Schedule	Microsoft Project Primavera	Acrobat pdf
Spending Plan	Microsoft Excel Primavera	Acrobat pdf
Project Communication	Prolog Manager Prolog Website	N/A
Requirements Document	Microsoft Word	Acrobat pdf
Presentations	Microsoft PowerPoint	Acrobat pdf
Plans and Procedures	Microsoft Word	Acrobat pdf
Requirements Verification Matrix	Microsoft Excel	Acrobat pdf
Process Flow diagrams	Microsoft Visio	Acrobat pdf
Piping and instrumentation diagram	Microsoft Visio	Acrobat pdf
Drawings/Models	SolidWorks 2008 Bentley Autoplant	Parasolid, Acrobat pdf
Drawings	AutoCAD 2006	AutoCad dwg,

Engineering/ Design Product	Tool	Final document format
	Bentley viewer	Acrobat pdf
Engineering Analysis	Engineering Equation Solver (EES)	Acrobat pdf
Engineering Analysis (Thermo-Hydraulic)	Flownex®	Output text file .txt
Engineering Analysis	Microsoft Excel	Acrobat pdf, (*.xls)
Pipe Stressing	Caesar II	
PDM/CM (EDMS)	ShawXNet	Project Records

Products and deliverables completed during the conceptual design phase will be archived in the project records in PDF and native format, for future use by the program. It should be noted that the native format files may have some limited value for use as a departure point for follow-on conceptual design work. These computer files can be made available to the follow-on project team as needed, but should be recognized as early conceptual in nature.

Other Software applications that are being developed and used for the DPP program and that may be used in the NGNP program are discussed in the WEC NGNP Technology Development Road Mapping Section 10: Software Code Verification and Validation, reference [3-5].

3.3.3.2 CTF Follow-On Phase Requirements

As the CTF enters the conceptual phase, the selected EPC project team in conjunction with INL (BEA) must reach consensus on CAE or IMS applications that will be used. The CTF is a somewhat unique project that will comprise a multipurpose facility with support utilities and spacious accommodations for the NGNP R&D engineering team to operate the test loops and collect data that will be used to validate the NGNP component performance. The primary focus of the work will certainly be on the design and then operation of test loops and the components being tested. The life cycle of these test loops is similar to systems in a power or process facility. These are not systems that would generally be considered in applications of Building Information Management (BIM) as is promulgated by the National BIM Standards Project Committee (NBIMS). BIM more often pertains mainly to facility life cycle management and is gaining recognition in the commercial building Architecture – Engineering and Construction (A-E-C) community. The emphasis of BIM standards is more on building space management, energy efficiency and management, and facility maintenance management.

The primary focus of attention within the CTF will be the design construction and operations of the test loops themselves in accordance with recognized power and process industry standards. The IMS or CAE applications that are expected to be used by the EPC

contractor in the follow on phases will be similar to those currently being used in the commercial nuclear power, fossil power and process industries.

The EPC contractor will be expected to develop and implement plans and procedures for design and configuration management throughout the project life cycle. An IMS or CAE plan must be submitted early after contract award to identify all design and engineering application software that will be used and the time phasing for implementation and integration, as well as the project IMS organization required for support. Funding constraints will naturally have significant impact on this effort.

Procedures must establish the work methods including standards and conventions for file naming, component names, and document names. Procedures will address use of 2D and 3D intelligent CAD, engineering applications, and EDMS systems early in conceptual design. There is also a significant effort required to develop and implement the engineering databases required for support of intelligent graphics. Later in the design process data systems to support purchasing and scheduling of construction activities will be introduced and integrated with the CAD systems.

The following are typical software applications that can form the framework for applications used by leading EPC contractors. These are just examples, but are representative of the capability of commonly utilized applications. Each EPC contractor will have its preferred suite of applications that perform similar functions.

3.3.3.2.1 SMARTPLANT PROCESS AND INSTRUMENTATION DIAGRAM P&ID

SmartPlant Piping and Instrumentation Diagram (P&ID) helps to reduce project risk by providing a more efficient way to create, access, and manage P&IDs and associated information. This is a rule-based engineering solution that creates intelligent P&IDs while building a comprehensive data model. It helps to develop and manage P&IDs with a focus on the plant asset rather than the document representation and exercises rules and connectivity checks to speed the entire engineering process without compromising design quality or integrity.

3.3.3.2.2 PLANT DESIGN SYSTEM (PDS)

Intergraph Plant Design System (PDS) is the software that contains a comprehensive suite of integrated design applications used to produce 3D models. It is based on an underlying CAD engine of Bentley MicroStation. The software establishes a framework of information and standards intended to support the efficient use of 2D and 3D CAE tools by all disciplines on the Project.

The PDS 3D modeling environment is built on a reference database (RDB) which emulates 3D graphics based on sets of rules. The 3D interfaces contained in the software are PD_Design used for modeling piping, PD_Equip for modeling mechanical, electrical and HVAC equipment, EE_RWAY used for modeling cable tray and conduit, PE_HVAC

for modeling ductwork systems and FW_PLUS which is the structural interface used for modeling concrete and structural members.

The PDS suite is equipped with the functionality to query the Oracle data through a Relational Interface System (RIS), to conduct dynamic reviews and walkthroughs to review the current design in an interactive environment, interference checking to manage clashes prior to fabrication, data reporting for accurate material take offs and drawing production for creating construction quality arrangement drawings and piping isometrics.

3.3.3.2.3 SMARTPLANT REVIEW (SPR)

SmartPlant Review (SPR) is the complete visualization environment for interactively reviewing and analyzing large, complex 3D models of process and power plants. The software provides all the visualization tools needed to review designs during engineering, construction, or maintenance. SPR supports the entire plant design workflow. During design, SPR provides views from any perspective so layouts can be reviewed more effectively than with traditional engineering models. To facilitate project approvals by management and clients, SPR allows clear presentations that technical and non-technical audiences can easily understand.

3.3.3.2.4 SMARTPLANT ELECTRICAL (SPEL)

SmartPlant Electrical (SPEL) is an application designed to address the specific requirements of electrical discipline designers and engineers. It will be used on the Project to produce electrical one-lines, panel schedules, schematic/wiring diagrams and project motor and electrical load lists.

3.3.3.2.5 SMARTPLANT MATERIALS (MARIAN)

Intergraph's SmartPlant Materials Management Solution will be used for Materials Management activities throughout the lifetime of the project execution phase. The SmartPlant Material (SPMat) application uses web based Oracle forms to provide users with access to the application allowing a broad range of materials management activities including engineering design requirement gathering through defining and importing bills of materials and generating requisitions; procurement and supply chain functions such as supplier management, inquiries, purchase orders, expediting, inspection, traffic, and logistics; construction and site activities such as receiving, inventory management with warehousing, material issuing, and construction material planning through forecasts and reservations.

3.3.3.2.6 SMARTPLANT FOUNDATION (SPF)

SmartPlant Foundation (SPF) is an electronic library capable of storing all plant life cycle data. SPF will utilize a publishing architecture to build a comprehensive data repository from SmartPlant P&ID, SPEL and PDS. This data can be used with viewing

capabilities provided to necessary project participants. During publishing, objects are created from a particular application and information from other applications is merged to provide a broad object dataset identified in accordance with the Plant numbering system.

Through its unique feature of relationship building during plant data publishing, users can navigate a particular item within the plant to all other objects and documents associated to it. The navigation path itself forms a reversible circle; users can select a Tag and then navigate to its related documents, then to instances of that object in the 3D design environment. Plant data once published cannot be deleted. By resetting the Plant Effective Date, users will be able to see the status of the plant back to a particular date, month, or year.

3.3.3.2.7 SUPPORT MODELER AND MANAGER (PSM&PMN)

Intergraph's Support Modeler (PSM) and Support Manager (PMN) are used for all pipe supports, both seismic and non-seismic. This software facilitates the 3D design of supports for piping systems, within the PDS environment. PSM can be used for modeling and detailing of both standard and engineered supports. Once incorporated into the PDS environment the 3D geometry for supports are available to Intergraph's Interference Checker software for clash detection purposes. Additionally, the supports will be visible from within Intergraph's SPR for discipline design review. Pipe support detail drawings with material takeoffs can be automatically generated from the support models and support index reports can be generated from the attribute information attached to the 3D support designs.

3.3.3.2.8 MICROSTATION

Bentley MicroStation is a graphic drafting and design software program. MicroStation is seamlessly coupled with the PDS suite of products as the graphic engine for representing the data input performed by the designer.

3.3.3.2.9 ISOGEN

The 3D project design will use Intergraph's PDS software suite. One of the menu options of the PDS main PD_Shell screen is Isometric Drawing Manager. For the sake of clarity, please note that the term ISOGEN is synonymous with Isometric Drawing Manager and its associated software.

Each Isometric will contain a complete bill of material for that particular sheet. During the isometric extraction process an IDF (Intermediate Data File) shall be produced by ISOGEN and stored in the isometric directory.

3.3.3.2.10 DOCUMENTUM

EMC's Documentum® Electronic Document Management System (EDMS) will be used to develop, publish, and access project documents, policies, procedures, and design documents for the project execution phase. Documentum® will be the project records repository and will contain the design output documents necessary to procure, construct, and operate the plant. The application is web-based, and uses Oracle for its relational database to manage the document content and associated metadata. A separate report writing application will be used to create controlled indices of technical documents. These indices are a fundamental element of the project design control program. An array of management reports are available and will be tailored to suit project requirements. All of these reports are also stored in Documentum ® for ease of access.

3.3.3.2.11 PRIMAVERA PROJECT PLANNER

Primavera Project Planner will be used to develop and execute the project activities as it relates to the project execution plan. The software will be used to produce schedules and reports. The key elements of the methodology are the development of detailed logic network that schedules the activities within the Work Breakdown structure (WBS); assignment of responsibility for each activity, control point, and milestones; estimates for each activity can be integrated with durations.

3.3.3.2.12 Conclusion

The above CAE applications are common examples that are currently used to manage large complex power and chemical process projects. It is recommended that the Request for Proposal for the continuation of the CTF request that EPC contractors include in their proposals a comprehensive strategy for implementation and integration of these powerful engineering, design and management tools.

3.4 References

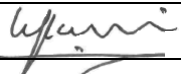
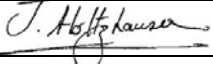
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NGNP and Hydrogen Production Conceptual Design Study

NGNP CTF Test Loop Preconceptual Design Report

Section 4: System Requirement Manual

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BACKGROUND INTELLECTUAL PROPERTY CONTENT

Section	Title	Description
N/A		

REVISION HISTORY**RECORD OF CHANGES**

Revision No.	Revision Made by	Description	Date
A	W.H. Kaiser	M-Tech internal review	November 21, 2008
B	W.H. Kaiser	First release to BEA	November 26, 2008
C	W.H. Kaiser	Updated release to BEA	November 29, 2008
D	W.H. Kaiser	Document updated following BEA review and 90 percent review meeting; December 02, 2008. Updated for consistency with regards to references and nomenclature	December 8, 2008
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DOCUMENT TRACEABILITY

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ACRONYMS

Abbreviation or Acronym	Definition
A	Accelerometer
A-E-C	Architecture – Engineering -Construction
AGR	Advanced Gas-cooled Reactor
AHJ	Authority Having Jurisdiction
AICE	American Institute of Chemical Engineers
AISC	American Institute of Steel Construction
AISI	American Iron and Steel Institute
ALARA	As Low As Reasonable Achievable
AMB	Active Magnetic Bearing
ANSI	American National Standards Institute
API	American Petroleum Institute
ASHRAE	American Society of Heating Refrigeration and Air Conditioning Engineers
ASME	American Society of Mechanical Engineers
AWS	American Welding Society
BEA	Battelle Energy Alliance
BIL	Basic Impulse Insulation Level
BIM	Building Information Management
BS	British Standard
Btu/hr	British thermal unit per hour
CAD	Computer Aided Design
CAE	Computer Aided Engineering
CBCS	Core Barrel Conditioning System
CCS	Core Conditioning System
CFR	Code of Federal Regulations
CH	Cold Header
CMAA	Crane Manufacturers Association of America
COR	Client Observation Room
COTS	Commercial Off-The-Shelve (Commercial Grade Items)
CQL	Component Qualification Loop
CQL1	Component Qualification Loop 1
CQL2	Component Qualification Loop 2
CTF	Component Test Facility
CTL	Circulator Test Loop
CV	Valve Flow Coefficient
DAQ	Data Acquisition
db	Dry Bulb

Abbreviation or Acronym	Definition
DB	Distribution Board
DC	Direct Current
DCD	Design Criteria Document
DCS	Distributed Control System
DDN	Design Data Need
DOE	Department of Energy
dP	Differential Pressure
DPP	Demonstration Power Plant
EDMS	Engineering Data Management System
EHR	Essener Hochdruck Rohrleitung
EIA	Electronic Industry Alliance
EMB	Electro-magnetic Bearing
ENS	Emergency Notification System
EPACT	Energy Policy Act (of 2005)
EPC	Engineering Procurement and Construction
ER	Environmental Requirement
ES&H	Environmental, Safety and Health
ESD	Emergency Shutdown
F	Flow Rate
FDD	Facility Design Description
FHA	Fire Hazard Analysis
FIPS	Federal Information Processing Standards
FM	Factory Mutual
FMS	Facility Monitoring System
FS	Flow rate (switch)
GA	Gas analyzer (composition)
GHEP	Guidelines for Hazard Evaluation Procedures
gpm	Gallon per minute (US)
GR	General Requirements
H ₂	Hydrogen Production Test (Specifically referring to H ₂ SO ₄ Decomposition Reactor Test)
H ₂ SO ₄	Sulfuric Acid
HAZOP	Hazard and Operational Study
HDBK	Handbook
HGD	Hot Gas Duct
HGDs	Hot Gas Ducts
HH	Hot Header
HICS	Helium Inventory Control System
HIPCS	Helium Inventory and Pressure Control System
HIRA	Hazard and Risk Identification Analysis

Abbreviation or Acronym	Definition
HLR	High Level Requirement
HMI	Human Machine Interface
HPS	Helium Purification System
HT	Heat Transfer
HTF	Helium Test Facility
HTGR	High Temperature Gas -Cooled Reactor
HTS	Heat Transport System
HTSE	High Temperature Steam Electrolysis
HTTR	High Temperature Test Reactor
HTTU	High Temperature Test Unit
HV	High Voltage (>132 000V)
HVAC	Heating, Ventilation, & Air Conditioning
HX	Heat Exchanger
HyS	Hybrid Sulfur
I&C	Instrumentation and Control
I/O	Input/Output
IBC	International Building Code
ICC	International Code Council
ICD	Initial Conceptual Design
ICEA	Insulated Cable Engineers Association
IDAPA	Idaho Administrative Procedure Act
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IFC	International Fire Code
IFGC	International Fuel Gas Code
IHX	Integrated Heat Exchanger
IHXA	Intermediate Heat Exchanger A
IHXB	Intermediate Heat Exchanger B
IMC	International Mechanical Code
IMS	Information Management Systems
INL	Idaho National Laboratory
IPMC	International Property Maintenance Code
ISA	International Society of Automation
ISO	International Organization for Standardization
JB	Junction Box
kg/s	Kilogram per second
kV	Kilovolt (1000 Volts)
kl/h	Kilolitre per hour
kPa	Kilopascal (1000 Pascal)
kW	Kilowatt (1000 Watts)

Abbreviation or Acronym	Definition
LCD	Liquid Crystal Display
LCP	Local Control Panel
LRFDS	Load and Resistance Factor Design Specification
LV	Low Voltage (<1000 V)
MBMA	Metal Building Manufacturers Association
MCC	Motor Control Center
MCR	Mission Critical Requirement
MDB	Main Distribution Board
MES	Manufacturing Execution System
MPa	Megapascal = million Pascal
MTI	M-Tech Industrial (Pty) Ltd.
MV	Medium Voltage (>1000V< 132 000V)
MW	Megawatt (Million Watts)
N	Speed
NBIMS	National BIM Standards Project Committee
NEC	National Electrical Code
NEMA	National Electrical Manufacturers Association
NEPA	National Environmental Policy Act
NESC	National Electrical Safety Code
NFPA	National Fire Protection Association
NGNP	Next Generation Nuclear Plant
NHI	National Hydrogen Institute
NIST	National Institute of Standards and Technology
NQA-1	ASME NQA-1 2000, Quality Assurance for Nuclear Facilities
OPC	Operating Procedure Checklist
OSHA	Occupational Safety and Health Administration
P	Pressure
P&ID	Piping and Instrument Diagram
PBMR	Pebble Bed Nuclear Reactor (RSA)
PCDR	Preconceptual Design Report
PCFC	Preconceptual Facility Configurations
PCHX	Printed Circuit Heat Exchanger
PCS	Process Control System
PDA	Potential Deviation Analysis
PDMS	Project Data Management System
PDS	Plant Design System
PFD	Process Flow Diagram
PHA	Preliminary Hazard Analysis
PHTS	Primary Heat Transport System
PLC	Programmable Logic Controller

Abbreviation or Acronym	Definition
PLCs	Programmable Logic Controllers
PMN	Support Manager
PRV	Pressure Relief Valve
psig	Pound per square inch gauge
PSM	Support Modeler
QC	Quality Control
QCP	Quality Control Plan
RCS	Reactivity Control System
RIS	Relational Interface System
RPV	Reactor Pressure Vessel
RSA	Republic of South Africa
SBS	System Breakdown Structure
SCADA	Supervisory Control and Data Acquisition System
scfm	Standard cubic feet per minute
SDD	System Design Description
SDI	Steel Door Institute or Steel Deck Institute
SG	Steam Generator
SHEQ	Safety, Health, Environmental and Quality
SHTS	Secondary Heat Transport System
SI	Sulfur Iodine
SIL	Safety Integrity Level
SIS	Safety Instrument System
SJI	Steel Joist Institute
SNM	Special Nuclear Materials
SPEL	SmartPlant Electrical
SPF	SmartPlant Foundation
SPMat	SmartPlant Material
SPR	SmartPlant Review
SPS	Standby Power System
SR	Safety Requirement
SRM	System Requirement Manual
SSC	Systems Structures and Components
SSDT	Small Scale Development Test
SSS	Site Selection Study
SSSB	Specification for Structural Steel Buildings
STD	Standard
T	Temperature
T&FR	Technical and Functional Requirement
TBD	To Be Determined
TDL	Technology Development Loop

Abbreviation or Acronym	Definition
TDRM	Technology Development Road Map
TEDS	Transducer Electronic Data Sheet
TEMA	Tubular Exchanger Manufacturers Association
THTR	Thorium High Temperature Reactor
TIA	Telecommunications Industry Association
TRL	Technology Readiness Level
TSR	Technical Safety Requirement
UL	Underwriters Laboratories
UL	Underwriters' Laboratories
UPC	Uniform Plumbing Code
UPS	Uninterruptable Power Supply
UUT	Unit Under Test
V&V	Verification and Validation
VHTGR	Very High Temperature Gas-Cooled Reactor
VL	Valve
VSD	Variable Speed Drive
wb	Wet Bulb
WBS	Work Breakdown Structure
WEC	Westinghouse Electric Company
WE-SA	Westinghouse Electric - South Africa
ϵ	Strain

SUMMARY AND CONCLUSIONS

The purpose of the System Requirement Manual (SRM) is first to compile Facility and Test Loop functions and requirements for the Component Test Facility (CTF). The SRM then provides a complete system description of the Test Loop systems.

The SRM is divided into two sections; the Facility Design Description (FDD) and the System Design Description (SDD). The FDD section outlines the functions and requirements that the facility must fulfil based on interface requirements driven by the various test loops. The Facility Designer will be responsible to take these requirements as input and develop the overall SRM to contain detailed functions and requirements for the Facility as well as a detailed overall FDD.

The SDD outlines all the requirements and design bases that have been developed in the preconcept design of the test loop systems.

The SDD section outlines the various test loops with details on design features, system boundaries and interfaces, physical layout, principle of operation, system reliability, system control features, and potential safety hazards. DOE Standard 3024 in reference [4-25] is used as a guide for the structure and content of this portion of the report.

The test loops that are discussed are:

- Small Scale Development Test (SSDT)
- Technology Development Loop (TDL)
- Component Qualification Loop 1 (CQL1)
- Component Qualification Loop 2 (CQL2)
- Circulator Test Loop (CTL).

This portion of the report is intended to be a compilation of design elements that have been originated and developed elsewhere in the CTF design package and as such should only be used for information and convenient reference.

4. SYSTEM REQUIREMENT MANUAL

4.1 Facility Design Description

The FDD section outlines the functions and requirements that the facility must fulfil based on interface requirements driven by the various test loops described in section 4.2. The Facility Designer will be responsible to take these requirements as input and develop the overall detailed SRM containing functions and requirements for the facility as well as detailed overall FDD.

In an FDD, all the systems in a facility or building shall be addressed with respect to their top-level functions and requirements. The FDD shall also contain the design basis and design criteria information that is pertinent to interfaces with the design requirements for the Test Loop systems described in Section 4.2

4.1.1 Inputs o the Facility Design Description

The FDD received inputs from various sources which include the High Level Requirement (HLR), reference [4-1], up to the Test loop designs.

This section gives a short outline of the Technical and Functional Requirement (T&FR), reference [4-2]. These requirements are divided into seven subsections as illustrated in Figure 4-1.

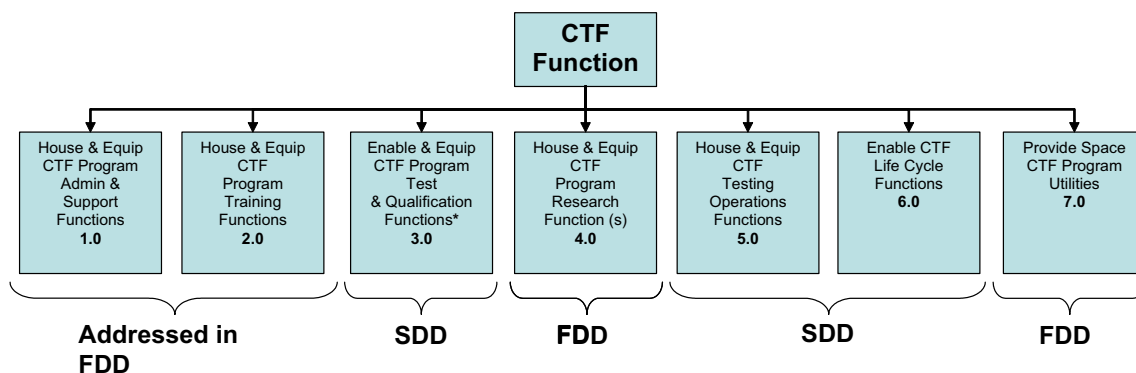


Figure 4-1: Functional and operating requirement top level breakdown.

Each of the applicable high-level functions is a briefly described below.

4.1.1.1 House and Equip CTF Program Administrative and Support Functions

The CTF will provide adequate space and appropriate equipment for the workspace occupation of CTF personnel, researchers, users, and visitors. The CTF will allow reconfiguration of personnel workspace(s), as necessary, to accommodate the needs of the Next Generation Nuclear Plant (NGNP) program and, ultimately, international end users.

4.1.1.2 House and Equip CTF Program Training Functions

The CTF will provide adequate space and equipment for ancillary training as well as adequately equipped space for an NGNP Maintenance Mock-up Capability.

4.1.1.3 House and Equip CTF Program Research Function(s)

The CTF researchers need adequate spaces to enable them to perform their designated work functions. This is the basis for design of the CTF Program Research Function(s).

4.1.1.4 Provide CTF Program Utilities

The CTF needs to distribute and supply the electrical power needed within the building for testing, operations, and associated workspaces and to the exterior of the building for access, egress, parking lighting, car heater receptacles, etc.

The CTF will also need the following utilities.

- Potable water
- Industrial water for fire suppression
- De-mineralized water
- Waste heat cooling
- Conditioned compressed air and instrument air
- Telephone and video conference capability
- Network connectivity capability
- Treatment and disposal capability for sanitary and industrial water
- Waste collection, treatment, and disposal; including waste testing
- The ability to store, condition, circulate and cool helium
- Heating Ventilation and Air-Conditioning (HVAC) throughout the CTF

These requirements for the CTF propagate to additional requirements on the facility as described in the following sections.

4.1.2 CTF Test Loops Driven Requirements for High Bay Facility Design

The following building features and systems are provided to meet the specific requirements of the CTF Test systems and supporting equipment:

- Architectural – The building shall be sized to accommodate installation of all equipment and piping in loops and Helium Inventory Control System (HICS), as well as space for loop component lay-down, and assembly, phased construction activities, and access for maintenance and change out of system components.
- Structural – Concrete slabs and foundations, and structural steel must be designed to accommodate equipment weights, crane loads, and seismic loading.
- Fire alarm and suppression systems.
- HVAC – System must provide adequate heat for comfort conditions and cooling to remove equipment heat loss while maintaining the maximum temperature below design values. Also provide adequate ventilation as required by code.
- Electrical – System must provide adequate power at correct voltages to meet all process equipment loads.
- Cooling Water – Adequate cooling at specified temperature and flow conditions to provide cooling for the TDL and SSDT coolers and steam loop condenser.
- Service Air as needed for tools and blow-down.
- Instrument Air - Instrument grade as needed for instrumentation and air operators in all loops.
- Process Air – High pressure compressed air to support High Temperature Steam Electrolysis (HTSE) test station.
- De-mineralized Water – For make up to steam systems.
- Process Water – For makeup and wash down activities.
- Steam – High pressure, superheated steam for HTSE test station.

These requirements are discussed in more detail in the following paragraphs.

4.1.3 Functional and Operational Requirements

4.1.3.1 Regulatory Requirements

The 2005 Energy Policy Act (EPACT) charges U.S. Department of Energy (DOE) and Idaho National Laboratory (INL) with demonstration of the High Temperature Gas Reactor (HTGR) technology for the production of electricity and hydrogen in a NGNP demonstration. The CTF is provided to enable performance of technology development and prototype testing in the interest of overall plant performance risk mitigation.

The following is a list of codes and standards that form the basic regulatory requirements for the CTF. Additional, more discipline specific codes are included in the paragraphs that follow reference [4-16].

- Building code: IBC (International Building Code).
- Mechanical Code: IMC (International Mechanical Code).
- Fire Code: NFPA (National Fire Protection Association) Codes and Standards

- Plumbing Code: UPC (Uniform Plumbing Code).
- Electric Code: NEC (National electric Code) (NFPA 70).
- INL-STD -139, INL Engineering Standards.

4.1.3.2 Interface Requirements

The CTF is part of the overall NGNP project and its cost is integrated into the overall NGNP program costs. The operator of the facility must interface with the NGNP R&D (Research and Development) and design teams to continually advance and develop the testing requirements and configurations of NGNP Systems Structures and Components (SSC). The public-private partnership will ultimately act as a systems integrator in addition to being a partner with the Government in the development of the facility.

The CTF will need a significant amount of electrical power to generate the heat and power requirements needed for component testing. Therefore, interfacing with the regional power utility will be vital in the development of the infrastructure for the facility.

4.1.3.3 Design Basis

The Facility design basis will continually evolve subject to configuration management throughout the follow-on design phases. This section will be further developed by the Facility Designer.

4.1.3.4 Facility Classification

The facility classification will be dependent on the final site selection for the CTF, along with overall facility Fire Hazard Assessment (FHA) and process hazard analysis conducted on the test loops. This section will be further developed by the Facility Designer.

4.1.3.5 Design Conditions and Constraints

Ultimately, the CTF will be available to the entire nuclear community that participated in the NGNP program to further the state of the art in nuclear reactors and applications.

The assumptions made in the preparation of this document are as follows:

- The CTF is anticipated to be a high hazard, non-radiological facility.
- The CTF will be subject to the National Environmental Policy Act (NEPA) process.
- The CTF will provide the necessary testing infrastructure, utilities, and space for tests and test equipment of the NGNP and National Hydrogen Institute (NHI) testing and licensing programs. End users will provide new or modified CTF infrastructure, utilities, or space for tests and test support equipment that cannot be accommodated within the CTF capabilities.
- Although there is a need for a thermal hydraulic scaled integrated test of reactor internals and Reactor Pressure Vessel (RPV), the CTF will NOT accommodate the larger envelope that might be required for integrated thermal hydraulic reactor core testing.
- There is a need for “up to full-scale” testing of the NGNP heat exchangers (HX) and circulators that will contribute to the basis for sizing the facility, associated test loops, test stations, and utilities.
- The functionality of the building may evolve, as the CTF testing program is refined and further detailed. This may require incorporation of additional functional scope in the CTF.
- The CTF will be a government-owned, contractor-operated facility. The DOE and the host state will provide the necessary regulatory and safety oversight of CTF construction and operations.
- The CTF will be designed for an operational life span of 40 years. However, the design lives of individual test equipment and engineering-scale demonstrations will vary according to need.

4.1.3.6 Civil and Site Work

An investigation into the INL engineering standards reference [4-13] was performed to identify the various codes and standards that are applicable in the CTF. These are listed in Design Criteria Document (DCD) reference [4-16].

Table 4-1 contains the loads of the various components in the test loops

Table 4-1: Test Loop Component Weights

Loop	Component	Mass (kg)	Mass (pound)	Comment
SSDT	Pressure vessel	6,000	13,230	^[1]
TDL	HTS Cold pipes	70	160	Mass per meter ^[1]
	HTS HGD	670	1,480	Mass per meter ^[1]
	Primary	12,920	28,490	^[1]

¹ Mass calculated excluding insulation, flanges, vessel internals, and support frames. It is recommended that a 50 percent allowance be added for these items.

Loop	Component	Mass (kg)	Mass (pound)	Comment
	Circulator vessel			
	Secondary Circulator vessel	12,920	28,490	[1]
	Primary Recuperators	55,360	122,050	[1]
	Secondary Recuperators	57,050	125,780	[1]
	Heater 1	41,640	91,810	[1]
	Heater 2	9,130	20,130	[1]
	IHX test vessel	81,400	179,460	[1]
	Primary loop cooler	8,460	18,660	[1]
	Secondary loop cooler	4,060	8,960	[1]
CQL1	HGD (piping)	670	1,480	Per meter [1]
	Hot/Cold Header	4,210	9,290	Top half header with 0.5 m nozzles [1]
CQL2	Total	3900,000	8598,030	[1][2]
CTF	Circulator	12,920	28,490	[3]

4.1.3.7 Structural (To be developed by the Facility Designer)

The structural criteria identified in the review of the INL engineering standards reference [4-23] are discussed in the DCD reference [4-16].

4.1.3.8 Architectural (To be developed by the Facility Designer)

The architectural criteria identified in the review of the INL engineering standards, reference [4-23] are discussed in the DCD, reference [4-16].

4.1.3.9 Mechanical

Provide mechanical systems to the CTF Facility in accordance with the requirements of the International Mechanical Code (IMC), the Uniform Plumbing Code, INL STD-139, and other applicable DOE and State codes.

² The CQL2 is a complete separate design, with more detail given in Section 8, reference [4-20]

³ The mass of the Circulator is unknown designed is still pending, thus a rough estimation was done based on the TDL Primary circulator vessel.

The mechanical systems required to support the facility include hot and cold potable water, sanitary and storm sewer systems, compressed air, and HVAC systems discussed in section 4.1.3.9.8 below.

The CQL2 is designed as an independent system, where all the mechanical auxiliary support systems are included as part of the design. Thus the CQL2 design values are not listed in the section below.

The mechanical systems required for the process equipment are listed below:

4.1.3.9.1 Cooling water

The CTF facility is to provide 20 °C (68 °F) cooling water to the equipment shown in the following table. The water will be returned at 45 °C (113 °F).

Table 4-2: CTF test loops cooling water requirements

Description	Equipment	Cooling Water Load (MW)	Cooling Water Flow(kg/s)	Cooling Water Flow (gpm)
TDL	Cooler CL - 1.1	8.31	79.4	1,260.6
	Cooler CL - 1.2	4.8	45.9	728.2
CQL1	Condenser CD - 4.1	11.6	110.9	1,759.7
CTL	Cooler CL 5 1.1	13	124.2	1,972.1
SSDT	Cooler CL 1 1.1	0.01	0.1	1.5
	Cooler CL 1 1.2	0.01	0.1	1.5

4.1.3.9.2 Service air

Provide 0.27 kg/s (500 scfm) of compressed air at 1034 kPa(g) (150 psig) for general industrial use. Quantities for service air to be confirmed in follow on design reference [4-16]

4.1.3.9.3 Instrument air

Provide 0.10 kg/s (200 scfm) of instrument quality (-40 °C (-40°F) dew point, particulate free, low hydrocarbon) compressed air at 1034 kPa(g) (150 psig). Quantities for instrument air to be confirmed in follow on design reference [4-16]

4.1.3.9.4 Process air

Provide 0.76 kg/s (1400 scfm) of 5600 kPa(g) (812 psig) of compressed air at 1760 °C (3500 °F) to the HTSE test station HX. Process Air quality will be similar to instrument air (-40 °C (-40 °F) dew point, particulate free, hydrocarbon free) to be confirmed in follow on design, reference [4-16].

4.1.3.9.5 De-ionized water

Provide 40 l/min (10 gpm) (maximum flow) of de mineralized or de-ionized water for steam system make-up to the Component Qualification Loop (CQL) skid, and other specific tests. Exact water chemistry requirements to be determined during follow on design, reference [4-16].

4.1.3.9.6 Process water

Provide 95 l/min (25 gpm) make up from potable grade water at 420 kPa(g) (60 psig) for general industrial use. Temperature range shall be from ground water temperature to ambient temperature, reference [4-16].

4.1.3.9.7 Process Steam

Provide steam at 5600 kPa(g) and 396°C (810 psig and 755°F) for use by the HTSE test station HX. Approximately 0.62 kg/s (4900 lb/hr) will be required. The steam shall be superheated to (later) °C, and returned to the facility system, reference [4-16].

4.1.3.9.8 Heating Ventilation and Air Conditioning

The safe and reliable operation and maintenance of the Test Loops require that the Heating Ventilation and Air Conditioning (HVAC) system provide the following from [4-16]:

Design Ambient temperatures per reference [4-23] are winter -28 °C (-19°F), Summer 35 °C dry bulb (db) (95° F db), 16 °C wet bulb (wb) (61° F wb). Periods that these values are exceeded are expected to be very short resulting on minimal impact on test loop operations, and maintenance activities.

The HVAC systems must maintain temperatures in the high-bay area at a minimum temperature of 18° C (65° F) during winter operations and a maximum temperature of 6°C (10° F) above ambient in the working spaces during summer. The heat releases from the test loop equipment is tabulated below and in Table 4-3. Supply

air shall be delivered to those areas of the building where people are expected to be working and be exhausted high in the space.

Additional strategically located or portable spot mechanical cooling may be required in certain work spaces to support maintenance activities and phased test loop equipment installation and commissioning. Details of this requirement shall be determined during the design process.

Electric rooms shall be air conditioned to maintain maximum temperatures below 30 °C (85°F) to ensure equipment reliability.

Provide space heating, ventilation, cooling, and air conditioning for occupied and unoccupied spaces per reference[4-23].

Cooling Loads

For conservatism it is assumed that the ambient temperature is 20°C (68°F) to calculate heat loads from hot component surfaces. Heat loads from electrical components is not dependent on the ambient temperature. The calculation is based on a single test loop of each. The heat released from the process equipment modules is estimated as follows:

Table 4-3: Estimated heat loads of the various test loops

Description	Component	kW	btu/hr	Comment
SSDT	Total	11	37540	
TDL	TDL Hot Gas Ducts (HGD)	302	1030,470	[4]
	IHX test vessel	228	777,970	[4]
	Recuperator vessels	251	856,450	[4]
	Heaters	208	709,730	[4]
	Total	989	3374,600	[4]
CQL1	Total	237	808,680	273 kW/m [5]
CQL2	TBD	TBD	TBD	[6]
CTL	Total	92	375,340	[7]

Ventilation

Provide adequate ventilation for all areas in accordance with the IMC and (American Society of Heating Refrigeration and Air Conditioning Engineers) ASHRAE standard 62.

⁴ Assuming that cold pipes, circulators and coolers are well insulated.

⁵ Assuming the CQL has only header pipes with a inside temperature of 1000 °C and a surface temperature of 200 °C.

⁶ The CQL2 is a complete separate design, with more detail given in Section 8: Component Qualification Loop (CQL), reference [4-20]

⁷ With an assumption of 20 °C temperature in the air temperature and the cladding temperature. This number is further multiplied with 1.2 due to high sensitivity to ambient conditions.

Applicable Codes and Standards for HVAC design

- International Mechanical Code (IMC).
- International Fuel Gas Code (IFGC).
- National Fire Protection Agency standards. NFPA 90A and 90B
- DOE O 420.1B “Facility Safety”
- ASHRAE 90.1, Energy Standard for Buildings Except Low-Rise Residential
- ASHRAE 62, Ventilation for Acceptable Indoor Air Quality.
- IDAPA 07.07.01 (Idaho Administrative Procedure Act), Rules Governing Installation of Heating, Ventilation, and Air Conditioning Systems, Division of Building Safety.

4.1.3.9.9 Fire Protection

A FHA will be performed during detail design to comprehensively and qualitatively assess the risk from fire within the CTF Facility to ensure DOE fire safety objectives are met. DOE fire protection criteria are outlined in DOE Order 420.1b and the FHA includes identifying the risks from fire and related hazards such as direct flame impingement, hot gases, smoke migration, fire-fighting water damage etc.

Fire suppression systems throughout the facility will generally consist of water sprinkler systems designed to NFPA 13 requirements, supplemented with portable fire extinguishers according to NFPA 10. Other types of suppression systems may be recommended based specific hazards identified, and on the findings of the FHA. Reference [4-16]

Process or Production Requirements

The utilities requirements for the process equipment are shown in Table 4-4.

It is important to note, that the values indicated are only for one TDL. For CQL2, the system is designed as a separate system with the equipment loads given in reference [4-20].

Table 4-4: CTF test loops equipment utility loads

Description	Equipment	Number	Electric Motor Loads (MW)	Electric Thermal Load (MW)	Cooling Water Load (MW)	Cooling water flow (l/min)	Cooling Water Flow(gpm)	Make Up Water to Tower	Heat Exchanger Rating (MW)
TDL	Circulator	CR 2A 1.1	0.23						
	Heater	HT 2A - 1.1		8.9					
	Heater	HT 2A - 1.2		4.9					
	IHX Test Vessel	TV 2A 1.1							4.9
	Recuperator	RX 2A 1.1							17.04

Description	Equipment	Number	Electric Motor Loads (MW)	Electric Thermal Load (MW)	Cooling Water Load (MW)	Cooling water flow (l/min)	Cooling Water Flow (gpm)	Make Up Water to Tower	Heat Exchanger Rating (MW)
	Circulator	CR 2A 2.1	0.23						
	Recuperator	RX 2A 2.1							15.39
	Cooler	CL 2A 1.1			8.31	47,729	1,260.6	116.34	
	Cooler	CL 2A 2.1			4.8	2752	728.2	67.2	
	HGD Mixing Chamber	TS 2A 1.1							
	Flow Meter	TS 2A 1.2							
	HTSE	TS 2A 1.3							0.57
CQL1	Pump P - 4.1	PU 3 1.1	0.03						
	Steam Generator SG - 4.1	TS 3 1.1							11.6
	Condenser CD - 4.1	CD 3 1.2			11.6	6,662	1,759.7	162.4	
	H ₂ SO ₄ Decomposer	TS 3 1.1							10
CTL	Circulator C - 5.1	TS 4 1.1	13						
	Cooler	CL 4 1.1			13	7,466	1,972.1	182	
SSDT	Heater	HT 1 1.1		0.02					
(typical for 3)	Cooler	CL 1 1.1			0.01	6	1.5	0.14	
	Cooler	CL 1 1.2			0.01	6	1.5	0.14	
	Pump	PU 1 1.1	0.002						

Some contingency margins have been applied which resulted in the values above and are documented in the test loop design sections of the report. Margins vary from 10 to 30 percent depending on the certainty of design input information available. It is expected that the Facility Designer will apply additional margins when loop related facility loads are added to the test loop loads and the facility equipment is selected. It is recommended that margins be revisited as the design progresses. Typically, margins can be reduced as certainty of design inputs improves for the test loops.

4.1.3.10 Electrical

Provide electric power to the process at the voltages and amperages indicated on the one-line diagram in referenced in Appendix B, and as indicated in the items listed below from reference [4-16]. The standards for the electric power are:

Motors less than 0.5 HP will be rated 115 V, 1 phase, 60 Hz. Motors 0.5 HP to 250 HP will be rated 460 V, 3 phase, 60 Hz. Generally, motors larger than 250 HP will be rated 4000 V, 3 phase, 60 Hz.

- Control circuit devices will generally be 115 V, 1 phase.

- UPS loads will be rated 115 V ac, 1 phase, 60 Hz.
- Variable frequency drive equipment will be specified to include filters to limit harmonic currents to within the 5 percent limits specified in Institute of Electrical and Electronics Engineers (IEEE-519).

Electrical design shall be performed in accordance with all applicable standards including the following:

- ANSI/NFPA 70 National Electrical Code (NEC).
- ANSI-C2, National Electrical Safety Code (NESC).
- NEMA Standards (National Electrical Manufacturers Association).
- UL Standards and Product Directories.
- FM Approval Guide, and FM Loss Prevention Data Sheets.
- ISA (International Society of Automation) Electrical Guide for Control Centers, Recommended Practice RP-60.
- ANSI/IEEE 242, Recommended Practice for Protection and Coordination of Industrial and Commercial Power Systems.
- ANSI/IEEE 493, Recommended Practice for Design of Reliable Industrial and Commercial Power Systems.
- DOE-HDBK-1092, Electrical Safety.
- DOE-HDBK-1132, Design Considerations.
- DOE O 420.1b, Facility Safety
- ICEA Standards (Insulated Cable Engineers Association).
- NFPA 780, (National Fire Protection Agency) Lightning Protection Code.
- Arco List 01000, Basic Impulse Insulation Level (BIL).

4.1.3.11 Instrumentation

Instrumentation for the facilities systems will be designed to the following standards, from reference [4-16]:

- STD-139-011000, General Design Requirements.
- STD-139-260000, Electrical Design.
- IEEE 315-75 & 315A-86, Graphic Symbols for Electrical and Electronics Diagrams.
- ISA, Standards and Practices for Instrumentation.

4.1.3.12 Control Systems (Additional details to be provided by Facility Designer)

The facility control systems will consist of a facility monitoring system and a building management system. The facility monitoring system will monitor the operations

within the building including alarm annunciation, status monitoring and event reconstruction capability.

The building management system will control the building energy consumption by controlling the HVAC, lighting, water usage, and electric power metering.

Applicable standards for control system include the following:

- DOE STD 1039 Guide to Good Practices for Control of Equipment and System Status.
- ISA S5.1 Instrumentation Symbols and Identification.
- ISA S5.3 Graphic Symbols for Distributed Control/Shared Display Instrumentation, Logic and Computer Systems.
- ISA S5.4 Instrument Loop Diagrams.
- ISA S5.5 Graphic Symbols for Process Displays.
- UL-1998 UL Standard for Safety for Software in Programmable Components.
- UL-1998-1998 UL Standard for Safety for Software in Programmable Components.
- NEMA ICS Standards.
- IEEE-1046 Application Guide for Safety for Software in Programmable Components.

4.1.3.13 Communications

CTF communication systems will consist of a different network tied into a sufficiently adequate telecommunications system as well as secure connections to the internet. The networks will follow the applicable standards from:

- TIA Telecommunications Industry Association.
- EIA Electronic Industry Alliance.
- IEEE Institute of Electrical and Electronic Engineers.

4.1.3.14 Safeguards & Security

The CTF security system needs the following access control capabilities:

- CTF access control capability.
- Area access control capability.
- Data access control capability.
- Personnel access control capability.
- Inventory capability.

This list is all-inclusive and could evolve during the design life cycle.

The CTF needs to comply with all applicable federal, state, local, and INL safety requirements in place at the time of construction.

The CTF needs to ensure protection of its occupants, equipment, components, and materials safety (test-adjacent areas) in the event of an operational, component, or integrated test failure.

As a minimum, the safety requirements contained in the following will be met:

- DOE order DOE-O-420.1B.
- OSHA standards (Occupational Safety and Health Administration).
- NFPA 101, Life Safety Code.
- DOE-STD-1189, Integration of Safety into the Design Process.
- AIChE, (American Institute of Chemical Engineers) Guidelines for Hazard Evaluation Procedures, Center for Chemical Process Safety.

4.1.3.15 Maintainability (Details to be provided by Facility Designer)

This section is to be addressed at a later stage with inputs from the Facility Designer.

4.1.3.16 Permits (Details to be provided by Facility Designer)

This section is to be addressed at a later stage with inputs from the Facility Designer.

4.1.3.17 Quality Assurance

The CTF facilities design will meet the Quality Assurance Requirements found in DOE O 414.1C.

4.1.3.18 Packaging and Transportation (Details to be provided by Facility Designer)

This section is to be addressed at a later stage, with inputs from the Facility Designer.

4.1.4 Orders, Codes and Standards

The orders, codes and standards are identified in the review of the INL engineering standards reference [4-23] are discussed in reference DCD reference [4-16].

4.1.5 Design Criteria

The design criteria are identified in the review of the INL engineering standards reference [4-23] are discussed in the DCD, reference [4-16].

4.1.6 Overall CTF High Bay Facility Design Description (Details to be Provided by Facility Designer)

4.1.6.1 Facility Objective

The CTF will provide for the enclosed space, its environmental conditions, furnishings, tools, instruments, and equipment necessary to meet the CTF mission; improved areas for parking, access, and egress; and an area for testing components, materials, and processes related to the NHI.

4.1.6.2 Facility Location (Details to be provided by Facility Designer)

This section is to be addressed at a later stage, with inputs from the Facility Designer.

4.1.6.3 Facility Functional Design (Details to be provided by Facility Designer)

This section is to be addressed at a later stage, with inputs from the Facility Designer.

4.1.6.4 Facility Description (Details to be provided by Facility Designer)

This section is to be addressed at a later stage, with inputs from the Facility Designer.

4.1.6.5 System Design Description Summary

4.1.6.5.1.1 CTF High Bay Facility Systems (Details to be provided by Facility Designer)

This section is to be addressed at a later stage, with inputs from the Facility Designer.

4.1.6.5.1.2 CTF High Bay System Design Description Summaries (Details to be provided by Facility Designer)

This section is to be addressed at a later stage, with inputs from the Facility Designer.

4.1.6.5.1.3 CTF Test Loops System Design Description Summaries

The CTF Test Loops SDD summaries are listed in section 4.2.4.

4.1.6.6 Receiving, Handling and Storage Systems (Details to be provided by Facility Designer)

This section is to be addressed at a later stage, with inputs from the Facility Designer.

4.1.6.7 Environmental, Safety and Health Systems (Details to be provided by Facility Designer)

This section is to be addressed at a later stage, with inputs from the Facility Designer.

4.1.6.8 HVAC Systems (Details to be provided by Facility Designer)

This section is to be addressed at a later stage, with inputs from the Facility Designer.

4.1.6.9 Civil and Structural Systems (Details to be provided by Facility Designer)

This section is to be addressed at a later stage, with inputs from the Facility Designer.

4.1.6.10 Communication and Control Systems

This section is to be addressed at a later stage, with inputs from the Facility Designer.

4.1.6.11 Design Support Documentation

This section is to be addressed at a later stage, with inputs from the Facility Designer.

4.2 System Design Description

The following section describes the requirements associated with the systems of the proposed test loops for the CTF as indicated in the System Identification. These requirements include general as well as specific requirements that may be applicable either individually or to all systems. Also, the intent of this section is to provide the supporting basis of these requirements. It should be noted that the system requirement manual (SRM) is a document under configuration management and will be subject to continual updates as further design work progresses.

4.2.1 Chapter 1: Introduction

4.2.1.1 System Identification

The demonstration of a NGNP for the combined production of electricity and hydrogen is proposed by INL in fulfillment of the 2005 Energy Policy Act. In order to support this commitment in terms of timely design and licensing a requirement for a large scale CTF has been identified [4-1]. This section of the SRM is applicable to the CTF test loops only. Additional restrictions on this documentation include the following:

- The requirements, bases and design descriptions in this document are limited to the component test stations or loops in order to satisfy the Technology Development Road Map (TDRM) and test plan requirements.
- All auxiliary or utility systems are addressed in terms of interface requirements. These systems are not included in this document.
- The content of this document also supports the integrated test schedule that was developed as part of the TDRM study.

4.2.1.2 Limitations of this System Design Description

The SRM is currently only applicable to the proposed test stations and loops as indicated in the System Identification (Paragraph 4.2.1.1.) The requirements currently include limited information from initial test plans as was developed as part of the TDRM.

4.2.1.3 Ownership of this System Design Description

The technical responsibility for the SDD falls currently with the subcontractor for the preconceptual design as awarded in reference [4-6]. It is however anticipated that the ownership could change depending on the future design studies and selection of different subcontractors.

4.2.2 Chapter 2: General Overview

4.2.2.1 System Functions

The system functions of the CTF are presented collectively and are primarily based on the mission statement that was developed for this facility reference [4-1]. Together with the mission statement, a number of HLRs as extracted from reference [4-1] are also presented.

The mission statement functions include:

- Provides qualification and testing of large scale components in a high-temperature, high-pressure environment such as the:
 - Intermediate Heat Exchanger (IHx)
 - Ducting and insulation
 - Mixing chambers
 - Steam generator (SG)
 - High temperature valves
 - Specific application high-temperature instrumentation
 - Industrial hydrogen components
 - Helium circulators
 - Scaled reactor pressure vessel integration and reactor internals testing
 - Chemistry control systems for helium coolant with associated contaminants and impurities
 - Steady-state and transient analysis of coupled systems and components
- Provides design code development verification and validation collaboration
- Provides for materials development and qualification
- Provides for manufacturer and supplier evaluation and development.

Additional functions that the CTF has to fulfil include [4-2]:

- Be open to the full range of suppliers in support of the HTGR community
- Be designed to support the DOE Nuclear Hydrogen initiative
- Support the development of the NNGP heat transfer system components
- Provide a means for:
 - Operator/ maintenance training
 - Off line trouble shooting of components and system problem of the NNGP
 - The technology development of the programs and processes that ultimately support the growing commercial needs of the NNGP.
- Be open during the full life cycle of the CTF for uses by full range of suppliers, end-users etc.
- Be constructed within industry standards
 - For industrial facilities, and
 - To meet local, state and national codes
- Comply with applicable DOE orders and INL site requirements

- Include safeguard considerations into the design for the protection of intellectual property of the vendors.
- An adequately sized, equipped, and operational test facility
- Test, examine, and calibrate instrumentation
- Test, examine, and qualify materials, fluids components, and component integration
- Provide the necessary testing infrastructure, utilities and space for tests and test equipment
- Provide the capability to test reactor and ancillary components which can be demonstrated without requiring the CTF to be NRC-licensed
- To have a operational life span of 40 years, with individual test equipment and engineering-scale demonstrations that will change according to need
- Provide an level of maintainability that minimizes the need for maintenance personal and cost
- Provide an in-service reliability greater than to be determined. The in-service reliability plan will be developed during design.

These functions currently include only system operations related requirements. Safety systems have not yet been included. The safety functions are limited to high level safety requirements as obtained from the PHA. Follow-on design phases will define the need for dedicated safety systems and their related safety functions in more detail.

4.2.2.2 System Classification

The CTF test loop systems are classified as Mission-critical.

4.2.2.3 Basic Operational Overview

In general, CTF test loops operate by heating an insulated volume inside a pressure boundary. The high temperatures are contained inside insulated spaces so that the pressure boundary can be maintained at a much lower temperature. The high temperature helium inside these systems is either circulated or used to create an environment for testing of HTGR components.

A typical operating procedure for a loop includes pressurization by the HICS, startup of the circulators, heat up, performing the test, followed by cool down and depressurization into the HICS. This procedure varies according to the specific test loop and brief overviews of the different systems are provided hereafter.

The CTF can be subdivided into the facility, and then all the technology development systems. For the purpose of this section, the term facility refers to the high-bay building, auxiliaries and all site utilities needed to support the technology development systems. This would typical include electrical, potable and industrial water

supply, compressed air, building, civil etc. and its applicable requirements are addressed in the FDD (Section 4.1).

The technology development systems refer to the different test loops that are proposed for fulfillment of the overall CTF functions. These systems are briefly described in the following sections.

4.2.2.3.1 Small Scale Development Tests

The SSDT deviates from the above general operating description in that it has no circulator. Otherwise, the operation is as described.

The SSDT is a collection of tests that do not require significant volume flow rates or large amounts of heat transfer. Most of the SSDT have in common the requirement for a high-temperature (950°C) high-pressure (9MPa) helium environment and can typically be regarded as simple pressure vessels providing these conditions.

Additional SSDT, like those that support the circulator development, utilize specialized mechanical test setups which require critical inputs from the full-scale NGNP design. Based on this requirement and the absence of the specific information, these SSDT have not been covered in the design process and would only be investigated once further trade studies have commenced.

The tests that require a high-temperature high-pressure helium environment, all comprise a generic setup using a low-temperature pressure vessel, internally insulated high temperature test vessel, heater (20kW) and small flow line water coolers (10kW each). The SSDT for the IHX unit cell fatigue tests is a system that is specifically designed and consists of heaters, coolers, a pressure vessel and hydraulic gas compression systems. A preliminary layout of these two different systems is indicated in Figure 4-2.

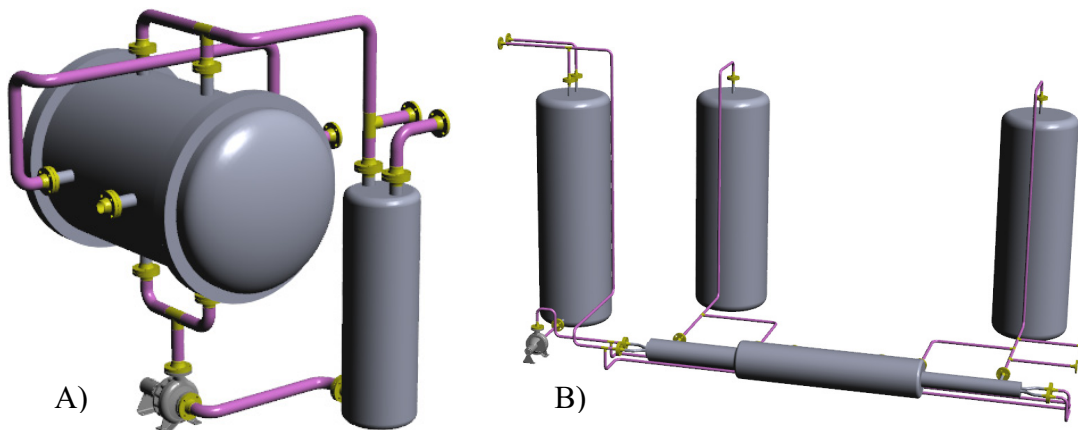


Figure 4-2: 3D layout of the SSDT. A) Generic vessel arrangement B) IHX unit cell test set-up

4.2.2.3.2 Technology Development Loop

The TDL is a larger scale test facility consisting of a primary and secondary loop with the capability of circulating high temperature helium at condition of 950°C and 9.6 MPa(g).

The primary function of the TDL is to provide testing capability for heat transfer components, such as IHX modules, while non-heat transfer components such as scaled Mixing Chambers (MC), Hot Gas Ducts (HGD), or even valves could also be tested.

The TDL also provides flexibility to expand with tertiary loops in support of hydrogen technology component testing. Interconnectivity with additional TDLs is also accommodated. This interconnectivity is meant to serve the CQL1 for larger scale tests as indicated in the applicable sections, reference [4-19].

Figure 4-3 shows a simple layout of this system with the designated primary and secondary loop. The test station vessel acts as the interconnecting component between these two circuits and refers to the location of heat transfer component testing.

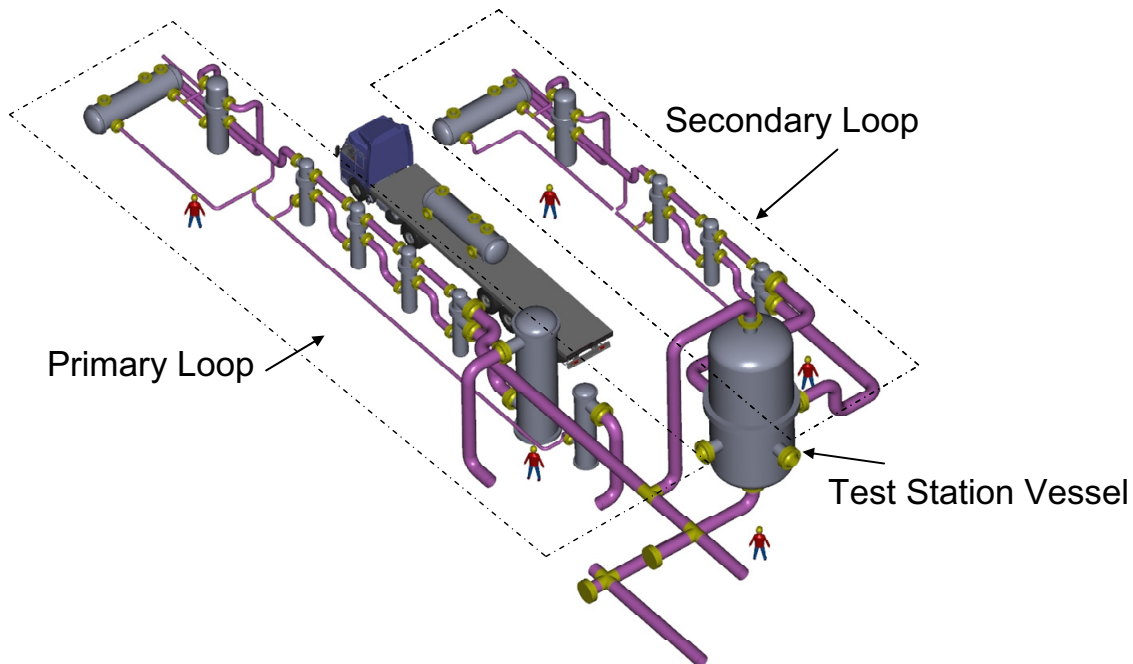


Figure 4-3: 3D layout of the TDL

4.2.2.3.3 Component Qualification Loop 1

The initial concept of the incorporation of a CQL1 within the CTF arose from the idea of using the combined helium mass flows of multiple TDL building blocks. Making use of such an approach permits larger component testing capabilities than those tested within the TDLs.

At present only two TDLs are incorporated into the thermal hydraulic calculations used for the anticipated operation of the CQL1. Each TDL has a blanked-off flanged section that is routed to the Hot Header (HH), which is the interface between the TDLs and the CQL1. These flanged sections will be connected to the HH interface flanges when CQL1 tests are to be run. In this configuration, no separate TDL tests would be allowed to commence whilst the CQL1 is in operation. That is unless it is decided to include more than two TDLs within the CTF.

Figure 4-4 illustrates this interconnectivity of two TDLs in order to provide testing for the intended CQL1. An additional aspect of the CQL1 is the fact that it currently only consists of HGD and the interconnecting headers. The anticipated components to be tested in this system are an integrated SG test configuration along with certain hydrogen technology components. These components, along with their associated secondary and tertiary loops, are considered as UUT and are only addressed with respect to expected interface requirements.

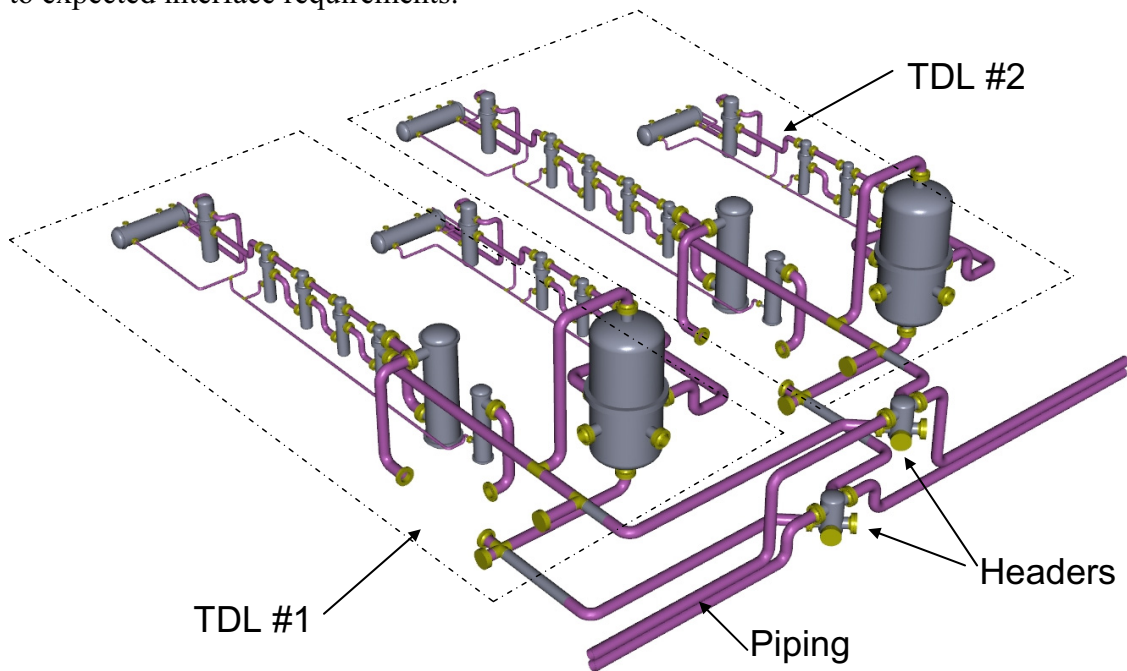


Figure 4-4: 3D layout of the CQL1

4.2.2.3.4 Component Qualification Loop 2

The CQL2 is a complete large scale test facility that comprises a primary and secondary flow system. Both the loops can be operated at conditions similar to that of the NGNP with pressures capable up to 9 MPa(g) and a high temperature section up to 950°C. The mass flow of CQL2 represents approximately 14 percent of the NGNP mass flow and totals 25kg/s. The design of CQL2 is also flexible in terms of catering for a vast array of different configurations in order to provide testing capabilities for a wide spectrum on HTGR components. Figure 4-5 indicates an artist rendition of the proposed facility.

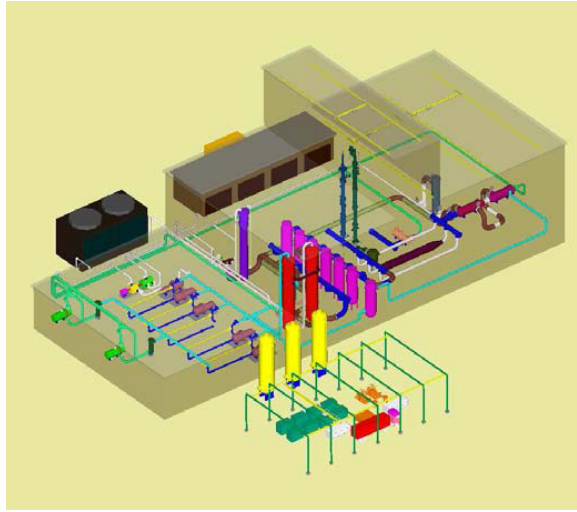


Figure 4-5: 3D layout of the CQL2

4.2.2.3.5 Circulator Test Loop

The CTL comprises a Test Station for a full-scale circulator for the NGNP plant, which operates at 160kg/s helium flow rate, at a maximum temperature of 350°C and a pressure of 9MPa(g). The CTL operates by opening or closing the valves in the pressure dissipating section to vary the system pressure drop characteristic seen by the circulator under test. The required loop temperature is reached with the heat added to the loop by the Circulator. When working temperature is reached, the loop temperature is controlled by a water cooled heat exchanger.

Due to the availability of high pressure drop (450kPa total) and high helium flow rate, several other tests can also be performed in the CTL. These include the calibration of flow meters for the full-scale NGNP, testing of flow-induced vibrations in the full-scale Helium Transport System (HTS) piping, testing of vibration damping devices in the mixing chamber and determination of the pressure drop coefficient of a full-scale one-way “flapper” valve.

Figure 4-6 shows a preliminary layout of the proposed CTL.

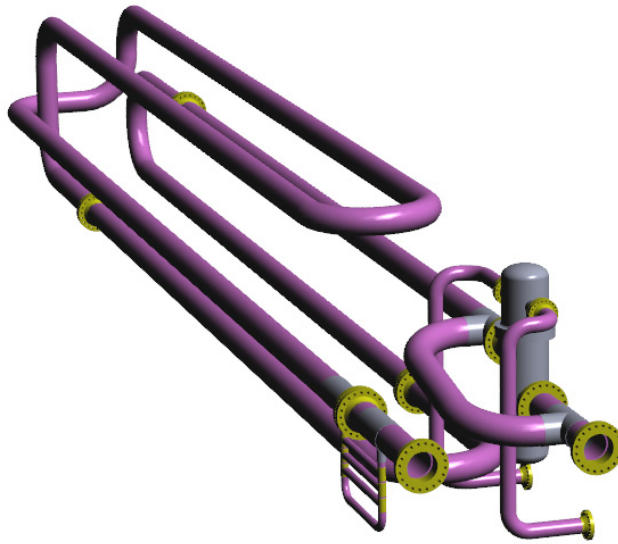


Figure 4-6: Simple diagram of the CTL

4.2.3 Chapter 3: Requirement and Bases

4.2.3.1 General Requirements

The general requirements for this section are classified in terms of their importance to safety, reliable system operations, maintenance, or conformance to environmental regulations. The following classifications are used:

- Safety Requirement (SR) – Those requirements identified which will increase the facility and worker safety.
- Environmental Requirement (ER) – Those requirements identified which address environmental permits.
- Mission Critical Requirement (MCR) – Those requirement that are necessary to prevent or mitigate substantial interruptions of the facility (test loops) operations.
- General Requirement (GR) – Those requirements that don not fit into other categories. Reference [4-25].

4.2.3.1.1 System functional requirements

This subsection states those functional requirements and their bases, for both safety requirements and non-safety requirements that are necessary to fulfil the system function statements.

Various requirement and basis have been developed, as part of the Technical and Functional Requirements (Reference [4-2]). The functional requirements applicable to the CTF can be divided into the 7 high level categories as illustrated in Figure 4-7 (inserted Figure 4-1 again for legible convenience).

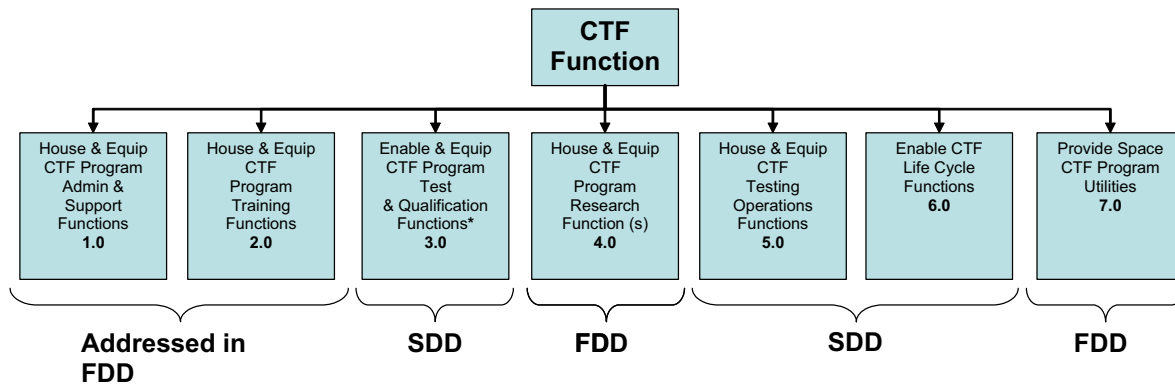


Figure 4-7: Functional and operating requirement top level breakdown.

A summary of these categories and their applicability to the Test Loop Design is given in the next sections.

4.2.3.1.1.1 Enable and Equip CTF Program Testing and Qualification Functions.

The CTF needs to provide the flexibility to test a range of component designs, configuration, operating conditions, materials, and heat transport fluids. The heat transport fluids might have controlled levels of impurities. Mock-ups or scaled representatives need to be tested in a representative environment.

The requirements for the qualification functions that enable and equip CTF program testing can be summarized as:

- Enable primary loop component tests with consideration of test scales, types, scenarios, components, Heat Transfer (HT') gas environment, and impurity control. More detail of this is given in the roadmap requirements in section 4.2.3.1.1.4
- Enable secondary loop component tests with consideration of test scales, types, scenarios, components, high-temperature gas environment, and impurity control. More detail of this is given in the roadmap requirements in section 4.2.3.1.1.4
- Enable tertiary/process heat applications component tests with consideration of test scales, types, and scenarios; components; HT' gas environment; and impurity control. More detail of this is given in the roadmap requirements in section 4.2.3.1.1.4
- Enable testing of scaled models of the NNGP reactor vessel and associated components/systems
- Enable full-scale circulator testing capability.
- Provide off-line trouble shooting of component and system problems.
- Enable coolant and heat transfer fluid tests.
- Equip areas for conducting instrumentation testing, qualification, and calibration.

- Provide facility features for protection of test/CTF assets.
- Provide and equip test monitoring and control areas.
- Enable test data collection, processing, recording, storage, transmission, and archiving capability.
- Provide and equip test component/HT materials/working HT fluids receiving area
- Provide and equip test component inspection and testing capability.
- Provide and equip test component and support equipment storage area(s).
- Provide and equip test support fabrication/assembly/ disassembly capability.
- Provide test component and material handling capability (e.g., test loop crane (s)).
- Provide test component/material/test equipment and associated facility equipment packaging and shipping capability.
- Enable vibration testing capability.
- Enable materials testing capability.
- Enable in-service inspection and testing capability.
- Enable development and qualification capabilities.
- Enable maintainability testing capability.
- Enable mechanical properties testing capability.

4.2.3.1.1.2 House and Equip CTF Testing Operations Functions

The CTF needs to house and equip CTF testing operation functions. These requirements can be summarized as:

- House and equip CTF operations monitoring and control function (e.g., loop(s), control room(s)).
- Provide for inventory control and testing under certain contamination conditions, including loop-to-loop leak detection.
- Provide space and equip for operational data collection, recording, and management capability.
- Provide and equip CTF operations ancillary/support areas.
- Enable and control heat rejection.

4.2.3.1.1.3 Enable CTF Life Cycle Functions

The requirement that enable the CTF life cycle functions can be summarized as:

- Provide features to facilitate commissioning/ decommissioning.
- Provide features for expandability and test space reconfigurable for qualification/international user facility applications.
- Provide features for recovery from anticipated failure events/modes.

4.2.3.1.1.4 Roadmap requirements

The NNGP testing program will have the highest priority in the use for the CTF reference [4-1]. Thus, the main driving force in the design will be the requirements as set out by the NNGP.

The NNGP consists of various SSC integrated into a functional plant capable of producing heat for hydrogen production as well as electricity for export. During various life cycle stages of the NNGP project, a number of SSC need to be developed up to a stage where it are commercially viable or have proven industry experience.

Not all SSC of the NNGP use technology that is either commercially available or has proven industry experience. Therefore, further technology development is needed for these SSC to achieve acceptable Technology Readiness Levels (TRL) for installation in the NNGP.

The various SSC TRL were evaluated and roadmaps were developed to assist the SSC in its maturation process.

Table 4-5: lists the various requirements as found in the various roadmaps. The roadmaps were reviewed to determine the applicable tests that need to be conducted at the CTF.

The primary selection was based on evaluating components as listed in the CTF mission statement. These component roadmaps were evaluated on which test needs to be conducted at pressure of 9 MPa(g) and a temperatures of above 300 °C, as well as the requirements as highlighted in the T&FR reference [4-2].

Table 4-5: briefly summarizes the various requirements as is found in the various roadmaps.

Table 4-5: The requirements as highlighted in the roadmaps

Section	Description	Test number	TRL	Ref.	Test type	Environment	Thermal size [MWt]	Pressure [MPa]	Temperature [°C]	Mass flow [kg/s] ⁸	Test duration [h]
Circulator	Electro Magnetic Bearings (EMBs), Catcher bearings Test Specification	WEC-TS-CIRC-001	TRL 6 - TRL 7	[4-7]	Validation test	Air	N/A	N/A	20	N/A	TBD
Circulator	Helium Rotating seals Test Specification	WEC-TS-CIRC-002	TRL 6 - TRL 7	[4-7]	Performance testing	He	N/A	9	350	N/A	TBD
Circulator	Partial or Full scale circulator Model Test Specification	WEC-TS-CIRC-003	TRL 6 - TRL 7	[4-7]	Validation test	TBD	TBD	TBD	TBD	TBD	TBD
IHX A (Metallic)	Corrosion Allowances for Alloy 617	WEC-TS-IHXA-006	TRL 2 - TRL 3	[4-8]	Exposure test	He	N/A	9	1000	N/A	10000
IHX A (Metallic)	Specification of testing of unit cell of compact HXs	WEC-TS-IHXA-012	TRL 4 - TRL 5	[4-8]	Integrity test	He with controlled impurities	N/A	9	950	N/A	TBD
IHX A (Metallic)	Testing of integrated compact HX module (~1.2MW) :	WEC-TS-IHXA-013	TRL 5 - TRL 6	[4-8]	Various	He with controlled impurities	1.2	9	950	1.217	N/A
IHX A (Metallic)	Operating effectiveness and behaviour in typical steady state pressure, temperature and temperature/pressure	WEC-TS-IHXA-013_01	TRL 5 - TRL 6	[4-8]	Operating effectiveness	He with controlled impurities	1.2	9	950	1.217	N/A

⁸ The mass flows are estimated from the thermal size of the IHX A

Section	Description	Test number	TRL	Ref.	Test type	Environment	Thermal size [MWt]	Pressure [MPa]	Temperature [°C]	Mass flow [kg/s] ^[8]	Test duration [h]
	drop environment (Helium)										
IHX A (Metallic)	Test compact HX module behaviour in typical pressure transient environment:	WEC-TS-IHXA-013_02	TRL 5 - TRL 6	[4-8]	Cyclic transient	He with controlled impurities	1.2	9	950	1.217	TBD
IHX A (Metallic)	Test compact HX module behaviour in typical temperature transient environment:	WEC-TS-IHXA-013_03	TRL 5 - TRL 6	[4-8]	Cyclic transient	He with controlled impurities	1.2	9	950	1.217	TBD
IHX A (Metallic)	Test compact HX module behaviour at varying process parameters:	WEC-TS-IHXA-013_04	TRL 5 - TRL 6	[4-8]	Varying process parameters	He with controlled impurities	1.2	9	950	3.651	N/A
IHX A (Metallic)	ASME III Code Case for Compact HX Designs	WEC-TS-IHXA-014	TRL 5 - TRL 6	[4-8]	Code validation	He	1.2	9	950	1.217	N/A
IHX A (Metallic)	Shell-side flow distribution and bypass leakage testing	WEC-TS-IHXA-015	TRL 6 - TRL 7	[4-8]	Flow distribution and leak test	Air	N/A	Am-bient	Am-bient	N/A	N/A
IHX A (Metallic)	Multi-module heat transfer testing (Evolves future work)	WEC-TS-IHXA-016	TRL 6 - TRL 7	[4-8]	Interaction and leakage	He	4	9	950	3.651	TBD
IHX A (Ceramic)	Testing of unit cell of compact HX (Cyclic loading)	WEC-TS-IHXA-030	TRL 4 - TRL 5	[4-8]	Integrity test	He	N/A	9	1000	N/A	TBD
IHX A	Specifications of	WEC-TS-	TRL 5 -	[4-8]	Various	He	1.2	9	950	1.217	TBD

Section	Description	Test number	TRL	Ref.	Test type	Environment	Thermal size [MWt]	Pressure [MPa]	Temperature [°C]	Mass flow [kg/s] ^[8]	Test duration [h]
(Ceramic)	testing of compact HX module (~1.2MW)	IHXA-031	TRL 6								
IHX A (Ceramic)	Test compact HX module operating effectiveness and behaviour in typical steady state pressure, temperature and temperature/pressure drop environment (Helium)	WEC-TS-IHXA-031_01	TRL 5 - TRL 6	[4-8]	Operating effectiveness in steady state	He	1.2	9	950	1.217	TBD
IHX A (Ceramic)	Test compact HX module behaviour in typical pressure transient environment:	WEC-TS-IHXA-031_02	TRL 5 - TRL 6	[4-8]	Cyclic loading	He	1.2	9	950	N/A	TBD
IHX A (Ceramic)	Test compact HX module behaviour in typical temperature transient environment:	WEC-TS-IHXA-031_03	TRL 5 - TRL 6	[4-8]	Cyclic transient	He	1.2	9	950	N/A	TBD
IHX A (Ceramic)	Test compact HX module behaviour at varying process parameters	WEC-TS-IHXA-031_04	TRL 5 - TRL 6	[4-8]	Varying process parameters	He	1.2	9	950	1.217	TBD
IHX A (Ceramic)	ASME III Code Case for Ceramic Compact HX Designs	WEC-TS-IHXA-032	TRL 5 - TRL 6	[4-8]	Code validation	He	1.2	9	950	1.217	TBD
IHX A	Shell-side flow	WEC-TS-	TRL 6 -	[4-8]	Flow	Air	N/A	Ambi	Ambi	N/A	N/A

Section	Description	Test number	TRL	Ref.	Test type	Environment	Thermal size [MWt]	Pressure [MPa]	Temperature [°C]	Mass flow [kg/s] ^{8]}	Test duration [h]
(Ceramic)	distribution and bypass leakage tests.	IHXA-033	TRL 7		distribution and leak test			ent	ent		
IHX A (Ceramic)	Multi-module heat transfer testing	WEC-TS-IHXA-034	TRL 6 - TRL 7	[4-8]	Interaction and leakage	He	4	9	950	3.651	TBD
IHX B	Corrosion Allowances for Alloy 800H	WEC-TS-IHXB-007	TRL 3 - TRL 4	[4-9]	Exposure test	He with controlled impurities	N/A	9	600 to 850	N/A	10000
IHX B	Specification of testing of Unit Cell of Compact HX	WEC-TS-IHXB-012	TRL 4 - TRL 5	[4-9]	Cyclic loading	He	N/A	9	760	N/A	TBD
IHX B	Specification of testing of compact HX module (~1.2MW)	WEC-TS-IHXB-013	TRL 5 - TRL 6	[4-9]	Specification testing	He with controlled impurities	1.2	9	760	0.547	TBD
IHX B	Operating effectiveness and behaviour in typical steady state pressure, temperature and temperature/pressure drop environment	WEC-TS-IHXB-013_01	TRL 5 - TRL 6	[4-9]	Operating effectiveness in steady state	He with controlled impurities	1.2	9	760	0.547	TBD
IHX B	Behaviour in typical pressure transient environment	WEC-TS-IHXB-013_02	TRL 5 - TRL 6	[4-9]	Transient	He with controlled impurities	1.2	9	760	N/A	TBD
IHX B	Behaviour in typical temperature transient environment	WEC-TS-IHXB-013_03	TRL 5 - TRL 6	[4-9]	Transient	He with controlled impurities	1.2	9	760	N/A	TBD
IHX B	Behaviour at varying	WEC-TS-	TRL 5 -	[4-9]	Varying	He with	1.2	9	760	0.547	TBD

Section	Description	Test number	TRL	Ref.	Test type	Environment	Thermal size [MWt]	Pressure [MPa]	Temperature [°C]	Mass flow [kg/s] ^[8]	Test duration [h]
	process parameters	IHXB-013_04	TRL 6		process parameters	controlled impurities					
IHX B	ASME Section III Code Case for Compact HX Designs	WEC-TS-IHXB-014	TRL 5 - TRL 6	[4-9]	Code validation	Helium	1.2	9	760	0.547	TBD
IHX B	Shell-side Flow Distribution and Bypass Leakage Testing	WEC-TS-IHXB-015	TRL 6 - TRL 7	[4-9]	Flow distribution and leak test	Air	N/A	Ambient	Ambient	N/A	N/A
IHX B	Multi-module Heat Transfer Testing	WEC-TS-IHXB-016	TRL 6 - TRL 7	[4-9]	Interaction and leakage	He	4	9	760	1.64	TBD
Piping	Effects of He infiltration on thermal conductivity of insulation material	WEC-TS-PIP-006	TRL 5 - TRL 6	[4-10]	Exposure test	He	N/A	9	950	N/A	TBD
Piping	The effect of fluid impurities (C) on insulation properties	WEC-TS-PIP-007	TRL 5 - TRL 6	[4-10]	Exposure test	He with controlled impurities	N/A	9	950	N/A	TBD
Piping	Performance and environmental testing of prototypical high-temperature and low-temperature piping/insulation system	WEC-TS-PIP-009	TRL 6 - TRL 7	[4-10]	Performance testing	He	N/A	9	950	3.651	TBD
Piping	Performance and environmental testing -	WEC-TS-PIP-	TRL 6 - TRL 7	[4-10]	Steady state	He	N/A	9	950	3.651	TBD

Section	Description	Test number	TRL	Ref.	Test type	Environment	Thermal size [MWt]	Pressure [MPa]	Temperature [°C]	Mass flow [kg/s] ^[8]	Test duration [h]
	Typical steady state pressure and temperature environment	009_01									
Piping	Performance and environmental testing - Typical pressure transient environment	WEC-TS-PIP-009_02	TRL 6 - TRL 7	[4-10]	Transient	He	N/A	9	950	N/A	TBD
Piping	Performance and environmental testing - Typical temperature transient environment	WEC-TS-PIP-009_03	TRL 6 - TRL 7	[4-10]	Transient	He	N/A	9	950	N/A	TBD
Mixing Chamber	Specification 1: Enhanced Mixing Devices Test Specification	WEC-TS-MC-001	TRL 6 - TRL 7	[4-11]	Performance testing	He	N/A	9	900	3.651	TBD
Mixing Chamber	Specification 2: Vibration Damping Devices Test Specification	WEC-TS-MC-002	TRL 6 - TRL 7	[4-11]	Performance testing	He/Air	TBD	9	900	3.651	TBD
Mixing Chamber	Partial or Full Scale Flow Mixing Chamber Model Test Specification	WEC-TS-MC-003	TRL 6 - TRL 7	[4-11]	Performance testing	He/Air	TBD	TBD	TBD	TBD	TBD
Hydrogen Production System	Process heat for Hydrogen production	TBD	TBD	[4-13]	TBD	He	8 to 10	TBD	TBD	TBD	TBD

Section	Description	Test number	TRL	Ref.	Test type	Environment	Thermal size [MWt]	Pressure [MPa]	Temperature [°C]	Mass flow [kg/s] ^[8]	Test duration [h]
Steam Generator	Performance testing in CTF	WEC-TS-SG-005	TRL 6 - TRL 7	[4-12]	Performance testing	He	TBD	TBD	TBD	TBD	TBD

4.2.3.1.1.5 Engineering judgment requirements to aid the testing maturation plan (GR)

A number of “engineering judgment” specifications based on experience from the PBMR Test Facilities have also been developed to aid the CTF testing technology maturation and design. These typically include:

- CTF flow meter calibration setup
- Impact of temperature on strain gauge
- Impact of helium on strain gauge

This test still needs to be defined and will depend on the design growth path of the CTF and requirements thereon. It is recommended that the CTF needs to provide a test bench with the correct environment where these tests could be performed in.

4.2.3.1.2 Subsystems and major components

This section identifies the general requirements that are unique to subsystems and major components.

4.2.3.1.2.1 Test loops design for heat exchanger (GR)

The test loop shall consist of two connected loops. There is a main loop, simulating to a certain degree, the NGNP primary loop, and a secondary loop, simulating aspects of the secondary loop of the NGNP.

The IHX needs to be tested under reactor simulated conditions as outlined in the T&FR, reference [4-2] as well as the applicable roadmaps, references [4-7] to [4-13] .

4.2.3.1.2.2 Interfacing of loops (GR)

The primary and secondary loops need to interface with each other to perform IHX testing

The basis for this requirement is the T&FR, reference [4-2].

4.2.3.1.2.3 Cyclic tests (GR)

Some parts of the test needs to be run under cyclic conditions for the testing of component, material or test failure.

The basis for this requirement is the T&FR, reference [4-2] as well as the applicable roadmaps, references [4-7] to [4-13] .

4.2.3.1.2.4 Enable coolant and heat transfer fluid tests.

The CTF will enable coolant and heat transfer fluid tests for various test scales, types and scenarios and fluid types.

The basis for this requirement is the T&FR, reference[4-2].

4.2.3.1.2.5 Flexibility (GR)

The CTF will provide features for the flexibility to test a range of component designs, configurations, operating conditions, heat and transport fluids.

The basis for this requirement is the T&FR, reference[4-2]. Furthermore, the CTF is an experimental facility, which will be open the full range of suppliers, as outlined in the HLR, reference [4-1].

4.2.3.1.2.6 Development of testing requirements and configurations (GR)

The CTF facility will have many interfaces with the NGNP R&D and design team to develop testing requirements and configurations.

The basis for this requirement is the HLR, reference [4-1].

4.2.3.1.2.7 System generic design (GR)

The test loop design should aim to minimize the types and materials used for the pipes and vessels.

The plant needs to be flexible as mentioned previously. To accommodate this requirement it is found that the design demands change over the life time of the plant and should thus be catered for.

4.2.3.1.2.8 CTF will NOT accommodate integrated thermal hydraulic reactor core testing. (GR)

Although there is a need for a thermal hydraulic scaled integrated test of reactor internals and reactor pressure vessel (RPV), the CTF will NOT accommodate the larger envelope that might be required for integrated thermal hydraulic reactor core testing.

The basis for this requirement is the T&FR, reference [4-2].

4.2.3.1.2.9 Number of test stations (GR)

The CTF will provide a number of test stations necessary to meet the needs of the CTF test program and test plans.

The basis for this requirement is the T&FR, reference [4-2].

4.2.3.1.2.10 Full scale testing of applicable component (GR)

The CTF needs to accommodate testing of full scale component of the NGNP such as heat exchangers and circulators. These types of equipment will form a basis for the sizing of the facility, associated test systems, test stations and utilities.

The basis for this requirement is the T&FR reference [4-1].

4.2.3.1.2.11 Main component selection in terms of commercial-off-the-shelf (MCR)

The CTF should strive to utilize commercial-off-the-shelf (COTS) items as far as possible.

COTS components should be one order more reliable than the components under test. This increases the reliability and availability of the components, which supports the facility life span of 40 years, and will provide a level of maintainability that optimizes the need for maintenance personnel and cost, reference [4-1]. This would also avoid additional technology development that might be needed for the CTF.

4.2.3.1.2.12 Component selection in terms of availability, cost, reliability etc (GR)

The various components of the CTF should be selected conservatively as related to availability, cost, reliability, durability and those which fit the requirements of the different CTF configurations and tests the best.

The facility has a life span of 40 years.

4.2.3.1.2.13 Numerous tests (GR)

The CTF should strive to have the capability of performing numerous tests at the same time.

This is needed to address the various long-term testing requirements from different clients, with a short timeframe in which these tests need to be completed.

4.2.3.1.2.14 Circulator redundancy (MCR)

Two times 100 percent capacity gas circulator/blower trains should be installed for both the main and the secondary loop. Each train consists of two blowers connected in parallel to obtain a higher combined pressure ratio.

The high availability requirement of the CTF justifies the redundancy in the blower/gas circulation function.

4.2.3.1.2.15 Circulator bearings (GR)

It is recommended to use fixed bearings (oil lubricated), and submerged rotor with TRL of at least 8.

The reason for using submerge rotors suspended on fixed bearings is because of industrial experience with such configuration e.g. the gas circulators of the Advanced Gas-cooled Reactor (AGR's) in the UK as well as the Helium blowers of the Thorium High Temperature Reactor (THTR) (Germany) and the High Temperature test Reactor (HTTR) (Japan).

4.2.3.1.2.16 Recuperator (GR)

The recuperator should be of conservative design with TRL of 8. The effectiveness shall be at least 80 percent. Depending on the cost of the unit, a higher effectiveness is recommended.

The minimum of 80 percent effectiveness is selected to keep the energy consumption at a realistic level.

4.2.3.1.2.17 Heater unit (GR)

Heater unit should be electric powered and shall provide for different power input.

The CTF should strive to utilize COTS components, with electric heaters to be a well known technology.

4.2.3.1.2.18 Piping (GR)

Cold piping shall be use where the American Society of Mechanical Engineers (ASME) code allows the operational conditions. Provision should also be made for moderated expected temperature transients.

It is not needed to be over conservative in the specification for piping because of the relative stable/steady state flow conditions and the intensive measuring and control system implemented.

4.2.3.1.2.19 Low temperature valves (GR)

Where valves are needed in the CTF, they should be mounted in the lowest temperature section of the flow-controlled section.

High temperature valves are typically UUT as defined in the TDRM; therefore such valve application in the CTF should be excluded or minimized.

4.2.3.1.2.20 Additional space in facility (GR)

Test vessels sizes are undefined in this preconceptual design study, therefore only sufficient space should be allowed in the test hall.

Identification of the number of test will increase as the study/design progresses.

4.2.3.1.2.21 Cooling system (GR)

Helium gas coolers can either be of gas-to-water type or gas-to-air type coolers. The gas inlet and outlet temperatures are excessively higher than the boiling point temperature of water at atmospheric pressure, therefore the water-side pressure should be elevated to avoid boiling/partial boiling or the minimum water mass flow should be maintained sufficiently to avoid boiling.

Experience in the industry with medium and high temperature water coolers indicate practical problems e.g. corrosion, stress corrosion etc. which means that adequate water treatment should be instated.

From a safety and control point of view, the gas-to-air coolers are the preferred option.

4.2.3.1.2.22 Minimum vessel dimension for IHX unit cell (GR)

The minimum dimension for the IHX unit cell vessel shall have internal dimensions of 700mm diameter by 1.26m length.

This space was calculated such that there is 300mm working space around an IHX unit cell for the installation of probes, sensors and tubes onto test specimens, as well as 200mm space along the length of the vessel for installation of a heating element [4-8]. (This can be revised if the vessel orientation is changed to a vertical bell-type configuration.) The space calculation is described in reference [4-8].

4.2.3.1.3 Boundaries and Interfaces

In this section the various boundaries and interfaces that exist are identified. For this section however, it is important to note again that the design of the system is limited the test loops only. The auxiliary systems that support these loops are not in the scope of this task.

4.2.3.1.3.1 Electrical infrastructure requirement (GR)

For planning purposes, it is assumed that the CTF has a maximum electric capacity of 50 000 kVA. This value need to be revisited in following design phases.

Commercial electric power is delivered to the operating areas at the INL Site by an extensive power transmission and distribution system (reference [4-3]) with maximum available load of 50 000 kVA (reference [4-5]).

4.2.3.1.3.2 No gas supply infrastructure (GR)

The design of the system should not be reliant on the supply of gas.

There are no gas or oil lines on the INL grounds, although individual facilities may have propane or fuel storage tanks [4-3].

4.2.3.1.3.3 Road transport (GR)

The plant should be designed that it is accessible by mainly road transport.

The area is located near a U.S. Highway and other paved and unpaved roads [4-3].

4.2.3.1.3.4 Support system (GR)

The CTF is to provide various support systems for the test loop designs. These include but are not limited to:

- Process air
- Water
- Helium storage
- Helium purification

In this preconceptual design, the requirements originate from the loop designs and are listed in the FDD part of this document.

4.2.3.1.4 Codes, Standards, and Regulations

This section identifies various codes and standards that are applicable for the CTF design. Additional discussion is included in the DCD, reference [4-16].

4.2.3.1.4.1 Hazard Evaluation (SR)

The Guidelines for Hazard Evaluation Procedures as published by the Center for Chemical and Process safety will be applied for the hazard assessment to all phases of CTF development (Reference [4-26]).

As a high risk, high hazard, non-nuclear facility, safety must be an integral part of all CTF activities, from design through operation. This requirement replaces the DOE standards 1189 as outlined in the HLR reference [4-1] seeing as the DOE standard 1189 applies primarily to nuclear facilities.

4.2.3.1.4.2 DOE standards 5400.1: General environmental requirement (GR)

The CTF will comply with the environmental related requirements and includes DOE order 5400.1: General environmental protection program”.

This requirement is outlined in the HLR, reference [4-1].

4.2.3.1.4.3 Comply with applicable DOE order and INL site requirements (GR)

The CTF will comply with the applicable DOE orders and INL site requirements

This requirement is outlined in the HLR, reference [4-1]

4.2.3.1.4.4 Subject to NEPA act (GR)

The CTF will be subject to the NEPA act process.

This requirement is outlined in the T&FR, reference [4-2].

4.2.3.1.4.5 NOT NRC-Licensed (SR)

The CTF test can be demonstrated without the requirement for the CTF to be NRC licensed.

This requirement is outlined in the T&FR, reference [4-2].

4.2.3.1.4.6 Design requirement as listed in the Design Criteria Document (GR)

A study was done to identify the various codes and standards that are applicable in the CTF. These are listed in the DCD) reference [4-16]. The DCD divides the codes and standards in two sections:

- Facility requirements
- Test loop requirements

The facility requirements are based on the INL Engineering standard reference [4-23]. A section by section investigation of this document was performed to identify the important codes and standards that are applicable from the CTF side towards the facility.

Various requirement for the test loops' Codes and Standards were identified.

A rather extensive list of codes and standards were compiled. As this list is quite extensive, these requirements are not repeated in this section but are listed in the DCD, reference [4-16].

4.2.3.1.5 Operability

The aim of this subsection is to state the specific operability conditions. Operability is divided into two parts namely:

- System operability in terms of TSR- The system is defined to be operable when it is capable of performing its specified function(s). Thus, it includes all the necessary instrumentation, control, and other auxiliary equipment to perform it specific function.
- Management operability - The additional operability requirements that are set out by facility management and which go beyond the TSR are listed here.

4.2.3.1.5.1 Safety Support Systems (SR)

The operability of the safety support systems need to be defined in the follow-on design phases of the project. At this stage the various high level hazard events are only listed, because operability requirements have not yet been defined. These events are:

- High temperature increase
- Increase in temperature
- Rupture of test stations
- Asphyxiation
- Violent release of energy

The basis for this requirement is the Preliminary Hazard Analysis (PHA) which only identified various high level hazards and made some initial recommendations to mitigate the potential hazards. Reference [4-14].

4.2.3.1.5.2 Open for use by full range of suppliers

During the life cycle of the CTF, the facility will be open for the use to a full range of suppliers, end-users, facilitators, government laboratories and other domestic and international community contributors supporting the development of the HTGR technology.

This requirement is outlined in the HLR reference [4-1].

4.2.3.2 Special Requirements

4.2.3.2.1 Radiation and Other Hazards

The purpose of this section is to identify the requirements that have been established due to radiation and other hazards. These hazards are defined to be beyond those typically accepted in industrial workplace as defined in the OSHA.

4.2.3.2.1.1 No-Radiation hazard (GR)

There should be no-radiation hazard on this site.

The CTF is anticipated to be a high hazard, non-nuclear facility as outlined in the HLR, reference [4-1] and therefore the CTF be does not need to be NRC-licensed and classified as a radiological facility [4-2].

4.2.3.2.1.2 Hydrogen process in a separate building (SR)

For the hydrogen process, it is recommended that the hydrogen facility be situated in a separate part of the test facility.

The CTF also needs to address the requirements as set out in the TDRM for hydrogen, reference [4-12]. This implies that a hydrogen safety system be implemented. If the whole facility needs to comply to the stringent requirements for hydrogen safety, the cost will increase dramatically. Furthermore, the TDRM for hydrogen production reflects only very early stages with development work. These factors support this recommendation.

4.2.3.2.2 As Low as Reasonable Achievable

The As Low as Reasonable Achievable (ALARA) requirements apply only to radiation exposure of personal at the facility. The CTF is anticipated to be a high hazard, non-nuclear as well as non-radiological facility. Thus the term ALARA is not be applicable to this site.

4.2.3.2.3 Nuclear Criticality Safety

The CTF is anticipated to be a high hazard, but non-nuclear as well as non-radiological facility. Therefore, nuclear critical safety requirement are not applicable.

4.2.3.2.4 Industrial Hazards

The CTF is defined as a high risk, high hazard, and non-nuclear facility. Safety is the primary goal for all CTF activities, from design through operation as stated in the HLR reference [4-1].

To assist the process of identifying Environmental, Safety and Health (ES&H) requirements pertaining to the system being described, a Preliminary Hazard Assessment PHA [4-14] was done.

The intent of the PHA was to identify the various risks and hazards of the test loops. At this stage only suggestions have been made for mitigation with further development work to be done at a later stage. This section only points out the high level risk hazards that need to be addressed.

4.2.3.2.4.1 Helium as a hazard (SR)

High exposure to Helium should be reduced as far as possible.

From the PHA (reference [4-14]) it is evident that helium is a hazard. Although helium is non-toxic and inert, inhalation in excessive concentrations can result in dizziness, nausea, vomiting, loss of consciousness, and death. The plant will be operated at high pressure of 9 MPa(g) with large volumes of gas.

4.2.3.2.4.2 Oxygen Monitoring System (SR)

The oxygen monitoring system will use sensors capable of measuring the atmospheric oxygen concentration in the range of 0 to 25 percent. The system will alert the personnel if the oxygen content of the air is below a predetermined value.

Helium is non-toxic and inert, but displaces oxygen. This requirement basis is to reduce the Helium hazard.

4.2.3.2.4.3 Include rupture disc in the design (SR)

In the event of a failure of the Pressure Relief Valve (PRV) a secondary safety measure should be incorporated into the design. For this a rupture disc is recommended.

The test loops are to be designed to handle a maximum pressure of 9 MPa(g). If there is an increase in pressure and the PRV fails, a secondary safety measure needs to be available as outlined in the PHA reference [4-14].

4.2.3.2.5 Operating Environment and Natural Phenomena

This section identifies the requirements related to the normal operating environment and natural phenomena that the system need to operate in.

4.2.3.2.5.1 Meteorological conditions temperature and humidity (GR)

For the meteorological conditions that influence the design, it is assumed that the facility will be designed to operate inside of a ventilated building. The design of the system should thus only be influenced by the ambient conditions. Other meteorological conditions which include wind, snow, rain etc are thus excluded.

Average monthly temperatures range from -9.0°C (15.8°F) in January to 20.1°C (68.2°F) in July. Recorded extremes at the Central Facilities Area (CFA) are from -44°C (-47°F) to 38 °C (101°F).

Average monthly relative humidity ranges from 15 percent in August to 89 percent in October and December.

The basis for this is that the CTF can be located at the INL reference [4-1] and the Site Selection Study (SSS) reference [4-3].

4.2.3.2.5.2 Protection from natural phenomena (SR)

It is recommended that the assumption/input of natural phenomena be conservative. One should follow at least the local (state) civil requirements for critical /sensitive structures. An agreed upon approach to the design for seismic events, tornados etc should be used in the designs. It is recommended that the facility be classified as PC-2. This is subject to a detailed follow-on hazards analysis and additional requirements that may be identified during the detail design.

Although the proposed CTF sites identified are not in great danger of earthquakes, tornadoes, volcanic eruptions and floods [4-3], the CTF is a mission critical (but not a nuclear or radiological safety critical) project Reference [4-1].

4.2.3.2.5.2.1 Catastrophic failure (SR)

The probability of catastrophic failure of high energy piping and vessels shall be less than 10^{-4} /year (To be verified during follow-on stages of the design).

The highest industrial standard is required because of the classification of the site where the CTF will be constructed and operated. This needs to be confirmed pending the previous requirement.

4.2.3.2.6 Human Interface Requirements

In this section the various requirement are identified relating to the design of the human interface system. The following points are addressed:

- Requirements that trigger manual safety and non-safety alarms;
- Requirements which are important for the human interface.

4.2.3.2.6.1 Develop Safety and Non-Safety alarms (SR)

The safety and non safety alarms are to be defined in the detail design of the project as part of detail modes and states of the various test loops.

4.2.3.2.6.2 Basic needs for operator training etc (GR)

The CTF will provide a means for operator/maintenance training, off-line trouble shooting of components and system problems during the operation of the NGNP.

This requirement originates from the HLR , reference [4-1].

4.2.3.2.6.3 Life cycle need (GR)

During the life cycle of 40 years the CTF the facility will then be open for use by the full range of suppliers.

This requirement originates from the HLR, reference [4-1]

4.2.3.2.6.4 Important human interface requirements (GR)

The CTF will provide valuable data and experience required to operate the NGNP by including control room simulation program data reference.

This requirement originates from the HLR, reference [4-1]

4.2.3.2.6.5 Operator displays (GR)

The operator displays and controls will be designed to human factors standards and to maintain situational awareness. Display of system safe operation parameters will take priority.

This requirement originates from the Preconceptual Facility Configurations (PCFC) study reference [4-5]

4.2.3.2.6.6 Hardware switches (SR)

Discrete hardware control such as shutdown switches will be reserved for the safety system. Experimental visualization and control may be incorporated into portions of the human interface.

This requirement originates from the PCFC study reference [4-5]

4.2.3.2.6.7 Simulation system (SR)

A facility for plant operation simulations will be provided for operational pre-job planning, experimentation, and practice. Operator virtual simulation and practice facilities will be provided.

This requirement originates from the PCFC study, reference [4-5].

4.2.3.2.6.8 Adaptable interface (GR)

The CTF is of experimental nature, which means that the circumstances differ continuously, therefore the man-machine interface should be adaptable to changes, but the logic and safe operation should remain.

The CTF will be used for a wide range of tests, which will be open to various vendors. Thus the different physical configurations, groups of simultaneous tests and operational conditions specified will require such operational flexibility.

4.2.3.2.6.9 Limited authority (SR)

The operators should have limited authority to change operational settings and interlock values.

The UUT have their own specific limitations to operational conditions, which are taken into account in the allowable operational profiles and control software of the tests. This is a safeguard to protect the UUT and thus human error will be limited by this. This requirement also supports the level of automation philosophy as outlined in reference [4-15].

4.2.3.2.7 Specific Commitments

This subsection identifies commitments that have been made with regards to operational events (such as incidents) to the DOE or other regulatory agency (EPA).

At this stage there are no specific commitments from an operational side which influence the safety of the identified system. This work is to be classified as future work. It should be noted that the end user(s) requirement to performance, access, safety, operation etc. shall be important to take into account in the next design phase of this process.

4.2.3.3 Engineering Disciplinary Requirements

The purpose of this section is to identify the unique requirements that are applicable to its particular discipline of engineering.

4.2.3.3.1 Civil and Structural

The outcome for this section is to identify civil and structural requirements.

4.2.3.3.1.1 Comply with International building code (GR)

The CTF facility will be constructed within industry standards for industrial facilities, including hydrogen use and handling and will meet local, state, and national codes, such as the International Building Code (IBC) and National Electric Code (NEC) as stated in section 4.2.3.1.4.

4.2.3.3.2 Mechanical and Materials

The outcome for this section is to mechanical or material engineering requirements. These requirements relate to the component specifications.

4.2.3.3.2.1.1 Plant layout (SR)

The plant should be designed, to minimize the movement of large masses (for example headers and vessels) across high energy system. This should be especially incorporated during construction of new/ revised/repair test-setups.

Damage of high-energy systems propagate in more serious scenarios, therefore prevention of damaging such systems are logic.

4.2.3.3.3 Chemical and Process

This section's purpose is to identify the chemical or process requirements, which include process environmental conditions (i.e. pressure, temperature, PH etc) as well as type of processing (batch or continuous).

4.2.3.3.3.1 CTF Envelope conditions (GR)

The CTF needs to accommodate the various conditions as outlined by the roadmaps. (Section 4.2.3.1.1.4). The envelope conditions can be reduced to three major types, which are listed in Table 4-6.

The various identified categories are based on grouping distinctive ranges of the mass flows together. The first category could be described as tests where the exposure to certain conditions over a prolonged period of time is important. The next three categories are distinguished by the different flow rates.

Table 4-6: Envelope conditions for the system

Category	Description	Pressure [MPa]	Temperature [°C]	Mass flow [kg/s]	Test duration [hrs]
1.	Exposure test	9	1000	NA	10 000
2.	Low mass flow test	9	1000	< 1.7	TBD
3.	Medium mass flow	9	1000	< 3.7	TBD
4.	Very high mass flow	9	1000	< 25	TBD

The basis of this requirement is the various roadmaps for the CTF components reference [4-7] to [4-13] as well as the HLR [4-1].

4.2.3.3.3.2 Representative gas environment of the NGNP (GR)

The CTF tests have to be performed in a helium environment with low levels of CO, CO₂, H₂, and H₂O. Provisions have to be made for the introduction, control, and measurement of impurity levels. The exact levels have not been defined at this stage.

The basis of this requirement is the various roadmaps for the CTF components reference [4-7] to [4-13] that specify what the test gas environmental conditions should be for the CTF.

4.2.3.3.3.3 Oxidation level on metals (GR)

The CTF should control the necessary oxidation inventory and chemistry levels which will maintain the oxidation levels on metals.

The basis for this requirement is the T&FR reference [4-2].

4.2.3.3.4 Electrical Power

This subsection identifies the electrical power engineering requirements related to the system being described. This section is divided into two parts:

1. Electrical power quality requirements
2. Backup power requirements

4.2.3.3.4.1 Site Power distribution (GR)

Normal power service to the CTF will be provided from a substation at 13.8 kV, three-phase. The 13.8 kV, 4160 V, and 480 V switchgear will be a double-ended with bus tie-breaker configuration to allow flexibility for outages and maintenance activities.

The basis for this is INL Engineering standard reference [4-23].

4.2.3.3.4.2 Site power quality (GR)

The site power supply quality should minimize the adverse effects of voltage level variations, transients, and frequency variations on equipment operation.

The basis for this is INL Engineering standard reference [4-23].

4.2.3.3.4.3 Monitoring the distribution system (GR)

The 13.8 kV, 4160 kV, and 480 V circuit breakers will, as a minimum, be monitored by a Supervisory Control and Data Acquisition System (SCADA) system for power quality, status of critical loads, and metering. The circuit breakers will also be tied into the SCADA system for load shedding purposes in the event if normal power is lost.

This requirement was identified as part of the PCFC Study, reference [4-5].

4.2.3.3.4.4 Standby Power Capacity (SR)

The SPS supports the safe shutdown of loads, including the process circulators and cooling system, during loss-of-site power or onsite power system failure.

This involves the safe shutdown of the operating the process circulators and cooling system to remove heat from the process to some acceptable level.

This requirement was identified as part of the PCFC Study, reference [4-5].

4.2.3.3.4.5 Standby Power Requirement (SR)

The SPS will be designed, maintained, and operated in accordance with Article 701 of the NEC, NFPA 110, IEEE-336, and DOE Standard 3003. The SPS and connected loads will be inspected and tested in accordance with the latest edition of IEEE-336.

The SPS will be designed to support maintenance and testing of the generators without loss of power to the supplied loads.

This requirement was identified as part of the PCFC Study, reference [4-5].

4.2.3.3.4.6 Monitoring of the SPS (GR)

The status of each generator and major circuit breaker in the SPS to the 480 V level will be monitored by the FMS to insure configuration control. Also, the SPS main feed circuit breakers will be monitored for power quality, status, and metering. Monitoring of the power status (quality and loss-of-power to important loads) should be included as inputs (using acceptable isolation) to the FMS.

This requirement was identified as part of the PCFC Study, reference [4-5].

4.2.3.3.4.7 Uninterruptible Power Supply (UPS) sizing (SR)

The UPS system will provide power to vital loads without interruption on loss of off-site power. Its purpose is to provide power to and protect sensitive loads, particularly computer based controllers and circulator Electro Magnetic Bearings (EMB) controller equipment, from power interruptions.

This requirement was identified as part of the PCFC Study, reference [4-5].

4.2.3.3.4.8 Uninterruptible Power Supply (UPS) quality (GR)

The UPS will be configured to function with the wider (60 Hz 10 percent) output frequency tolerance of the standby power system (SPS) generators. The UPS power status (quality and loss-of-power) monitoring will be included as a feed (using acceptable isolation) to the Facility Monitoring System (FMS).

This requirement was identified as part of the PCFC Study reference [4-5].

4.2.3.3.4.9 UPS design requirements (GR)

The UPS system will be designed, installed, tested, maintained, and operated in accordance with Article 700.12(A) of the NEC, NFPA 111, IEEE-336, IEEE-944, NEMA PE-1, and DOE Standard 3003. As per NFPA 111, the UPS will be classified as a Type 0, Class [TBD], Level 2, Category A system and will be designed to meet the requirements of IEEE-519 for harmonic distortion recommendations.

This requirement was identified as part of the PCFC Study, reference [4-5].

4.2.3.3.4.10 UPS system integration (GR)

The UPS will be designed to maintain independence from the normal power system (after the over current protective device feeding the UPS) and avoid single-point and common mode failures, particularly from maintenance outages, earthquakes, fires, flooding, or spraying by fire sprinklers.

The UPS wiring, including the normal power feeder circuit, will occupy separate conduit from other power systems and general wiring or provide at least a 25.4 mm (1-in.) physical separation when within the same enclosure.

The UPS will be designed to ensure ease of maintenance and testing without unduly compromising the functionality of connected loads, and is testable without loss of power to the connected loads.

This requirement was identified as part of the PCFC Study reference [4-5].

4.2.3.3.5 Instrumentation and Control (I&C)

The focus of this subsection is to identify those instrumentation and hardware control engineering requirements related to the system being described. This section focuses mainly on hardware controls, which include:

- Operational requirement - Requirements for manual and automatic actions for system initiation and control, indicators, alarms, and manual controls that are used to operate the system. This section identifies required ranges and accuracies.
- Instrumentation requirements influenced by the TSR
- Additional measurement requirements as identified are also listed

4.2.3.3.5.1 Accommodate instrumentation requirements as outlined by the roadmaps (GR)

The CTF has to provide the minimum test instrumentation for the various UUT. The minimum range of instrumentation is provided in Table 4-7

Table 4-7: Summary of the test instrumentation requirements for the CTF based on the roadmaps

Mass flow	Pressure	Temperature	Other
Mass flow	Pressure	Temperature	Fluid composition
Mass flow (in)	Internal Pressure	Temperature chamber wall	Leak rates
Mass flow (Out)	External pressure	Local streak temperature deviation walls	Impurities level
	Inlet pressure	Local streak temperature deviation walls	Impurities primary
	Outlet pressure	T _{IN}	Impurities secondary
		T _{Out}	Strain
		Temperature gradient	Thermal conductivity
		T _{IN PRIMARY}	Duration of exposure
		T _{OUT PRIMARY}	Acoustic induced spectra
		T _{IN SEC}	Flow induced spectra
		T _{OUT SEC}	Chamber wall loads

Mass flow	Pressure	Temperature	Other
			Frequency and amplitudes of loads
			Post test exam

The bases for these requirements are the various roadmaps references [4-7] to [4-13]. A detail table indicating the instrumentation that is needed per test, is given in Appendix E.

4.2.3.3.5.2 Control room simulation data requirement (GR)

The CTF has to provide valuable data and experience to operate the NGNP by providing control room simulation program data.

The basis for this requirement is outlined in the HLR , reference [4-1].

4.2.3.3.5.3 Accommodate new technology (GR)

The CTF has to accommodate new technology during the lifecycle of the project.

Due to the rapid renewal of control system technologies, and the long plant life requirement of 40 years, the CTF has to accommodate new technologies. This is further supported by the requirement of a phased approach, reference [4-15].

4.2.3.3.5.4 Instrumentation testing, qualification and calibration (GR)

The CTF will provide for the testing, qualification and calibration of instrumentation under comparable conditions to that envisaged for the NGNP operating conditions.

The basis for this requirement is outlined in the T&FR reference [4-2].

4.2.3.3.5.5 Test Instrumentation development work (MCR)

The CTF needs to provide an environment where development work can be performed on certain instrumentation.

Instrumentation does not always behave similarly in adverse conditions. Therefore, it needs to be tested firstly in a similar environment before it can be used in the NGNP. A typical example of this can be found in strain gauges' operational limits which need to be verified at high temperature; high pressure in a helium environment.

4.2.3.3.5.6 Use of industry standard protocols (GR)

In the CTF the industry standard protocols will be used while minimizing the number of protocols.

This requirement originates from general I&C philosophies [4-15].

4.2.3.3.5.7 Provide sufficient network ports (GR)

The data network of the CTF needs to provide sufficient network ports with connection for instrumentation devices, data collection/control system. It is recommended that the CTF has to provide at least double the initial capacity and network points.

This requirement originates from general I&C [4-15].

4.2.3.3.5.8 Ease of movement (GR)

The location and the number of network ports will support the ease of movement of instrumentation or instrument cluster without the network disruption or major restructuring.

The network points need to be movable to support the requirement of flexibility as is outlined in the section 4.2.3.1.2 and which is also recommended in reference [4-15].

4.2.3.3.5.9 Protection of network interference (GR)

For the CTF, all communication in the network will be protected from external interference and the network will maintain the data's integrity.

This requirement originates from the security considerations which will be included in the design protection of intellectual property as is outline in the HLR, reference [4-1] and which are also recommended in reference [4-15].

4.2.3.3.5.10 Network components diagnostic (GR)

All network components in the CTF must be self-checking to as far as possible, support system diagnostics and perform alternate routing.

This requirement basis is the T&FR [4-2] that states the CTF should provide the capacity for off-line trouble shooting of a component. This requirement is also recommended in reference [4-15].

4.2.3.3.5.11 Closed loop control (GR)

The process control system will be capable of providing programmable control, to the heaters, motors, and other actuators. The controller needs to implement the steady-state and transient temperature and flow profiles.

This requirement originates from the I&C philosophies as is provided in reference [4-15].

4.2.3.3.5.12 Subsystem individual controllers (GR)

Each system or sub-system will have its own controllers to control variables inside that relevant system.

This requirement originates from the I&C philosophies as is provided in reference [4-15].

4.2.3.3.5.13 Control of parameters (GR)

The parameters of each system (pressure, flow and temperature etc.) must be controlled throughout the systems operating ranges.

This requirement originates from the I&C philosophies as is provided in reference [4-15]

4.2.3.3.5.14 Level op automation (GR)

The control of each process will have the maximum level of automation requiring the minimum amount of operator action.

This requirement originates from the I&C philosophies as is provided in reference [4-15].

4.2.3.3.6 Computer Hardware and Software

This subsection identifies requirements that are unique to the computer hardware and software engineering. This section concentrates on the following parts:

- Data requirements
- Design and development requirements
- Administrative programs which support quality and configuration management.

4.2.3.3.6.1 Instrumentation for Verification and Validation (V&V) (GR)

The CTF will be instrumented to support the validation and verification of the units under test. This data needs to support the methods and codes used for licensing and future commercial applications and qualification of components.

This requirement originates from the T&FR, reference [4-2].

4.2.3.3.6.2 Instrumentation for code case support (GR)

The CTF will be instrumented to support the code case support.

This requirement originates from the T&FR, reference [4-2]. This will notably be used for the code cases for the IHX as outlined in the heat exchanger roadmaps, references [4-8] and [4-9].

4.2.3.3.6.3 Enable test data collection, processing recording storage transmission and archiving capability (GR)

The CTF will provide the equipment to enable test data collection processing recordings and transmission, storage as well as archiving capability.

This requirement originates from the T&FR, reference [4-2].

4.2.3.3.6.4 Performance testing verification (GR)

The CTF needs to accommodate for performance verification testing, which could serve as empirical validation for thermal-hydraulic design methods and analysis.

This requirement originates from the T&FR, reference [4-2].

4.2.3.3.6.5 Measurement Redundancy (MCR)

Critical instruments on the plant need to be identified and a associated level of redundancy needs to be assigned, depending on the criticality of the measurement as well the application of the instrument.

The redundancy increases the plant availability, by mitigating single instrument and control hardware failure. This requirement originates from general I&C philosophies as is provided in [4-15].

4.2.3.3.6.6 Standard Instrumentation (GR)

Standard industrial instrumentation will be used unless the accuracy or pressure/temperature environment requires a special instrument.

The requirement supports the COTS components philosophy which should be used as far as possible. This requirement originates from general I&C philosophies as is provided in [4-15].

4.2.3.3.6.7 Data confidentiality (GR)

The data management system will be designed to ensure the information contained in the system is not disclosed to unauthorized individuals, processes, or devices. It will provide access control to maintain, vendor and experiment data separation.

Experimental data and experimental data collection will be kept under access control to assure that instrument data and control signals associated with proprietary components are protected.

The basis for the requirement is the HLR reference [4-1] which states that the security consideration need to be included in the design of the facility and which is also recommended in reference [4-15].

4.2.3.3.6.8 Data integrity (GR)

The data management system will be designed to ensure that information has not been modified or deleted in an unauthorized manner. Data will be recorded with accurate time stamps and associated with a unique instrument identifier so that the data can be traced to a specific instrument.

This requirement supports the verification and validation requirement as outlined in the T&FR reference [4-2] and which is recommended in reference [4-15].

4.2.3.3.6.9 Data quality (GR)

Quality requirements defined in ASME NQA-1 2000 requirements shall be applied to data collection and storage. All data will be completely traceable to the source, time, and method it was produced. The sampling and compression of the data will be determined by the requirements for the instrument. Collected data shall be considered quality records.

This requirement supports the verification and validation requirement as outlined in the T&FR reference [4-2] and which is recommended in reference [4-15].

4.2.3.3.6.10 Separate system for loops and data collection (GR)

The experimental data collection will be separate system that are isolated from the individual loop control systems.

The basis for this requirement is that data confidentiality and is a requirement in the PCFC study, reference [4-5].

4.2.3.3.7 Fire Protection

This subsection describes the requirements for fire protection features within the system, which includes detection, suppression, and other mitigation features. This section concentrates on the following parts:

- Fire protection safety and mitigation features.
- The identification of special fire suppression areas and applicable fire protection measures

This section is dependent on a detail Fire Hazard Analysis (FHA), which will identify the fire hazards in the system and place additional requirements on the facility.

4.2.3.3.7.1 Automatic sprinkler system (SR)

Automatic fire sprinkler protection will be provided throughout all facilities installed as part of the CTF.

This fire protection will follow all applicable National Fire Protection Association (NFPA) codes and standards, International Code Council codes such as the IBC and International Fire Code, and DOE requirements.

This requirement was identified as part of the PCFC study, reference [4-5].

4.2.3.3.7.2 Fire Detection and Alarms for the Hydrogen facility (GR)

Specialized fire detection systems will be provided throughout the hydrogen production and storage areas. Hydrogen leak detection will be provided in a manner that is capable of detecting small leaks. Use of area leak detection at the ceiling is not considered capable of meeting this requirement in a large area or high-airflow area.

This requirement was identified as part of the PCFC study, reference [4-5].

4.2.3.4 Testing and Maintenance Requirements

4.2.3.4.1 Testability

In this section the different requirements are identified for features that make the system testable.

4.2.3.4.1.1 Commissioning of the system (GR)

The construction process shall provide for stepwise commissioning of the system. All commissioning tests shall follow approved commissioning plans.

The high cost, safety requirements, high energy conditions, first of a kind integrated system etc, requires a careful consideration during the commissioning phases to reach maximum operational conditions.

4.2.3.4.2 TSR-Required Surveillances

This subsection identifies the type(s) of surveillance required (that is, checks, inspections, functional tests, or calibrations); identify how often the surveillance is required to be performed (including any grace period that may be allowed); state the acceptance criteria for each surveillance and describe those features provided in the design to facilitate those surveillance actions.

4.2.3.4.2.1 Critical instrumentation and pressure relief valve calibration interval period (SR)

An instrumentation calibration program should be compiled and approved before and operation activities commence. All critical safety instrumentation and PRVs should be included in this plan. The interval period should be determined, but is recommended to be between 6 to 12 months.

The risk to workers shall be as small as possible and shall be in line with the general criteria of the INL site, which require a safety surveillance program.

4.2.3.4.2.2 Calibration plan (GR)

Instrumentation on the CTF will be calibrated according to the class they fall into. The classes will distinguish the frequency and accuracy of calibration.

A calibration plan needs to be developed for this requirement. For example, pressure indicators could be calibrated using a secondary standard with an interval period of between 12 months. The calibration plan will be in accordance with requirements of NQA-1.

It is recommended that a certified calibration laboratory be situated on site. All instruments will have calibration certificates traceable to National Institute of Standards and Technology (NIST).

This requirement supports the verification and validation requirement as outlined in the T&FR reference [4-2] as well as the calibration requirement as set out in reference [4-15].

4.2.3.4.2.3 Safety surveillance system (SR)

A system safety surveillance program should be compiled and approved before any operational activities commence.

The risk to workers shall be as small as possible and shall be in line with the general criteria of the INL site. This requires a safety surveillance program.

4.2.3.4.2.4 Detail HAZOP assessment (SR)

Safety studies should be performed to identify potential hazards, and appropriate mitigation features in the design and the operation of the system. The potential hazards shall be identified by performing of HAZOP 1 to 6 studies/analyses.

The CTF is a high hazard facility where safety needs to be an integral part of the design process, which is outlined in the HLR reference [4-1]. Due to this requirement, all relevant HAZOP studies need to be performed as part of the detail design process.

4.2.3.4.2.5 SSC classification (SR)

A practical SSC functional classification should be implemented. The classification shall be for non-nuclear facilities/systems. The DOE criteria for non-nuclear plants/systems on nuclear sites should be followed.

Although the CTF is non-nuclear, it is situated on a nuclear research site, therefore safety classification is needed.

4.2.3.4.3 Non-TSR Inspections and Testing

The outcome of this section is to describe the inspection, testing, or surveillance requirements that are beyond those specified in the TSRs/OSRs.

4.2.3.4.3.1 Off-line trouble shooting (GR)

The CTF needs to provide a means for off-line trouble shooting of component and system as problems during the operation of the NGNP

This requirement is outlined in the HLR, reference [4-1] as well as the T&FR, reference [4-2].

4.2.3.4.4 Maintenance

The maintenance activities that are required by the manufacturer or which are otherwise required to ensure continued reliability are identified in this section.

4.2.3.4.4.1 Maintainability (GR)

The CTF will provide a level of maintainability that minimizes the need for maintenance personnel and costs.

The basis for this requirement is the T&FR, reference [4-2].

4.2.3.4.4.2 In service reliability (GR)

The CTF will provide for an in-service reliability still to be determined. The in-service reliability plan will be developed during the detail design. The required numerical value for reliability will be developed based on sensitivity of the component test plans to outages during test execution.

The basis for this requirement is the T&FR, reference [4-2].

4.2.3.4.4.3 Maintenance of subsystem and components (FR)

Sub-systems and components shall be serviced/maintained as per the manufactures/suppliers prescriptions. This requirement need to be further populated in the detail design

Product guarantee and effective/safe operation requires a comprehensive maintenance plan, especially with the need for a 40 years service life.

4.2.3.5 Other Requirements**4.2.3.5.1 Security and Special Nuclear Materials Protection**

Requirements that exist related to general security of the facility or to the need to protect Security and Special Nuclear Materials (SNM) are listed in this section.

4.2.3.5.1.1 Protection of intellectual property (GR)

Security considerations will be included in the design to ensure the protection of intellectual property of vendors and agencies participating in testing at the facility.

This requirement is outlined in the HLR, reference [4-1].

4.2.3.5.1.2 Safeguard of facilities

The construction at the INL may require evaluation of security considerations to determine if the facility access control is required beyond what may be required by process safety or intellectual property considerations.

This requirement is outlined in the HLR, reference [4-1].

4.2.3.5.1.3 No SNM protection (GR)

The CTF is anticipated to be a high hazard, non-nuclear [4-1]. This facility thus has no need to protect SNM.

4.2.3.5.2 Special Installation Requirements

Requirements that may exist related to special arrangements, locations, or installation of components of the system being described. This section addresses the following requirements:

- Instrumentation installation requirements
- Hardware installation requirement
- Maintenance access requirement

4.2.3.5.2.1 Flow measurement requirements (GR)

Measurement of fluid flow by means of pressure differential devices inserted in circular-cross section influence the upstream and downstream lengths. These lengths are done according to the following up-to-date standards (or similar with relevant addendums):

- ISO 5167-1: Part 1: General principles and requirements
- ISO 5167-2: Part 2: Orifice plates
- ISO 5167-3: Part 3: Nozzles and Venturi nozzles
- ISO 5167-4: Part 4: Venturi tubes.

4.2.3.5.2.2 Hardware requirements (GR)

The hardware requirements are dependent on the vendor or manufacturer of the equipment. In the concept phase of the design, possible vendors are suggested, but this might change in the detail design.

It is recommended that this section be done under future work as part of the detail design.

4.2.3.5.2.3 Maintenance access requirements (GR & SR)

The maintenance access requirements are dependent on the:

- Vendor or manufacturer of the equipment.
- Human factor requirements

This section needs to be further developed in the detail design where maintenance access requirements investigated more in detail.

4.2.3.5.3 Reliability, Availability, and Preferred Failure Modes

4.2.3.5.3.1 High reliability of the design (MCR)

The CTF will be designed with reliability of at least 98 percent (To be confirmed) on mission critical components. Sufficient frequency should be built in to accommodate the long tests that are anticipated.

The CTF will be used for tests with a long duration of up to 10 000hrs. These tests need to produce reliable data, where interruptions will adversely affect the results. Consequently, the CTF needs to be designed to minimize maintenance with a high reliability.

4.2.3.5.3.2 Plant Availability (GR)

The availability of the CTF to provide a specific operational condition will be at least 98 percent (To be confirmed).

Industrial Petro-chemical plants have this order of availability. This is further supported by the requirement of high reliability and anticipated complexity of obtaining test condition stabilization.

4.2.3.5.3.3 End of normal operational requirements (GR)

Normal operational occurrences should always end in a fail-safe condition. The design should provide for the bundle of anticipated operational occurrences.

Operational occurrences are associated with high frequency of acceptable small events; therefore the functions or systems should always fail-safe.

4.2.3.5.3.4 Preferred failure requirement (SR)

Serious accidents should practically never occur, i.e. with frequency $< 10^{-5}/y$. (This number should be verified)

The CTF is a non-nuclear facility, but this is recommended due to the high profile of this facility in the nuclear community and political environment.

4.2.3.5.4 Quality Assurance

4.2.3.5.4.1 NQA-1 quality assurance

The CTF shall be designed, manufactured and installed under the NQA-1 (ASME NQA-1 2000, Quality Assurance for Nuclear Facilities) quality management system or as preferred by the end-user.

The CTF will provide adequate equipment and instrumentation to support Validation and Verification (V&V) work. For this a quality assurance system needs to be implemented. This is also outlined in the Statement of Work (SOW), reference [4-6].

4.2.3.5.5 Miscellaneous

4.2.3.5.5.1 Manufacturer and supplier evaluation and development (GR)

For the NGNP various manufacturer and supplier need evaluation and development.

This requirement basis is the T&FR, reference [4-2].

4.2.4 Chapter 4: System Description

This section provides system descriptions of the various test loops for the CTF. This section describes both safety features and non-safety features, emphasizing the features provided to meet the requirements of the system. The following test loops are described in this section:

- Small Scale Development Test (SSDT)
- Technology Development Loop (TDL)
- Component Qualification Loop 1 (CQL1)
- Component Qualification Loop 2 (CQL2)
- Circulator Test Loop (CTL)

Each of the sections will be described for each of the following sections:

- Configuration Information
 - Description of System, Subsystems, and Major Components
 - Boundaries and Interfaces
 - Physical Location and Layout
 - Principles of Operation
 - System Reliability Features
 - System Control Features
- Operations

4.2.4.1 Small Scale Development Test

4.2.4.1.1 Configuration Information

4.2.4.1.1.1 Description of System, Subsystems, and Major Components

The Small-Scale Development Tests (SSDTs) are a collection of tests that do not require significant volume flow rates or large amounts of heat transfer. Most of the SSDTs have a common requirement for a high-temperature (950°C) high-pressure (9MPa(g)) helium environment. The rest of the SSDTs, like those that support the Circulator development, utilize specialized mechanical test setups which require critical inputs from the full-scale NNGP design. Therefore, their designs are not covered in this report.

For the tests that require a high-temperature high-pressure helium environment, a generic setup is designed that comprises a low-temperature pressure vessel, internally insulated high-temperature test vessel, heater (20kW) and small flow line water coolers (10kW each). Specifically for the IHX unit cell fatigue tests, a specialized system is

designed that comprises heaters, coolers, a pressure vessel and hydraulic gas compression systems. The Process Flow Diagram (PFD) of the SSDT is shown in Figure 4-8.

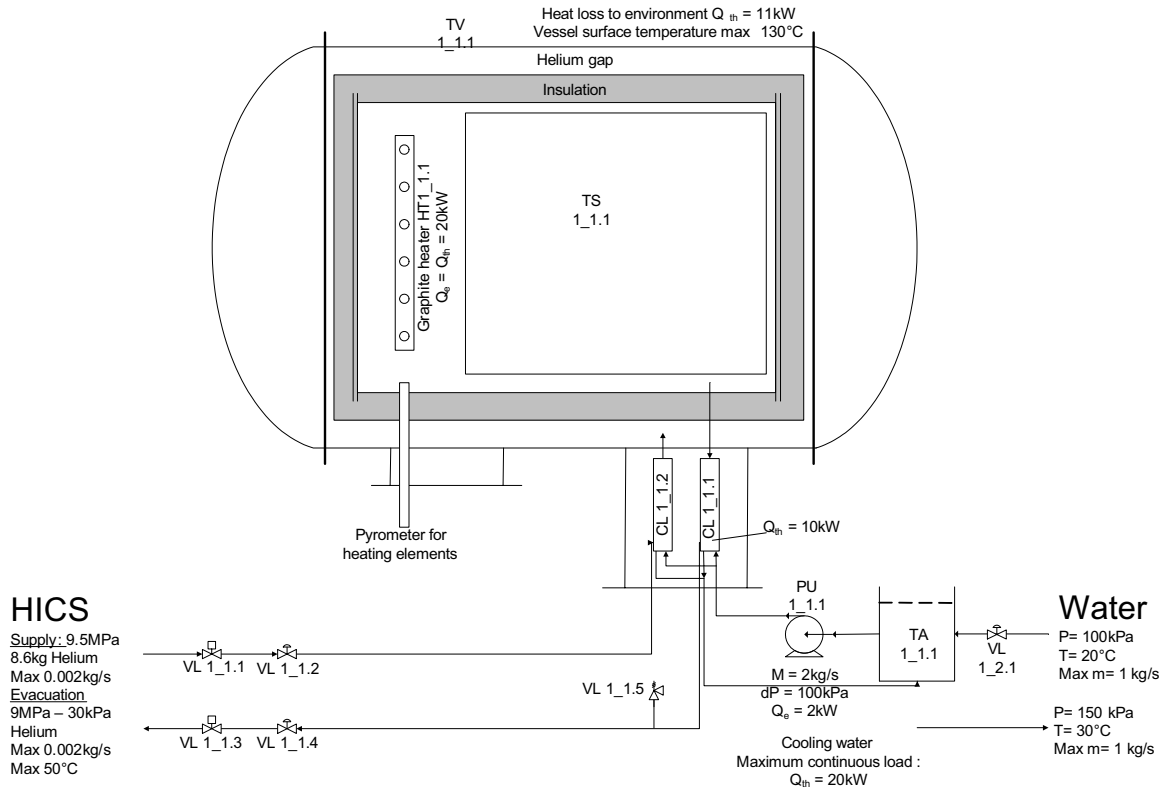


Figure 4-8: PFD of the Small Scale Development Test.

The major components of the SSDT are:

- Pressure vessel
- Internal high temperature-vessel
- A graphite heater element (20kW)
- Flow line coolers (10kW each)
- Cooling water pump
- Cooling water reservoir

4.2.4.1.1.2 Boundaries and Interfaces

4.2.4.1.1.2.1 Mechanical

The mechanical boundaries and interfaces include the following:

1. The CTL interfaces mechanically by means of flanges with the HICS and Cooling water systems.
2. The SSDT has a footprint of

- Height: 3 m
 - Width: 4 m
 - Length: 4 m
3. The SSDT's largest component is the pressure vessel, which has a mass of 4000 kg. This has an influence on the lifting capacity of the crane and the lay down area provided.
 4. The interface with the unit under test (inside the high-temperature test vessel) consists only of mounting lugs or support points, which is determined by the specific test.

4.2.4.1.1.2.2 Electrical power requirement

The electrical boundaries and interfaces forms part of the systems integration as indicated on the electrical one line drawing [NGNP-CTF-E-WIR-001-2]. The SSDT continuous operation electrical power rating is 20kW.

4.2.4.1.1.2.3 Support system

HVAC

The estimated heat loss to the environment is 11kW (at 30°C ambient temperature⁹).

Cooling water

The maximum cooling water requirement is 0.5 kg/s at 20°C supply and 30°C return temperature. Other interface conditions with the HICS system are given in Table 4-8.

Table 4-8: Water supply at the cooler interface.

Description	Value	Unit
P_w	300	kPa
$T_{w \text{ in}}$	20	°C
$T_{w \text{ out, max}}$	45	°C

Helium Inventory Control System

Based on first estimates for pipe lengths, the helium inventory is 8.6kg. Other specifications for the interface conditions with the HICS system are given in Table 4-9.

Table 4-9: HICS Interface requirement

Description	Value	Unit
$P_{\text{range he}}$	30 – 9500	kPa
$T_{\text{he in}}$	20	°C
$T_{\text{he out}}$	80	°C
$m_{\text{he total}}$	8.6	kg

⁹ Conservative calculation from SSDT section. Normal ambient temperature taken as 20°C.

4.2.4.1.1.2.4 Instrumentation and control (I&C)

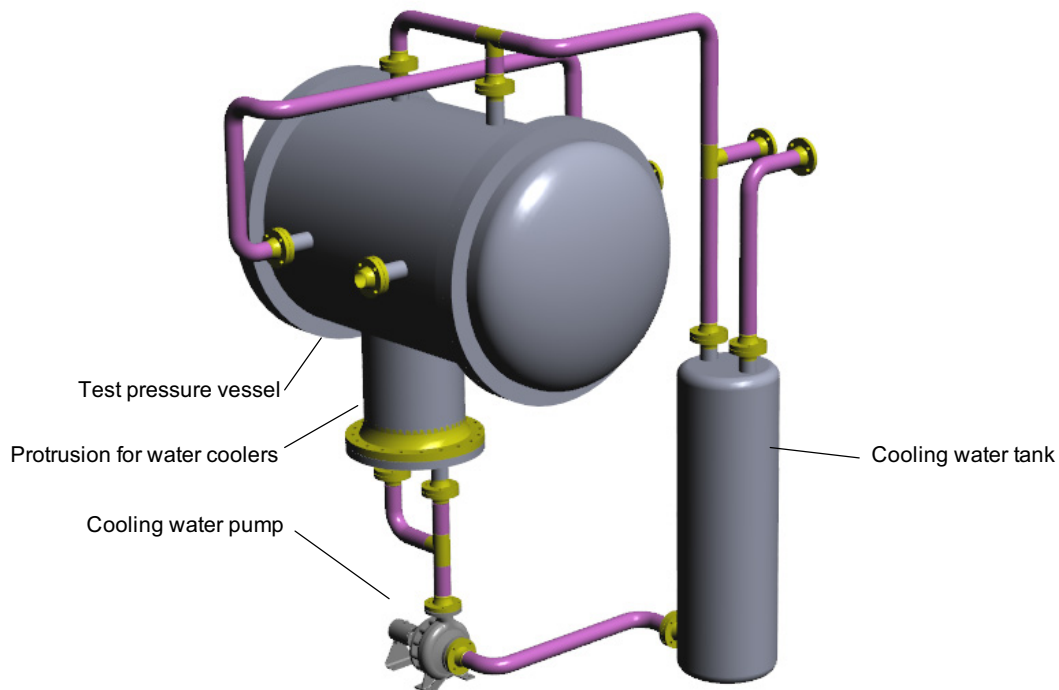
A list of the various instruments that ensure the proper functioning of the support system is listed in Table 4-10.

Table 4-10: Boundary interface instrumentation

Support system	Instrument	Description
Water	T3	Water inlet temperature
HICS	P1	Pressure indicator

4.2.4.1.1.3 Physical Location and Layout

The arrangement and layout of a single SSDT is shown in Figure 4-9.

**Figure 4-9: 3D layout of the SSDT: Generic vessel arrangement.**

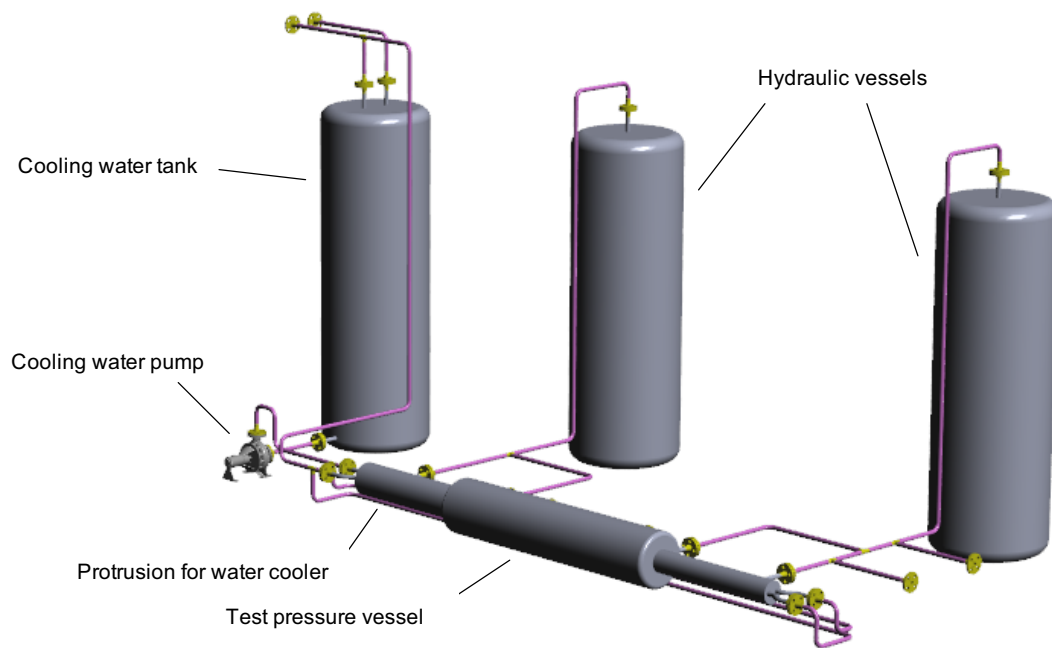


Figure 4-10: 3D layout of the SSDT: IHX unit cell test set-up.

However, more than one SSDT may be required. Several SSDTs can be arranged as shown in Figure 4-11.

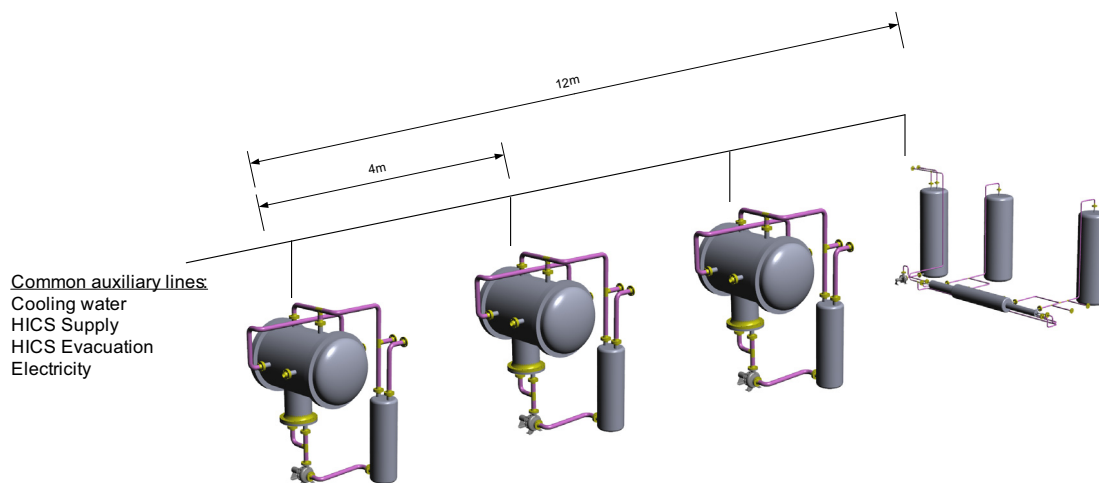


Figure 4-11: Arrangement of the four SSDTs.

4.2.4.1.1.4 Principles of Operation

The SSDTs operation relies on the containment of the high-temperature (950°C to 1000°C) area inside an internal, insulated vessel so that a low-temperature (100°C to 200°C) pressure vessel can be used for containing the required 9 MPa(g) pressure.

4.2.4.1.1.4.1 Creep Testing of unit cells of compact heat exchangers

This test is to be done using the SSDT vessel with a sealed HX unit cell in the high-temperature test space. Depending on the required pressure direction, either the secondary or the primary side is connected to the low pressure HICS line. At HX failure, the test environment is capable of withstanding the impact of the unit cell failure. The schematic layout is shown in Figure 4-12.

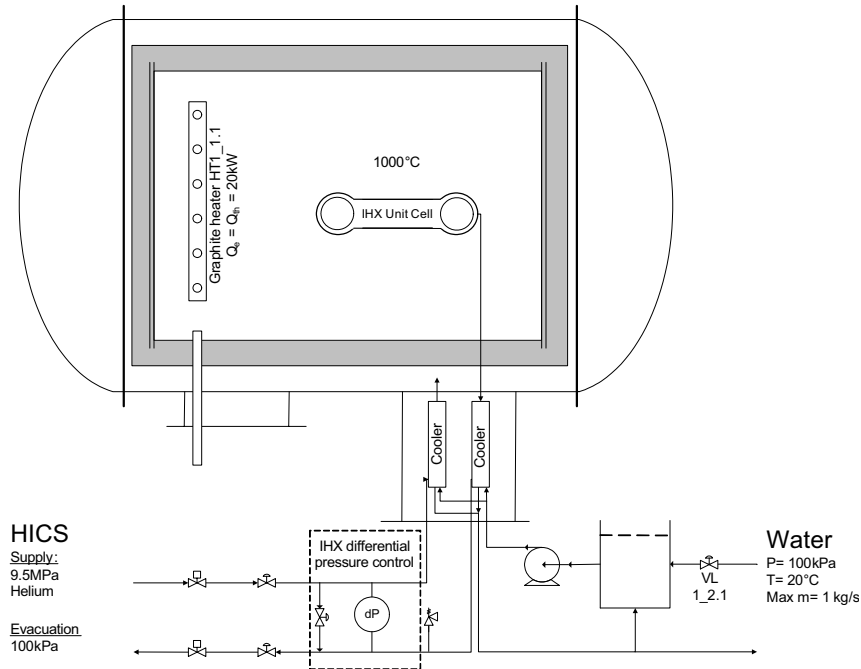


Figure 4-12: Schematic layout of IHX Unit cell creep test setup.

4.2.4.1.1.4.2 Insulation tests

The insulation test is used to determine the effect of Helium infiltration on thermal conductivity of insulation material, as well as the effect of depressurization (WEC-TS-PIP-006). The effect of fluid impurities on insulation properties (WEC-TS-PIP-007) can also be done with a conductivity measurement system inside the high-temperature vessel. When only structural damage to the insulation, due to compression, is tested, insulation material samples can be heated in an SSDT, depressurized and examined after cool down.

4.2.4.1.1.5 System Reliability Features

The SSDT relies on simplicity and robustness of construction for its reliability. The only components with moving parts are the valves in the connection to the HICS and the cooling water pump.

4.2.4.1.1.6 System Control Features

The Systems will be controlled primarily by the Process Control System (PCS). The PCS will be responsible for all the start-up operating and shut-down sequences and operation. Interlocking and alarming will be handled by this system. Closed loop control systems will also be executed by the PCS.

SYSTEM MONITORING

The initial minimum required instrumentation is given next with the usage (protection/safety, control, V&V and/or testing) and range to indicate in which conditions that the instruments will have to operate in. All instruments will typically be used for verification and validation, but the V&V column is only marked if the instrument performs the primary measurement identified for V&V. The types, accuracies and locations will be determined at a later stage. The instrument abbreviations are as follows:

A – Accelerometer

dP – differential pressure

F – Flow rate

FS – Flow rate (switch)

GA – Gas analyzer (composition)

N – Speed

P – Pressure

T – Temperature

VL – Valve

ϵ – Strain

Table 4-11: General SSDT instrumentation

Instrument	Protection	Control	V&V	Testing	°C	kg/s	MPa	Other
F1			x		0-50	0-2	0-0.2	
FS1	x				0-50	0-2	0-0.2	
GA1		x		x	0-100		0-11	TBD
L1	x				0-50	0-2	0-0.2	
P1		x		x		0-0.005	0-11	
T1		x					0-11	
T2	x				0-50	0-2	0-0.2	
T3	x	x			0-50	0-2	0-0.2	
T4	x						0-11	
T5	x						0-11	
T6		x					0-11	
T7		x		x			0-11	
T8	x	x			0-100	0-0.005	0-11	
VL 1_1.1	x				0-40	0-150	0-11	
VL 1_1.2		x			0-60	0-150	0-11	

Instrument	Protection	Control	V&V	Testing	°C	kg/s	MPa	Other
VL 1 1.3	x				0-40	0-150	0-11	
VL 1 1.4		x			0-60	0-150	0-11	
VL 1 2.1					0-50	0-2	0-0.2	
ε1				x			0-11	TBD

CONTROL CAPABILITY AND LOCATION

The control of each process will have the maximum level of automation requiring the minimum amount of operator action. The Client will require a specific order of events for them to be able to test their test components. Software will be designed such that the specified order of events can be effortlessly added into a recipe. The recipe will be a software sequence that will guide and control the plant through the required transients or sequence of events. This recipe with the required conditions and transients for the test will be fed into the system beforehand. The system will however have a pause or manual takeover capability with associated security access codes. The recipe can typically be paused and updated during testing, which might be a requirement of the client.

Related systems will be controlled from the same control room where the control room design will be such that the display information of systems that are also sub-systems to other systems (TDL's) will be clearly visible to the control station of the larger system (CQL) but that each sub-system can still be separately and independently controlled.

Since the control of the conditioning loops that provide the required system conditions for the UUT will be supervised by CTF personnel, separate Client Observation Rooms (COR) with appropriate access security will be provided where clients can monitor their own testing process. Interfaces will also be provided in the COR's for dynamic scheduling of tests. This implies that the original test schedule/sequence provided can be altered in the event of an unforeseen occurrence.

AUTOMATIC AND MANUAL ACTIONS

Different modes of control will exist:

- Automated
- Semi-automated
- Manual
- Maintenance

In the automated mode the PCS will control all sequence of events. The semi-automated mode will enable the manual initialization and termination of test processes and sequence of events. The manual mode will enable the startup or shutdown of individual systems or sections utilized by the processes and the maintenance mode will enable control over individual equipment/instruments.

The safety and equipment protection systems will be active in all modes except for the maintenance mode where only the safety protection systems will be active.

All manual actions will be limited as far as possible to pre- and post-testing occurrences. The manual actions will comprise opening and closing of hand valves, etc. and will be encapsulated in an Operating Procedure Checklist (OPC). The control system will as far as possible be able to sense all manual actions to ensure the readiness for automatic plant start-up or safe storage after plant shutdown.

The control actions taken upon reaching particular values as detected by a specific instrumentation channel or displayed by a specific indicating device is still to be determined. Alarm conditions, safety actions and operator actions to be taken are still to be determined.

4.2.4.1.2 Operations

The modes and transitions of the SSDT loops can be subdivided into the stream sequences', process sequences' and system sequences' modes and transitions respectively as discussed in the control and instrumentation philosophy. The sequences of the different tests will typically look the same especially on stream sequence level. Figure 4-13 respectively portrays a stream, process and system sequence for a typical steam generation test.

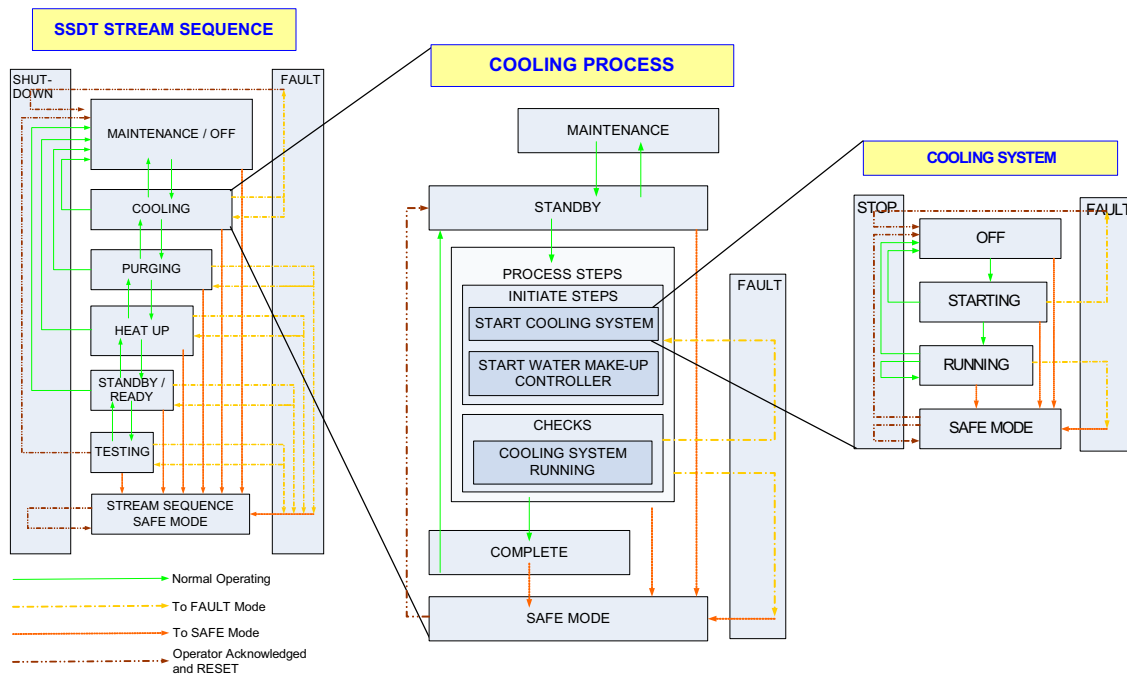


Figure 4-13: Typical SSDT stream, process and system sequence.

The SSDT operation relies on the containment of the high-temperature (950°C to 1000°C) area inside an internal, insulated vessel so that a low-temperature (100°C to 200°C) pressure vessel can be used for the 9 MPa(g) pressure.

A typical operating procedure could be as follows:

- **Startup:**
The vessel is pressurized to about 5 MPa(g) before switching on the heating element.
After switching on the heating element, the pressure rises accordingly.
- **Testing.**
The internal temperature is controlled by means of the heat input. The pressure level is controlled by either blowing in helium from the HICS supply line of venting off helium to the HICS extraction line.
- **Cool down.**
Any gas let out of the vessel is extracted from inside the high-temperature vessel and passed through the water cooler to the HICS extraction line. A significant amount of heat is removed when depressurizing through the coolers in this way. Fresh cool helium can be blow in from the HICS system and again extracted through the coolers to remove more heat. Apart from this, the SSDT will also cool down by heat loss to the environment, due to the passive cooling of the pressure vessel.

4.2.4.2 Technology Development Loop

4.2.4.2.1 Configuration Information

4.2.4.2.1.1 Description of System, Subsystems, and Major Components

The TDL is a high temperature (950 °C) high pressure (9.6 MPa(g)) helium test loop. A short systems and component description of the TDL is given and Figure 4-14 shows a PFD of the TDL and its components as well as the interface requirements and component sizes.

The TDL in its basic form consists of two conditioning loops, supplying helium at the desired conditions to test stations consisting of either test vessels or simple flange connections where components under test can be installed and tested under controlled and monitored conditions. The primary and secondary conditioning loops both have two circulators (two 100 percent circulators for redundancy) to circulate the helium through the test section. Both loops have recuperators, used to recover energy, thus reducing the heater size required. There is a cooler in both the primary and secondary loop to remove heat in order to maintain the helium temperature low enough for circulator operation. The primary loop has two heaters which are used to heat the helium. The TDL conditioning loops can be connected to test vessels, test stations and the CQL to conduct tests under controlled and measured conditions.

The TDL has the following basic components:

- 4 x Circulators 227 kW Gardner Denver Circulators (two circulators per conditioning loop)

- Primary Loop Recuperator (17.04 MWth)
- Secondary Loop Recuperator (15.36 MWth)
- Primary Loop Heater 1 (8.9 MW electrical)
- Primary Loop Heater 2 (4.9 MW electrical)
- Primary Loop Cooler (8.31 MWth)
- Secondary Loop Cooler (4.8 MWth)
- Helium Transport System (HTS) “Cold Pipes” (Diameter = 0.14 m)
- HTS HGD (Diameter of liner = 0.26 m; Internal diameter pressure boundary = 0.5 m)
- Water cooler control valves
- Helium flow control valves
- IHX test vessel (Internal diameter = 3.29 m; Length = 6.89 m)
- HTSE test station (Flange connections)
- HGD and Mixing Chamber test station (Flange connections)

The TDL Interfaces with the following:

- Cooling water system
- Helium Inventory Control System (HICS) system (includes the Helium Purification System (HPS))
- Electrical supply
- Heating Ventilation and Air Conditioning (HVAC) system
- Air supply interface (High Temperature Steam Electrolysis (HTSE) test)
- Steam supply interface (HTSE test)
- Instrumentation and Control (I&C) interface

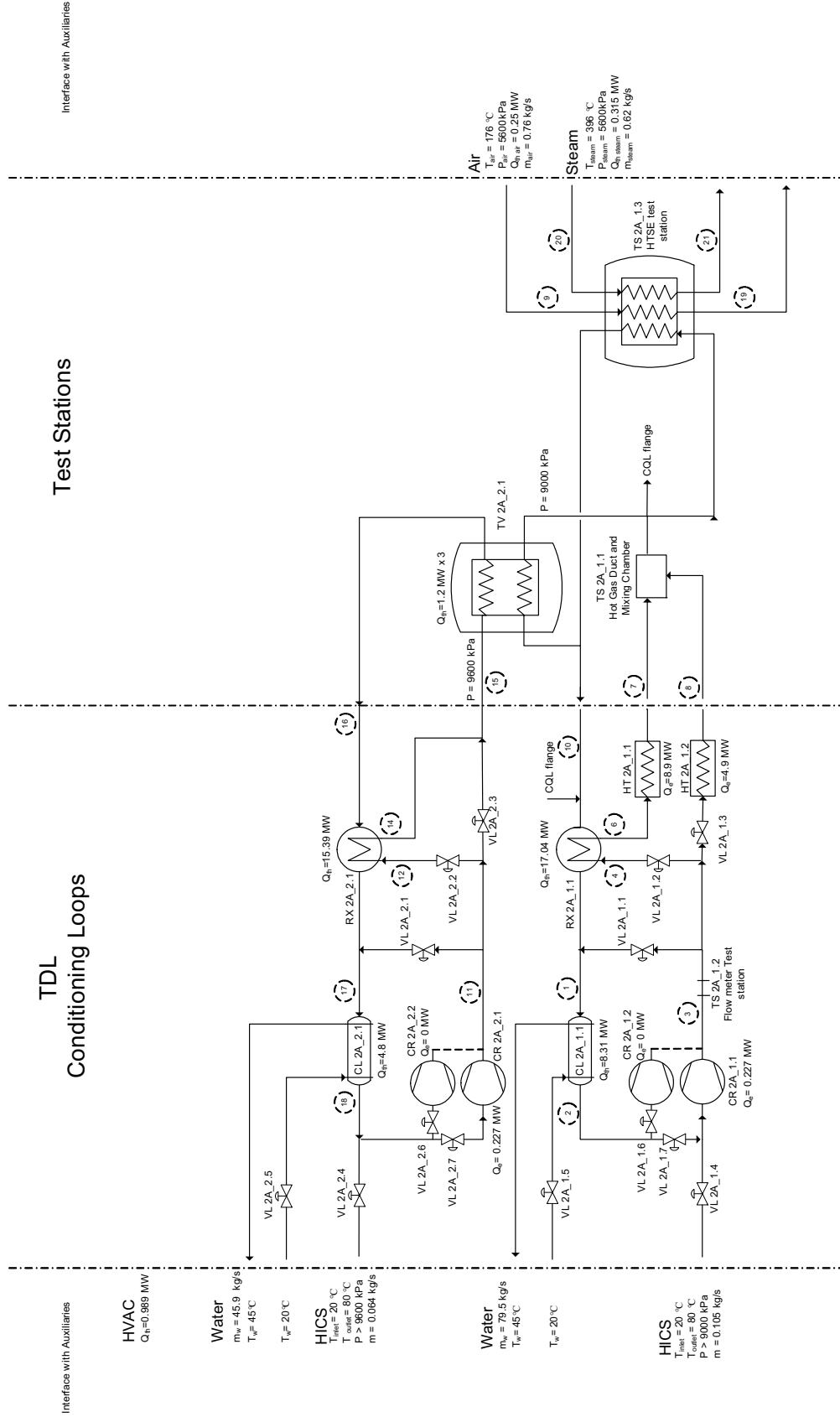


Figure 4-14: PFD of the TDL showing the component sizes as well as interface requirements.

4.2.4.2.1.2 Boundaries and Interfaces

The TDL has the following boundaries and interfaces:

4.2.4.2.1.2.1 Mechanical

The boundaries and interfaces on a mechanical level include the following.

- The TDL interfaces mechanically by means of flanges with the HICS, Cooling water, Air and Steam supply systems.
- The TDL has a footprint of
 - Height: 12.2 m
 - Width: 18.3 m
 - Length: 43.3 m
- Initial mass calculations for a TDL indicate that the mass of the pressure boundary, excluding insulation, flanges and vessel internals are as shown in Figure 4-13. The mass indicated for the recuperators and coolers are the total component mass.

Table 4-12: Initial calculation of pressure boundary mass for a TDL.

Description	Value	Unit
HTS Cold pipes	42	kg/m
HTS HGD	442	kg/m
Primary Circulator vessel	8 608	kg
Secondary Circulator vessel	8 608	kg
Primary Recuperators	36 902	kg
Secondary Recuperators	38 027	kg
Heater 1	27 759	kg
Heater 2	6 083	kg
IHX test vessel	54 266	kg
Primary loop cooler	5 635	kg
Secondary loop cooler	2 701	kg

- The mechanical interface between the TDL and the Test stations is done by means of flanges and blank off flanges, depending on the test configuration required.

4.2.4.2.1.2.2 Electrical

The electrical boundaries and interfaces form part of the systems integration as indicated on the electrical one line drawing [NGNP-CTF-E-WIR-001-2]. The electrical requirement for the TDL is shown in Table 4-13.

Table 4-13: TDL Electrical requirements.

Description	Value	Unit
Heater 1 (HT 2A_1.1)	8.9	MW
Heater 2 (HT 2A_1.2)	4.9	MW
Primary Circulator (CR 2A_1.1)	0.227	MW
Primary Circulator (CR 2A_2.1)	0.227	MW
Total	14.25	MW

4.2.4.2.1.2.3 Support systems

The boundaries and interfaces of the support systems, including: HICS, HVAC, Cooling Water, HTSE Steam and HTSE Air systems are shown in Table 4-14 till Table 4-20.

Table 4-14: HICS Primary Loop

Description	Value	Unit
$P_{\text{range He}}$	10 - 9000	kPa
$T_{\text{He in}}$	20	°C
$T_{\text{He out}}$	80	°C
$d_{\text{internal pipe}}$	0.02	m
m_{He}	0.105	kg/s
$m_{\text{He total}}$	759	kg

Table 4-15: HICS Secondary Loop

Description	Value	Unit
$P_{\text{range He}}$	10 - 9600	kPa
$T_{\text{He in}}$	20	°C
$T_{\text{He out}}$	80	°C
$d_{\text{internal pipe}}$	0.02	m
m_{He}	0.064	kg/s
$m_{\text{He total}}$	459	kg

Table 4-16: HVAC Interface.

Description	Value	Unit
TDL HGDs	302	kW
IHX test vessel	228	kW
Recuperator vessels	251	kW
Heaters	208	kW
Total	989	kW

Table 4-17: Primary cooler water interface supply.

Description	Value	Unit
P_w	300	kPa
$T_{w \text{ in}}$	20	°C
$T_{w \text{ out}}$	45	°C
m_w	79.5	kg/s

Table 4-18: Secondary cooler water interface supply.

Description	Value	Unit
P_w	300	kPa
$T_{w \text{ in}}$	20	°C
$T_{w \text{ out}}$	45	°C
m_w	45.9	kg/s

Table 4-19: Secondary cooler water interface supply.

Description	Value	Unit
P_{steam}	5600	kPa
T_{steam}	396	°C
m_{steam}	0.62	kg/s

Table 4-20: HTSE air requirements

Description	Value	Unit
P_{air}	5600	kPa
T_{air}	176	°C
m_{air}	0.76	kg/s

Instrumentation and control

A list of the various instruments that ensure the proper functioning of the support system is listed in Table 4-21.

Table 4-21: Boundary interface instrumentation

Support system	Instrument	Description
Water	T25	Water inlet temperature
	T26	Water outlet temperature
	T23	Water inlet temperature
	T24	Water outlet temperature
	F51	Water flow switch
	F51	Water flow switch
HICS	P1	Pressure indicator
	P2	Pressure indicator
Air	T34	Air inlet temperature
Steam	T33	Steam inlet temperature

4.2.4.2.1.3 Physical Location and Layout

The TDL follows a modular approach which allows additional TDL's to be built or existing TDL's to be expanded as the need arises. Figure 4-15 shows the layout of a TDL.

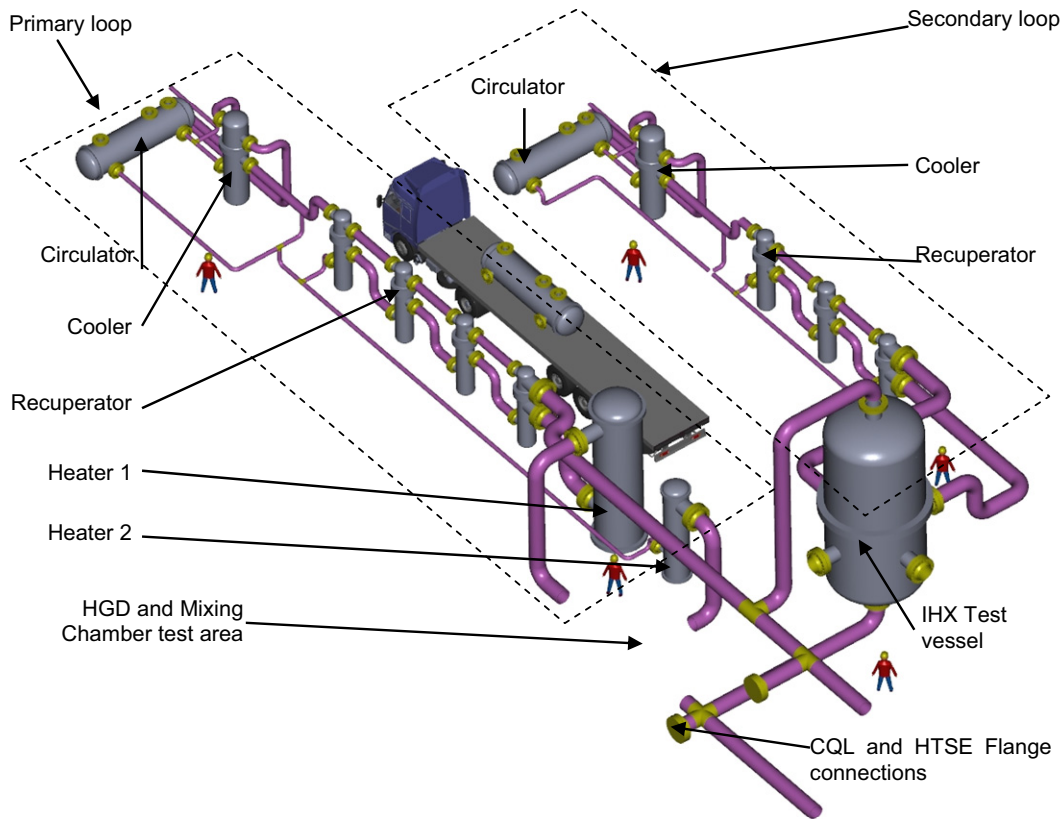


Figure 4-15: 3D Layout of a TDL

The layout of the TDL was driven by the following:

- Easy access to conditioning loop components during construction and maintenance by crane or vehicle
- Easy access to test stations and IHX test vessel during test set up
- Adequate lay down area during maintenance and test set up
- Modular approach, to allow TDL to connect to CQL and HTSE
- To give the TDL flexibility of design for future expansion and the construction of additional TDL's as the need arises

4.2.4.2.1.4 Principles of Operation

The following component tests, obtained from the Technology Development Roadmaps, are envisioned to be conducted in the TDL:

- IHX related performance tests

- HGD related performance tests
- Mixing chamber related performance tests
- HTSE HX related performance tests and CQL connection

The principles of operation of the TDL will be discussed in conjunction with the above mentioned tests, referring to the specific test PFD:

- During IHX testing, both primary and secondary loops will be connected to the IHX test vessel. Helium will be heated up in the primary loop heater and the heat will be transferred by the IHX under test (inside the test vessel) to the secondary loop where the heat will be rejected by the cooler. The test set up and conditions for 3 x 1.2 MW IHX A test modules are shown in PFD [MT-TLDR-TDL-02-0006].
- During HGD tests, only the primary loop will be used to circulate helium through the HGD. Depending on if actively or passively cooled HGD's are tested, both heater 1 and heater 2 (actively cooled) or just heater 1 (passively cooled) will be used. The TDL is not connected to the IHX test vessel during HGD testing. The test set up and conditions for the HGD tests are shown in PFD [MT-TLDR-TDL-02-0003].
- During Mixing Chamber tests, only the primary loop will be used to circulate helium through the Mixing Chamber. Both heaters will be used to heat the different helium streams entering the Mixing Chamber. The TDL is not connected to the IHX test vessel during mixing chamber testing. The test set up and conditions for the Mixing Chamber tests are shown in PFD [MT-TLDR-TDL-02-0004].
- During HTSE and CQL testing, only the primary loop will be used to supply helium to the HTSE or CQL. The helium will be returned to the TDL without passing through the IHX test vessel.

4.2.4.2.1.5 System Reliability Features

The TDL's reliability features can be divided into reliability and redundancy.

Reliability:

- Coolers, both primary and secondary loop coolers are shell and tube coolers which are proven and robust technology.
- Recuperators, both primary and secondary loop coolers are shell and tube recuperators which are proven and robust technology.
- The valves are off the shelf components, previous experience with the "Velan" valves were obtained at the Helium Test Facility (HTF) (South Africa).
- Circulators are of the shelf air circulators by Gardner Denver. Previous experience with air circulators being used in a Nitrogen environment were obtained at the High Pressure Test Unit (South Africa).
- Heaters are based on the Hendel heater design and previous experience with graphite heaters were obtained at the High Temperature Test Unit (South Africa).

- HGD design is based on passive cooling.

Redundancy:

- Redundancy in the system is incorporated into critical components such as the circulators. Two circulators are provided per conditioning loop to provide backup should the one operating circulators fail.
- Redundancy is incorporated into the I&C to serve as backup should the one I&C system fail.
- Critical interface requirements such as the cooling water supply should be redundant should the supply fail.

4.2.4.2.1.6 System Control Features

The Systems will be mainly controlled by the Process Control System (PCS). The PCS will be responsible for all the start-up operating and shut-down sequences and operation. Interlocking and alarming will be handled by this system. Closed loop control systems will also be executed by the PCS.

SYSTEM MONITORING

The initial minimum instrumentation requirements are given next with the usage (protection/safety, control, V&V and/or testing) and range to indicate in which conditions the instrument will have to operate. All instruments will typically be used for verification and validation, but the V&V column is only marked if the instrument is primarily identified for V&V. The types, accuracies and locations will be determined at a later stage. The instrument abbreviations are as follows:

Table 4-22: General TDL instrumentation

Instrument	Protection	Control	V&V	Testing	Temperature [°C]	Mass flow [kg/s]	Pressure [MPa]	Pressure diff [kPa]	Other
A1				x	0-1100	0-5	0-10		TBD
dP1		x			0-100	0-5	0-10	400	
dP10				x	0-1100	0-5	0-10	TBD	
dP11			x		0-500	0-5	0-10	10	
dP12			x		0-600	0-5	0-11	15	
dP13			x		0-900	0-5	0-11	100	
dP14			x		0-1100	0-5	0-11	60	
dP15			x		0-900	0-5	0-10	100	
dP16			x		0-800	0-5	0-10	150	
dP17				x	0-1100	0-5	0-10	TBD	
dP18	x			x	0-500	0-1	0-7	TBD	

Instrument	Protection	Control	V&V	Testing	Temperature [°C]	Mass flow [kg/s]	Pressure [MPa]	Pressure diff [kPa]	Other
dP19	x			x	0-250	0-1	0-7	TBD	
dP2		x			0-100	0-5	0-11	400	
dP3				x	0-100	0-5	0-10		
dP4				x	0-100	0-5	0-10		
dP5				x	0-100	0-5	0-10		
dP6				x	0-1100	0-5	0-10	150	
dP7				x	0-1100	0-5	0-11	150	
dP8	x				0-1100	0-5	0-11	TBD	
dP9				x	0-1100	0-5	0-10	TBD	
F1	x	x		x	0-100	0-5	0-10		
F2		x		x	0-1100	0-5	0-10		
F3		x		x	0-800	0-2	0-10		
F4	x	x			0-100	0-5	0-11		
F5		x			0-900	0-5	0-11		
F6			x		0-100	0-5	0-11		
FS1	x				0-40	0-60	0.5		
FS1	x				0-40	0-100	0.5		
GA1	x			x	0-100	0-0.2	0-10		TBD
GA2	x			x	0-100	0-0.2	0-11		
N1		x							4000 rpm
N2		x							4000 rpm
P1	x	x			0-100	0-5	0-10		
P2	x	x			0-100	0-5	0-11		
T1	x	x			0-100	0-5	0-10		
T10		x			0-900	0-5	0-11		
T11	x				0-900	0-5	0-10		
T12	x				0-1100	0-5	0-11		
T13			x		0-600	0-5	0-11		
T14			x		0-400	0-5	0-10		
T15			x		0-900	0-5	0-11		
T16		x			0-800	0-5	0-10		
T17				x	0-1100	0-5	0-10		
T18				x	0-900	0-5	0-10		
T19				x	0-900	0-5	0-11		
T2		x			0-100	0-5	0-10		
T20				x	0-1100	0-5	0-11		
T21			x		0-500	0-5	0-10		
T22			x		0-600	0-5	0-11		

Instrument	Protection	Control	V&V	Testing	Temperature [°C]	Mass flow [kg/s]	Pressure [MPa]	Pressure diff [kPa]	Other
T23			x		0-40	0-60	0.5		
T24			x		0-60	0-60	0.5		
T25			x		0-40	0-100	0.5		
T26			x		0-60	0-100	0.5		
T27	x				0-1100	0-5	0-11		
T28				x	0-1100	0-5	0-10		
T29				x	0-1100	0-5	0-10		
T3				x	0-100	0-5	0-10		
T30				x	0-1100	0-5	0-10		
T31				x	0-1000	0-1	0-7		
T32				x	0-1000	0-1	0-7		
T33				x	0-500	0-1	0-7		
T34				x	0-250	0-1	0-7		
T4				x	0-100	0-5	0-10		
T5				x	0-100	0-5	0-10		
T6	x	x		x	0-1100	0-5	0-10		
T7	x	x		x	0-800	0-2	0-10		
T8		x			0-100	0-5	0-11		
T9	x	x			0-100	0-5	0-11		
VL 2 1.1	x	x			0-100	0-5	0-10		
VL 2 1.2	x	x			0-100	0-5	0-10		
VL 2 1.3	x	x			0-100	0-5	0-10		
VL 2 1.4	x				0-100	0-0.2	0-10		
VL 2 1.5		x			0-40	0-60	0.5		
VL 2 2.1	x	x			0-100	0-5	0-11		
VL 2 2.2	x	x			0-100	0-5	0-11		
VL 2 2.3	x	x			0-100	0-5	0-11		
VL 2 2.4	x				0-100	0-0.2	0-11		
VL 2 2.5		x			0-40	0-100	0.5		
ε1	x			x	0-1100	0-5	0-11		TBD

CONTROL CAPABILITY AND LOCATION

Only a concept philosophy for control capability and location is defined at this stage, which is the same for all the test loops. A brief discussion was given in section 4.2.4.1.1.6.

AUTOMATIC AND MANUAL ACTIONS

Only a concept philosophy for the automatic and manual actions is defined at this stage, which is the same for all the test loops. A brief discussion was given in section 4.2.4.1.1.6.

4.2.4.2.2 Operations

The modes and transitions of the TDL loops can be subdivided into the stream sequences', process sequences' and system sequences' modes and transitions respectively as discussed in the control and instrumentation philosophy. The sequences of the different tests will typically look the same especially on stream sequence level. Figure 4-16 portrays a stream, process and system sequence for a typical IHX test respectively.

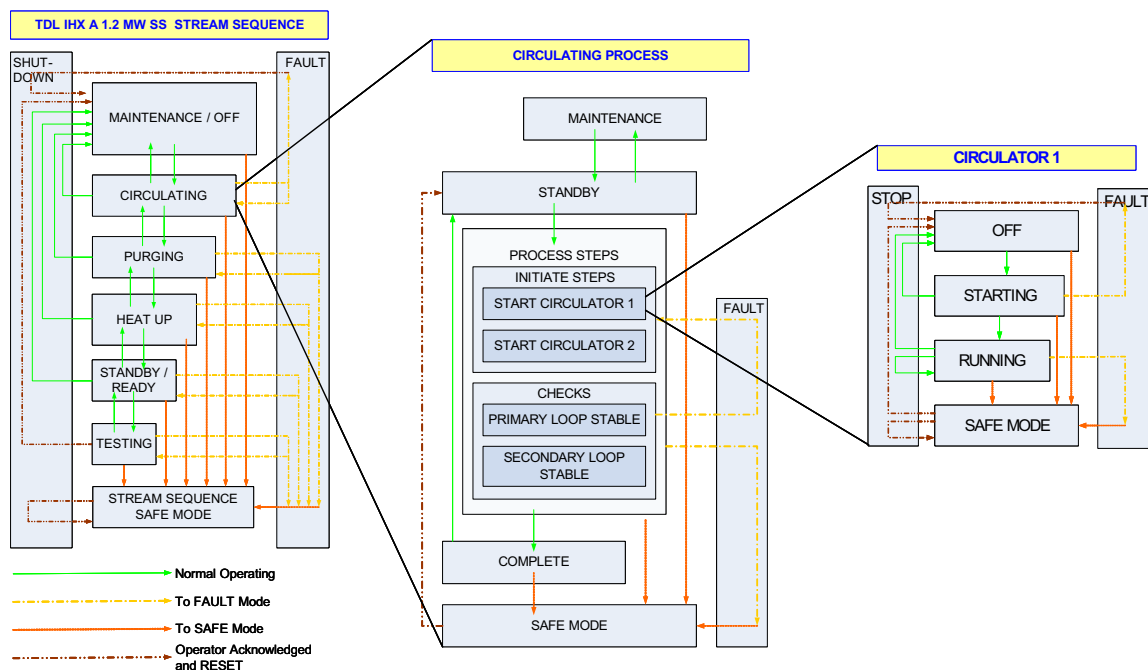


Figure 4-16: Typical TDL stream, process and system sequence.

This section describes the typical start-up sequence of the various plants. For the TDL, CQL1, CQL2. The only difference for the CTL is that it does not have a heating up cycle. At this stage the various operations of the loops are still in concept phase and are thus not repeated in the other sections.

INITIAL CONFIGURATION (PRE-STARTUP)

The auxiliary systems (gas, instrument air, cooling water supply, etc) will be controlled externally to the loop control systems. The loop control system will therefore send requests to the auxiliary control system to prepare the prescribed auxiliary system temperatures, pressures and flow rates prior to system start-up. The system will be able to sense when all auxiliaries are on line and ready. The auxiliary system conditions will also be monitored during the testing process.

SYSTEM STARTUP

Typical startup for TDL; CQL,

System startup will include performing any required calibrations checks and running all diagnostic tests. Steps in the startup procedure are:

- Purging
- Circulating
- Heating

The systems will be purged and pressurized to a given level before circulation commences. At a given mass flow rate the heaters will be powered to heat up the gas. During the heating process there will be a further increase in pressure. When the required temperatures, flow rates and pressures are reached, the system will be ready for normal operation.

NORMAL OPERATIONS

The normal operations are still to be determined. It will identify all the normal operating modes of the system; describe when each mode is appropriate, and generally how mode changes are accomplished. A reference shall be provided to the procedures that cover system operations, including operational mode changes, to the extent that such procedures exist. This section will then focus on and describe the most frequently used mode of operations, including routine checks on system performance and performance data logging that are performed by the operations staff to verify that the system is operating normally, including the key parameters and their nominal values.

This section will also identify the types of automatic records or logs that are maintained by or for the system in the central control area. This section will also briefly address Conduct of Operations as it applies to this particular system, for example, at shift turnover.

OFF-NORMAL OPERATIONS

The off-normal operations are still to be determined. It will identify off-normal conditions for which the system is intended to operate. For each off-normal event, this section will identify how the upset would be detected, describe the impact of the event on functional capability of the system (and to the extent appropriate, the impact on the facility). It will briefly summarize the recovery actions for each type of off-normal condition.

SYSTEM SHUTDOWN

The system shutdown procedures are still to be determined. It will include the shutdown sequence and timing requirements.

4.2.4.3 Component Qualification Loop 1

4.2.4.3.1 Configuration Information

4.2.4.3.1.1 Description of System, Subsystems, and Major Components

The CQL1 uses the combined mass flows of two (or more) TDL systems, which delivers the required helium heated to temperatures of 900 °C at 9 MPa(g) pressure. Whilst the CQL1 is in operation, TDL testing space is sacrificed (used by CQL1 testing space) unless more than two TDLs are anticipated for the CTF. This report deals with the assumption that only two TDLs are necessary to provide helium at a large enough mass flow necessary to achieve thermal duties of ~11.6 MW for the anticipated SG test and ~8.4 MW for the anticipated H₂SO₄ Decomposition Reactor test. The final proto-typical designs of both these units to be tested will determine the eventual heat duty capacities.

The process flow diagram below shows the typical expected process values for both the SG and the H₂SO₄ Decomposition Reactor tests at nominal capability i.e. heater power of 6.16 MW_{th} per TDL. This value was obtained from the IHX test specification, specifically the anticipated IHX test where three modules are tested in parallel within a TDL test station vessel – refer to reference [4-17], regarding the component sizing and mass flow rates of the IHX test.

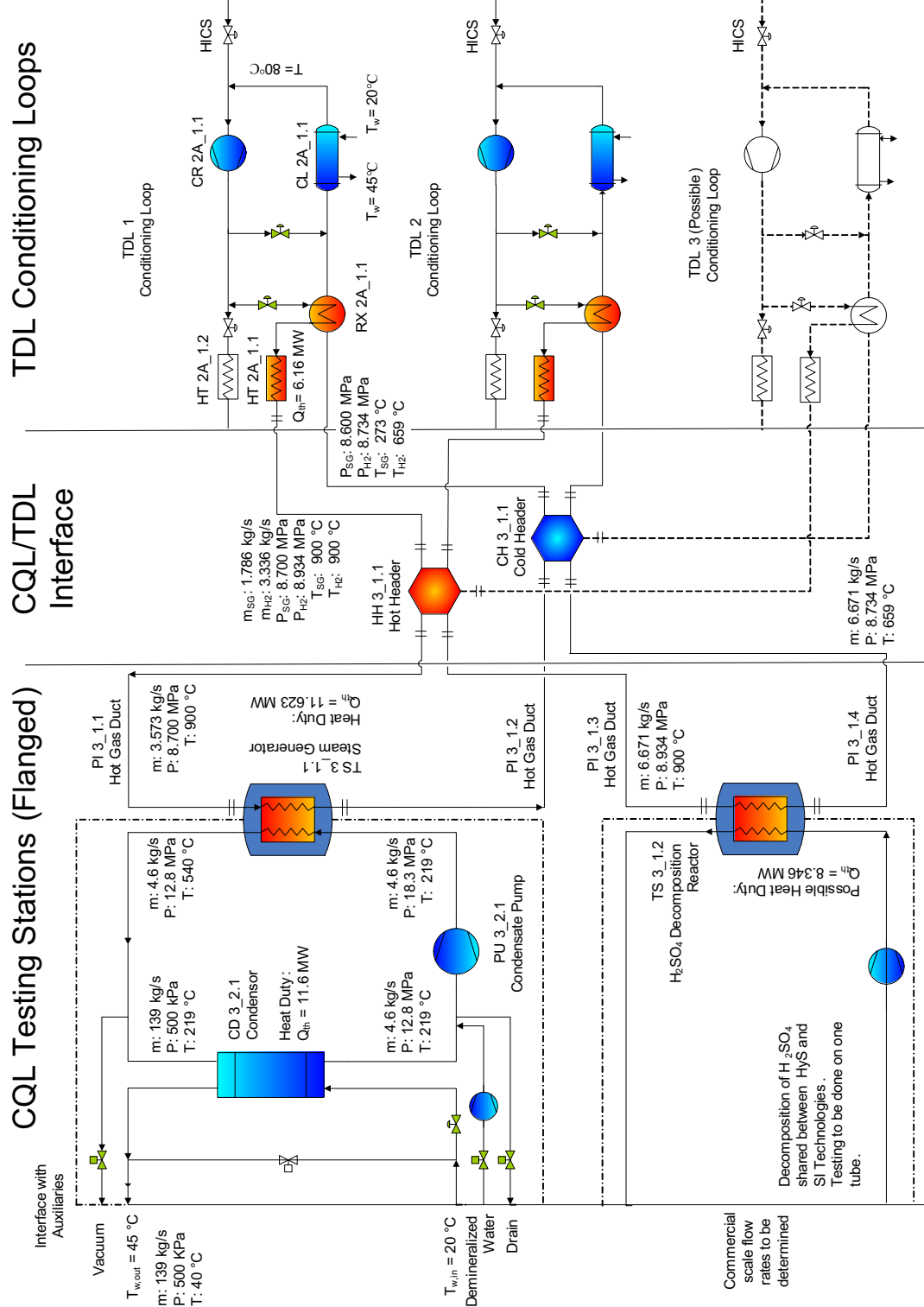


Figure 4-17: PFD of CQL1 indicating key process values for the two anticipated CQL1 tests.

Due to the proto-typical test unit designs still to be finalized, CQL1 is defined at delivering helium-gas process heat headed for the two anticipated test stations i.e. TS 3_1.1 and TS 3_1.2 (refer to Figure 4-17 above). The HGDs extending all the way from the HH to the two test stations are blanked-off at the HH, whilst a flange coupling is provided at the test station interface. Similar flanged sections are provided at the interface of the test station outlet sides where the HGDs tie up with the cold header before departing into two separate TDL streams for hot → cold recuperation followed by subsequent cooling, cold → hot recuperation and lastly heating before heading to the HH once more.

Interfaces for CQL1 are given in the paragraph below.

4.2.4.3.1.2 Boundaries and Interfaces

CQL1 could be sub-divided into three sections i.e.:

1. CQL1/TDL Conditioning Loop Interface
2. CQL1 HGDs and Hot and Cold Headers
3. CQL1/ Test Station Interface

As far as boundaries and interfaces are concerned for CQL1, the following sub-divisions were categorized:

4.2.4.3.1.2.1 Mechanical Boundaries

Mechanical boundaries encompass the following:

- HGD flange at CQL1/TDL interface i.e. situated at the outlet of the TDL Heater (HT 2A_1.1 and HT 2B_1.1).
- HH flanges situated within CQL1 to connect to test station HGDs at HH 3_1.1.
- Cold Header flanges situated within CQL1 to connect to HGDs coming from test stations at CH 3_1.1.
- Flanges situated at inlet and outlet sides of both CQL1 test stations.

All flange connections to be secured for specific test configurations during cold plant shutdowns. Standard Operating Procedures (SOPs) and Inspection Check Lists need to be developed.

4.2.4.3.1.2.2 Electrical Boundaries

At preconceptual design level electrical requirements foreseen for CQL1 are to drive the condensate pump within the water/steam loop for the anticipated SG test. A

high pressure pump will also be required to pressurize the water during test start-ups. In summary, the electrical boundaries encompass the following:

- Electrical power for the condensate pumps (PU 3_2.1).
- Electrical power for pressurizing pump.
- Electrical requirements to drive valves / actuators within the secondary loop of the SG circuit – dependent on proto-typical design.

Electrical requirements foreseen for CQL1 H₂SO₄ Decomposition Reactor testing are to be determined and will be considered in future work. It is also foreseen that electricity will be necessary to circulate the H₂SO₄ as well as to drive valves / actuators within the secondary loop of the H₂SO₄ Decomposition Reactor circuit.

4.2.4.3.1.2.3 Supporting Systems

Supporting systems could be categorized under plant auxiliaries concerned with fluids necessary for heat exchange.

CQL1 uses helium within its primary circuit acquired from the TDL HICS supply. Other supporting fluids used for anticipated CQL1 component testing are:

- Cooling water on the TDL coolers.
- De-mineralized water to be supplied to the secondary loop of the SG test.
- Cooling water for the tertiary loop of the SG test circuit to condense the superheated steam back to water.
- H₂SO₄ to be used for anticipated H₂SO₄ Decomposition Reactor testing.

Similar mass flow rates as for the TDL are used when helium is to be delivered via two TDLs to CQL1. The HICS interface for CQL encompasses the following:

- Inlet temperature of 20 °C.
- Outlet temperature of 80 °C.
- Mass flow rate of 0.524 kg/s.
- Pressure higher than 9.0 MPa.

In terms of cooling water requirements on the TDL coolers (CL 2A_1.1 and CL 2B_1.1) during CQL1 testing, the following is necessary:

- Inlet temperature of 20 °C.
- Outlet temperature of 45 °C (less than 50 °C).
- Mass flow rate of 3.81 kg/s for the CQL1 SG test.
- Mass flow rate of 19.87 kg/s for the CQL1 H₂SO₄ Decomposition Reactor test.

In terms of de-mineralized water requirements for the secondary loop of the SG test circuit, the following conditions apply:

- De-mineralized water to be pumped into loop via high pressurizing pump.
- Circulating mass flow rate within secondary steam loop is 4.65 kg/s.
- De-mineralized water to be evacuated from secondary loop when SG tests are completed.

In terms of cooling water requirements for the tertiary loop of the SG test circuit i.e. to condense the superheated steam to water within the condenser (CD 3_2.1), the following is applicable to the supporting boundary (interface):

- Inlet temperature of 20 °C.
- Outlet temperature of 45 °C.
- Cooling water mass flow rate of 111.3 kg/s. When the outlet temperature is reduced to 40 °C, the cooling water mass flow rate increases to 139.1 kg/s.

In terms of the H_2SO_4 to be used as heat exchanging fluid within the H_2SO_4 Decomposition Reactor, no process values have been determined due to the proto-typical design of this reactor unit still to be completed.

4.2.4.3.1.2.4 Instrumentation and Control

A list of the various instruments that ensure the proper functioning of the support system is listed in Table 4-21.

Table 4-23: Boundary interface instrumentation

Support system	Instrument	Description
Water	T 8	Water inlet temperature
	FS 1	Water flow switch
H_2SO_4	T 11	Inlet temperature
	P 6	Inlet pressure
	F 2	Flow meter
	FS 2	Flow switch
Hot header	T 1	Gas inlet temperature
	T 3	Gas inlet temperature
	P 1	Gas inlet pressure
	P 2	Gas inlet pressure
	F 2 of the TDL	Gas mass flow
	F 3 of the TDL	Gas mass flow

4.2.4.3.1.3 Physical Location and Layout

The physical layout of CQL1 (helium delivery) does not take up much space compared to a typical TDL circuit. The physical layouts of the two anticipated CQL1 tests cannot be pinned down at the writing of this report without the UUT designs being finalized.

The physical CQL1 layout thus only comprises the components consisting within CQL1, which are:

- Hot Gas Ducts (HGDs)
- Hot Header (HH)
- Cold Header (CH)
- Interface (Blanked-off Flanges) with test stations

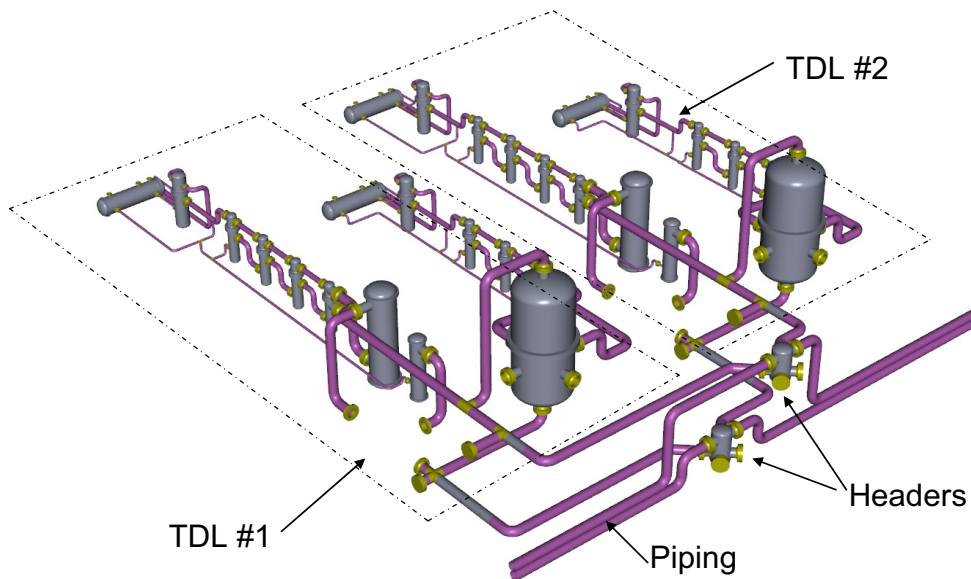


Figure 4-18: General view showing two TDL loops in the background and CQL1 (piping and headers) in the foreground.

Optimization of the specific footprint of CQL1 piping needs to be done at a later stage.

4.2.4.3.1.4 Principles of Operation

Testing requirements for CQL1 are made up of two test specifications, namely:

- Steam Generator (SG) UUT. The SG vessel design on the SG unit still needs to be finalized.
- H₂SO₄ Decomposition Reactor UUT. At the writing of this report, there is no design on this unit either.

Heat duty requirements for both the anticipated CQL1 tests have been calculated using the assumption that both of these tests will use combined mass flows of two (2) TDLs. This was purely based on engineering judgment taking into consideration that the maximum possible heat duty attainable from one TDL only would not be sufficient for either SG or H₂SO₄ Decomposition Reactor testing. Should smaller heat duties (<6 MWth) be feasible for both mentioned component testing, the need for CQL1 would be superfluous.

The basis for CQL1 conceptual design arose from enveloping all the different test specifications proposed for CTF testing. From these test specifications, the IHX test stood out to be of primary importance, yet small enough for anticipated TDL testing. The TDL has accordingly been designed to accommodate testing of three IHX modules, totaling a heat duty of 3.6 MW. This specific IHX test has been used as corner stone for TDL and subsequent CQL1 conceptual designs. Throughout the concept design, a maximum of two TDLs were envisaged to conduct a CQL1 test.

Assuming steady state conditions and using basic thermodynamic equations, the following logical steps of events were used to obtain enveloping process parameters for CQL1.

1. The heater in the primary circuit of a TDL (HT 2A_1.1) is designed to supply enough thermal heat for testing three IHX modules in parallel, each having a heat duty of 1.2 MW. In terms of heat duty requirements, the IHX test is the largest of all the anticipated CTF tests to be run within a TDL.
2. The above requirement lead to a primary TDL heater design delivering 6.16 MWth. This value was based on an electrical-to-thermal efficiency of 90 percent. The maximum theoretical mass flow attainable from this heater size (refer to document MT-TLDR-CAL-F-T-0705) is 3.65 kg/s.
3. The large delta in helium temperature anticipated for the SG test, i.e. from 900 °C to 273 °C, places some restriction on the mass flow of the helium as is evidenced from the following basic equations:

$$m = \frac{Q}{(h_{in} - h_{out})} \dots\dots\dots \text{Equation 1}$$

$$m = \frac{Q}{C_p (T_{in} - T_{out})}$$

where m = mass flow, Q = heat duty, h = enthalpies, Cp = specific heat capacity at constant pressure and T = temperature. The bottom equation can be used since helium does not change phase between the two extreme process conditions.

4. The larger the temperature drop, the less the attainable mass flow.
5. The temperature drop anticipated for the SG test, i.e. from 900 °C to 273 °C allows for a mass flow of 1.786 kg/s per TDL, taking all the process conditions into consideration. Using two TDLs increases the mass flow to 3.573 kg/s per SG CQL1 test.
6. The temperature drop anticipated for the H₂SO₄ Decomposition Reactor test, i.e. from 900 °C to 659 °C allows for a mass flow of 3.336 kg/s per TDL, taking all

the process conditions into consideration. Using two TDLs increases the mass flow to 6.671 kg/s per H₂SO₄ Decomposition Reactor CQL1 test.

Each of the main components is further more discussed under the thermal hydraulic design, reference [4-19].

Regarding the two QCL1 tests, the following can be summarized for each as far as principles of operation are concerned:

SG Test: The maximum attainable mass flow from two TDLs is 3.573 kg/s at 900 °C and 8.700 MPa(g). These process conditions give the following maximum thermal duties on the major components of the TDLs and anticipated ST test unit during nominal TDL operational conditions, as listed in Table 4-24

Table 4-24: Maximum thermal duties

Description	Value	Unit
SG Test Unit:	11.632	MWth
TDL Cooler:	0.395	MWth
TDL Circulator:	0.046	MWth
TDL Recuperator:	1.393	MWth
TDL Heater:	6.160	MWth

H₂SO₄ Decomposition Reactor Test: The maximum attainable mass flow from two TDLs is 6.671 kg/s at 900 °C and 8.934 MPa(g). These process conditions give the following maximum thermal duties on the major components of the TDLs and anticipated H₂SO₄ Decomposition Reactor test unit during nominal TDL operational conditions.

Table 4-25: Maximum thermal duties

Description	Value	Unit
SG Test Unit:	8.345	MWth
TDL Cooler:	2.073	MWth
TDL Circulator:	0.087	MWth
TDL Recuperator:	7.945	MWth
TDL Heater:	6.160	MWth

The above calculations were simply determined using given helium inlet and outlet temperatures and pressures as per the two test specifications anticipated for CQL1 component testing. The thermal duties of the two test units as well as the subsequent heat duties of the TDL components during circulation of the primary stream helium were calculated in order to establish an upper limit for these two units when using two TDLs.

4.2.4.3.1.5 System Reliability Features

Reliability is built into the system by using proven Commercially-off-the-Shelf (COTS) components within the conditioning loops of the TDLs. CQL1 builds upon the reliability of the TDLs in the sense that it does not use moving or heat exchanging components other than HGDs and the hot and cold headers.

Redundancy is incorporated into the I&C philosophy. Furthermore, by making provision for standby circulators (primary and secondary sides of TDLs) and standby pumps i.e. all mechanical devices for circulating cooling water and other heat exchanging fluids redundancy is adhered to minimize both reliability as well as utilization of valuable plant productivity.

4.2.4.3.1.6 System Control Features

The systems will mainly be controlled by the PCS. The PCS will be responsible for all the start-up operating and shut-down sequences and operation. Interlocking and alarming will be handled by this system. Closed loop control systems will also be executed by the PCS.

SYSTEM MONITORING

The initial minimum instrumentation requirements are given next with the usage (protection/safety, control, V&V and/or testing) and range to indicate in which conditions the instrument will have to operate. All instruments will typically be used for verification and validation, but the V&V column is only marked if the instrument is primarily identified for V&V. The types, accuracies and locations will be determined at a later stage. The instrument abbreviations are as follows:

Table 4-26: General CQL1 instrumentation

Instrument	Protection	Control	V&V	Testing	Temperature [°C]	Mass flow [kg/s]	Pressure [MPa (g)]	Pressure diff [kPa]	Other
A1	x			x	0-1100	0-6	0-20		TBD
dP1	x			x	0-1100	0-5	0-10	TBD	
dP2				x	0-1100	0-8	0-6	TBD	
F1		x			0-300	0-6	0-14		
F2		x			TBD	TBD	TBD		
FS1		x			0-300	0-150	0-0.7		
FS2		x			TBD	TBD	TBD		
L1	x			x	0-1100		0-20		0-100 percent
L2		x			0-300	0-150	0-0.7		0-100 percent

Instrument	Protection	Control	V&V	Testing	Temperature [°C]	Mass flow [kg/s]	Pressure [MPa (g)]	Pressure diff [kPa]	Other
P1	x			x	0-1100	0-5	0-10		
P2				x	0-1100	0-8	0-6		
P3	x			x	0-700	0-6	0-14		
P4	x			x	0-300	0-6	0-20		
P5		x			0-300	0-6	0-14		
P6		x			TBD	TBD	TBD		
P7		x			TBD	TBD	TBD		
T1	x			x	0-1100	0-5	0-10		
T10		x			0-100	0-150	0-0.7		
T11		x			TBD	TBD	TBD		
T12		x			TBD	TBD	TBD		
T2	x			x	0-400	0-5	0-10		
T3				x	0-1100	0-8	0-6		
T4				x	0-800	0-8	0-6		
T5	x			x	0-700	0-6	0-14		
T6	x			x	0-300	0-6	0-20		
T7		x			0-300	0-6	0-14		
T8		x			0-300	0-150	0-0.7		
T9		x			0-100	0-150	0-0.7		

CONTROL CAPABILITY AND LOCATION

Only a concept philosophy for control capability and location is defined at this stage, which is the same for all the test loops. A brief discussion was given in section 4.2.4.1.1.6.

AUTOMATIC AND MANUAL ACTIONS

Only a concept philosophy for the automatic and manual actions is defined at this stage, which is the same for all the test loops. A brief discussion was given in section 4.2.4.1.1.6.

4.2.4.3.2 Operations

The modes and transitions of the CQL1 loops can be subdivided into the stream sequences', process sequences' and system sequences' modes and transitions respectively as discussed in the control and instrumentation philosophy. The sequences of the different tests will typically look the same especially on stream sequence level. Figure 4-19 portrays a stream, process and system sequence for a typical steam generation test.

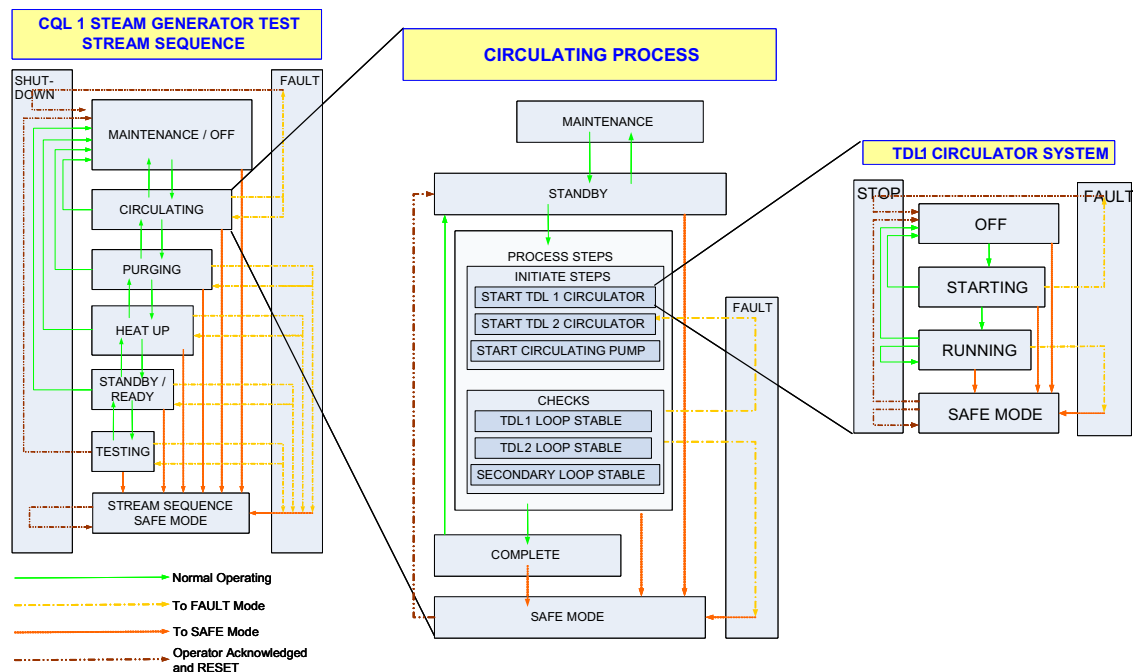


Figure 4-19: Typical CQL1 stream, process and system sequence.

The stream sequence of CQL1 is similar to TDL and it describe in more detail in section 4.2.4.2.2

4.2.4.4 Component Qualification Loop 2

4.2.4.4.1 Configuration Information

4.2.4.4.1.1 Description of System, Subsystems, and Major Components

NGNP CTF Feasibility and Recommendation Study document of February 2008, reference [4-4].

This concept proposes a two-loop flow system that simulates the NGNP demonstration plant primary and secondary loops. Both the loops use Helium as flow medium.

The CQL2 system operating pressure will be similar to the NGNP at 9 MPa(g). A high-temperature section, reaching temperatures of up to 950°C will be included.

The mass flow of CQL2 will be 25 kg/s, representing approximately 14 percent of anticipated NGNP maximum flow.

The blower section of the loop runs at 250°C in order to accommodate the use existing technology (TRL 8) blowers. The TRL summary and description is contained in reference [4-19].

TEST LOOP

The design of the CQL2 is conservative, flexible and suitable for qualification of large NGNP components.

It makes provision for a number of different configurations, in order to allow testing of a wide spectrum of high temperature reactor system components in five different test bays. These are for example, and not limited to:

- The primary loop test bay for testing
 - IHX
 - Hot pipes
 - Valves
 - Core flow model
 - Etc.
- The secondary loop test bay for testing
 - Instrumentation
 - Seals
 - Etc.
- The SG loop for testing
 - High temperature SGs
 - Mixing chambers
 - Process heat experiments
 - Etc.
- The ultra-high temperature test bay for testing
 - Control rods and control rod drives
 - Reserve shutdown systems
 - Etc.
- The gas turbine set test bay for testing
 - Co-generation components.

The loop will be housed in a closed building with four different function sections, for example:

- Blower hall housing the
 - Blowers,
 - Filters and
 - Coolers
- Energy tower, housing the
 - Recuperators,
 - SG and
 - Heaters
- High temperature test section housing the
 - High temperature and

- Ultra-high temperature test loops including the high bay with
 - i. RCS (Reactivity Control System) and
 - ii. Reserve shutdown system
- Open test section housing the
 - Valve tests
 - Core flow model
 - Instrumentation
 - Seal systems
- Control room will be housed above one of the low bays.

The services/auxiliaries will be housed in separate buildings adjacent the main loop building complex. Services includes, but not limited to:

- Helium Purification Facility (HPF)
- Helium Inventory and Pressure Control System (HIPCS)
 - Helium make-up
 - Helium storage
 - Pressure control
- Electrical Substation
 - HV (High Voltage) switch gear
 - Transformers
 - MCC (Motor Control Center) room
 - UPS
 - DCS (Distributed Control System) room
- HVAC plant room
- Cooling water system
 - Cooling towers
 - Coolant circulation pumps
 - Water treatment plant
 - Effluent treatment plant
- Admin building and engineering offices
- Maintenance workshop

The pressure boundary conditioning system provides cooling helium to the high temperature equipment pressure boundary, such as the hot pipes, pressure vessels and valves. This is a dedicated separate system that will not influence experimental flow measurements.

The main and secondary loops can be arranged in different configurations to make best use of capabilities, to run most economically and provide for the widest possible needs. It also takes into account the late delivery or bad availability of, for instance the IHX's. The main configuration will be:

- Principle 2-loop configuration
- High-efficiency component test
- Main loop process component test

- Intermediate HX with hydrogen generation
- Brayton cycle test
- Basic component test
- Steam generator coupled to secondary loop

The facility will be situated on the INL site.

The plant will be operated and maintained by INL employees. It is anticipated that the plant will have to be operated at 24h/day, which means a three-shift operation. The plant will be automatically controlled and be self protected by electronically control and protection systems operating through a dedicated Emergency Shut-Down (ESD).

FLOW DIAGRAM

The simplified block flow diagram below in Figure 4-20 demonstrates the integrated system with some of the different couplings for the different test configurations. The diagram does not reflect an operational configuration.

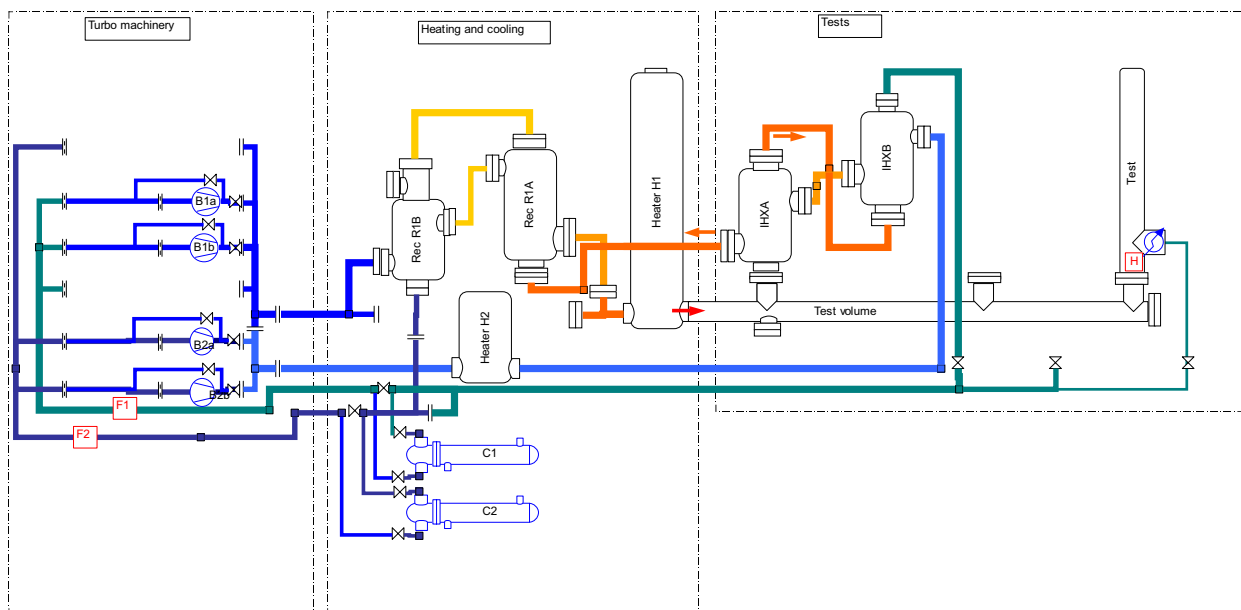


Figure 4-20: Simplified block flow diagram

Refer to reference [4-19] for process description, design data and operational (control) descriptions.

DESCRIPTION OF MAIN COMPONENTS

The Blowers in the main and secondary loop will be 100 percent redundant, each with a capacity of 25 kg/s @ 9 000 kPa and ΔP at 250 kPa.

Provision is made for testing of UUT blowers in the main and secondary loops, e.g. similar sized electromagnetic bearing blowers. Existing technology limits blower

temperatures to approximately 300°C, therefore all gas streams to blowers will be pre-cooled before entering the blowers.

The recuperator has to transfer approximately 76 MW of energy from the secondary to primary loop. It is estimated that the industrially available high temperature recuperators (e.g. spiral wound) will be in the order of 80-85 percent effective.

The size of the commercially available recuperators is such that 4 to 6 units may have to be coupled in parallel. The cold side temperatures of both streams are moderate which will be used to cool the pressure boundary, but the hot stream temperatures will be between 900 and 950 °C which have to be kept away from the boundary by utilizing co-axial designs.

The electrical heaters will be vertically mounted double- or triple skinned internally insulated and conditioned units. Proposed heater units will be 6MW each of which five will be mounted in parallel. The proposed heater Voltage will be 6.6 kV, in order to make use of commercially available burst-fire type thyristor heater controllers.

Coolers will be fin-tube air-cooled units for high-temperature applications (>250°C) and shell and tube liquid cooled units for low temperature (<250°C) applications. It is proposed that air-to-gas cooling for high-temperature application is used in order to achieve better control and avoid film boiling on water (shell) side of tubes. Cooling liquid will be water with coolant enhancing additives for improved heat transfer, as well as anti-foam, anti-scale and anti-fungal additions.

All coolers will be configured with a by-pass system to assist with controllability of the gas stream reaching the blowers.

Piping will be low temperature piping, <600°C and high temperature co-axial piping for temperatures exceeding 600°C. The ASME B31.3 pressure piping code will be used for pipe pressure boundaries, using Vector compact flange design seals. Custom designed, with assistance from Essener Hochdruck Rohrleitung (EHR) of Germany, co-axial 'hot duct' piping will be used for higher temperatures. The design will be based upon THTR and HTF experience. Pipe pressure boundaries will be conditioned with cooler helium from a dedicated conditioning system.

4.2.4.4.1.2 Boundaries and Interfaces

4.2.4.4.1.2.1 Mechanical

The interfaces to buildings and piping are still being developed and the work in progress listed in the appendixes to reference [4-19] and is depicted in two lists:

- Internal interface requirements, listing;
 - vessel and other equipment sizes,
 - mass,
 - electrical interfaces,

- instrumentation interfaces,
 - cooling water flow interfaces
 - instrument air (for pneumatically operated valves)
 - emergency standby power
 - nozzle sizes and
 - approximate height from floor to top for vessels and other components.
- External interface requirements, listing requirements from the site to the facility such as;
 - electricity,
 - roads,
 - water supply,
 - effluent and waste disposal,
 - communications,
 - boundary protection,
 - safety,
 - security,
 - etc.
- A preliminary set of lay-out drawings are provided in reference [4-19], indicating approximate building sizes associated with housing CQL2.
- Large vessels, such as the HICS vessels, are to be situated outside the buildings, due to their mass and height (first estimate over 180 tons and 18 m height), making rigging inside buildings extremely difficult.
- Heater vessels, the SG and recuperators, of similar mass, are to be housed inside the buildings due to their more intricate electrical interfaces and expected maintenance intensive. However, should cost constraints require a re-think, the aforementioned equipment can also be constructed in open air, and serviced by mobile cranes instead of the planned overhead girder cranes.
- The Blowers, the gas turbine system, compressors and all electrical switch gear are to be housed inside the buildings.

4.2.4.4.1.2.2 Electrical

The CQL2 electrical load list as well as a single line diagram is included in the appendices of reference [4-19].

Total electrical requirements for CQL2 are approximately 50 MWe.

The two step-down transformers (132kV to 6.6kV) are each sized to provide 40 MW, which is approximately 100 percent of the estimated load at any time, if diversity is factored in. Thus 100 percent redundancy is provided for in transformer capacity.

Emergency power is supplied by a 250 kVA diesel generating set and transformer (11kV/6.6kV) which is sized to supply power to the plant's SCADA, DCS, ESD, emergency lighting, emergency HVAC and essential utility power outlets (office computers, telecommunication systems, safety and security systems) in the event of a mains power failure.

An additional uninterruptible power supply is provided for the DCS of the plant.

Should electro-mechanical bearings be employed for the blowers or circulators, these will be supplied with their own UPS systems to protect the bearings in the event of a mains power failure.

The SG experiment can be coupled to a packaged steam turbine power conversion unit and approximately 10 MW electrical energy can be reclaimed and fed back into the heater's electrical supply.

4.2.4.4.1.2.3 Support systems

An assessment of the existing on- and off-site capacities of services such as access roads bearing capacity, electrical power availability, effluent capacity, fresh water availability, telecommunications network, housing for staff etc.

Only once the availability of such services have been established, can the professional team assess and design their systems to fully utilize existing services and enhance or provide additional services to suit the CQL2 requirements.

Compressed air and instrument air requirements are small, with a first estimate for compressors and dryers to provide 100 l/s (215cfm) at 700 kPa(g).

Water and effluent requirements are not fixed yet but a first order of magnitude requirement is 10 kl/h. (240 m³/day)

4.2.4.4.1.3 Physical Location and Layout

The proposed CQL2 buildings have various height sections, with the tallest section approximately 45 m in height. This area houses a full-sized RCS and RSS test set-up. The tall section will be serviced by a 30 ton overhead crane.

The next highest section, where the heaters are housed, is approximately 30 m high and is serviced by a 200 ton overhead crane.

Provisional CQL2 building modules are based on column spacing of 5 m with a maximum span for large (>50t) bridge cranes of 10 m.

The HICS building should be the first structure erected on site and will be used during construction as a site assembly and fabrication workshop.

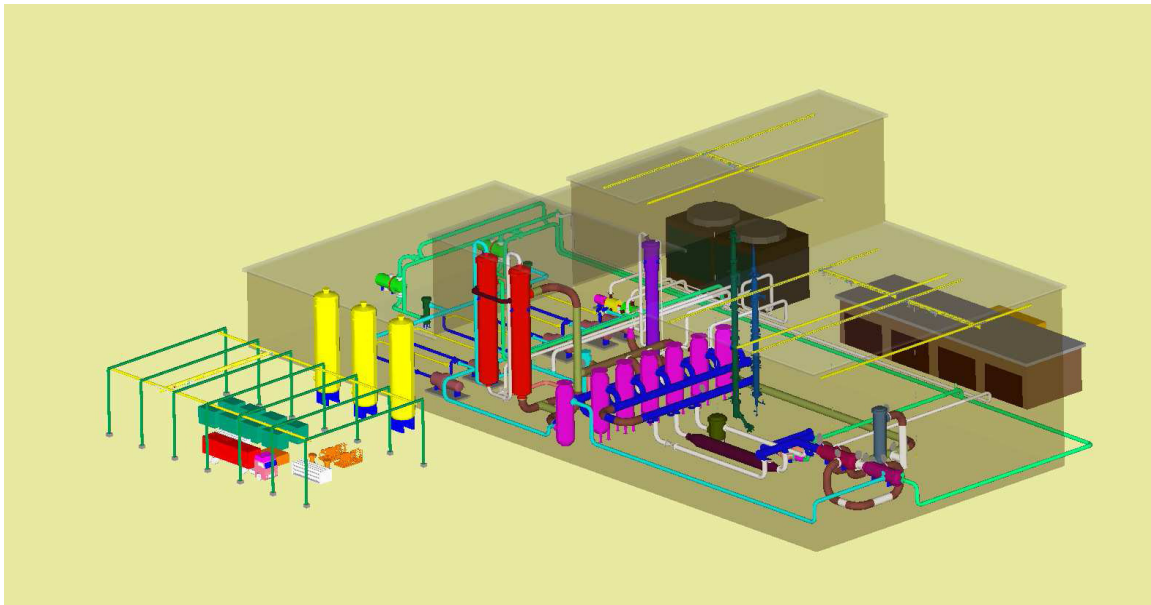


Figure 4-21: 3-D lay-out of the CQL2 Plant

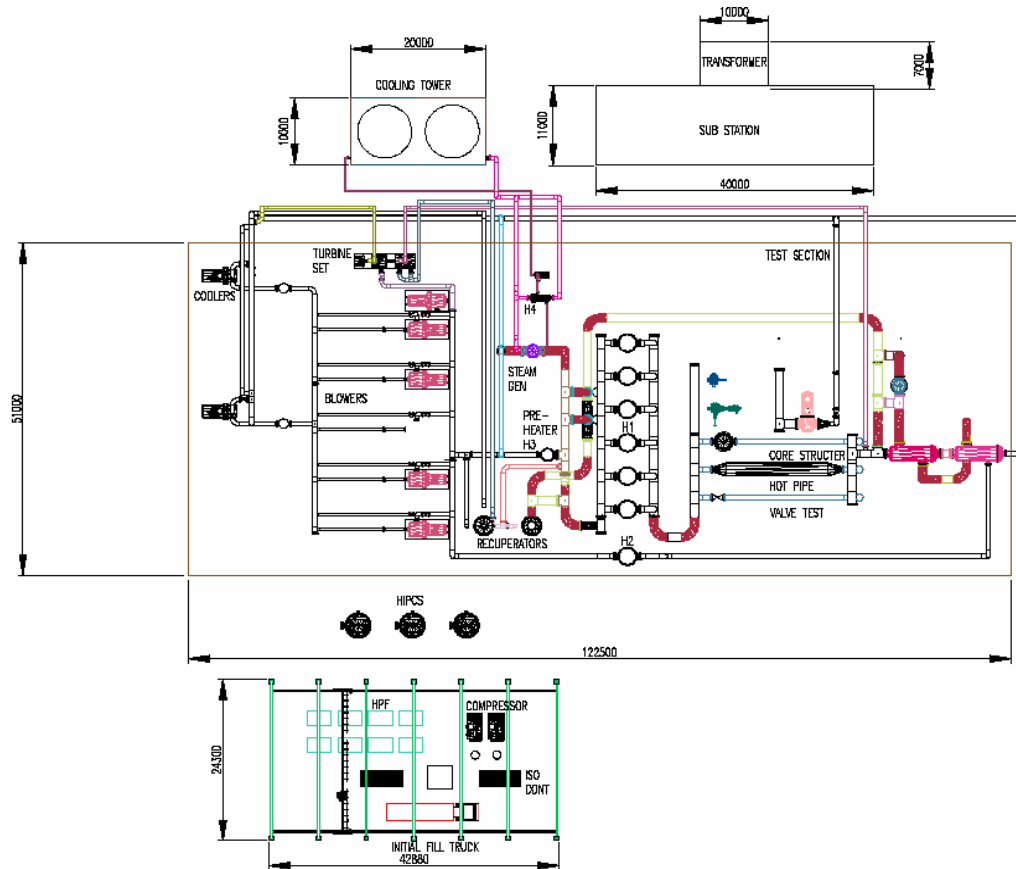


Figure 4-22: CQL2 plant lay-out drawing

The site layout drawings for CQL2 are provided in the appendices to reference [4-19]. Overall layout and placing of equipment as well as order of magnitude sizes are as per the drawing above.

The particular layout was conceptualized to group similar types of equipment together in order to ease construction and maintenance. Units under test are grouped together in accordance with operating temperatures.

A site of approximately 300 x 300 m is required to house the project in its entirety.

4.2.4.4.1.4 Principles of Operation

Plant operation and control is discussed in detail in reference [4-19] and will not be repeated in this section.

- The IHX can be tested simultaneously with other tests. As all major test set-ups, it will be coupled to a dedicated data acquisition system.
- The SG simulates a full-length size of a proposed NGNP SG. Steam will be used by the steam pre-heater section of the process heat component test loop of configuration 3 or may be used with an off-the-shelf power conversion unit. It is necessary to convert the steam to feed water by extracting the maximum energy from it, in order to avoid noise pollution associated with blow-down release of high-pressure steam.
- A scaled-down circulator can be installed next to the main loop circulators and in parallel with the main loop circulators. It will thus provide additional redundancy to the main loop circulators and although they are seen as UUT, it can be advantageous to increase plant overall availability.

4.2.4.4.1.5 System Reliability Features

The CQL2 design is based upon main components of TRL level 8 statuses, with a high reliability and reduced risk of operation failure.

In addition, some of the key components, such as blowers and transformers, have been doubled up in order to provide 100 percent redundancy improve reliability.

In addition the ESD, DCS and SCADA is provided with a UPS and emergency electrical generating set, to allow controlled plant shut-down during mains power failure and also prevent loss of test data during such occurrence.

The multiple configurations of the design makes it possible for operational and maintenance staff to reconfigure the plant for another set of tests, if any particular test proves to be troublesome.

- Blower is off the shelf (Proposed Gardner Denver)
- Passive and active cooling of pressure boundary is proven technology
- Shell and tube HXs uses proven technology
- Redundant blowers will be installed
- Instrumentation reliability has been tested and proven on the HTF
- High level of Safety integrity Level (SIL) classification of key control elements
- Expected behavior will be simulated before tests and interlock levels set in accordance with rates, alarms and trips lists, as compiled in HAZOP and Failure Mode Effect and Critical Analysis (FMECA) studies.
- Two circulators, Used only when one fails – 2 x 100 percent blower capacity
- The 25 MW heater H1 system is divided into five parallel connected units, each providing 6 MW, thus, should one fail there is still nearly 100 percent heating capacity.

4.2.4.4.1.6 System Control Features

4.2.4.4.2 Operations

The modes and transitions of the CQL2 loops can be subdivided into the stream sequences', process sequences' and system sequences' modes and transitions respectively as discussed in the control and instrumentation philosophy. The sequences of the different tests will typically look the same especially on stream sequence level. Figure 4-23 portrays a stream, process and system sequence for a typical steam generation test.

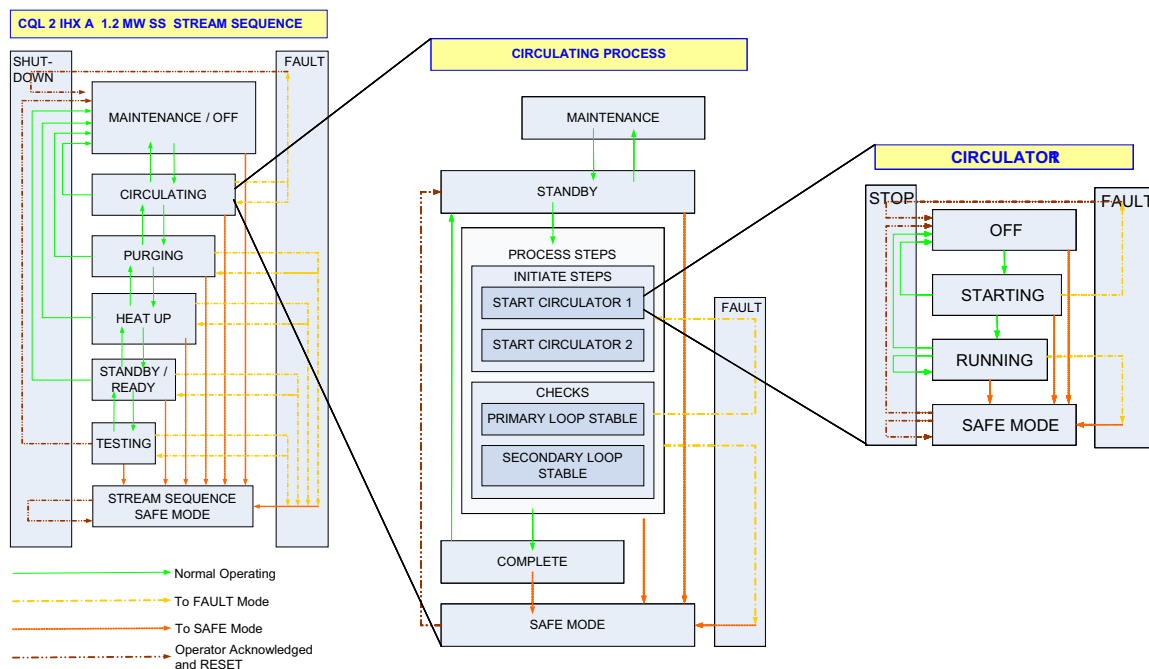


Figure 4-23: Typical CQL2 stream, process and system sequence.

The stream sequence of CQL2 is similar to TDL and it describe in more detail in section 4.2.4.2.2

4.2.4.5 Circulator Test Loop

4.2.4.5.1 Configuration Information

4.2.4.5.1.1 Description of System, Subsystems, and Major Components

The CTL comprises a Test Station for a full-scale circulator system for the NGNP plant, which operates at 160kg/s helium flow rate, at a maximum temperature of 350°C and a pressure of 9MPa(g). Due to the availability of a high helium flow rate at a high pressure drop (450kPa total), several other tests can be done in the CTL. These are the calibration of flow meters for the full-scale NGNP, testing of flow-induced vibrations in the full-scale Heat Transport System piping (HGDs), testing of vibration damping devices in the mixing chamber and determination of the pressure drop coefficient of a full-scale check valve.

The test loop is heated by means of the circulator heat input, while loop temperature control is done by a controlled water cooler. The CTL PFD is shown in Figure 4-24.

Thus, the major components of the CTL are:

- Pressure dissipation orifice
- Pressure dissipation valves (open/close)
- Pressure dissipation valve (control)
- Mixing chamber test section
- HGD vibration test section
- Flow meter calibration test station
- Three flow measurement orifices
- Connections for the Circulator test station

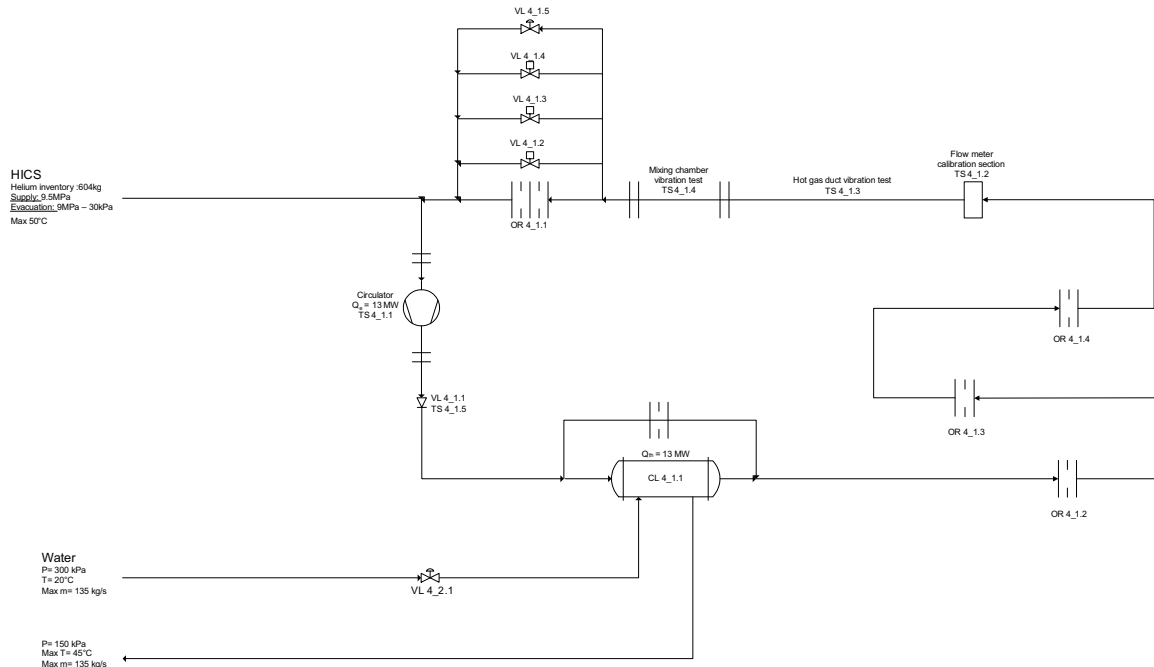


Figure 4-24: PFD of the CTL.

4.2.4.5.1.2 Boundaries and Interfaces

The CTL has the following boundaries and interfaces

4.2.4.5.1.2.1 Mechanical

The mechanical boundaries and interfaces include the following:

5. The CTL interfaces mechanically by means of flanges with the HICS, Cooling water and Air supply systems.
6. The CTL has a footprint of
 - Height: 7.6 m
 - Width: 5.5 m
 - Length: 41.6 m (excluding the Circulator Test station)
7. The CTL's largest component has a mass is presented in Table 4-27, which has an influence on the lifting capacity of the crane and the lay down area provided.

Table 4-27: Initial calculation of pressure boundary mass for a TDL

Description	Value	Unit
HTS Cold pipes	42	kg/m
HTS HGD	442	kg/m
Primary Circulator vessel	8 608	kg
Secondary Circulator vessel	8 608	kg
Primary Recuperators	36 902	kg
Secondary Recuperators	38 027	kg

Description	Value	Unit
Heater 1	27 759	kg
Heater 2	6 083	kg
IHX test vessel	54 266	kg
Primary loop cooler	5 635	kg
Secondary loop cooler	2 701	kg

8. The mechanical interface between the CTL and the test stations is achieved by means of flanges and blank off flanges, depending on the test configuration required. The CTL is built with flanged pipe spool pieces in the place of the mixing chamber and HGD test sections.

4.2.4.5.1.2.2 Electrical power requirement

The electrical boundaries and interfaces forms part of the systems integration as indicated on the electrical one line drawing [NGNP-CTF-E-WIR-001-2]. The CTL continuous operation electrical power rating is 13MW, which is for the Circulator test station.

4.2.4.5.1.2.3 Support systems

Cooling water

The cooling water requirement is 155 kg/s at 20°C supply and 40°C return temperature. Other interface conditions with the HICS system are given in Table 4-28.

Table 4-28: Water supply at the cooler interface.

Description	Value	Unit
P_w	300	kPa
$T_{w \text{ in}}$	20	°C
$T_{w \text{ out, max}}$	45	°C

Helium Inventory Control System

Based on first estimates for pipe lengths, the helium inventory is 604kg. Other specifications for the interface conditions with the HICS system is given in Table 4-9

Table 4-29: HICS Interface requirement

Description	Value	Unit
$P_{\text{range he}}$	30 – 9500	kPa
$T_{\text{he in}}$	20	°C
$T_{\text{he out}}$	80	°C
$m_{\text{he total}}$	604	kg

HVAC

The estimated heat loss to the environment is 92kW (at 30°C ambient temperature).

4.2.4.5.1.2.4 Instrumentation and Control

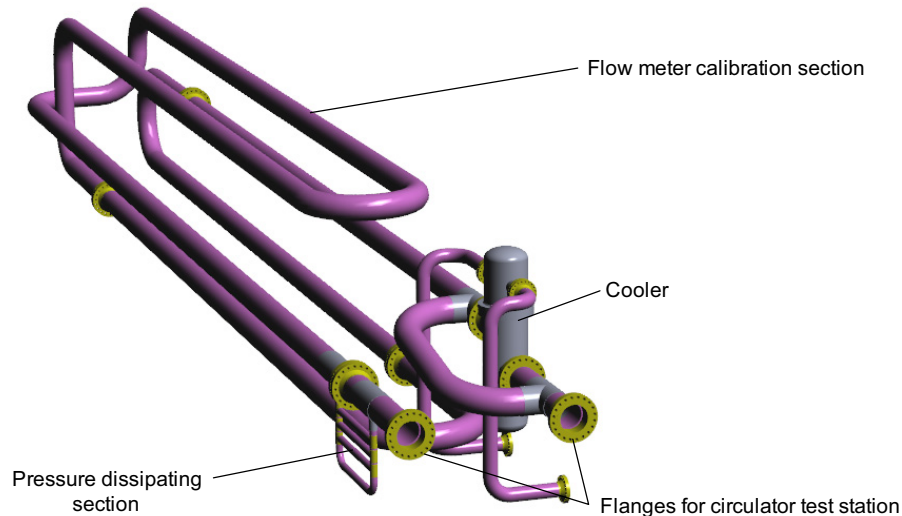
A list of the various instruments that ensure the proper functioning of the support system is listed in Table 4-21.

Table 4-30: Boundary interface instrumentation

Support system	Instrument	Description
Water	T 7	Water inlet temperature
	F 5	Water mass flow
	P 5	Water pressure

4.2.4.5.1.3 Physical Location and Layout

The arrangement and layout of the CTL is shown in Figure 4-25.

**Figure 4-25: Physical layout of the CTL**

This layout was chosen for easy access for crane or vehicle to loop components during construction and maintenance. The long pipe lengths are required to ensure high accuracy of the orifice flow meters.

4.2.4.5.1.4 Principles of Operation

The various tests that can be accommodated by the CTL are discussed briefly in the next sections.

4.2.4.5.1.4.1 Prototype Circulator Test (WEC-TS-CIRC-003)

The primary purpose of the CTL is to perform this test. The full-scale NGNP Circulator is tested by providing a variable pressure drop characteristic by means of four valves in parallel to an orifice. All the other tests in the loop are only dependent on the flow rate set up by the Circulator.

4.2.4.5.1.4.2 HTS Piping (Hot gas duct): vibration (WEC-TS-PIP-009) and Mixing chamber: Vibration Damping Devices (WEC-TS-MC-002)

This test is done by measuring acceleration of parts in a full-scale HGD and mixing chamber while varying the flow rate with the combination of circulator and pressure dissipation valves. The pressure level of the loop could be reduced to reach a helium density that corresponds to the density at 950°C, in order to attain the correct dimensionless parameters for these test results to apply to the full-scale high-temperature case.

4.2.4.5.1.4.3 Flow meter calibration

Calibration of the flow meter in Test Station TS 4_1.2 is done by measuring the flow with the three orifices while the flow is varied with the combination of Circulator and dissipating valves.

The helium in the loop is heated to the operating temperature of 350°C by the heat input from the circulator. The temperature is then controlled by controlling the water flow rate on the secondary side of the cooler. Only part of the total helium flow stream goes through the cooler so that the cooler has some control margin without exceeding a water outlet temperature of 45°C.

4.2.4.5.1.5 System Reliability Features

The CTL relies on simplicity and robustness of contraction for its reliability. The only components with moving parts are the pressure dissipating valves, of which there are four in parallel. This also increases the reliability of the pressure dissipating section.

4.2.4.5.1.6 System Control Features

The Systems will be mainly controlled by the Process Control System (PCS). The PCS will be responsible for all the start-up operating and shut-down sequences and operation. Interlocking and alarming will be handled by this system. Closed loop control systems will also be executed by the PCS.

SYSTEM MONITORING

The initial minimum instrumentation requirements are given next with the usage (protection/safety, control, V&V and/or testing) and range to indicate in which conditions the instrument will have to operate. All instruments will typically be used for verification and validation, but the V&V column is only marked if the instrument is primarily identified for V&V. The types, accuracies and locations will be determined at a later stage. The instrument abbreviations are as follows:

Table 4-31: General CTL instrumentation

Instrument	Protection	Control	V&V	Testing	Temperature [°C]	Mass flow [kg/s]	Pressure [MPa]	Pressure diff [kPa]	Other
A1				x	TBD	TBD	0-11		TBD
A2				x	TBD	TBD	0-11		TBD
A3				x	TBD	TBD	0-11		TBD
A4				x	TBD	TBD	0-11		TBD
A5				x	TBD	TBD	0-11		TBD
dP1	x	x		x	TBD	TBD	0-11	TBD	
dP2	x	x		x	TBD	TBD	0-11	TBD	
dP3	x	x		x	TBD	TBD	0-11	TBD	
dP4				x	TBD	TBD	0-11	TBD	
dP5			x		TBD	TBD	0-11	TBD	
dP6				x	TBD	TBD	0-11	TBD	
dP7				x	TBD	TBD	0-11	TBD	
dP8				x	TBD	TBD	0-11	TBD	
dP9				x	TBD	TBD	0-11		
F4				x	TBD	TBD	0-11		
F5		x			0-40	0-150	0-0.4		
N1	x			x	TBD	TBD	0-11		TBD
P1	x	x		x	TBD	TBD	0-11		
P2	x	x		x	TBD	TBD	0-11		
P3	x	x		x	TBD	TBD	0-11		
P4				x	TBD	TBD	0-11		
P5	x				0-40	0-150	0-0.4		
P6	x				0-60	0-150	0-0.4		
T1	x	x		x	TBD	TBD	0-11		
T10				x	TBD	TBD	0-11		
T11				x	TBD	TBD	0-11		
T2	x	x		x	TBD	TBD	0-11		
T3	x	x		x	TBD	TBD	0-11		
T4		x		x	TBD	TBD	0-11		

Instrument	Protection	Control	V&V	Testing	Temperature [°C]	Mass flow [kg/s]	Pressure [MPa]	Pressure diff [kPa]	Other
T5		x		x	TBD	TBD	0-11		
T6				x	TBD	TBD	0-11		
T7	x	x			0-40	0-150	0-0.4		
T8	x	x			0-60	0-150	0-0.4		
T9				x	TBD	TBD	0-11		
VL 4 1.2		x		x	TBD	TBD	0-11		
VL 4 1.3		x		x	TBD	TBD	0-11		
VL 4 1.4		x		x	TBD	TBD	0-11		
VL 4 1.5		x		x	TBD	TBD	0-11		
VL 4 2.1	x	x			0-40	0-150	0-0.4		

CONTROL CAPABILITY AND LOCATION

Only a concept philosophy for control capability and location is defined at this stage, which is the same for all the test loops. A brief discussion was given in section 4.2.4.1.1.6.

AUTOMATIC AND MANUAL ACTIONS

Only a concept philosophy for the automatic and manual actions is defined at this stage, which is the same for all the test loops. A brief discussion was given in section 4.2.4.1.1.6.

4.2.4.5.2 Operations

The modes and transitions of the CTL loop can be subdivided into the stream sequences', process sequences' and system sequences' modes and transitions respectively as discussed in the control and instrumentation philosophy. The sequences of the different tests will typically look the same especially on stream sequence level. portray a stream, process and system sequence for a typical steam generation test.

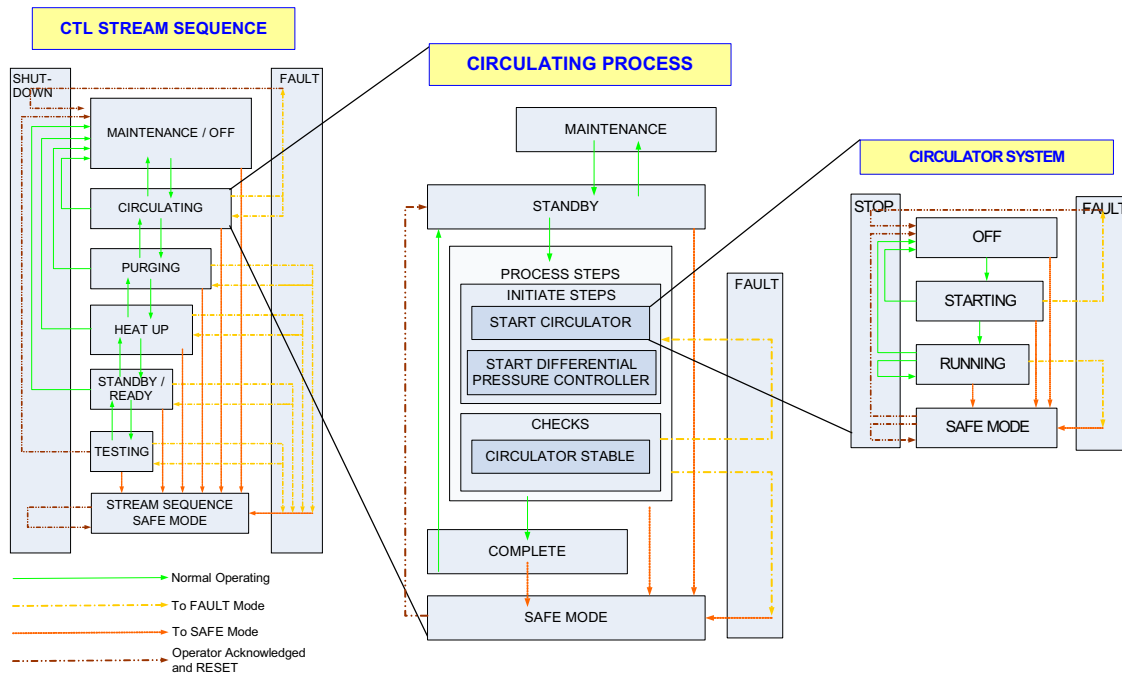


Figure 4-26: Typical CTL stream, process and system sequence

The stream sequence of CTL is similar to TDL 2 and it describe in more detail in section 4.2.4.2.2

APPENDIX A. SOURCE DOCUMENTS

INL and Westinghouse requirements

- [4-1] “HIGH LEVEL REQUIREMENTS High temperature Gas Reactor (HTGR) - Component Test Facility (CTF),” INL/MIS-08-14156, April 2008
- [4-2] “Technical and Functional Requirements, High Temperature Gas- Cooled Reactor (HTGR) Component Test Facility (CTF),” INL/EXT-08-14150
- [4-3] “Site Selection Study for the High Temperature Gas-Cooled Reactor (HTGR) Component Test Facility (CTF),” INL/EXT-08-14052
- [4-4] “HTGR Component test facility (CTF) Feasibility and recommendations,” NNGNP-CTF
- [4-5] “Preconceptual Facility Configuration Study of the High Temperature Gas-Cooled Reactor Component Test Facility,” INL/EXT-08-14132
- [4-6] “Statement of Work Westinghouse Electric Company Component Test Facility (CTF) Conceptual Design studies for the NNGNP with Hydrogen production,” SOW-6391

Roadmap reference

- [4-7] “NNGNP and Hydrogen Production Conceptual Design study WEC NNGNP Technology Development Road Mapping Section 3: PHTS Circulator,” NNGNP-CTF MTECH-TDRM-003
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APPENDIX B.SYSTEM DRAWINGS

Electrical one line diagrams.

- [4-27] COMPONENT TEST FACILITY (CTF) ONE – LINE DIAGRAM NGNP-CTF-E-WIR-001-1
- [4-28] COMPONENT TEST FACILITY (CTF) ONE – LINE DIAGRAM NGNP-CTF-E-WIR-001-2

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- [4-29] “General Small Scale Development Test Vessel PFD,” MT-TLDR-SSDT-02-0001
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- [4-33] “Technology Development Loop Hot Gas Duct,” MT-TLDR-TDL-02-0003
- [4-34] “Technology Development Loop Mixing Chamber,” MT-TLDR-TDL-02-0004
- [4-35] “Technology Development Loop 1.2 MW IHX A,” MT-TLDR-TDL-02-0005
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- [4-40] “COMPONENT QUALIFICATION LOOP Process Flow Diagram,” MT-TLDR-CQL1-02-0001

- [4-41] “COMPONENT QUALIFICATION LOOP Process Flow Diagram – Steam Generation,” MT-TLDR-CQL1-02-0002
- [4-42] “COMPONENT QUALIFICATION LOOP Process Flow Diagram – H2 Production,” MT-TLDR-CQL1-02-0003
- [4-43] “Circulator Test Loop PFD,” MT-TLDR-CTL-02-0001

Process and instrumentation diagrams

- [4-44] “General Small Scale Development Test Vessel P&ID,” MT-TLDR-SSDT-03-0001
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- [4-46] “Technology Development Loop P & ID,” MT-TLDR-TDL-03-0001
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APPENDIX C.SYSTEM PROCEDURES

No procedures have been identified at this stage.

APPENDIX D.SYSTEM HISTORY

Not done at this stage, as this is optional.

APPENDIX E. TEST INSTRUMENTATION MATRIX

Test instrumentation matrix

Section	Description	Test number	Mass flow (in)	Mass flow (Out)	Pressure	Internal Pressure	External pressure	Inlet pressure	Outlet pressure	Temp	Temp chamber wall	Local streak	Local streak	Temp in	Temp Out	Temperature gradient	T IN PRIMARY	T OUT PRIMARY	T IN SEC	T OUT SEC	Fluid composition	Leak rates	Impurities level	Impurities primary	Impurities secondary	Strain	Thermal conductivity	Duration of exposure	Acoustics induced	Flow induced spectra	Chamber wall loads	Frequency and	Post test exam
Circulator	EMBs, Catcher bearings Test Specification	WEC-TS-CIRC-001																															
Circulator	Helium Rotating seals Test Specification	WEC-TS-CIRC-002																															
Circulator	Partial or Full scale circulator Model Test Specification	WEC-TS-CIRC-003																															
IHX A (Metallic)	Corrosion Allowances for Alloy 617	WEC-TS-IHXA-006			Y					Y																						Y	
IHX A (Metallic)	Specification of testing of unit cell of compact Heat Exchangers	WEC-TS-IHXA-012	N A		Y					Y																						Y	

Section	Description	Test number	Mass flow (in)	Mass flow (Out)	Pressure	Internal Pressure	External pressure	Inlet pressure	Outlet pressure	Temp	Temp chamber wall	Local streak	Temp in	Temp Out	Temperature gradient	T IN PRIMARY	T OUT PRIMARY	T IN SEC	T OUT SEC	Fluid composition	Leak rates	Impurities level	Impurities primary	Impurities secondary	Strain	Thermal conductivity	Duration of exposure	Acoustics induced	Flow induced spectra	Chamber wall loads	Frequency and	Post test exam
IHX A (Metallic)	Testing of integrated compact HX module (~1.2MW)	WEC-TS-IHXA-013			Y					Y					Y	Y	Y	Y	Y	Y	Y										Y	
IHX A (Metallic)	ASME III Code Case for Compact HX Designs	WEC-TS-IHXA-014																														
IHX A (Metallic)	Shell-side flow distribution and bypass leakage testing	WEC-TS-IHXA-015																														
IHX A (Metallic)	Multi-module heat transfer testing	WEC-TS-IHXA-016																														
IHX A (Ceramic)	Testing of unit cell of compact HX	WEC-TS-IHXA-030			Y				Y																						Y	
IHX A (Ceramic)	Specifications of testing of compact HX module (~1.2MW)	WEC-TS-IHXA-031	Y			Y	Y								Y	Y	Y	Y	Y	Y	Y										Y	

Section	Description	Test number	Mass flow (in)	Mass flow (Out)	Pressure	Internal Pressure	External pressure	Inlet pressure	Outlet pressure	Temp	Temp chamber wall	Local streak	Temp in	Temp Out	Temperature gradient	T IN PRIMARY	T OUT PRIMARY	T IN SEC	T OUT SEC	Fluid composition	Leak rates	Impurities level	Impurities primary	Impurities secondary	Strain	Thermal conductivity	Duration of exposure	Acoustics induced	Flow induced spectra	Chamber wall loads	Frequency and	Post test exam
IHX A (Ceramic)	Specifications of testing of compact HX module (~1.2MW)	WEC-TS-IHXA-031_01	Y			Y Y									Y	Y	Y	Y	Y	Y Y											Y	
IHX A (Ceramic)	ASME III Code Case for Ceramic Compact HX Designs	WEC-TS-IHXA-032																														
IHX A (Ceramic)	Shell-side flow distribution and bypass leakage tests.	WEC-TS-IHXA-033																														
IHX A (Ceramic)	Multi-module heat transfer testing	WEC-TS-IHXA-034																														
IHX B	Corrosion Allowances for Alloy 800H	WEC-TS-IHXB-007																				Y Y	Y Y								Y	
IHX B	Specification of testing of Unit Cell of Compact HX	WEC-TS-IHXB-012			Y																											Y

Section	Description	Test number	Mass flow (in)	Mass flow (Out)	Pressure	Internal Pressure	External pressure	Inlet pressure	Outlet pressure	Temp	Temp chamber wall	Local streak	Local streak	Temp in	Temp Out	Temperature gradient	T IN PRIMARY	T OUT PRIMARY	T IN SEC	T OUT SEC	Fluid composition	Leak rates	Impurities level	Impurities primary	Impurities secondary	Strain	Thermal conductivity	Duration of exposure	Acoustics induced	Flow induced spectra	Chamber wall loads	Frequency and	Post test exam
IHX B	Specification of testing of compact HX module (~1.2MW)	WEC-TS-IHXB-013	Y			Y	Y			Y						Y					Y	Y			Y						Y		
IHX B	ASME Section III Code Case for Compact HX Designs	WEC-TS-IHXB-014																															
IHX B	Shell-side Flow Distribution and Bypass Leakage Testing	WEC-TS-IHXB-015																															
IHX B	Multi-module Heat Transfer Testing	WEC-TS-IHXB-016																															
Piping	Effects of He infiltration on thermal conductivity of insulation material	WEC-TS-PIP-006			Y					Y													Y			Y	Y						

Section	Description	Test number	Mass flow (in)	Mass flow (Out)	Pressure	Internal Pressure	External pressure	Inlet pressure	Outlet pressure	Temp	Temp chamber wall	Local streak	Local streak	Temp in	Temp Out	Temperature gradient	T IN PRIMARY	T OUT PRIMARY	T IN SEC	T OUT SEC	Fluid composition	Leak rates	Impurities level	Impurities primary	Impurities secondary	Strain	Thermal conductivity	Duration of exposure	Acoustics induced	Flow induced spectra	Chamber wall loads	Frequency and	Post test exam
Piping	The effect of fluid impurities (C) on insulation properties	WEC-TS-PIP-007			Y					Y										Y	Y	Y					Y						
Piping	Performance and environmental testing of prototypical high-temperature and low-temperature piping/insulation system	WEC-TS-PIP-009			Y					Y										Y												Y	
Mixing Chamber	Specification 1: Enhanced Mixing Devices Test Specification	WEC-TS-MC-001	Y	Y				Y	Y					Y	Y																		
Mixing Chamber	Specification 2: Vibration Damping Devices Test Specification	WEC-TS-MC-002	Y	Y				Y	Y																			Y	Y	Y			

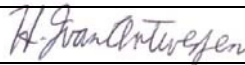
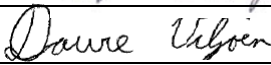
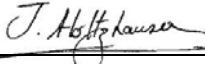
Section	Description	Test number	Mass flow (in)	Mass flow (Out)	Pressure	Internal Pressure	External pressure	Inlet pressure	Outlet pressure	Temp	Temp chamber wall	Local streak	Local streak	Temp in	Temp Out	Temperature gradient	T IN PRIMARY	T OUT PRIMARY	T IN SEC	T OUT SEC	Fluid composition	Leak rates	Impurities level	Impurities primary	Impurities secondary	Strain	Thermal conductivity	Duration of exposure	Acoustics induced	Flow induced spectra	Chamber wall loads	Frequency and	Post test exam
Mixing Chamber	Partial or Full Scale Flow Mixing Chamber Model Test Specification	WEC-TS-MC-003	Y	Y			Y	Y			Y	Y	Y																	Y	Y		
Steam Generator	Performance testing in CTF	WEC-TS-SG-005																															

NGNP and Hydrogen Production Conceptual Design Study

NGNP CTF Test Loop Preconceptual Design Report

Section 5: Small Scale Development Test (SSDT)

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ACRONYMS

Abbreviation or Acronym	Definition
A	Accelerometer
A-E-C	Architecture – Engineering -Construction
AGR	Advanced Gas-cooled Reactor
AHJ	Authority Having Jurisdiction
AICE	American Institute of Chemical Engineers
AISC	American Institute of Steel Construction
AISI	American Iron and Steel Institute
ALARA	As Low As Reasonable Achievable
AMB	Active Magnetic Bearing
ANSI	American National Standards Institute
API	American Petroleum Institute
ASHRAE	American Society of Heating Refrigeration and Air Conditioning Engineers
ASME	American Society of Mechanical Engineers
AWS	American Welding Society
BEA	Battelle Energy Alliance
BIL	Basic Impulse Insulation Level
BIM	Building Information Management
BS	British Standard
Btu/hr	British thermal unit per hour
CAD	Computer Aided Design
CAE	Computer Aided Engineering
CBCS	Core Barrel Conditioning System
CCS	Core Conditioning System
CFR	Code of Federal Regulations
CH	Cold Header
CMAA	Crane Manufacturers Association of America
COR	Client Observation Room
COTS	Commercial Off-The-Shelf (Commercial Grade Items)
CQL	Component Qualification Loop
CQL1	Component Qualification Loop 1
CQL2	Component Qualification Loop 2
CTF	Component Test Facility
CTL	Circulator Test Loop
CV	Valve Flow Coefficient
DAQ	Data Acquisition
db	Dry Bulb
DB	Distribution Board

Abbreviation or Acronym	Definition
DC	Direct Current
DCD	Design Criteria Document
DCS	Distributed Control System
DDN	Design Data Need
DOE	Department of Energy
dP	Differential Pressure
DPP	Demonstration Power Plant
EDMS	Engineering Data Management System
EHR	Essener Hochdruck Rohrleitung
EIA	Electronic Industry Alliance
EMB	Electro-magnetic Bearing
ENS	Emergency Notification System
EPACT	Energy Policy Act (of 2005)
EPC	Engineering Procurement and Construction
ER	Environmental Requirement
ES&H	Environmental, Safety and Health
ESD	Emergency Shutdown
F	Flow Rate
FDD	Facility Design Description
FHA	Fire Hazard Analysis
FIPS	Federal Information Processing Standards
FM	Factory Mutual
FMS	Facility Monitoring System
FS	Flow rate (switch)
GA	Gas analyzer (composition)
GHEP	Guidelines for Hazard Evaluation Procedures
gpm	Gallon per minute (US)
GR	General Requirements
H ₂	Hydrogen Production Test (Specifically referring to H ₂ SO ₄ Decomposition Reactor Test)
H ₂ SO ₄	Sulfuric Acid
HAZOP	Hazard and Operational Study
HDBK	Handbook
HGD	Hot Gas Duct
HGDs	Hot Gas Ducts
HH	Hot Header
HICS	Helium Inventory Control System
HIPCS	Helium Inventory and Pressure Control System
HIRA	Hazard and Risk Identification Analysis
HLR	High Level Requirement
HMI	Human Machine Interface

Abbreviation or Acronym	Definition
HPS	Helium Purification System
HT	Heat Transfer
HTF	Helium Test Facility
HTGR	High Temperature Gas -Cooled Reactor
HTS	Heat Transport System
HTSE	High Temperature Steam Electrolysis
HTTR	High Temperature Test Reactor
HTTU	High Temperature Test Unit
HV	High Voltage (>132 000V)
HVAC	Heating, Ventilation, & Air Conditioning
HX	Heat Exchanger
HyS	Hybrid Sulfur
I&C	Instrumentation and Control
I/O	Input/Output
IBC	International Building Code
ICC	International Code Council
ICD	Initial Conceptual Design
ICEA	Insulated Cable Engineers Association
IDAPA	Idaho Administrative Procedure Act
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IFC	International Fire Code
IFGC	International Fuel Gas Code
IHX	Integrated Heat Exchanger
IHXA	Intermediate Heat Exchanger A
IHXB	Intermediate Heat Exchanger B
IMC	International Mechanical Code
IMS	Information Management Systems
INL	Idaho National Laboratory
IPMC	International Property Maintenance Code
ISA	International Society of Automation
ISO	International Organization for Standardization
JB	Junction Box
kg/s	Kilogram per second
kV	Kilovolt (1000 Volts)
kl/h	Kilolitre per hour
kPa	Kilopascal (1000 Pascal)
kW	Kilowatt (1000 Watts)
LCD	Liquid Crystal Display
LCP	Local Control Panel
LRFDS	Load and Resistance Factor Design Specification

Abbreviation or Acronym	Definition
LV	Low Voltage (<1000 V)
MBMA	Metal Building Manufacturers Association
MCC	Motor Control Center
MCR	Mission Critical Requirement
MDB	Main Distribution Board
MES	Manufacturing Execution System
MPa	Megapascal = million Pascal
MTI	M-Tech Industrial (Pty) Ltd.
MV	Medium Voltage (>1000V< 132 000V)
MW	Megawatt (Million Watts)
N	Speed
NBIMS	National BIM Standards Project Committee
NEC	National Electrical Code
NEMA	National Electrical Manufacturers Association
NEPA	National Environmental Policy Act
NESC	National Electrical Safety Code
NFPA	National Fire Protection Association
NGNP	Next Generation Nuclear Plant
NHI	National Hydrogen Institute
NIST	National Institute of Standards and Technology
NQA-1	ASME NQA-1 2000, Quality Assurance for Nuclear Facilities
OPC	Operating Procedure Checklist
OSHA	Occupational Safety and Health Administration
P	Pressure
P&ID	Piping and Instrument Diagram
PBMR	Pebble Bed Nuclear Reactor (RSA)
PCDR	Preconceptual Design Report
PCFC	Preconceptual Facility Configurations
PCHX	Printed Circuit Heat Exchanger
PCS	Process Control System
PDA	Potential Deviation Analysis
PDMS	Project Data Management System
PDS	Plant Design System
PFD	Process Flow Diagram
PHA	Preliminary Hazard Analysis
PHTS	Primary Heat Transport System
PLC	Programmable Logic Controller
PLCs	Programmable Logic Controllers
PMN	Support Manager
PRV	Pressure Relief Valve
psig	Pound per square inch gauge

Abbreviation or Acronym	Definition
PSM	Support Modeler
QC	Quality Control
QCP	Quality Control Plan
RCS	Reactivity Control System
RIS	Relational Interface System
RPV	Reactor Pressure Vessel
RSA	Republic of South Africa
SBS	System Breakdown Structure
SCADA	Supervisory Control and Data Acquisition System
scfm	Standard cubic feet per minute
SDD	System Design Description
SDI	Steel Door Institute or Steel Deck Institute
SG	Steam Generator
SHEQ	Safety, Health, Environmental and Quality
SHTS	Secondary Heat Transport System
SI	Sulfur Iodine
SIL	Safety Integrity Level
SIS	Safety Instrument System
SJI	Steel Joist Institute
SNM	Special Nuclear Materials
SPEL	SmartPlant Electrical
SPF	SmartPlant Foundation
SPMat	SmartPlant Material
SPR	SmartPlant Review
SPS	Standby Power System
SR	Safety Requirement
SRM	System Requirement Manual
SSC	Systems Structures and Components
SSDT	Small Scale Development Test
SSS	Site Selection Study
SSSB	Specification for Structural Steel Buildings
STD	Standard
T	Temperature
T&FR	Technical and Functional Requirement
TBD	To Be Determined
TDL	Technology Development Loop
TDRM	Technology Development Road Map
TEDS	Transducer Electronic Data Sheet
TEMA	Tubular Exchanger Manufacturers Association
THTR	Thorium High Temperature Reactor
TIA	Telecommunications Industry Association

Abbreviation or Acronym	Definition
TRL	Technology Readiness Level
TSR	Technical Safety Requirement
UL	Underwriters Laboratories
UL	Underwriters' Laboratories
UPC	Uniform Plumbing Code
UPS	Uninterruptable Power Supply
UUT	Unit Under Test
V&V	Verification and Validation
VHTGR	Very High Temperature Gas-Cooled Reactor
VL	Valve
VSD	Variable Speed Drive
wb	Wet Bulb
WBS	Work Breakdown Structure
WEC	Westinghouse Electric Company
WE-SA	Westinghouse Electric - South Africa
ϵ	Strain

SUMMARY AND CONCLUSIONS

The Small-Scale Development Tests (SSDTs) are a collection of tests that do not require significant volume flow rates or large amounts of heat transfer. Most of the SSDTs have a common requirement for a high-temperature (950°C) high-pressure (9MPa) Helium environment. The rest of the SSDTs, like those that support the Circulator development, utilize specialized mechanical test setups which require critical inputs from the full-scale Next Generation Nuclear Plant (NGNP) design. Therefore, their designs are not covered in this report.

For the tests that require a high-temperature high-pressure Helium environment, a generic setup is proposed that comprises a low-temperature pressure vessel, internally insulated high-temperature test vessel, heater (20kW) and small flow line water coolers (10kW each). Specifically for the Intermediate Heat Exchanger (IHX) unit cell fatigue tests, a specialized system is designed that comprises heaters, coolers, a pressure vessel and hydraulic gas compression systems.

5. SMALL SCALE DEVELOPMENT TESTS (SSDT)

5.1 SSDT: Design Inputs and Requirements

The Component Test Facility (CTF) is required to perform the list of tests described in the CTF Test Loop Preconceptual Design Report (PCDR) Section 4: System Requirement Manual, reference [5-1], as derived from the Technology Development Road Mapping, reference [5-9]. The following tests are considered small scale development tests and their conceptual experimental designs are covered in this section.

Table 5-1: List of Test Specifications for Small-Scale Development Tests, reference [5-9].

Section	Description	Test number
Circulator	EMBs, Catcher bearings Test Specification	WEC-TS-CIRC-001
Circulator	Helium Rotating seals Test Specification	WEC-TS-CIRC-002
IHX A (Metallic)	Corrosion Allowances for Alloy 617	WEC-TS-IHXA-006
IHX A (Metallic)	Specification of testing of unit cell of compact Heat Exchangers	WEC-TS-IHXA-012
	IHX joint integrity	WEC-TS-IHXA-012_1
	IHX creep lifetime tests: 1000°C	WEC-TS-IHXA-012_2
	IHX Unit cell fatigue life test	WEC-TS-IHXA-012_3
IHX A (Ceramic)	Testing of unit cell of compact heat exchanger	WEC-TS-IHXA-030
IHX B	Corrosion Allowances for Alloy 800H	WEC-TS-IHXB-007
IHX B	Specification of testing of Unit Cell of Compact Heat Exchanger	WEC-TS-IHXB-012
	IHX joint integrity	WEC-TS-IHXB-012_1
	IHX creep lifetime tests	WEC-TS-IHXB-012_2
	IHX Unit cell fatigue life test	WEC-TS-IHXB-012_3
Piping	Effects of He infiltration on thermal conductivity of insulation material	WEC-TS-PIP-006_1
	Effect of sudden depressurization on insulation at 9MPa, 950°C	WEC-TS-PIP-006_2
Piping	The effect of fluid impurities (C) on insulation properties	WEC-TS-PIP-007

As input to the test setup design, the following paragraphs discuss the requirements from each test to do enveloping of the test setups in terms of pressure, temperature and physical size.

5.1.1 Electromagnetic Bearing (EMB) Catcher Bearings Test Program

This section refers to the following test specification(s): WEC-TS-CIRC-001

In the absence of a circulator design, this test cannot yet be allocated to a specific facility or a test setup. The FLP 500 facility in Germany could be considered as a possibility for doing some of these tests.

5.1.2 Dry Gas Seal Small Scale Development Test

This section refers to the following test specification(s): WEC-TS-CIRC-002.

This test could probably be done by the Original Equipment Manufacturer. If necessary, a test could be designed to make provision for testing the leak rate and power consumption of a full-scale dry gas seal.

5.1.3 Corrosion Allowances for Alloy 617 and 800H

This section refers to the following test specification(s): WEC-TS-IHXA-006; WEC-TS-IHXB-007

This test requires a facility for exposure of Alloy 617 and 800H to He (700°C to 1,000°C) at 9 MPa with low levels of CO, CO₂, H₂, H₂O, and CH₄ for up to 10,000 hours.

5.1.4 Creep Testing of Unit Cells of Compact Heat Exchangers

This section refers to the following test specification(s): WEC-TS-IHXA-012 (Metallic), WEC-TS-IHXA-030 (Ceramic), WEC-TS-IHXB-012 (Metallic)

These are destructive tests to determine the time before break for a heat exchanger unit cell under pressure difference at working temperature. The heat exchanger unit cell has to be tested at 9 MPa pressure difference in both directions, i.e. with primary at 9 MPa and with secondary at 9 MPa.

With the construction of the plate-fin heat exchangers as described in the Intermediate Heat Exchanger (IHX) Special Study, reference [5-2], one of the flow paths has its inlet and outlet open to the environment in which the heat exchanger is situated, with sealing between inlet and outlet on the body of the heat exchanger.

When the enclosed side is pressurized, the test need not be done inside a pressure vessel, as the heat exchanger itself acts as the pressure vessel. When the outer side (non-enclosed) of the heat exchanger is pressurized, the test has to be done inside a pressure vessel to set up the pressure difference.

When the heat exchanger fails, the high-pressure Helium has to be released into an enclosed volume to prevent equipment damage or induce safety risks.

5.1.5 Fatigue Testing of Unit Cells of Compact Heat Exchangers

This section refers to the following test specification(s): WEC-TS-IHXA-012 (Metallic), WEC-TS-IHXA-030 (Ceramic), WEC-TS-IHXB-012 (Metallic).

The unit cells of heat exchangers have to be fatigue-tested for a certain combination of differential pressures and temperatures, which still has to be determined from the NGNP design. The thermal and pressure loading conditions could be fixed and the number of cycles to failure could be the result of the test.

5.1.6 Effect of He Infiltration and Depressurization on Thermal Conductivity of Insulation Material

This section refers to the following test specification(s): WEC-TS-PIP-006.

This test entails measurement of thermal conductivity in a high-pressure (9 MPa), high temperature (950°C) environment. Due to the natural convection of gas in a porous medium subjected to a temperature gradient, the orientation of the measurement also has to be taken into account.

In the Composite Materials Special Study, reference [5-3], there is a Design Data Need (DDN) on Insulation materials that requires the effect of depressurization to be checked for various insulation types, specifically aerogel types of insulation. This can be done as part of the conductivity test.

5.1.7 Effect of Fluid Impurities on Insulation Properties

This section refers to the following test specification(s): WEC-TS-PIP-007.

Similar to the previous test, this test entails measurement of thermal conductivity in a high-pressure (9 MPa), high temperature (950°C) environment with controlled and measured contaminant levels in the Helium.

5.1.8 Leak Rate Test on Check Valve

This test is required in the NGNP PCDR Section 6, reference [5-5], but only referred to in the Circulator Technology Development Roadmap, reference [5-6]. A “flapper-type”, self-actuated check valve is integrated with the circulator to limit backflow through the main loop. This is particularly important when cooling is being provided by the Core Conditioning System. The typical operating conditions of the check valve will be 350°C, 160kg/s (open) at a pressure level of 9 MPa.

5.2 SSDT: Thermal Hydraulic Design

5.2.1 System-Level Process Design

The SSDT have more than one unique test setup. Therefore, the test setup designs are grouped according to common test requirements.

5.2.2 Electro Magnetic Bearing Catcher Bearings Test Program

This section refers to the following test specification(s): WEC-TS-CIRC-001

The function of the EMB is to support the shaft of the circulator when the magnetic bearing fails or when a transient load exceeds the magnetic bearing capability. To function successfully, the catcher bearings need to be positioned such that there exists only a small clearance of between a few microns to about a millimeter from the magnetically suspended circulator shaft.

A full-scale rotating assembly is required for this test, with a solid disk representing the impeller. Thus, this test will be part of the eventual circulator development tests which could be done at the supplier. The FLP-500 facility in Germany represents the rotating assembly of a typical large-scale magnetically suspended circulator and is shown schematically in Figure 5-1.

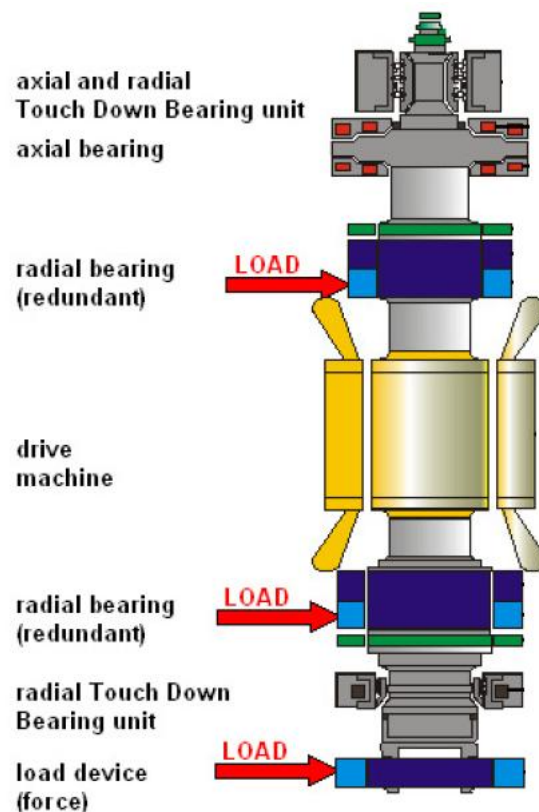


Figure 5-1: Schematic layout of the FLP-500 EMB Test facility in Zittau, Germany.

5.2.3 Dry Gas Seal SSDT

This section refers to the following test specification(s): WEC-TS-CIRC-002.

If necessary, a test could be designed to make provision for testing the leak rate and power consumption of a full-scale dry gas seal. A concept for a dry gas seal leak test setup is shown in Figure 5-2.

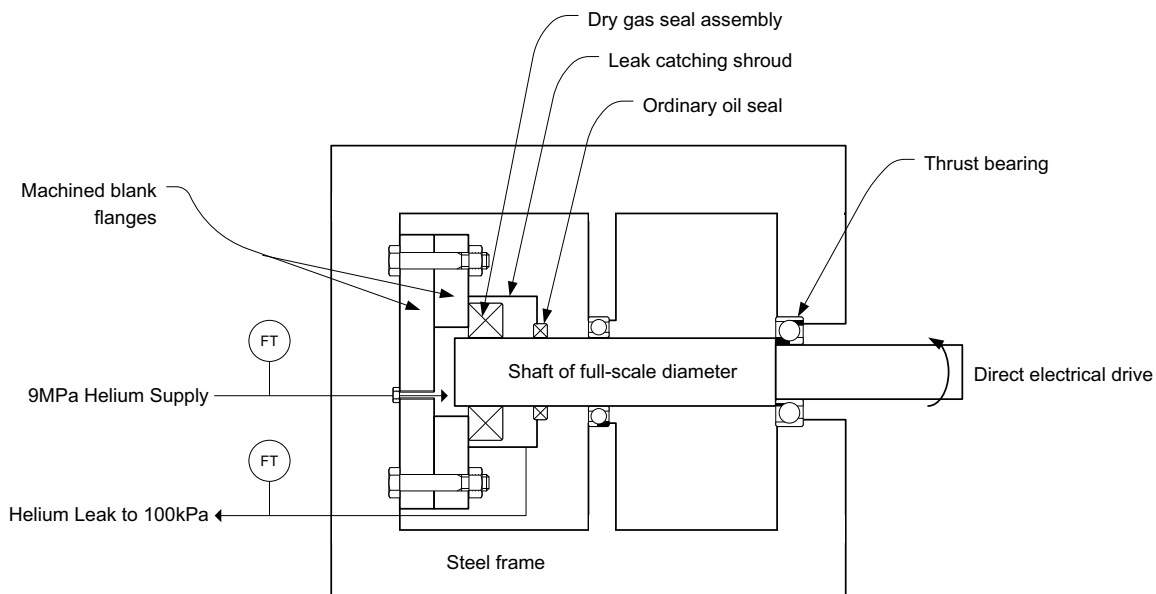


Figure 5-2: Schematic diagram of a concept for testing the leak flow rate of a dry gas seal.

5.2.4 Leak Rate Test on Check Valve

This test can be done with pipe spool pieces and blank flanges of the Circulator Test Loop, where the check valve can be flow-tested. By connecting the high-pressure and low-pressure sides of the valve respectively to the supply line from the Helium Inventory Control System (HICS) and an evacuation line to the HICS system, a pressure difference can be set up across the closed check valve. The flow rate through the HICS system will then be the leak rate.

As part of the detail design, the appropriate non-dimensional numbers should be found for characterization of the check valve leak rate characteristic. As part of that study, it should be determined if the leak rate characteristic could be determined using compressed air.

5.2.5 Corrosion Allowances for Alloy 617 and 800H

This section refers to the following test specification(s): WEC-TS-IHXA-006; WEC-TS-IHXB-007.

The CTF SSDTs can assist with these tests by using these alloys as materials-of-construction for some parts of the high-temperature internals of the Test Loops. As all the conditions inside each setup will be logged, the temperature and loading history for the support structures inside the test loops will be known. Typical temperatures are 700°C to 1000°C with exposure to Helium with low levels of CO₂, H₂, H₂O and CH₄. Some of these compounds will be present in the test setups due to the release of water by the insulation. The gas composition will be analyzed and provision be made for introducing these impurities into the gas.

After sufficient operation time, these components can be removed and analyzed. In that way, the structures inside the test setups themselves can also be experimental objects to support the ASME codification effort for these materials.

5.2.6 Design Calculations: 950°C 9 MPa Test Setup

Creep Testing of unit cells of compact heat exchangers

WEC-TS-IHXA-012 (Metallic),

WEC-TS-IHXA-030 (Ceramic),

WEC-TS-IHXB-012 (Metallic)

Effect of He infiltration on thermal conductivity of insulation material, as well as the effect of depressurization

WEC-TS-PIP-006

Effect of fluid impurities on insulation properties

WEC-TS-PIP-007

The abovementioned tests have a common requirement for a 9 MPa 950°C Helium environment with no significant volume flow rates. Therefore, a standard high-temperature, high-pressure unit can be designed, duplicated and customized for each of the tests.

The requirement of 9 MPa Helium pressure is addressed by installing the entire test setup inside a pressure vessel.

The requirement of 950°C is addressed by installing an insulated high-temperature test vessel inside the pressure vessel.

5.2.6.1 High-Temperature Vessel

The heated volume is determined by the maximum test unit size required by any of the abovementioned tests. The IHX unit cells are the largest units to be tested. Their sizes are given in Table 5-2. Some of the dimensions of the unit cell was derived from the IHX Special Study, reference [5-2], and are stated here as assumptions.

The header section of a unit cell is assumed to have a 80mm diameter, based on the ratio to the 50mm wide flow path width, as seen in the Figures in the IHX Special Study, reference [5-2].

Based on the dimensions of heat exchanger cells described in the IHX Special Study, reference [5-2], the thickness of a unit cell was calculated to be 5.5mm.

Table 5-2: Estimated representative Unit Cell sizes to be tested inside a SSDT Vessel.

	H	L	W
IHX A Unit Cell: Metallic, plate-fin:	5.5mm	$155\text{mm} + 2 \times 80\text{mm} = 375\text{mm}$	80mm
IHX B Unit Cell: plate-fin:	5.5mm	$300\text{mm} + 2 \times 80\text{mm} = 460\text{mm}$	80mm

For the purpose of this work, an assembly of TEN (10) unit cells is assumed to be a representative test specimen.

Thus, the maximum specimen size for the SSDT Test Vessel has a length of 460mm, a width of 80mm and a height of 55mm

An open space of 300mm is allowed on all sides of the test specimen for instrumentation, mountings and ease of access. This results in the following test space requirement: 1060mm x 680mm x 655mm. If 200mm allowance is added for the heating element, a cylindrical space is created with horizontal orientation and length 1260mm and diameter 700mm, as shown in Figure 5-3.

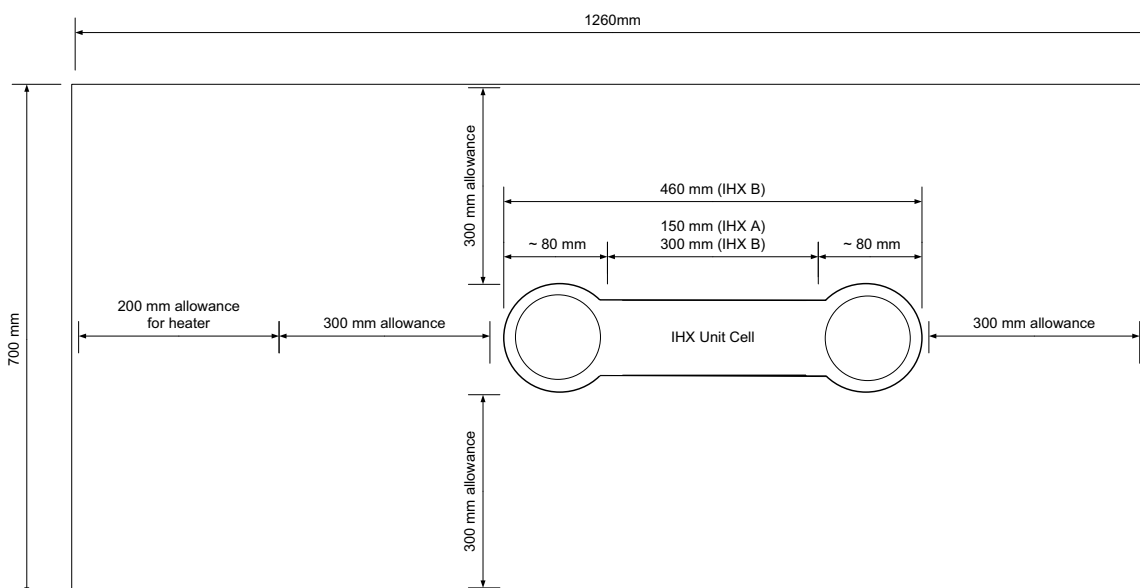


Figure 5-3: Establishment of the Test Vessel inner dimensions

In order to contain the high-temperature test vessel at 950°C, several layers of insulation are used.

5.2.6.2 Heater Considerations

For tests requiring a reducing atmosphere as found in the NGNP Primary Heat Transport System (PHTS) (due to the large amount of graphite in the reactor), it is proposed to heat the test space up to 950°C with graphite heating elements. The heating element is expected to corrode due to the unavoidable presence of traces of water. Therefore, the graphite heating elements are to be treated as consumables.

For tests requiring a mildly oxidative atmosphere as could possibly occur in the NGNP Secondary Heat Transport System (SHTS) (due to the absence of graphite), metal type heating elements could be investigated and SiO₂ refractory bricks be used for the inner insulation.

5.2.6.3 Cooler Considerations

Any inflow and outflow from the SSDT Vessel has to prevent heat-up of the pressure boundary. Therefore, a water-cooled helium-cooling unit is installed alongside the high-temperature test vessel inside the pressure vessel.

It is proposed that all gas flow lines into the vessel should pass through individual high-temperature water cooler, located inside one of the bottom flanged protrusions.

This includes the connections to the HICS system as well as pressure impulse lines and the pressure vessel safety relief valve.

A shell-and-tube heat exchanger with a u-tube configuration is proposed, with low-pressure water on the tube side. This configuration is used to simplify cooler construction.

5.2.6.4 SSDT Cooling Water Loop Concept

In order to remove the heat from the graphite heater, the nominal cooler size (i.e. with inlet 20°C and outlet 30°C) is set at 10kW. For a helium temperature reduction of 900°C, this represented a mass flow rate of 0.002kg/s. In order to increase instantaneous transient capacity and redundancy, a circulating loop and reservoir tank is used, so that in the event of a helium flow exceeding 0.002kg/s, the cooler outlet water could increase higher than 45°C while there is only a slight increase in the average tank and loop temperature increases.

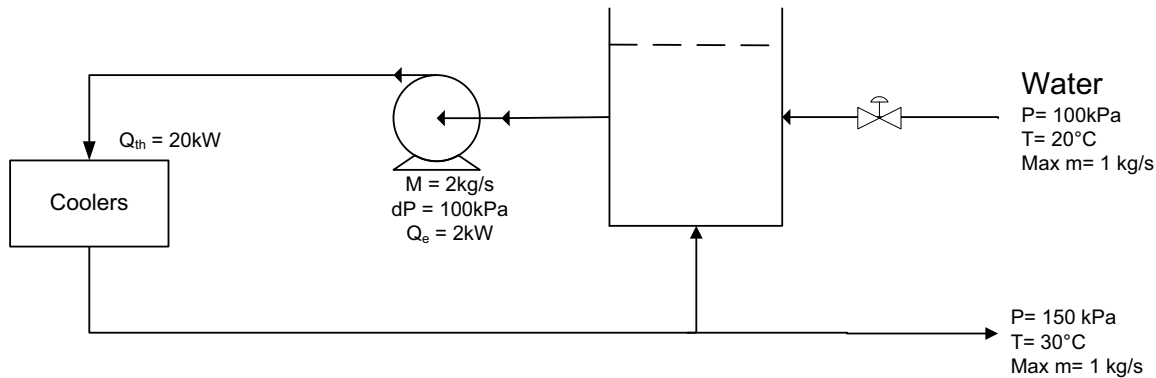


Figure 5-4: Cooling water loop layout.

5.2.6.5 Pressure Vessel Considerations

In order to provide access for instrumentation and any other connections to the internals of the high-temperature vessel, there will be blank flanges available on the SSDT Vessel.

To facilitate easy access to the experimental setup, the SSDT Vessel has a horizontal orientation, with the high-pressure outer vessel dished end and the high-temperature inner vessel end flange installed such that they can be readily opened and moved out of the way. The outer vessel dish end may be connected to a wheeled trolley or its own dedicated overhead crane or a bracketed swing-arm from the vessel shell.. This detail has to be resolved during further design stages.

The combination of materials and expected chemical composition has to be clarified during further design stages.

The outside of the high-temperature metal vessel is insulated and a layer of polished stainless steel cladding is added for additional radiative insulation.

with polished stainless steel for additional radiative insulation to the outer pressure vessel.

The process described above resulted in the concept that is described in the attached Process Flow Diagram (PFD) in reference [5-11].

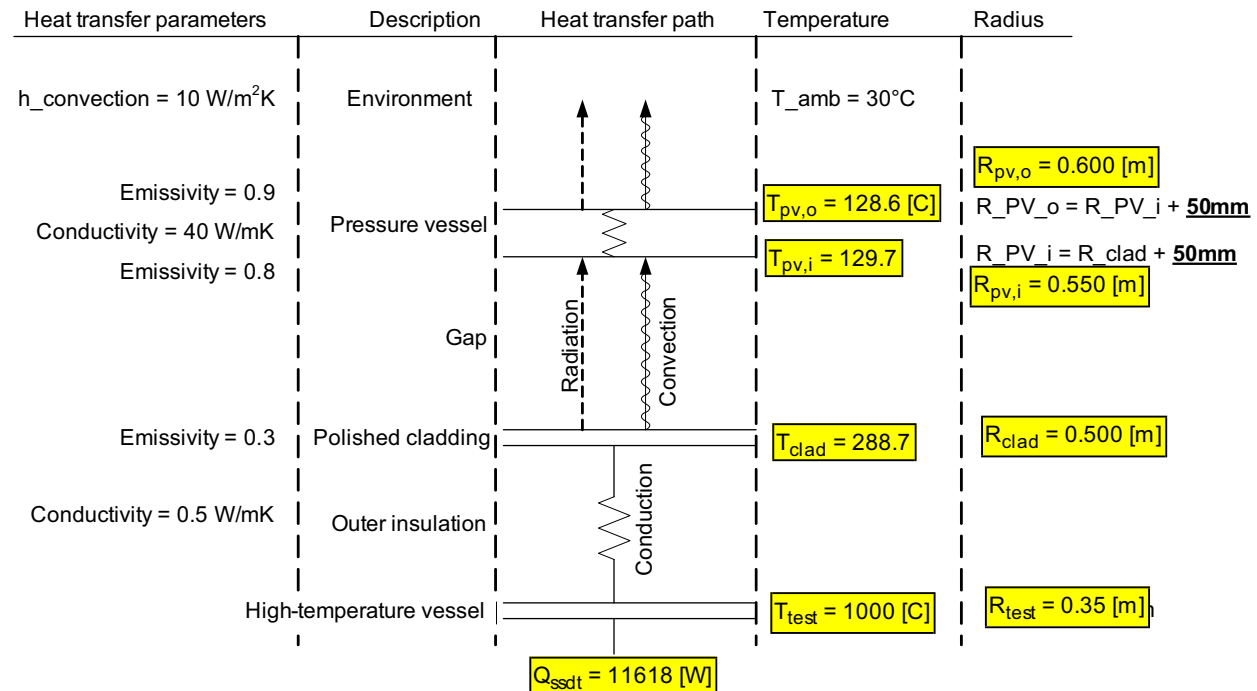


Figure 5-5: Assumptions, inputs and thermal-fluid calculations of the temperatures in the various layers of the SSDT Vessel.

The results shown in Figure 5-5 were calculated in reference [5-10]. As the heat loss to the environment is the only steady-state heat load on the SSDT, the internal heater is sized as approximately double the heat loss.

5.2.7 Creep Testing of Unit Cells of Compact Heat Exchangers

This test is to be done using the SSDT vessel with a sealed heat exchanger unit cell in the high-temperature test space. Depending on the required pressure direction, either the secondary or the primary side is connected to the low pressure HICS line. At heat exchanger failure, the test environment is capable of withstanding the impact of the unit cell failure. The schematic layout is shown in Figure 5-6

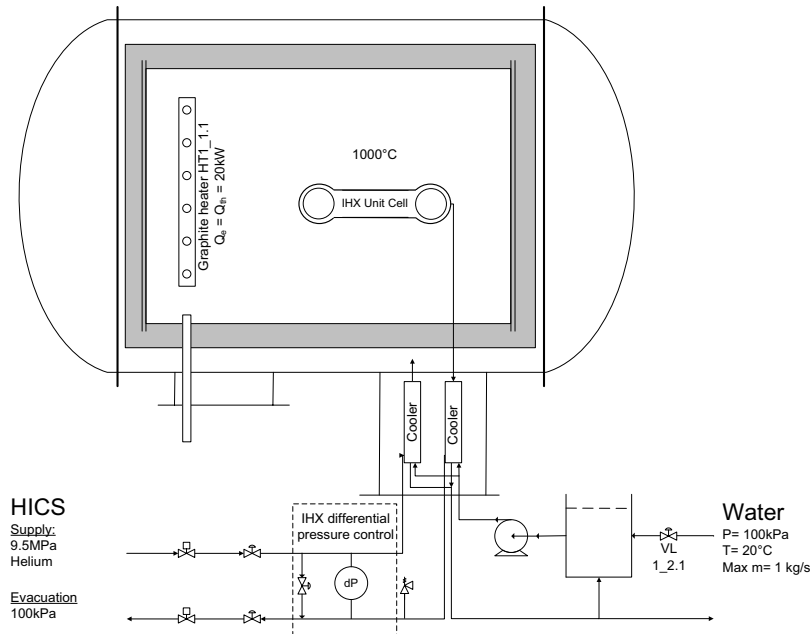


Figure 5-6: Schematic layout of IHX Unit cell creep test setup.

5.2.8 Fatigue Testing of Unit Cells of Compact Heat Exchangers

This section refers to the following test specification(s): WEC-TS-IHXA-012 (Metallic); WEC-TS-IHXA-030 (Ceramic); WEC-TS-IHXB-012 (Metallic).

Cyclic loading can be applied by means of differential temperature or pressure. If the cyclic load is only differential pressure, then the amplitude and frequency of the load variation determines the test setup design, as shown schematically in Figure 5-7.

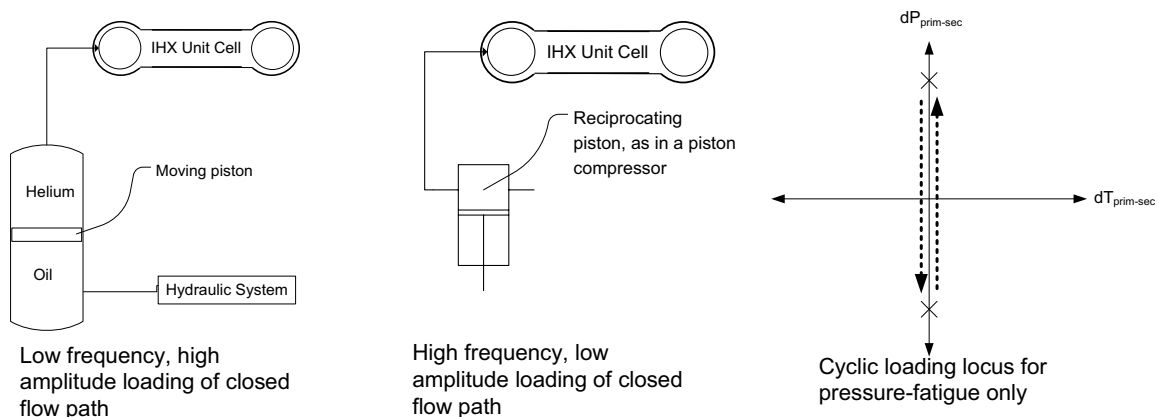


Figure 5-7: Methods for cyclic pressure-loading depending on amplitude and frequency.

If the loading on a unit cell is to be only differential temperature, a setup such as shown in Figure 5-8 could be used.

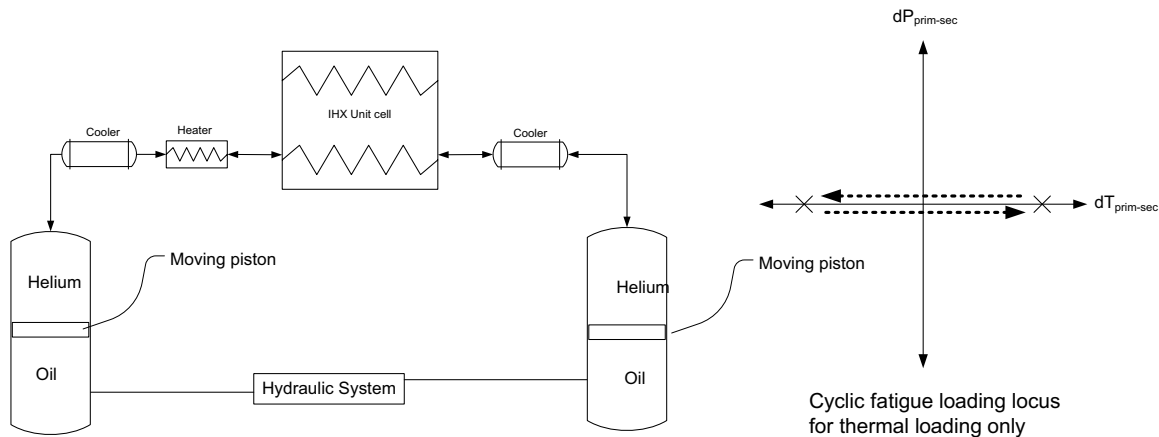


Figure 5-8: Method for cyclic differential-temperature-loading.

A thermal-only test as described in Figure 5-8 could be done at atmospheric pressure inside a 950°C environment, such as a high-temperature oven.

However, the purpose of knowing the IHX fatigue lifetime is to determine the number of starts-stops for the NGNP. In the NGNP, the IHX cyclic load will be a combination of differential temperature and pressure, which will only be known after design of the NGNP. A hypothetical loading locus plot is shown in Figure 5-9.

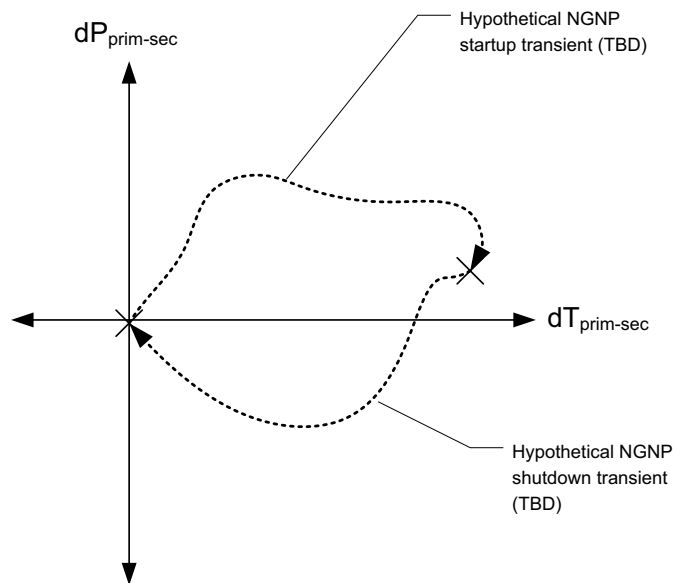


Figure 5-9: Hypothetical transient IHX loads during startup and shutdown.

In order to test simultaneous pressure and thermal loading, the system shown in Figure 5-10 is proposed. The correct loading is accomplished by a combination of hydraulic cylinder compression and control valve action.

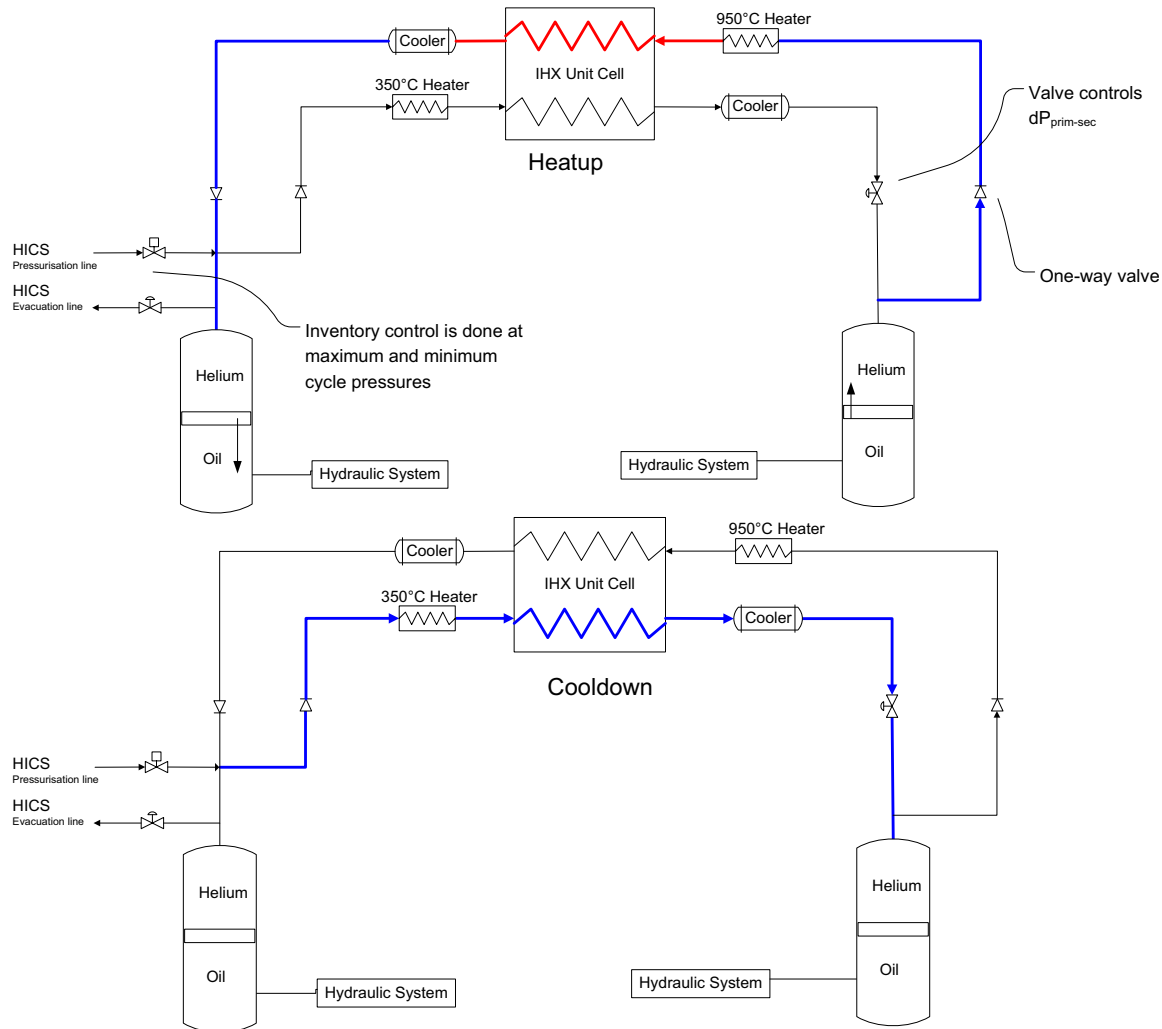


Figure 5-10: System for simultaneous thermal and differential pressure loading on an IHX unit cell.

The heater concept (max 10kW per heater) consists of electrically heated parallel tubes of which the total thermal mass is larger than that of the IHX unit cell. The heater tube itself should be capable of 950°C, 9 MPa, i.e. ~6mm OD, ~3mm ID

For the water cooler concept (max 10kW per cooler), the same shell-and-tube type, u-tube configuration is used as proposed for the SSDT Vessel. For this fatigue-testing setup, a minimized pressurized volume minimizes the required hydraulic system size. The physical arrangement of components in the IHX Fatigue test setup is shown schematically in Figure 5-11.

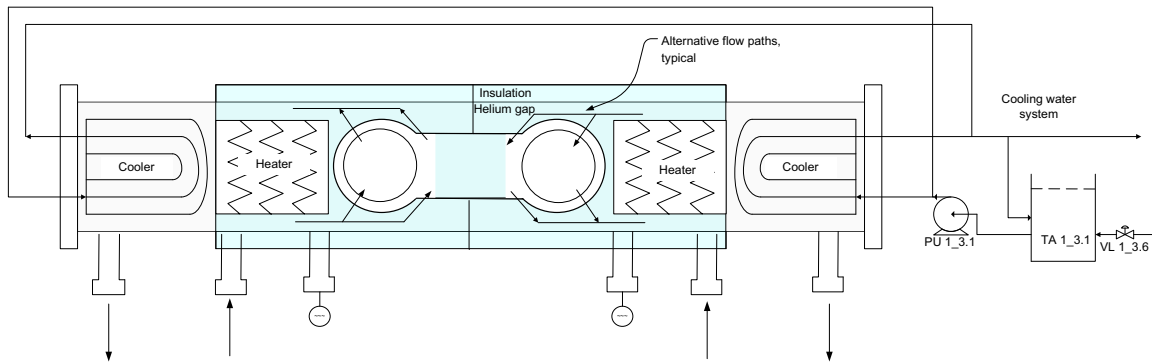


Figure 5-11: Schematic diagram of the physical arrangement of the IHX Fatigue test.

The IHX Fatigue Test Process Flow Diagram is attached in reference [5-13].

5.2.9 System Breakdown Structure

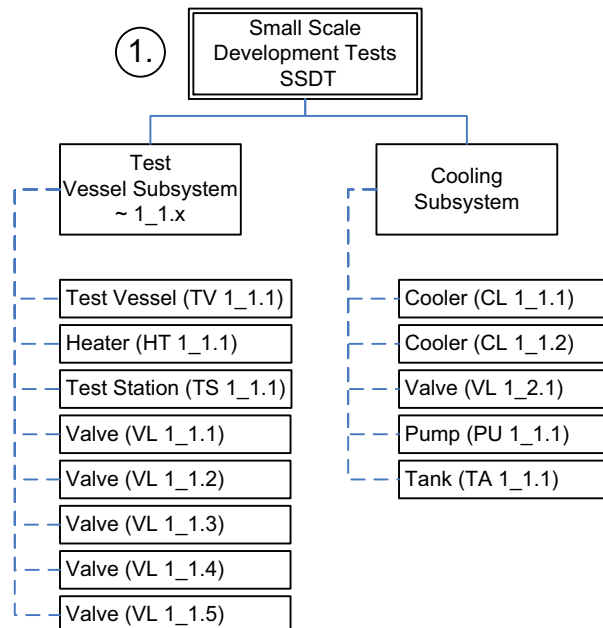


Figure 5-12: System breakdown structure for a general Small Scale Development Test setup.

5.2.10 Component Performance Specifications

5.2.10.1 Test Vessel

This section refers to the following component(s): TV 1_1.1

Pressure vessel

Description	Unit	Value
Pressure	MPa	9.5
Wall temperature	°C	130
Inner diameter	M	1.1
Length (flange to flange)	M	1.66

Mounted horizontally with two ~400mm diameter protrusions of 600mm length on the underside.

5.2.10.2 Heater

This section refers to the following component(s): HT 1_1.1

The calculated heat loss from the vessel is 11kW (reference [5-10]). For overcapacity and to reduce heatup time, the heater is specified to be 20kW.

For reducing atmospheres:

Description	Unit	Value
$P_{he,max}$	MPa	9.5
$T_{he,max}$	°C	1,000
Q_{th}	kW	20
Material		Graphite

For oxidative atmospheres:

Description	Unit	Value
$P_{he,max}$	MPa	9.5
$T_{he,max}$	°C	1,000
Q_{th}	kW	20
Material		Kanthal or Alloy 617 or 800H or coated Graphite

The installation space for the heater is described by a horizontally orientated cylinder with height 200mm and diameter 700mm.

5.2.10.3 Test Station

This section refers to the following component(s): TS 1_1.1

Description	Unit	Value
Pressure	MPa	9.5
dP _{inner/outer}	kPa	0
Inner temperature	°C	950
Inner diameter	mm	700
Length	m	1.26
Material		Alloy 617 or 800H

5.2.10.4 Valves

This section refers to the following component(s): VL 1_1.1, VL 1_1.3

The function of these valves is to isolate the SSDT from the HICS system during testing, after the correct pressure level is reached.

Isolation valves

Description	Unit	Value
P _{he,max}	MPa	9.5
T _{he,max}	°C	100
Line diameter	mm	25

5.2.10.5 Valves

This section refers to the following component(s): VL 1_1.2, VL 1_1.4

The function of these valves is to adjust the pressure level in the SSDT during testing.

Description	Unit	Value
P _{he,max}	MPa	9.5
T _{he,max}	°C	100
Line diameter	mm	25

5.2.10.6 Pressure Relief Valve

This section refers to the following component(s): VL 1_1.5
Safety pressure relief valve

Description	Unit	Value
P _{he,max}	MPa	9.5

Description	Unit	Value
$T_{he,max}$	°C	100
Line diameter	mm	25

5.2.10.7 Coolers

This section refers to the following component(s): CL 1_1.1, CL 1_1.2

Small-Scale Development Test Coolers

Description	Unit	Value
P_{he}	kPa	9,000
$T_{he\ in}$	°C	950
$T_{he\ out}$	°C	50
m_{he}	kg/s	0.002
P_w	kPa	120
$T_{w\ in}$	°C	20
$T_{w\ out}$	°C	30
m_w	kg/s	0.25
Q_{th}	kW	10

5.2.10.8 Cooling Water Control Valve

This section refers to the following component(s): VL 1_2.1

Description	Unit	Value
P_w	kPa	200
T_w	°C	20
Line diameter	mm	50

5.2.10.9 Cooling Water Circulation Pump

This section refers to the following component(s): PU 1_1.1

Description	Unit	Value
P_w	kPa	100
T_w	°C	20 – 40
m_w	kg/s	2

5.2.10.10 Cooling Water Tank

This section refers to the following component(s): TA 1_1.1

Description	Unit	Value
P_w	kPa	100
T_w	°C	20 – 40
Volume	Liter	200

5.3 SSDT: Component Design

5.3.1 SSDT Test Vessel

This section refers to the following component(s): TV1_1.1

The inputs to the SSDT Test Vessel design are given below:

Description	Unit	Value
Pressure	MPa	9.5
Wall temperature	°C	130
Inner diameter	m	1.1
Length (flange to flange)	m	1.66

The vessel is mounted horizontally with two 300mm diameter protrusions of 500mm length on the underside, of which one is shown in Figure 5-15. The vessel outline dimensions are shown in Figure 5-13.

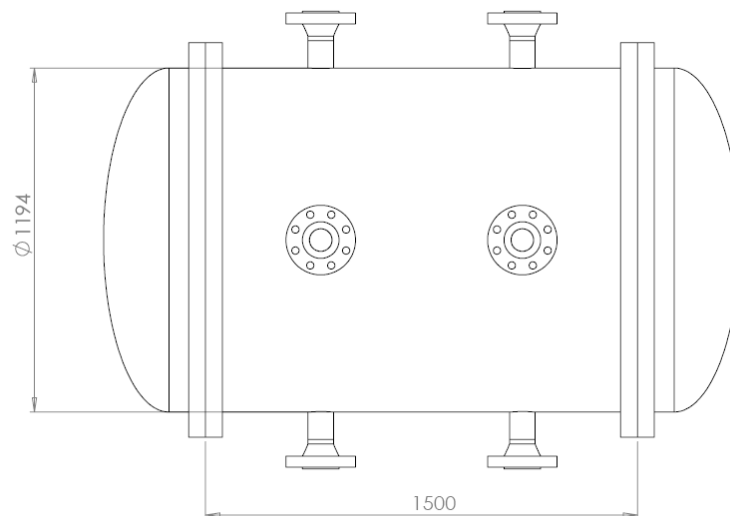


Figure 5-13: Outline dimensions of the SSDT pressure vessel.

The pressure vessel data sheet is attached in reference [5-15], and its calculation sheet in reference [5-16].

5.3.2 Heater

This section refers to the following component(s): HT 1_1.1

The heater is specified to have a heating capacity of 20kW.

Description	Unit	Value
$P_{he,max}$	MPa	9.5
$T_{he,max}$	°C	1,000
Q_{th}	kW	20

The installation space for the heater is described by a horizontally orientated cylinder with height 200mm and diameter 700mm.

For reducing atmospheres, an uncoated graphite element can be used. For oxidative atmospheres, a metal element made of Kanthal or Alloy 617 or 800H could possibly be used.

From HTF experience, a power density of 1kW per meter of 4mm Kanthal wire is an appropriate value. To reach 20kW, this would require 20m of heating wire in the permitted space. The power density could possibly be increased to 2kW per meter, however, some difficulty in fitting such a ceramic-supported metal wire element in the permitted space can be expected.

Another alternative is to use a Boron Nitride or Silicon Carbide coated graphite element. Uncoated as well as coated elements are available in a flat disc-shaped geometry as shown in Figure 5-14.

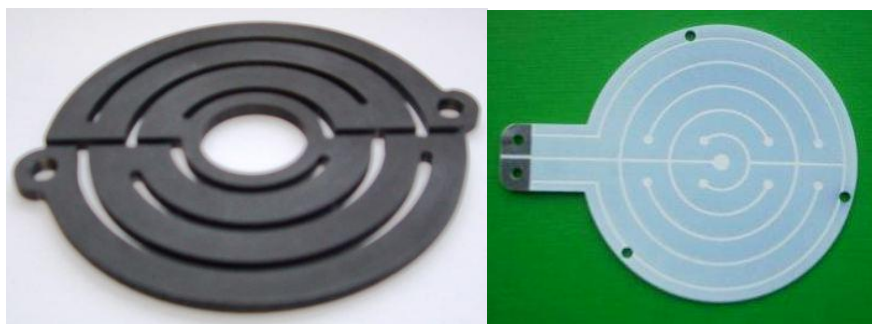


Figure 5-14: Disc shaped uncoated graphite element (left) and Boron Nitride coated element (right) (Ceramisis, reference [5-7]).

These elements are commercially available. The data sheet for the heating element is available in reference [5-16].

5.3.3 SSDT Cooler

This section refers to the following component(s): CL1_1.1, CL1_1.2

A shell and tube type heat exchanger with a u-tube configuration is proposed for the SSDT Cooler. The water is on the tube-side and the hot Helium (1,000°C) is on the shell side. This design has the advantage that it has no thermal expansion bellows or points of intense temperature gradients which typically cause thermal fatigue. The other advantage is that the water-cooled tubes are loaded in compression, which reduced the possibility of a tube rupture.

Description	Unit	Value
P_{he}	kPa	9,000
$T_{he\ in}$	°C	950
$T_{he\ out}$	°C	50
m_{he}	kg/s	0.002
P_w	kPa	120
$T_{w\ in}$	°C	20
$T_{w\ out}$	°C	30
m_w	kg/s	0.25
Q_{th}	kW	10

5.3.4 Critical Systems Structures and Components

The Systems Structures and Components (SSC) listed in Table 5-3 are considered critical for this test setup. Their development status is also indicated.

Table 5-3: Critical SSC's for the SSDT

SSC	COTS/Require development
Heating element HT1_1.1	COTS
Test vessel TV1_1.1	COTS
High temperature vessel and insulation	Require development
Coolers CL1_1.1	COTS

The high temperature vessel and insulation system requires development with regards to the insulation that is to be used. It is proposed that this be done as an initial SSDT test, where the SSDT itself is the experiment. No additional tests are performed inside the high temperature vessel, but the vessel is heated up to normal working temperature while the pressure vessel temperature is measured. After maintaining the SSDT at working pressure and temperature for sufficient time without exceeding a threshold pressure vessel temperature, the vessel is opened and the insulation integrity evaluated.

5.4 SSDT: 3D Mechanical Layout

A possible layout for the SSDT and its cooling system is shown in Figure 5-15.

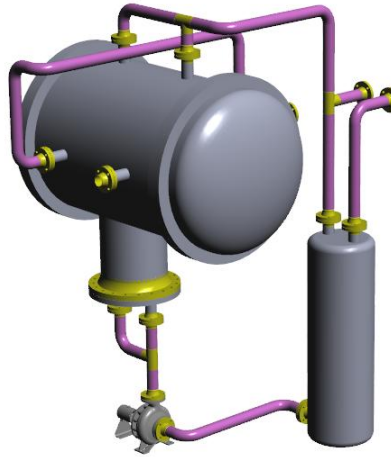


Figure 5-15: Physical Layout of the SSDT Vessel.

A possible layout for the IHX Fatigue test, its cooling system and hydraulic vessels is shown in Figure 5-15.

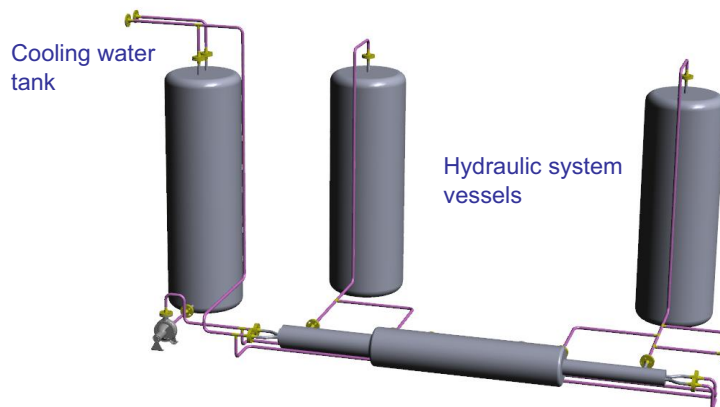


Figure 5-16: Physical layout of the IHX Fatigue test setup.

A multitude of SSDT can be expected during the lifetime of the CTF. This makes it possible to install these systems alongside each other in order to connect to auxiliaries such as cooling water, HICS pipelines, power supply lines and instrumentation connections, as shown in Figure 5-17.

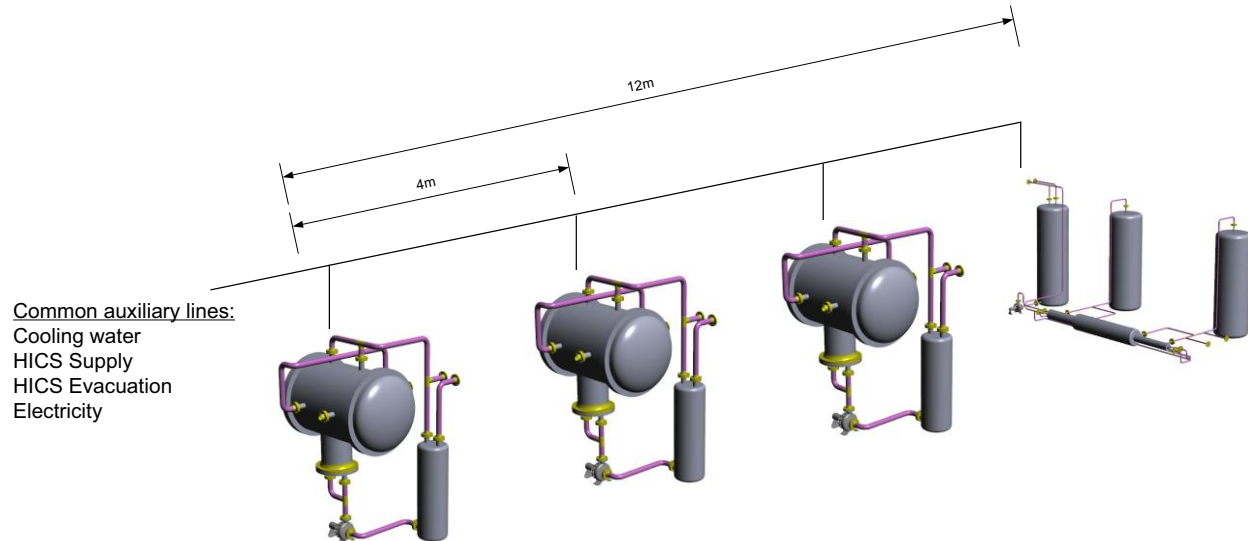


Figure 5-17: Possible arrangement of SSDT vessels with an IHX Fatigue test

5.5 SSDT: Instrumentation and Control Design

This section will address the following:

- Typical modes and transitions
- Control loops
- Initial instrumentation specification

5.5.1 Standard Operating Procedure

The SSDT has to be pre-pressurized to 4.5 MPa prior to heating. This is to prevent over pressurization due to the thermal expansion of the gas during heat-up.

5.5.2 Typical Modes and Transitions

The modes and transitions of the SSDT loops can be subdivided into the stream sequences', process sequences' and system sequences' modes and transitions respectively as discussed in the control and instrumentation philosophy. The sequences of the different tests will typically look the same especially on stream sequence level. Figure 5-18, Figure 5-19 and Figure 5-20 respectively portray a stream, process and system sequence for a typical test.

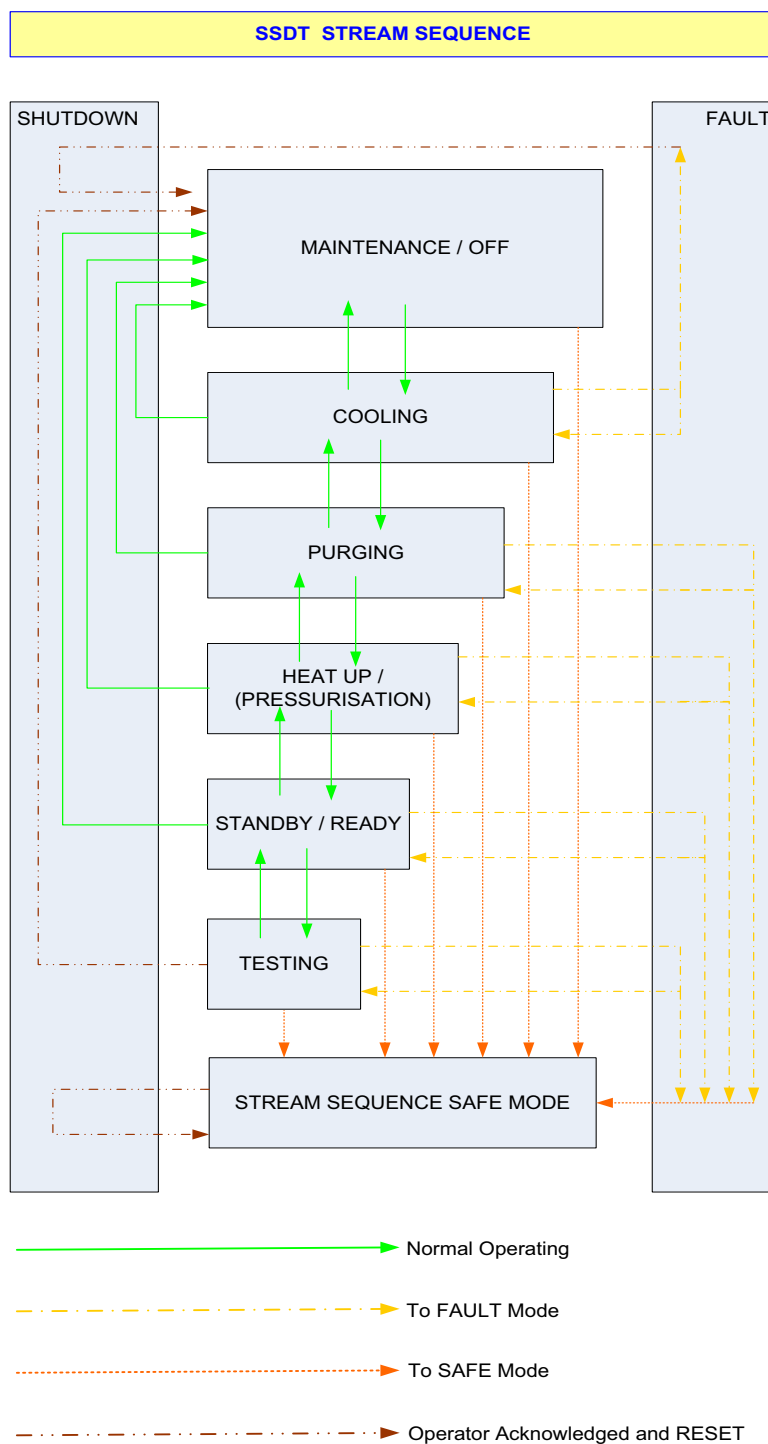


Figure 5-18: Typical SSDT stream sequence

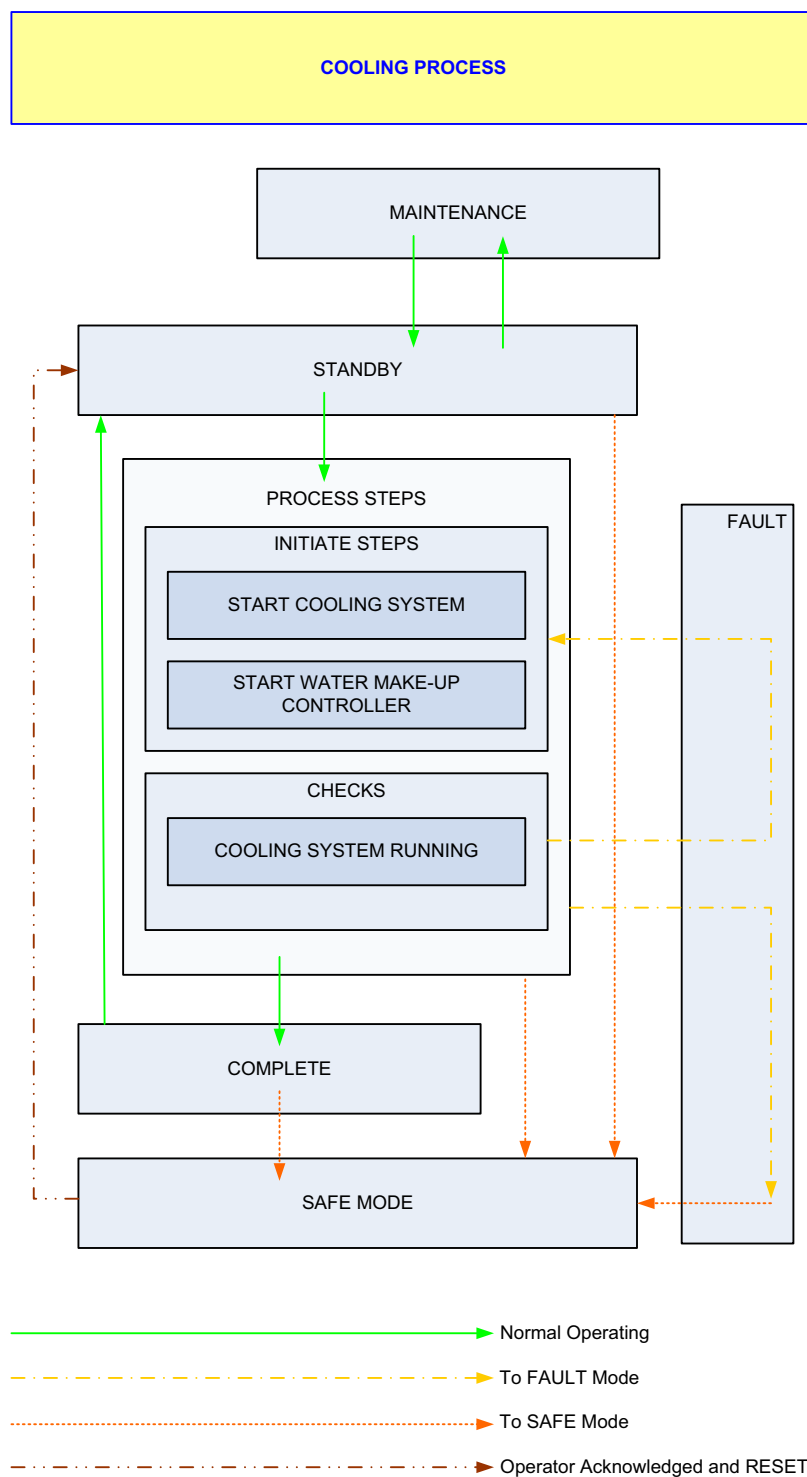


Figure 5-19: Typical SSDT process sequence

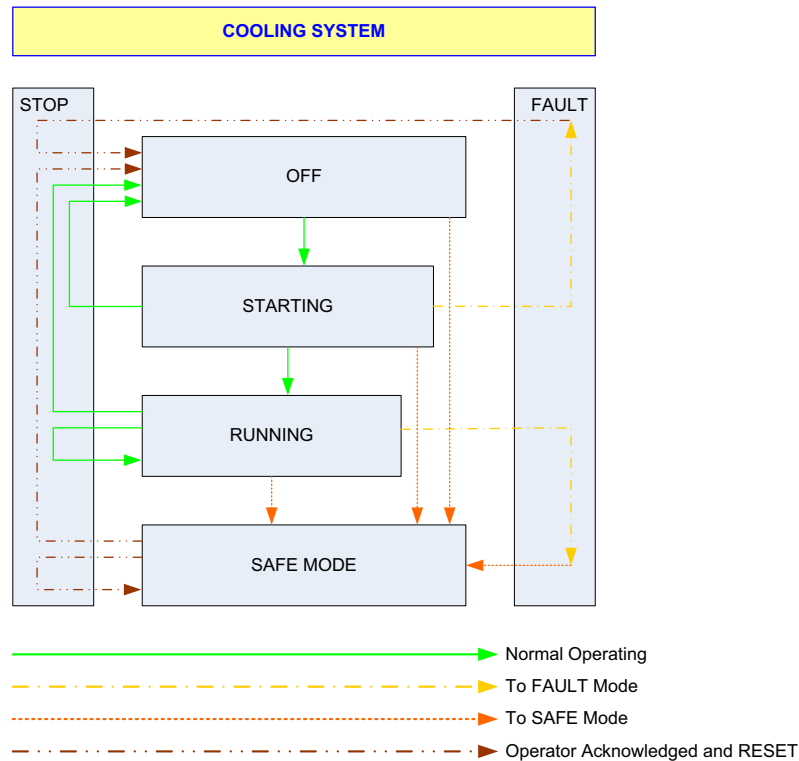


Figure 5-20: Typical SSDT system sequence

5.5.3 Control Loops for General SSDT Loop

With reference to the P&ID's for the general SSDT loop the following types of controllers are discussed:

- Temperature control
- Pressure control

5.5.3.1 Temperature Control

The temperature (T6) at the test vessel (TV1_1.1) will be controlled by adjusting the graphite heater (HT1_1.1) power (Figure 5-21).

The temperature (T1) at the gas side outlet of the cooler situated at the vessel outlet (CL1_1.1) will be controlled by the cooler outlet valve (VL1_1.4) as illustrated in Figure 5-22.

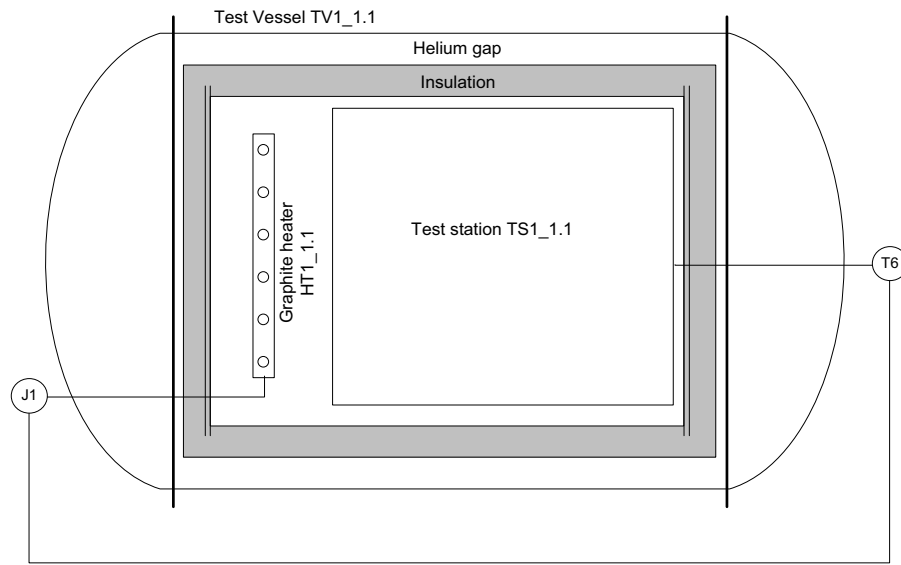


Figure 5-21: SSDT internal temperature control loop

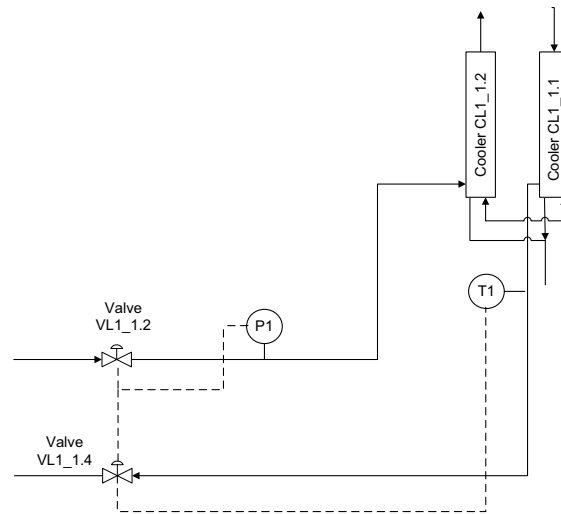


Figure 5-22: SSDT Pressure level control with the HICS.

The temperature of the water at the outlet of the cooler situated at the vessel outlet (CL1_1.1) will be controlled by the buffer tank inlet valve (VL1_2.1) as illustrated in Figure 5-23.

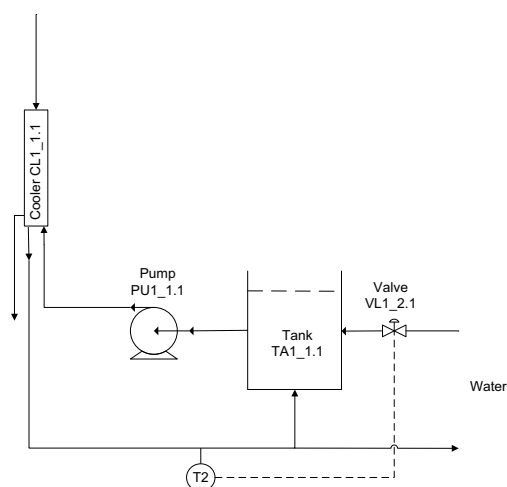


Figure 5-23: Cooling water loop average temperature control

5.5.3.2 Pressure Control

The pressure (P1) at the gas side inlet of the cooler situated at the vessel inlet (CL1_1.2) will be controlled by this cooler's gas side inlet valve (VL1_1.2) as well as the valve (VL1_1.4) situated at the gas outlet side of the cooler on the vessel outlet line (CL1_1.1) as illustrated in Figure 5-22.

It must be noted that the pressure level control of the SSDTs and the large Test Loops (TDL, CTL) is done differently. While the pressure level control of the large loops is the responsibility of the HICS system, the pressure level control of the SSDTs is done locally. Two pipelines are required from the HICS, namely a high-pressure supply line at 9.5MPa and a low-pressure (30kPa) evacuation line.

The reason for this is that there could be up to four SSDTs which have to be operated independently with an inventory of 8.6kg/SSDT, while the large Test Loops have inventories in the range of 400kg to 600kg per loop, resulting in a total of at least 1000kg Helium. Thus, four SSDTs have a combined inventory of about 34kg which is expected to be about 3.4 percent of the large loop inventory. Therefore, for these low flow rates, it is considered feasible to require the HICS to maintain one line at 9.5MPa and another at vacuum.

5.5.4 Control Loops for IHX Unit Cell Fatigue SSDT Loop

With reference to the P&ID's for the IHX unit cell fatigue SSDT loop the following types of controllers are discussed:

- Temperature control
- Pressure control
- Differential pressure control

5.5.4.1 Temperature Control

The temperature control of the IHX Cooling water loop is the same as for the SSDT.

The temperature of the heaters (T15 for HT1_3.2 and T12, T13 for HT2_3.2) will be controlled by adjusting the respective heater powers (Figure 5-24).

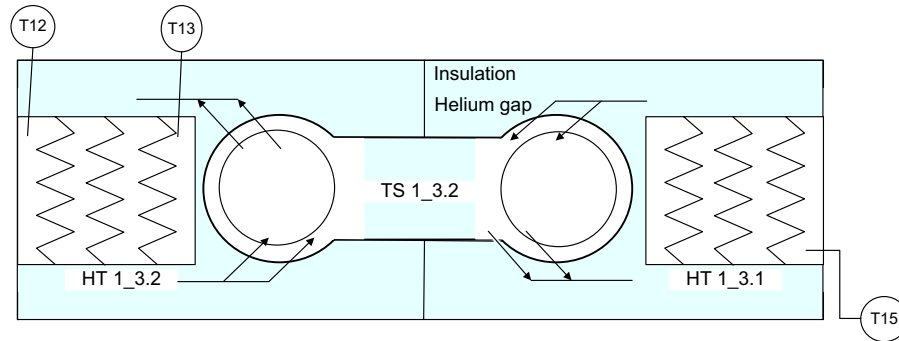


Figure 5-24: Heater inlet and outlet temperatures for controlling IHX Fatigue Test Heaters.

5.5.4.2 Pressure Control

The inventory pressure will be regulated by adjusting the gas inlet and outlet valves (VL1_3.4 and VL1_3.5) so that the hydraulic systems of the tanks (TA1_3.3 and TA1_3.2) will be able to control the pressure (P1 and P2) between the required minimum and maximum values (see Figure 5-25 and Figure 5-26).

The hydraulic systems of the tanks (TA1_3.3 and TA1_3.2) will control the pressures (P1 via TA1_3.3 and P2 via TA1_3.2). The hydraulic systems will be controlled via a dedicated test computer (see Figure 5-25 and Figure 5-26).

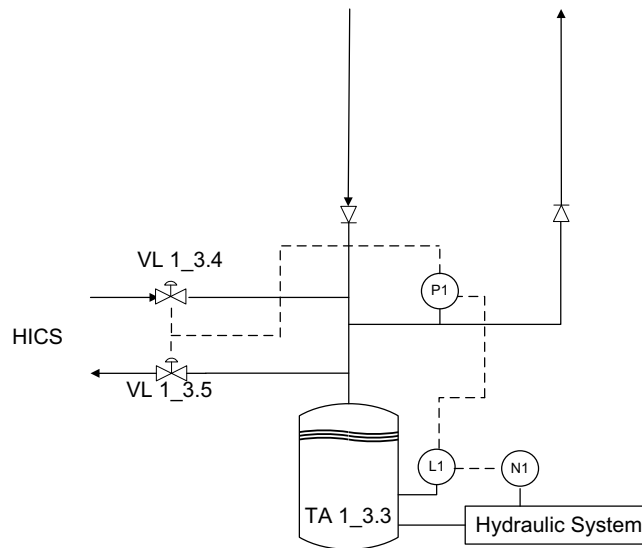


Figure 5-25: IHX Fatigue test inventory control loop.

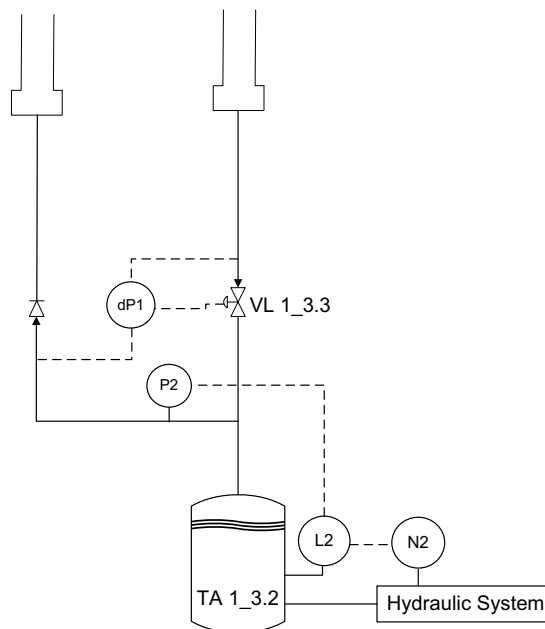


Figure 5-26: Loop for controlling the differential pressure between the IHX Unit cell primary and secondary sides.

5.5.4.3 Differential Pressure Control

The differential pressure between the inlet and outlet sides to the test unit will be controlled by adjusting the test unit outlet valve (VL1_3.3) as illustrated in Figure 5-26.

5.5.5 Initial Instrumentation Specification

Table 5-4 and Table 5-5 show the minimum instrument requirements for the general SSDT and IHX unit cell fatigue SSDT respectively. The tables give an indication of whether the instrument will be used for protection, control or validation and verification and whether it is required for a specific test specification. The maximum nominal conditions are given at which each instrument will be operating. Preliminary operating ranges for each instrument were obtained from the maximum nominal conditions.

As the heating elements are electrically charged and expected to be at a higher temperature than 950°C, it is expected that temperature measurement of the element by means of metallic thermocouples could be difficult. Therefore, it is proposed to measure the heating element surface temperature with a pyrometer, located at the bottom of the test vessel. Depending on the technical feasibility of using a quartz window for a 9 MPa pressure boundary, the pyrometer optical unit could be located outside the pressure vessel. This has to be confirmed during later design stages.

Table 5-4: General SSDT Initial Instrumentation Specification

Component	Instrument	Protection	Control	V&V	Test spec	Temperatures (°C)		Mass flows (kg/s)		Pressures (MPa)		Other	
						Max nom	Range	Max nom	Range	Max nom	Range	Max nom	Range
HT 1_1.1	T1		x							9.5	0-11		
	T4	x								9.5	0-11		
	T5	x								9.5	0-11		
	T6		x	x						9.5	0-11		
TS 1_1.1	T7		x	x	WEC-TS-PIP-006_1 WEC-TS-PIP-007_012_2					9.5	0-11		
	ε1				WEC-TS-IHX A-012_2 WEC-TS-IHX B-012_2								
	T2	x				30	0-50	1	0-2	0.15	0-0.2		
	T8	x	x			50	0-100	0.002	0-0.005	9.5	0-11		
CL 1_1.1	F1			x		30	0-50	1	0-2	0.15	0-0.2		
	FS1	x				30	0-50	1	0-2	0.15	0-0.2		
	GA1		x		WEC-TS-CSC-007	50	0-100			9.5	0-11	TBD	TBD
	VL 1_2.1					20	0-50	1	0-2	0.1	0-0.2		
TA 1_1.1	T3	x	x			20	0-50	1	0-2	0.1	0-0.2		
	L1	x				20	0-50	1	0-2	0.1	0-0.2		
					WEC-TS-PIP-006_1 WEC-TS-PIP-006_2 WEC-TS-PIP-007								
	P1		x					0.002	0-0.005	9.5	0-11		
VL 1_1.1	VL 1_1.1	x						0.002	0-0.005	9.5	0-11		
VL 1_1.2	VL 1_1.2		x					0.002	0-0.005	9.5	0-11		
VL 1_1.3	VL 1_1.3	x				50	0-100	0.002	0-0.005	9.5	0-11		
VL 1_1.4	VL 1_1.4		x			50	0-100	0.002	0-0.005	9.5	0-11		

Table 5-5: IHX Unit Cell Fatigue SSDT Initial Instrumentation Specification. Exact values and ranges to be determined from test specification.

Component	Instrument	Protection	Control	V&V	Test spec	Temperatures (°C)			Mass flows (kg/s)			Pressures (MPa)			Diff Press (kPa)			Other		
						Max nom	Range		Max nom	Range		Max nom	Range		Max nom	Range		Max nom	Range	
TA 1_3.3	L1		x																	
TA 1_3.2	L2		x																	
VL 1_3.3	P1		x																	
	dP1		x																	
VL 1_3.6	P2		x																	
TA 1_3.3	N1																			
TA 1_3.2	N2																			
VL 1_3.3	F1																			
VL 1_3.6	F2																			
TS 1_3.2	T1		x																	
TS 1_3.2	T2		x																	
TS 1_3.2	T3		x																	
TS 1_3.2	T4		x																	
TS 1_3.2	T5		x																	
TS 1_3.2	T6	x																		
VL 1_3.6	T7			x																
VL 1_3.3	T8		x																	
TS 1_3.2	T9	x																		
TS 1_3.2	T10	x																		
TS 1_3.2	T11	x																		
HT 1_3.2	T12		x																	
HT 1_3.2	T13		x																	
TS 1_3.2	T14		x																	
HT 1_3.1	T15		x																	
VL 1_3.2	T16		x																	
TA 1_3.1	T17	x	x																	
TA 1_3.1	L3	x																		
	T18	x	x																	
	F3			x																

Component	Instrument	Protection	Control	V&V	Test spec	Temperatures (°C)		Mass flows (kg/s)		Pressures (MPa)		Diff Press (kPa)		Other	
						Max nom	Range	Max nom	Range	Max nom	Range	Max nom	Range	Max nom	Range
	FS1	x													
VL 1_3.1	VL 1_3.1														
VL 1_3.2	VL 1_3.2														
VL 1_3.3	VL 1_3.3														
VL 1_3.4	VL 1_3.4														
VL 1_3.5	VL 1_3.5														
VL 1_3.6	VL 1_3.6														
VL 1_3.7	VL 1_3.7														

5.6 SSDT: Electrical Design

The electrical loads required by the SSDT components were calculated from the steady state analysis of the test requirements. The electrical requirements are given below:

Description	Unit	Value
Heater (HT 1_1.1)	kW	20
Pump (PU 1_1.1)	kW	2
Total	kW	22
Total x 4 SSDT's (TBD)	kW	88

The power requirement for the measurement instrumentation is not catered for in the values provided in the table above.

5.6.1 One-Line Diagrams

An electrical one-line diagram including the required voltages and interface requirements for each system are available as part of the NNGNP-CTF design in reference [5-8].

5.7 SSDT: Future Work

The first components to be constructed for the CTF are the “cold” parts of the TDL, namely the circulator, surge valve, cooler and TDL flow meter calibration loop setup. This is necessary to verify the parameters at which the circulators for the CTF operate reliably.

- The representative size of a heat exchanger unit cell has to be determined. There should be representative unit cells such that the boundary cells do not affect the outcome of inner cell testing.
- The orientation of the SSDT pressure vessel and high temperature vessel has to be reconsidered during detail design. A “bell and bottom flange” configuration may be more practical as it will enable opening and closing of the SSDT by means of the overhead crane. In a “bell and bottom flange” configuration, the test setup, heater, coolers and all other protrusions are mounted on the bottom flange. The test setup and instrumentation is installed when the high temperature “bell” vessel and pressure vessel “bell” are lifted off. This configuration negates the requirement for accessibility and space between the pressure vessel and the test setup, thereby considerably reducing the size of the vessel. Additionally, this configuration does not require a resealable high-temperature flange, as does the horizontally-orientated high temperature vessel described in this report.

- A detail design of the SSDT Graphite Heater and Metal Heater has to be done.
- The effect of, and presence of impurities at the heater have not been specified in a test specification. There will be chemical interaction with the graphite of the heater, which will have to be taken into account.
- Investigate the possibility of using ultrasonic sound to detect leaks in the IHX.
- Investigate methods to measure strain at high temperatures inside a 9 MPa atmosphere.
- Investigate the feasibility of using a pyrometer either inside or outside the pressure vessel to measure high temperatures. The technical feasibility of placing the pyrometer outside the pressure vessel will depend on the possibility of using quartz glass windows at a pressure differential of 9MPa.
- The SSDT unit is also anticipated to be used for tests for development of hydrogen process components, such as ceramic/steel seals for H₂SO₄, 950°C, 9 MPa. At the time of writing, no test specifications were available. SSDTs involving chemicals other than helium and cooling water will be housed in the hydrogen process building.
- Provision has to be made for introducing and controlling the contaminant concentration inside the SSDT. As the type of contaminant determines the system design, a chemical composition study should first be done to determine the exact requirements.

5.8 Interface Specification / Requirements

Cooling water

The maximum continuous cooling water requirement is 0.5 kg/s at 20°C supply and 30°C return temperature, i.e. 20kW.

Helium Inventory Control System

Based on first estimates, the helium inventory is 8.6kg per SSDT.

The supply pipeline is required to be maintained at 9.5MPa, while the evacuation line is required to be maintained at 30kPa, as discussed in Paragraph 5.5.3.2 Pressure Control.

Electrical power requirement

The SSDT requires 22kW, thus 88kW for four SSDTs.

Heating, Ventilation and Air Conditioning (HVAC)

The estimated heat loss to the environment is 11kW (at 30°C ambient temperature) per SSDT.

Hoisting/Crane requirement

The heaviest component is the Pressure Vessel with a weight of 4,000kg

Physical space requirement

The footprint of one SSDT is estimated at 4m x 4m. The maximum height requirement of the SSDT is estimated at 3m.

The loads and Interfaces Requirements list is given in Table 5-6.

5.9 References

- [5-1] “NGNP-CTF-MTECH-TLDR-0004. NGNP CTF Test Loop Pre-Conceptual Design Report. Section 4: System Requirement Manual”, dated December 2008.
- [5-2] “NGNP Conceptual Design Study: IHX and Heat Transport System.” NGNP-HTS-RPT-TI001, dated April 01, 2008.
- [5-3] “NGNP Conceptual Design Study: COMPOSITES R&D TECHNICAL ISSUES. NGNP-NHS-RPT.000.S05.” DDN COMP-01-04: Insulation Materials, on p128, dated October 2008.
- [5-4] “A Contribution On The Investigation Of The Dynamic Behaviour Of Rotating Shafts With A Hybrid Magnetic Bearing Concept (Hmbc) For Blower Application. Gronek, M., Rottenbach T., Worlitz, F” (2008) Proceedings of the 4th International Topical Meeting on High Temperature Reactor Technology, HTR2008 September 28-October 1, 2008, Washington, DC USA. Dated 2008.
- [5-5] “NGNP-PCDR Section 6, Heat Transport System,” p6-18 of 100, dated May 2007
- [5-6] “NGNP Technology Development Road Mapping Section 3: PHTS Circulator,” NGNP-RM-RPT-03, Par 3.6.2, p19 of 38, dated December 2008
- [5-7] “Graphite Heating Elements. Ceramisis,” http://www.ceramisis.com/carbons_graphites_heaters.htm. Accessed November, 28 2008.
- [5-8] “NGNP-CTF-E-WIR-001-2 NGNP,” CTF Electrical One-Line Diagram, dated December 2008
- [5-9] “NGNP Technology Development Road Mapping Report” NGNP-CTF MTECH-TDRM, dated December 2008

5.10 Appendices: Supporting Documentation

The following files are associated with this document:

- [5-10] Appendix A.1 SSDT Calculation Sheet

- [5-11] Appendix A.2 SSDT PFD for report
- [5-12] Appendix A.3 SSDT PID for report
- [5-13] Appendix A.4 IHX SSDT PFD for report
- [5-14] Appendix A.5 IHX SSDT PID for report
- [5-15] Appendix B.1 SSDT Test Vessel Data Sheet
- [5-16] Appendix B.2 SSDT Test Vessel Calculation Sheet
- [5-17] Appendix C Heating Element Data Sheet

Appendix A



M - T e c h
i n d u s t r i a l

***Attachment to Section 5: Small-Scale Development
Tests
Appendix A.1 SSDT Calculation Sheet***

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Revision: 1

Status: Approved

H.J. van Antwerpen

November 2008

CHANGE HISTORY

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Calculation Identification Number:	MT-TLDR-CAL-F-T-0501
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Original Signed Copy at CMC

Distribution					
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Confirmation Required Status			
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Revision	Description of Changes
A	Initial Draft
1	Document Approved

References to this document
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Change Forecast

The document format and contents have been approved.

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1. Objective

The objective of the calculation is to determine the heat loss from the SSDT Test Vessel, as well as component temperatures as determined by the dimensions of the insulation, helium gap and pressure vessel when performing a Small-Scale Development Test at a temperature of 950°C.

2. Methodology

2.1 APPROACH

The thickness of the insulation was varied to minimise heat loss from the SSDT pressure vessel, without having excessively thick insulation. In addition, a 50mm helium gap between the cladding on the insulation was introduced. The calculated total heat loss from the SSDT pressure vessel is used to size the internal heater.

The internal temperature, heat resistances and environment temperature was fixed.

2.2 COMPUTER PROGRAMS

The computer program used is Engineering Equation Solver (EES). EES automatically recognizes the relationships between variables in the various equations and uses an iterative Newton-Raphson algorithm to solve sets of simultaneous equations. Therefore, it is not necessary for equations to be arranged such that the calculated variable is the subject of the equation, or for equations to be entered in a specific order. This has to be kept in mind when reviewing the equations in this document.

EES also has built-in thermodynamic property tables for many fluids. This built-in fluid property database is used as the source for thermodynamic and heat transfer properties in these calculations.

3. Inputs and Assumptions

3.1 ASSUMPTIONS

- A passively cooled pressure vessel is used
- Negligible temperature difference is assumed across internal insulation cladding.
- Negligible temperature difference is assumed across high-temperature vessel wall
- Radiative Area_{environment} is infinitely large. This simplifies the radiation heat transfer calculation
- Environment temperature is taken as 30°C in order to calculate the highest possible pressure vessel wall temperature
- The convection heat transfer coefficient to ambient conditions is assumed to be 10W/m²K. From previous experience on the Helium Test Facility in South Africa, this was found to be quite accurate.
- The radiative heat transfer view factor from vessel surface to environment equals one.

- $k_{\text{insulation}} = 0.5 \text{ [W/mK]}$ Based on an assessment of current insulation materials, this is a conservative assumption. It agrees with results from the HENDEL tests as reported in "Construction and Performance Tests of Helium Engineering Demonstration Loop (HENDEL) for VHTR, Hishida et al., JAERI, 1984"
- Cladding: polished stainless steel: emissivity: $\text{eps\_clad} = 0.3$
- Pressure vessel inside: plain carbon steel: emissivity: $\text{eps\_pv\_i} = 0.8$
- Pressure vessel outside: painted surface: emissivity $\text{eps\_pv\_o} = 0.9$

The above emissivity values are from: Heat and Mass Transfer, Incropera and De Witt, Fifth Edition, 2002

3.2 INPUTS

- Test vessel temperature: 1000°C [Tests WEC-TS-IHXA-012 (metallic), WEC-TS-IHXA-030 (ceramic): Creep Testing of unit cells of compact heat exchangers, NGNP-CTF MTECH-TLDR-0005]
- High-temperature vessel radius: 0.35 m (diameter = 0.7m) [NGNP-CTF MTECH-TLDR-0005]
- High-temperature vessel length: 1.26 m [NGNP-CTF MTECH-TLDR-0005]

4. Equations Used and Calculations

The following equations are used:

One-dimensional radial conductive heat transfer

Radiative heat transfer between two opaque, grey, diffuse surfaces.

All equations are from: Heat and Mass Transfer, Incropera and De Witt, Fifth Edition, 2002

The equations are described in Attachment A: SSDT HEAT LOSS AND WALL TEMPERATURES EES Calculation Sheet.

5. Results

The results are summarised in Figure 5-1.

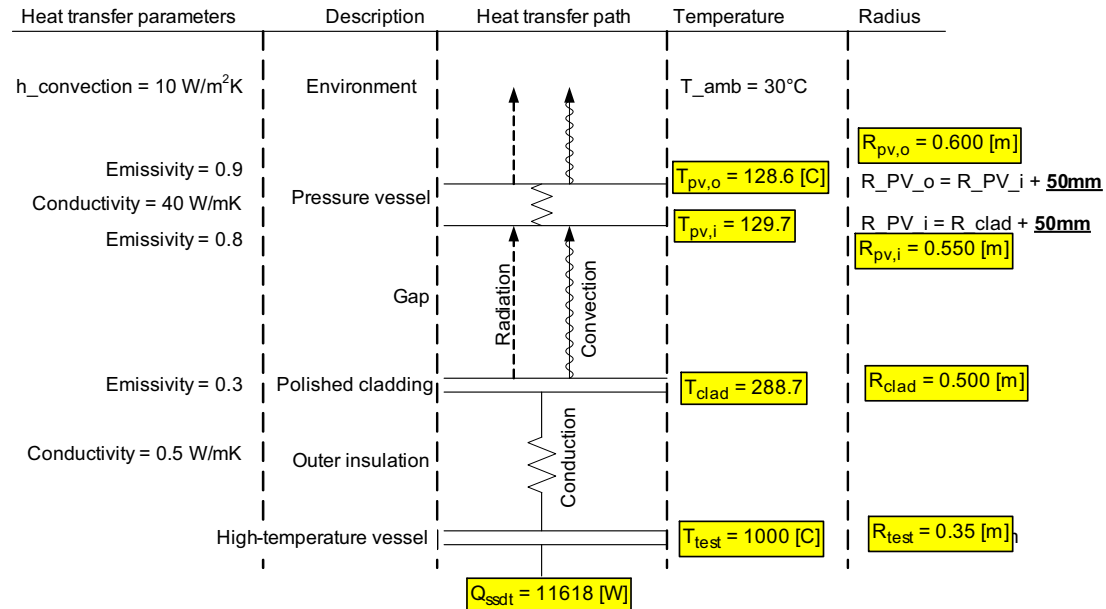


Figure 5-1. Calculated temperatures through the SSDT wall assembly.

6. Conclusions

The wall temperatures and heat transfer to the environment was calculated for the Small-Scale Development Test vessel assembly consisting of the high-temperature test vessel, insulation, cladding and the pressure vessel wall.

Attachment A

SSDT HEAT LOSS AND WALL TEMPERATURES EES Calculation Sheet

*SSDT heat loss calculation**This calculation supports the document:**SSDT Calculation Sheet: MT-TLDR-CAL-F-T-0501**Assumptions**A passively cooled pressure vessel is used**It is assumed that there is a zero ΔT across the internal High-temperature vessel and across the polished cladding**Radiative heat transfer view factor from vessel surface to environment = 1**Radiative Area_{environment} is infinitely large. This simplifies the radiation heat transfer calculation* $T_{\text{amb}} = 30$ [C] *Ambient temperature* $h_{\text{amb,conv}} = 10$ [W/m²K] *Typical value for ambient convection* T_{clad} [C] *Calculation result* $T_{\text{pv,i}}$ [C] *Calculation result**Material properties Units Reference* $k_{\text{insulation}} = 0.5$ [W/mK] *Based on an assessment of current insulation materials, this is a conservative assumption**It agrees with results from the HENDEL tests:**Construction and Performance Tests of Helium Engineering Demonstration Loop (HENDEL) for VHTR, Hishida et al., JAERI, 1984* $\epsilon_{\text{ps}_{\text{clad}}} = 0.3$ $\epsilon_{\text{ps}_{\text{pv,i}}} = 0.8$ $\epsilon_{\text{ps}_{\text{pv,o}}} = 0.9$ *All the above emissivities from Heat and Mass Transfer, Incropera and De Witt, Fifth Edition, 2002* $k_{\text{gap}} = k$ ['Helium' , T = 80 , P = 9000] $k_{\text{steel}} = k$ ['Carbon_{steel,AISI1010}' , 80]*Geometry Units Reference* $T_{\text{test}} = 1000$ [C] *Test requirements*

$$R_{\text{test}} = 0.35 \text{ [m] From SSDT High Temperature vessel sizing}$$

$$L_{\text{test}} = 1.06 + 0.2 \text{ [m] 0.2 m assumed for graphite heating element}$$

$$R_{\text{clad}} = R_{\text{test}} + 0.15 \text{ [m] Assume 150mm insulation}$$

$$L_{\text{gap}} = 0.05 \text{ Gap at the pressure vessel heads, only for area calculation}$$

$$R_{\text{pv,i}} = R_{\text{clad}} + 0.05 \text{ [m] 50mm gap assumed between inner cladding and outer pressure vessel}$$

$$L_{\text{pv}} = 0.05$$

$$R_{\text{pv,o}} = R_{\text{pv,i}} + 0.05 \text{ [m] 50mm pressure vessel wall assumed}$$

$$A_{\text{pv,o}} = 2 \cdot \pi \cdot R_{\text{pv,o}} \cdot [L_{\text{test}} + 2 \cdot (R_{\text{pv,o}} - R_{\text{test}})] + 2 \cdot \pi \cdot R_{\text{pv,o}}^2$$

$$A_{\text{clad}} = 2 \cdot \pi \cdot R_{\text{clad}} \cdot [L_{\text{test}} + 2 \cdot (R_{\text{clad}} - R_{\text{test}})] + 2 \cdot \pi \cdot R_{\text{clad}}^2$$

$$L_{\text{pressurevessel}} = L_{\text{test}} + 2 \cdot [R_{\text{pv,i}} - R_{\text{test}}]$$

Equations

Conductive heat transfer across insulation

$$Q_{\text{ssdt}} = k_{\text{insulation}} \cdot \left[2 \cdot \pi \cdot \frac{L_{\text{test}}}{\ln\left(\frac{R_{\text{clad}}}{R_{\text{test}}}\right)} + 2 \cdot \pi \cdot \left(\frac{R_{\text{clad}}^2}{R_{\text{clad}} - R_{\text{test}}}\right) \right] \cdot [T_{\text{test}} - T_{\text{clad}}]$$

Radiative heat transfer coefficient across helium gap

$$h_{\text{gap,rad}} = 5.670\text{E-}08 \text{ [W/m}^2\text{-K}^4] \cdot [T_{\text{clad}} + 273 + T_{\text{pv,i}} + 273] \cdot \left[\frac{(T_{\text{clad}} + 273)^2 + (T_{\text{pv,i}} + 273)^2}{\frac{1 + \text{eps}_{\text{clad}}}{\text{eps}_{\text{clad}}} + 1 + \frac{1 + \text{eps}_{\text{pv,i}}}{\text{eps}_{\text{pv,i}}}} \right]$$

Convective heat transfer coefficient across helium gap, no buoyancy effects included

$$v_{\text{lam}} = 4.36$$

$$\frac{1}{h_{\text{gap,conv}}} = \frac{L_{\text{gap}}}{k_{\text{gap}} \cdot v_{\text{lam}}} + \frac{L_{\text{gap}}}{k_{\text{gap}} \cdot v_{\text{lam}}}$$

Combined heat transfer across gap

$$Q_{\text{ssdt}} = [h_{\text{gap,rad}} + h_{\text{gap,conv}}] \cdot A_{\text{clad}} \cdot [T_{\text{clad}} - T_{\text{pv,i}}]$$

Conductive heat transfer across vessel wall

$$Q_{\text{ssdt}} = k_{\text{steel}} \cdot \left[2 \cdot \pi \cdot \left(\frac{L_{\text{test}} + 2 \cdot [R_{\text{pv,i}} - R_{\text{test}}]}{\ln\left[\frac{R_{\text{pv,o}}}{R_{\text{pv,i}}}\right]} \right) + 2 \cdot \pi \cdot \frac{R_{\text{pv,o}}^2}{L_{\text{pv}}} \right] \cdot [T_{\text{pv,i}} - T_{\text{pv,o}}]$$

$$T_1 = T_{\text{amb}} + 273$$

$$T_2 = T_{pv,o} + 273$$

$$h_{amb,rad} = 5.670E-08 \text{ [W/m}^2\text{-K}^4] \cdot [T_1 + T_2] \cdot \left[\frac{T_1^2 + T_2^2}{\frac{1 + \epsilon_{pv,o}}{\epsilon_{pv,o}} + 1} \right]$$

Heat and Mass Transfer, Incropera and De Witt, Fifth Edition, 2002

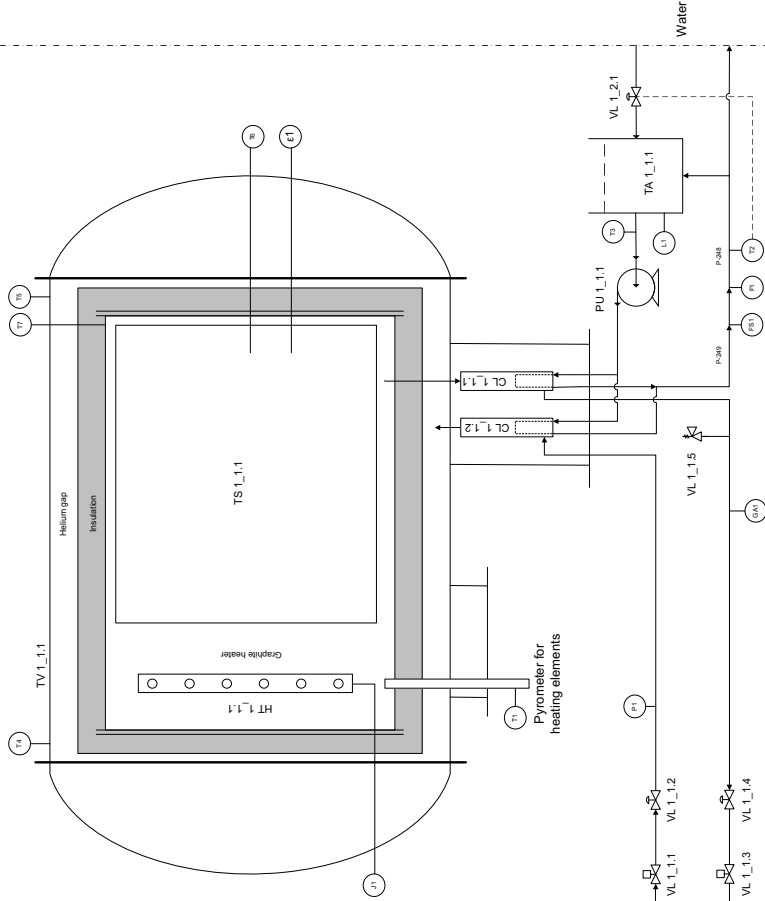
$$Q_{ssdt} = [h_{amb,conv} + h_{amb,rad}] \cdot A_{pv,o} \cdot [T_{pv,o} - T_{amb}]$$

Heat and Mass Transfer, Incropera and De Witt, Fifth Edition, 2002

Small-Scale Development Test

Interface with Auxiliaries

Interface with Auxiliaries



Symbol	Instrument
A	Accelerometer
dP	Differential Pressure
F	Flow
FS	Flow Switch
GA	Gas Analyser
N	Rotational speed
P	Pressure
Q	Volume Flow
T	Temperature
ε	Strain

Symbol	Description
CD	Condenser
CH	Cold Header
CL	Cooler
COL	Component Qualification
CR	Circulator
CTL	Circulator Test Loop
HH	Hot Header
HCS	Helium Inventory Control System
HT	Heater
OR	Offgas
PI	Pipe
PU	Pump
RK	Recombiner
SSDT	Small Scale Development Test Station
TA	Tank
TDL	Technology Development Loop
TS	Test Station
TV	Test Vessel
VL	Valve



M-Tech Industrial
MTECH INDUSTRIAL PTY LTD
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PO BOX 1885
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SOUTH AFRICA

REFERENCE DRAWINGS

REV	REASON FOR REVISION	DATE	BY
A	DRAFT	20/10/2018	HWA
B	DRAFT	20/10/2018	HWA
1	APPROVED	12/03/2019	HWA

AUTHORISATION	
DRAWN	HWA
REVIEWED	RB
APPROVED	JH

PROJECT

HWA	Herman van Antwerpen
JH	Jacques Huischausen
RB	Riaan de Bruyn

DOCUMENT NUMBER

M7.1LDR5SDT.03.0001

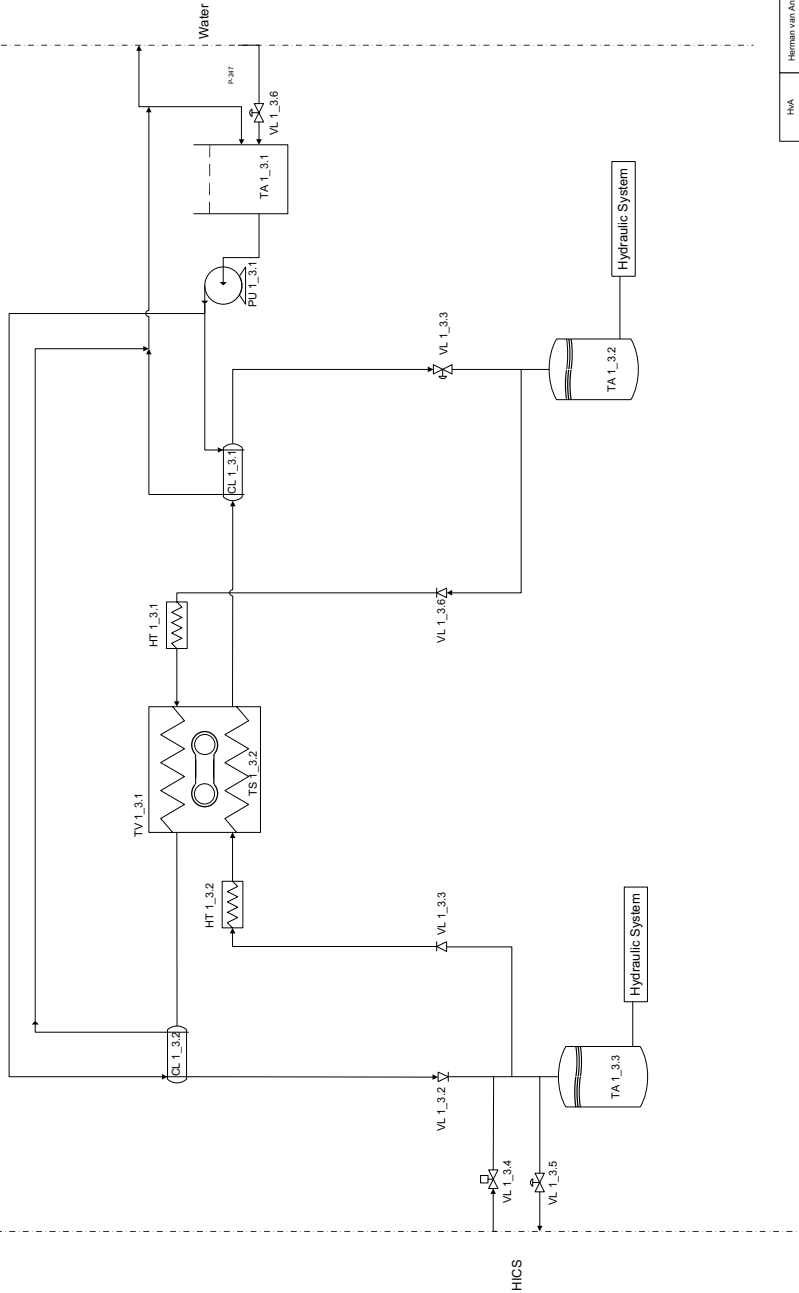
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Small-Scale Development Test
Fatigue Test

Interface with Auxiliaries

Interface with
Auxiliaries



Symbol	Description
CD	Condenser
CH	Cold Header
CL	Cooler
CCL	Component Qualification
CR	Circulator
CTL	Circulator Test Loop
HH	Hot Header
HICS	Hydraulic Inventory Control System
HT	Heater
OR	Orifice
PI	Pipe
PU	Pump
RK	Recompressor
SSDT	Small-Scale Development Test Section
TA	Tank
TDL	Technology Development Loop
TS	Test Station
TV	Test Vessel
VL	Valve

ITEM NUMBER	DESCRIPTION
1.1	Small-Scale Development Test
1.2	Small-Scale Development Test
1.3	Small-Scale Development Test
1.4	Small-Scale Development Test
1.5	Small-Scale Development Test
1.6	Small-Scale Development Test
1.7	Small-Scale Development Test
1.8	Small-Scale Development Test
1.9	Small-Scale Development Test
1.10	Small-Scale Development Test
1.11	Small-Scale Development Test
1.12	Small-Scale Development Test

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Configuration Management

M - T e c h industrial

MLT-INDUSTRIAL PTY LTD
107 GLEN STREET
DURBAN 4001
SOUTH AFRICA
PO BOX 1885
NOORDKAP, 2022
SOUTH AFRICA

REFERENCE DRAWINGS

REV	REASON FOR REVISION	DATE	BY
A	ISSUED	2011/06/06	N/A
B	ISSUED	2011/06/06	N/A
C	ISSUED	2011/06/06	N/A
D	ISSUED	2011/06/06	N/A
E	ISSUED	2011/06/06	N/A
F	ISSUED	2011/06/06	N/A
G	ISSUED	2011/06/06	N/A
H	ISSUED	2011/06/06	N/A
I	ISSUED	2011/06/06	N/A

REVISIONS ISSUED	DATE	BY
A	2011/06/06	N/A
B	2011/06/06	N/A
C	2011/06/06	N/A
D	2011/06/06	N/A
E	2011/06/06	N/A
F	2011/06/06	N/A
G	2011/06/06	N/A
H	2011/06/06	N/A
I	2011/06/06	N/A

AUTHORISATION

DESIGNED

DRAWN

CHECKED

APPROVED

PROJECT

PROJECT

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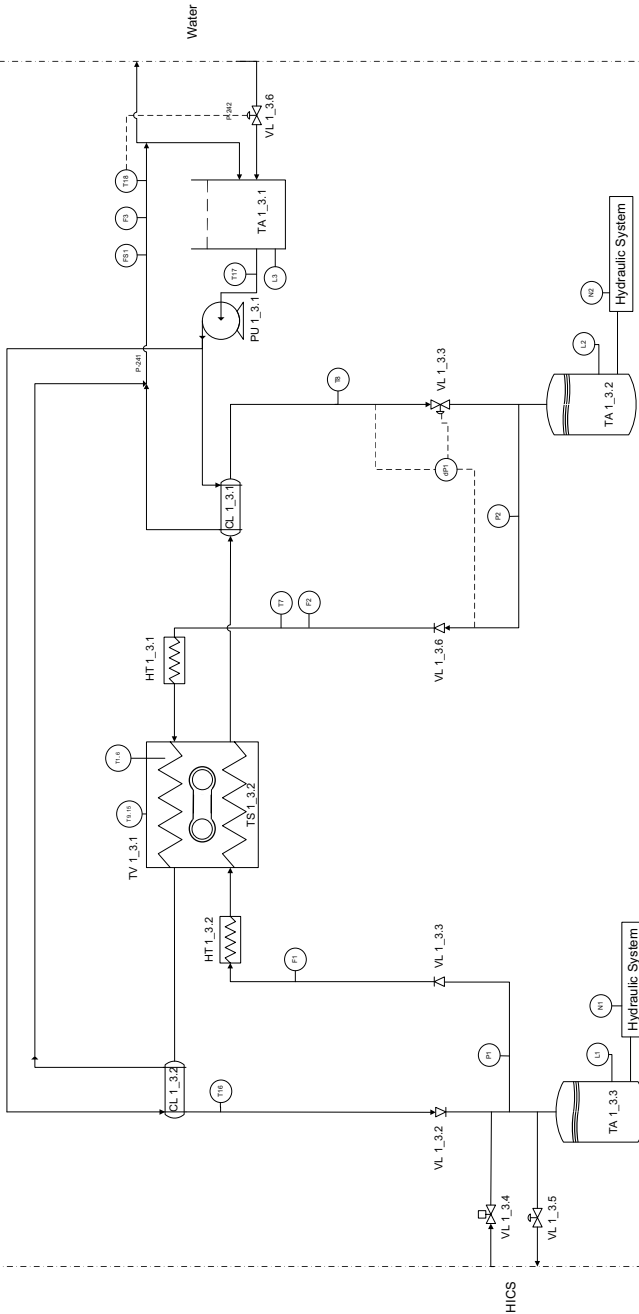
N/A	Herman van Antwerpen
JH	Jacques Huisman
RdB	Riaan de Bruyn

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Small-Scale Development Test
Fatigue Test

Interface with
Auxiliaries

Interface with Auxiliaries



Symbol	Instrument
A	Accelerometer
dP	Differential Pressure
F	Flow
FS	Flow Switch
GA	Gas Analyser
N	Rotational speed
P	Pressure
Q	Volume Flow
T	Temperature
ε	Strain

Symbol	Description
CD	Condenser
CH	Cold Header
CL	Cooler
COL	Component Qualification
CR	Circulator
CTL	Circulator Test Loop
HH	Hot Header
HICS	High Pressure Test Cell
HT	Heater
OR	Office
PI	Pipe
PU	Pump
RC	Recompressor
SSDT	Small-Scale Development Test Station
TA	Tank
TDL	Technology Development Loop
TS	Test Station
TV	Test Vessel
VL	Valve

Symbol	Description
CD	Condenser
CH	Cold Header
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CR	Circulator
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SSDT	Small-Scale Development Test Station
TA	Tank
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TS	Test Station
TV	Test Vessel
VL	Valve

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REFERENCE DRAWINGS

REVISIONS ISSUED

REV	REASON FOR REVISION	DATE	BY
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DRAWN	N/A	12/05/08
REVIEWED	N/A	12/05/08
APPROVED	N/A	12/05/08

PROJECT

NSMP CTF Test Loop Pre-Conceptual Design

TITLE

Small-Scale Development Test

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DOCUMENT NUMBER

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Appendix B

Appendix B.1

Component Specification Sheet

Company:	M-Tech Industrial (Pty) Ltd		
Location:	Potchefstroom, South Africa		
Document Number:	MT-TLDR-SSDT-CMPT-05-0001		
Component:	SSDT Test Vessel (TV 1_1.1)		
Date:	11 December 2008	Rev. No.:	2

Authorisation			
Action	Name	Signature	Date
Preparer	Bennie Nel		December 11, 2008
Reviewer	David Viljoen		December 11, 2008
Approver	Riaan de Bruyn		December 17, 2008

Record of Changes	
Revision	Description of Changes
A	Initial Draft
1	Document Approved
2	Configuration tables added

TV 1_1.1		
Component Specification Sheet		
	<u>Value & Unit</u>	<u>Remarks</u>
P _{he} :	9 600 kPa	Nominal Pressure.
T _{he in} :	130 °C	Inlet temperature.
d _{internal vessel} :	1.077 m	
L _{vessel}	2.466 m	Length of Shell body + 2 elliptical heads.
Fluid:	Helium	
T _{design} :	200 °C	
P _{design} :	9 600 kPa	
<u>Shell:</u>		
Length:	1 500 mm	
Outside diameter:	1 194 mm	
Wall thickness:	58.4 mm	
Corrosion allowance:	0 mm	
<u>Nozzles:</u>		
No. of protrusions:	8	
Length:	483 mm	
Outside diameter:	88.9 mm	
Wall thickness:	5.5 mm	
<u>Elliptical Head:</u>		
Head ratio:	2 : 1	
Height:	227.3 mm	Height before and after forming.
Wall thickness before:	58.4 mm	
Wall thickness after:	58.4 mm	
Skirt:	127 mm	
Assembled mass:	4 000 kg	
<u>Material:</u>		
Component material:	SA-516 Gr.70	
Allowable stress:	115.14 MPa	



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***Attachment to Section 5: Small-Scale
Development Tests (SSDT)
Appendix B.2 SSDT Test Vessel Calculation Sheet***

Document number: MT-TLDR-CAL-M-0502

Revision: 1

Status: Approved

H.J. van Antwerpen

December 2008

CHANGE HISTORY

Configuration Control	
Client Name:	Westinghouse Electric Company
Project Number:	NGNP-CTF MTECH-TLDR
Project Name:	NGNP-CTF-Test Loop Preconceptual Design
Calculation Title:	SSDT Test Vessel Calculation Sheet
Calculation Identification Number:	MT-TLDR-CAL-M-0502
Quality Level:	3

Template No: MT-TLDR-CAL-REP rev 1

Authorisation			
Action	Name	Signature	Date
Preparer	H J van Antwerpen	_____	December, 4, 2008
Reviewer	D J Viljoen	_____	December, 4, 2008
Approver	R de Bruyn	_____	November, 29, 2008

Original Signed Copy at CMC

Distribution					
Discipline	Name	Discipline	Name	Discipline	Name

Confirmation Required Status			
Calculation Page	Input/Assumption that Requires Confirmation	Preparer and Date Input/Assumption Confirmed	Reviewer and Date Input/Assumption Approved

Record of Changes	
Revision	Description of Changes
A	Initial Draft
1	Document Approved

References to this document
NGNP-CTF MTECH-TLDR-0005

Change Forecast

The document format and contents have been approved.

Calculation Table of Contents

Calculation Table of Contents.....	4
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2. Methodology.....	5
2.1 APPROACH.....	5
2.2 COMPUTER PROGRAMS.....	5
3. Inputs and Assumptions	5
3.1 ASSUMPTIONS	5
3.2 INPUTS.....	5
4. Equations Used and Calculations	5
5. Results	6
6. Conclusions.....	6
Attachment A.....	7
Attachment B	8

1. Objective

The objective of the calculation is to perform sizing calculations for the SSDT Test Vessel according to the required pressure and temperature.

2. Methodology

2.1 APPROACH

The prescribed calculation methods of the applicable ASME code were used to set up a general calculation sheet that has as inputs: the inner diameter, length, pressure and temperature of the required pressure vessel.

2.2 COMPUTER PROGRAMS

The calculation is performed in Microsoft Excel, using Visual Basic Macros. In this way, only the inputs and the results are visible but the calculation method can not be altered from the spreadsheet.

3. Inputs and Assumptions

3.1 ASSUMPTIONS

- All pressure boundary calculations are done using a MS Excel spreadsheet incorporating ASME Code VIII Div 1 2001, No Addenda
- No corrosion allowance was included
- All pressure boundary outside temperatures are taken as 200°C

3.2 INPUTS

- Proposed material is SA-516 Gr.70
- Allowable stress was taken as 20 KSI at 204°C (400°F) from ASME material property database
- Internal pressures taken as 9.6 MPa
- All other related input can be found in the attached calculation spreadsheet and are included in sections: **Dimensions** and **Material and Conditions**

4. Equations Used and Calculations

All equations used are included in the calculation spreadsheet.

5. Results

The vessel shell and elliptical wall thicknesses were calculated as 2.3 inches (58.4 mm).

The pressure vessel shell mass was calculated as 5409 lbs (2453 kg).

The elliptical head mass was calculated as 1706 lbs (774 kg).

6. Conclusions

A pressure vessel was calculated that is capable of handling the required pressure and temperature. There were no special cases to be calculated or designed so that the vessel is considered well within the current state of the art.

Attachment A

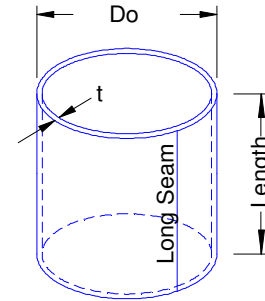
Pipe and Shell TV1_1.1

Pipe and Shell TV1_1.1

ASME Code VIII Div I 2001 edition no addenda

ASME L-2.2.1 <- BM **1** <- BM Item #**Verification Calc #3** <- Vessel, description**1** <- BM Qty**Dimensions:**

47.000 <- Do - Outside Diameter
2.300 <- t - Nominal Wall Thickness
59.050 <- Length
0.000 <- Corr, Corrosion Allowance

**Material and Conditions:**

SA-516 <- Material
20,000 <- S, Allowable Stress Level (psi)
0.85 <- E1 - Longitudinal Efficiency (circ. stress)
0.65 <- Ec - Circ. Connecting Efficiency (longitudinal stress)
0.0% <- UTP, Undertolerance allowance (%) **48.25** <- Volume (cubic ft)
0.000 <- UTI, Undertolerance allowance (inch) **5,409.1** <- Material Weight (lbs cs)
1392.4 <- P, Interior Pressure
0.0 <- Pa, Exterior Pressure
1 <- B, From exterior pressure curve **0.012248** <- A (use to lookup B)

Variables:

UT = $t \cdot \text{UTP} + \text{UTI}$ = $2.3 \cdot 0 + 0$ undertolerance UT = **0.000**
 $R_i = \text{Do} / 2 - t + \text{corr}$ = $47 / 2 - 2.3 + 0$ inside radius Ri = **21.200**
 $n_t = t - \text{Corr} - \text{UT}$ = $2.3 - 0 - 0$ nominal thick nt = **2.300**
 $L_{Do} = L / \text{Do}$ = $59.05 / 47$ LDo = **1.256**
 $\text{DoT} = \text{Do} / n_t$ = $47 / 2.3$ DoT = **20.435**

Interior Pressure UG-27 (c) (1,2)

$t_a = P \cdot R_i / (S \cdot E_1 - 0.6 \cdot P)$ = $1392.4 \cdot 21.2 / (20000 \cdot 0.85 - 0.6 \cdot 1392.4)$ $t_a = \mathbf{1.826}$
 $t_b = P \cdot R_i / (2 \cdot S \cdot E_c + 0.4 \cdot P)$ = $1392.4 \cdot 21.2 / (2 \cdot 20000 \cdot 0.65 + 0.4 \cdot 1392.4)$ $t_b = \mathbf{1.112}$
 $t_{min} = \text{Max}(t_a, t_b) \leq n_t$ **Okay** $t_{min} = \mathbf{1.826}$
 $P_{MaxA} = (S \cdot E_1 \cdot n_t) / (R_i + 0.6 \cdot n_t)$ = $(20000 \cdot 0.85 \cdot 2.3) / (21.2 + 0.6 \cdot 2.3)$ $P_{MaxA} = \mathbf{1731.6}$
 $P_{MaxB} = (2 \cdot S \cdot E_c \cdot n_t) / (R_i - 0.4 \cdot n_t)$ = $(2 \cdot 20000 \cdot 0.65 \cdot 2.3) / (21.2 - 0.4 \cdot 2.3)$ $P_{MaxB} = \mathbf{2948.7}$
 $P_{Max} = \text{Min}(P_{MaxA}, P_{MaxB})$ **Okay** $P_{Max} = \mathbf{1731.6}$
 $t_{r1} = P \cdot R_i / (S \cdot 1 - 0.6 \cdot P)$ = $1392.4 \cdot 21.2 / (20000 \cdot 1 - 0.6 \cdot 1392.4)$ $t_{r1} = \mathbf{1.540}$

Exterior Pressure UG-28 (c)

A = Interpolated from IID Part D Table G $A = \mathbf{0.012248}$
 $P_{aMax} = 4 \cdot B / (3 \cdot \text{DoT})$ = $4 \cdot 1 / (3 \cdot 20.435)$ **Okay** $P_{aMax} = \mathbf{0.1}$
 $t_{re} = (3 \cdot \text{Do} \cdot P_a) / (4 \cdot B)$ = $(3 \cdot 47 \cdot 0) / (4 \cdot 1)$ $t_{re} = \mathbf{0.000}$

Shell stress relief -UCS-79(d), UNF-79(d), UHA-44(d)

$R_f = (\text{do} - t) / 2$ = $(47 - 2.3) / 2$ $\mathbf{22.35}$
 $\% \text{ elong} = (50 \cdot t / R_f) \cdot (1 - 0)$ = $(50 \cdot 2.3 / 22.35) \cdot (1 - 0)$ $\% \text{ elongation} = \mathbf{5.1}$

0.1% <- Max Elongation**Yes** <- Cold formed **5.1%** <- Elongation**no** <- Vessel carries lethal substances (Yes/no)**no** <- Impact testing is required (Yes/no)**no** <- Greater than 10% reduction in thickness**no** <- Formed between 250 and 900 Degrees F**YES** <- Shell is greater than 5/8" thick before forming

Required	Yes ?
no	no
no	no
no	no
no	no
no	no
no	no
Stress Relieve ?	no

Attachment B

Elliptical Head TV1_1.1

Elliptical Head TV1_1.1

Page 1 of 1

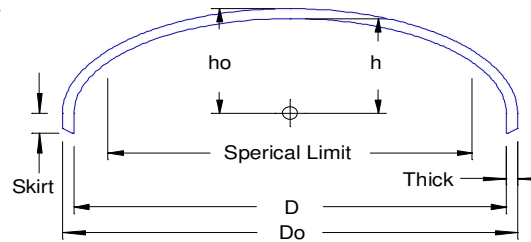
ASME Code VIII Div I 2001 no Addenda

<- BM <- BM Item # <- BM Qty

Heads <- Component

Dimensions:

47.000 <- Do, outside diameter
8.950 <- h
2.300 <- tb, thickness before forming
2.300 <- tf, thickness after forming
0.000 <- Corr, corrosion allowance
5.000 <- Skirt, straight skirt length

**Material and Conditions:**

SA-516 <- material
20,000 <- S, allowable stress level (psi)
1.00 <- E, efficiency
1392.4 <- P, interior pressure
0.0 <- Pa, exterior pressure
1 <- B, from exterior pressure curve

Calculated Properties:

57.7 <- Approximate blank diameter
1706.5 <- Approximate weight for steel, (lbs)
8.96 <- Volume (cuft, includes skirt)
33.92 <- Spherical Limit (0.8 * D)
0.00651 <- A value to lookup B

Variables:

D = Do-2*t = 47-2*2.3 = 42.40
 ho = h+t = 8.95+2.3 = 11.25
 D/2h = D/(2*h) = 42.4/(2*8.95) = 2.369
 Do/2ho = Do/(2*ho) = 47/(2*11.25) = 2.089
 K = Interpolated value from table 1-4.1 interior = 1.265
 Kone = Interpolated value from table UG-37 spherical = 1.066
 Kzero = Interpolated value from table UG-33.1 exterior = 0.940
 t = tf-corr = 2.3-0 = 2.300
 Ro = Ko*Do = 0.94*47 = 44.180

Interior Pressure App 1-4(c)(d), UG-37 1(a)

TMinl = (P*D*K)/(2*S*E-0.2*P) <= t TMinl (min thickness) = **1.880**
 = (1392.4*42.4*1.265)/(2*20000*1-0.2*1392.4) <= 2.3 **Okay**
 PMax = (2*S*E*t)/(K*D+0.2*t) >= P PMax = **1701**
 = (2*20000*1*2.3)/(1.265*42.4+0.2*2.3) >= 1392 **Okay**
 TSpl = (P*D*Kone)/(2*S*E-0.2*P) TSpl (required sphere zone thick) = **1.584**
 = (1392.4*42.4*1.066)/(2*20000*1-0.2*1392.4)

Exterior Pressure UG-33(d), UG-28(d)

A = 0.125/(Ro/t) = 0.125/(44.18/2.3) **Okay**
 PaMax = B/(Ro/t) >= Pa = 1/(44.18/2.3) >= 0 A = **0.006507**
 TMinE = (Ro*Pa)/B = (44.18*0)/1 PaMax = **0.1**
 TMinE = **0.000**

Head stress relief UCS-79(d), UNF-79(d), UHA-44(d)

% elong = ((75*t)/h)*(1-0) = ((75*2.3)/8.95)*(1-0) % elong = **19.3**

5.0% <- Max Elongation
Yes <- Cold Formed **19.3%** <- Elongation
no <- Vessel carries lethal substances(Yes/no)
no <- Impact testing is required (Yes/no)
no <- Formed between 250 and 900 Degrees F
no <- Greater than 10% reduction in thickness
Yes <- Head is greater than 5/8" thick before forming

Required	Yes ?
no	no
no	no
no	no
no	no
Yes ?	YES
Stress Relieve ?	YES

Appendix C

Appendix C

Component Specification Sheet

Company:	M-Tech Industrial (Pty) Ltd		
Location:	Potchefstroom, South Africa		
Document Number:	MT-TLDR-SSDT-CMPT-05-0002		
Component:	SSDT Heating Element (HT 1_1.1)		
Date:	11 December 2008	Rev. No.:	2

Authorisation			
Action	Name	Signature	Date
Preparer	Bennie Nel		December 11, 2008
Reviewer	David Viljoen		December 11, 2008
Approver	Riaan de Bruyn		December 17, 2008

Record of Changes	
Revision	Description of Changes
A	Initial Draft
1	Document Approved
2	Configuration tables added

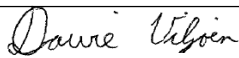
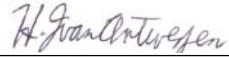
HT 1_1.1 Component Specification Sheet		
<u>Performance</u>	<u>Value & Unit</u>	<u>Remarks</u>
P _{he} :	9 600 kPa	Nominal Pressure.
T _{he in} :	1 000 °C	Test environment temperature.
Power rating:	20 kW	
<u>Available space for heater:</u>		
Diameter (Cylindrical):	0.7 m	
Height (Cylindrical):	0.2m	
Orientation of cylindrical space:	Horizontal	
<u>Material:</u>	Graphite	Uncoated for creating reducing atmospheres. Coated with Pyrolytic Boron Nitride or Silicon Carbide for helium atmospheres with oxygen as contaminant. More information at http://www.ceramisis.com/carbons_graphites_heaters.htm .

NGNP and Hydrogen Production Conceptual Design Study

NGNP CTF Test Loop Pre-Conceptual Design Report

Section 6: Technology Development Loop (TDL)

APPROVALS

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ACRONYMS

Abbreviation or Acronym	Definition
A	Accelerometer
A-E-C	Architecture – Engineering -Construction
AGR	Advanced Gas-cooled Reactor
AHJ	Authority Having Jurisdiction
AICE	American Institute of Chemical Engineers
AISC	American Institute of Steel Construction
AISI	American Iron and Steel Institute
ALARA	As Low As Reasonable Achievable
AMB	Active Magnetic Bearing
ANSI	American National Standards Institute
API	American Petroleum Institute
ASHRAE	American Society of Heating Refrigeration and Air Conditioning Engineers
ASME	American Society of Mechanical Engineers
AWS	American Welding Society
BEA	Battelle Energy Alliance
BIL	Basic Impulse Insulation Level
BIM	Building Information Management
BS	British Standard
Btu/hr	British thermal unit per hour
CAD	Computer Aided Design
CAE	Computer Aided Engineering
CBCS	Core Barrel Conditioning System
CCS	Core Conditioning System
CFR	Code of Federal Regulations
CH	Cold Header
CMAA	Crane Manufacturers Association of America
COR	Client Observation Room
COTS	Commercial Off-The-Shelf (Commercial Grade Items)
CQL	Component Qualification Loop
CQL1	Component Qualification Loop 1
CQL2	Component Qualification Loop 2
CTF	Component Test Facility
CTL	Circulator Test Loop
CV	Valve Flow Coefficient
DAQ	Data Acquisition
db	Dry Bulb
DB	Distribution Board

Abbreviation or Acronym	Definition
DC	Direct Current
DCD	Design Criteria Document
DCS	Distributed Control System
DDN	Design Data Need
DOE	Department of Energy
dP	Differential Pressure
DPP	Demonstration Power Plant
EDMS	Engineering Data Management System
EHR	Essener Hochdruck Rohrleitung
EIA	Electronic Industry Alliance
EMB	Electro-magnetic Bearing
ENS	Emergency Notification System
EPACT	Energy Policy Act (of 2005)
EPC	Engineering Procurement and Construction
ER	Environmental Requirement
ES&H	Environmental, Safety and Health
ESD	Emergency Shutdown
F	Flow Rate
FDD	Facility Design Description
FHA	Fire Hazard Analysis
FIPS	Federal Information Processing Standards
FM	Factory Mutual
FMS	Facility Monitoring System
FS	Flow rate (switch)
GA	Gas analyzer (composition)
GHEP	Guidelines for Hazard Evaluation Procedures
gpm	Gallon per minute (US)
GR	General Requirements
H ₂	Hydrogen Production Test (Specifically referring to H ₂ SO ₄ Decomposition Reactor Test)
H ₂ SO ₄	Sulfuric Acid
HAZOP	Hazard and Operational Study
HDBK	Handbook
HGD	Hot Gas Duct
HGDs	Hot Gas Ducts
HH	Hot Header
HICS	Helium Inventory Control System
HIPCS	Helium Inventory and Pressure Control System
HIRA	Hazard and Risk Identification Analysis
HLR	High Level Requirement
HMI	Human Machine Interface

Abbreviation or Acronym	Definition
HPS	Helium Purification System
HT	Heat Transfer
HTF	Helium Test Facility
HTGR	High Temperature Gas -Cooled Reactor
HTS	Heat Transport System
HTSE	High Temperature Steam Electrolysis
HTTR	High Temperature Test Reactor
HTTU	High Temperature Test Unit
HV	High Voltage (>132 000V)
HVAC	Heating, Ventilation, & Air Conditioning
HX	Heat Exchanger
HyS	Hybrid Sulfur
I&C	Instrumentation and Control
I/O	Input/Output
IBC	International Building Code
ICC	International Code Council
ICD	Initial Conceptual Design
ICEA	Insulated Cable Engineers Association
IDAPA	Idaho Administrative Procedure Act
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IFC	International Fire Code
IFGC	International Fuel Gas Code
IHX	Integrated Heat Exchanger
IHXA	Intermediate Heat Exchanger A
IHXB	Intermediate Heat Exchanger B
IMC	International Mechanical Code
IMS	Information Management Systems
INL	Idaho National Laboratory
IPMC	International Property Maintenance Code
ISA	International Society of Automation
ISO	International Organization for Standardization
JB	Junction Box
kg/s	Kilogram per second
kV	Kilovolt (1000 Volts)
kl/h	Kilolitre per hour
kPa	Kilopascal (1000 Pascal)
kW	Kilowatt (1000 Watts)
LCD	Liquid Crystal Display
LCP	Local Control Panel
LRFDS	Load and Resistance Factor Design Specification

Abbreviation or Acronym	Definition
LV	Low Voltage (<1000 V)
MBMA	Metal Building Manufacturers Association
MCC	Motor Control Center
MCR	Mission Critical Requirement
MDB	Main Distribution Board
MES	Manufacturing Execution System
MPa	Megapascal = million Pascal
MTI	M-Tech Industrial (Pty) Ltd.
MV	Medium Voltage (>1000V< 132 000V)
MW	Megawatt (Million Watts)
N	Speed
NBIMS	National BIM Standards Project Committee
NEC	National Electrical Code
NEMA	National Electrical Manufacturers Association
NEPA	National Environmental Policy Act
NESC	National Electrical Safety Code
NFPA	National Fire Protection Association
NGNP	Next Generation Nuclear Plant
NHI	National Hydrogen Institute
NIST	National Institute of Standards and Technology
NQA-1	ASME NQA-1 2000, Quality Assurance for Nuclear Facilities
OPC	Operating Procedure Checklist
OSHA	Occupational Safety and Health Administration
P	Pressure
P&ID	Piping and Instrument Diagram
PBMR	Pebble Bed Nuclear Reactor (RSA)
PCDR	Preconceptual Design Report
PCFC	Preconceptual Facility Configurations
PCHX	Printed Circuit Heat Exchanger
PCS	Process Control System
PDA	Potential Deviation Analysis
PDMS	Project Data Management System
PDS	Plant Design System
PFD	Process Flow Diagram
PHA	Preliminary Hazard Analysis
PHTS	Primary Heat Transport System
PLC	Programmable Logic Controller
PLCs	Programmable Logic Controllers
PMN	Support Manager
PRV	Pressure Relief Valve
psig	Pound per square inch gauge

Abbreviation or Acronym	Definition
PSM	Support Modeler
QC	Quality Control
QCP	Quality Control Plan
RCS	Reactivity Control System
RIS	Relational Interface System
RPV	Reactor Pressure Vessel
RSA	Republic of South Africa
SBS	System Breakdown Structure
SCADA	Supervisory Control and Data Acquisition System
scfm	Standard cubic feet per minute
SDD	System Design Description
SDI	Steel Door Institute or Steel Deck Institute
SG	Steam Generator
SHEQ	Safety, Health, Environmental and Quality
SHTS	Secondary Heat Transport System
SI	Sulfur Iodine
SIL	Safety Integrity Level
SIS	Safety Instrument System
SJI	Steel Joist Institute
SNM	Special Nuclear Materials
SPEL	SmartPlant Electrical
SPF	SmartPlant Foundation
SPMat	SmartPlant Material
SPR	SmartPlant Review
SPS	Standby Power System
SR	Safety Requirement
SRM	System Requirement Manual
SSC	Systems Structures and Components
SSDT	Small Scale Development Test
SSS	Site Selection Study
SSSB	Specification for Structural Steel Buildings
STD	Standard
T	Temperature
T&FR	Technical and Functional Requirement
TBD	To Be Determined
TDL	Technology Development Loop
TDRM	Technology Development Road Map
TEDS	Transducer Electronic Data Sheet
TEMA	Tubular Exchanger Manufacturers Association
THTR	Thorium High Temperature Reactor
TIA	Telecommunications Industry Association

Abbreviation or Acronym	Definition
TRL	Technology Readiness Level
TSR	Technical Safety Requirement
UL	Underwriters Laboratories
UL	Underwriters' Laboratories
UPC	Uniform Plumbing Code
UPS	Uninterruptable Power Supply
UUT	Unit Under Test
V&V	Verification and Validation
VHTGR	Very High Temperature Gas-Cooled Reactor
VL	Valve
VSD	Variable Speed Drive
wb	Wet Bulb
WBS	Work Breakdown Structure
WEC	Westinghouse Electric Company
WE-SA	Westinghouse Electric - South Africa
ϵ	Strain

SUMMARY AND CONCLUSIONS

The Technology Development Loop (TDL) is a high temperature high pressure helium test system. The TDL is capable of providing helium at a temperature of up to 950 °C, pressure of up to 9.6 MPa(g) and a mass flow rate of up to 3.65 kg/s. The objective of the TDL is to provide a system capable of supplying helium at the desired temperature, pressure and mass flow to components under test and to provide a means of measuring the performance of the component under test. The TDL design is based on the test specifications of various components as listed in the Technology Development Road Maps (TDRM). These specifications were used to guide the design process, taking into consideration that the TDL's design life is 40 years and therefore incorporating flexibility into the design that allows the TDL to be used for a multitude of applications that might be required in the future. The TDL's design is modular, therefore allowing sections of a TDL or complete TDLs to be installed as the need arises. The TDL's design also allows for interfacing with other facilities such as the Component Qualification Loop1 (CQL1). In the TDL's design, the focus was placed on designing the TDL, where possible, with proven robust technology and components of the shelf. This was done to give the TDL conditioning loop a high reliability as well as robustness.

The TDL, in its basic form, consists of two conditioning loops, supplying helium at the desired conditions to test stations consisting of either test vessels or simple flange connections where components under test can be installed and tested. The latter will be under controlled and monitored conditions. This report describes the preconceptual design of the TDL. Initial thermal hydraulic calculations on systems level served as input to initial thermal hydraulic and mechanical design calculations on subsystem and component level. The pre-conceptual design forms a base for further design and points towards areas where future work and further investigation is required.

6. TECHNOLOGY DEVELOPMENT LOOP (TDL)

6.1 TDL: Design Inputs and Requirements

The TDL design process was primarily driven by the test requirements as listed in the Technology Development Road Maps (TDRM). Components to be tested with their respective test specifications were identified in the TDRM and served as input into the TDL design. These typically included Intermediate Heat Exchanger (IHX), Mixing chambers, hydrogen production items as listed in the table below.

Table 6-1: Test Specification Requirements

Test Description	Test number
IHX A (Metallic)	
Testing of integrated compact heat exchanger module (~1.2MW)	[WEC-TS-IHXA-013] in Reference [6-6].
Establishing ASME III Code Case for Metallic Compact Heat Exchanger Designs	[WEC-TS-IHXA-014] in Reference [6-6].
Multi-module (3 x 1.2 MW) heat transfer testing	[WEC-TS-IHXA-016] in Reference [6-6].
IHX A (Ceramic)	
Testing of integrated compact heat exchanger module (~1.2MW)	[WEC-TS-IHXA-031] in Reference [6-6].
Establishing ASME III Code Case for ceramic Compact Heat Exchanger Designs	[WEC-TS-IHXA-032] in Reference [6-6].
Multi-module (3 x 1.2 MW) heat transfer testing	[WEC-TS-IHXA-034] in Reference [6-6].
IHX B	
Testing of integrated compact heat exchanger module (~1.2MW)	[WEC-TS-IHXB-013] in Reference [6-6].
Establishing ASME III Code Case for Metallic Compact Heat Exchanger Designs	[WEC-TS-IHXB-014] in Reference [6-6].
Multi-module (3 x 1.2 MW) heat transfer testing	[WEC-TS-IHXB-016] in Reference [6-6].
Mixing Chamber	
Enhanced mixing devices test specification	[WEC-TS-MC-001] in Reference [6-6].
Vibration damping devices test specification	[WEC-TS-MC-002] in Reference [6-6].
Partial or full scale flow mixing chamber model test specification	[WEC-TS-MC-003] in Reference [6-6].

HTSE (Hydrogen production)	
Hydrogen Plant Alternative Study, HTSE Review Package	Reference [6-5]
HTS (Hot Gas Duct)	
Performance and environmental testing of prototypical high temperature and low temperature HGD/insulation system	[WEC-TS-PIP-009] in Reference [6-6].

The IHX A (Metallic), IHX A (Ceramic) and IHX B test specifications include the steady state testing of a single (1.2 MW IHX module) as well as 3 x 1.2 MW IHX modules. It also includes transient temperature and pressure testing of the IHX modules and establishment of code cases for ASME. Due to a lack of information and depth of the current NNGP design, other transient tests cannot be specified now and will be done in future work as the design matures and more detail becomes available.

The mixing chamber tests include the testing of mixing devices as well as vibration damping devices. Since the TDL is not able to provide the full-scale flow rate, testing will be done on scale models of the mixing chamber.

Little information is available about the High Temperature Steam Electrolysis (HTSE) tests. From the information available, the TDL will supply hot helium at a given pressure to the HTSE process coupling heat exchanger.

From the Helium Transport System (HTS) Hot Gas Duct (HGD) test specification, the TDL need to supply hot helium at a given temperature and pressure to do HGD specific tests. The TDL will not be able to supply the full scale HGD mass flow and therefore scale models will have to be tested in the TDL.

The main design consideration driving the TDL size was the IHX test requirements since no information regarding the mass flow and thermal heat transfer for the HGD and Mixing chamber tests were available. It was therefore decided to base the TDL design mass flow on the mass flow required for multi-module (3 x 1.2 MW) heat transfer testing for IHX A. With this mass flow as basis, the TDL's component sizes were calculated to provide the desired mass flows, pressures and temperatures for the other test requirements listed above.

As a result of the 40 year life span requirement of the plant, the TDL conditioning loop component capacities were oversized by $\approx 30\%$ to allow for future expansion or unforeseen conditions. The modular approach of the TDL also provides the capability to build additional TDL's or sections thereof as the need arises. The design of the TDL was also driven by the fact that other components will be tested in the future for which the requirements are not currently known. The design therefore incorporates test stations with flange connections where future test components or test vessels can be installed.

Little or no information is available on the pressure and temperature transient tests as listed in the test requirements above. It was therefore decided to include these tests in future

work and to design the TDL for transient events once the test specifications are more clearly defined.

6.2 TDL: Thermal Hydraulic Design

6.2.1 System-Level Process Design

The system process design originated from the NGNP CTF Recommendation and Feasibility study as referenced in [6-1]. The design was further developed in conjunction with the test specifications (listed above in Table 6-1) to address the requirements and tests specifications to provide a test system with flexibility that allows testing of various types of components. The TDL consists of a high temperature high-pressure helium test loop with a Primary Loop and a Secondary Loop. Both the Primary Loop and Secondary Loop consist of a conditioning loop and a testing loop. The conditioning loop houses the circulator, cooler, heater (only in Primary Loop) and recuperator. Both conditioning loops provide the selected mass flows, temperatures and pressures to the test loops where component testing can be facilitated.

Steady state analyses of the test requirements were performed and the component sizes (heat transfer requirement), mass flows, temperatures, pressures as well as auxiliary requirements such as cooling water flow and power supply were determined from each steady state calculation. Additionally, the Heating Ventilation and Air Conditioning (HVAC) and Helium Inventory Control System (HICS) requirements were calculated and serve as an input to the auxiliaries specification requirements for the TDL as shown in Reference [6-26]. Inputs to the steady state calculations were obtained from the test requirements in the TDRMs. The inputs, assumptions and calculations are provided in Reference [6-7] to [6-13]. The following calculations were used in the process design of the TDL:

6.2.1.1 IHX A (Ceramic and Metallic)

This section refers to the following test specification(s):

- WEC-TS-IHXA-013 in Reference. [6-6].
- WEC-TS-IHXA-016 in Reference. [6-6].
- WEC-TS-IHXA-031 in Reference. [6-6].
- WEC-TS-IHXA-034 in Reference. [6-6].

The IHX inlet and outlet flow conditions were provided in the TDRM Reference [6-2] and was used as input into the model. The mass flow needed to give the desired heat transfer rate between the IHX primary and secondary side was then calculated. The component sizes (heat transfer requirement) were determined by means of an energy balance after which the auxiliary supply requirements for the TDL were calculated.

Assumptions

- Adiabatic flow conditions assumed in the TDL, no heat loss to surroundings.

- Circulator outlet flow temperature = 85 °C (Assume isentropic efficiency ~ 72.5%, Initial estimate to determine heat input into TDL for the Process Flow Diagram (PFD))
- Recuperator effectiveness assumed to be 80%
- Coolers are assumed to be water-cooled shell and tube heat exchangers
- No pressure drop through pipes and components
- Circulator inlet flow temperature = 80 °C
- Cooler inlet water temperature = 20 °C
- Cooler outlet water temperature = 45 °C
- Cooling water pressure = 300 kPa

Inputs

- Primary loop nominal Pressure = 9000 kPa (Reference [6-2])
- Secondary loop nominal Pressure = 9600 kPa (Reference [6-2])
- IHX Inlet and outlet temperature conditions (Reference [6-2])

The results of the steady state analyses are indicated on the PFD [MT-TLDR-TDL-02-0005 and MT-TLDR-TDL-02-0006] in Reference [6-7] and the calculations are shown in the calculation sheet [MT-TLCR-CALC-T-0601] in Reference [6-7]

6.2.1.2 IHX B [WEC-TS-IHXB-013; WEC-TS-IHXB-016]

The IHX B inlet and outlet flow conditions were given in the TDRM (Reference[6-3]) and was used as input into the model. The mass flow needed to give the desired heat transfer rate between the IHX primary and secondary side could then be calculated. The component sizes (heat transfer requirement) were determined by means an energy balance and the auxiliary supply needs to the TDL calculated.

Assumptions

- Adiabatic flow conditions assumed in the TDL, no heat loss to surroundings.
- Circulator outlet flow temperature = 85 °C (Assume isentropic efficiency ~ 72.5%, Initial estimate to determine heat input into TDL for PFD's)
- Recuperator effectiveness assumed to be 80%
- Coolers are assumed to be water cooled shell and tube heat exchangers
- No pressure drop through pipes and components
- Circulator inlet flow temperature = 80 °C
- Cooler inlet water temperature = 20 °C
- Cooler outlet water temperature = 45 °C
- Cooling water pressure = 300 kPa

Inputs

- Primary loop nominal Pressure = 9000 kPa (Reference [6-3])
- Secondary loop nominal Pressure = 9600 kPa (Reference [6-3])

- IHX Inlet and outlet temperature conditions (Reference [6-3])

The results of the steady state analyses are indicated on the PFD [MT-TLDR-TDL-02-0007 and MT-TLDR-TDL-02-0008] in Reference [6-7] and the calculations are shown in the calculation sheet [MT-TLCR-CALC-T-0601] in Reference [6-7].

6.2.1.3 Mixing Chamber

This section refers to the following test specification(s):

- WEC-TS-MC-001 in Reference. [6-6]
- WEC-TS-MC-002 in Reference. [6-6]
- WEC-TS-MC-003 in Reference. [6-6]

The Mixing Chamber inlet and outlet temperatures were given in the TDRM (Reference [6-4]) and were used as input into the model. The Mixing Chamber tests do not indicate a required mass flow and it was therefore assumed that the total mass flow for the Mixing Chamber tests are equal to the mass flow required for 3 x 1.2 MW IHX A modules tests (3.65 kg/s). An energy balance was performed to determine the mass flows for the cold and hot leg inputs into the Mixing Chamber according to the specified cold and hot leg inlet temperatures and combined outlet temperature as specified in the test requirements. The TDL component thermal sizes were determined by means an energy balance. The auxiliary supply requirements to the TDL were calculated as required for mixing chamber testing.

Assumptions

- Adiabatic flow conditions assumed in the TDL, no heat loss to surroundings.
- Circulator outlet flow temperature = 85 °C (Assume isentropic efficiency $\approx$ 72.5%, Initial estimate to determine heat input into TDL for PFD's)
- Recuperator effectiveness assumed to be 80%
- Cooler is assumed to be water cooled shell and tube heat exchangers
- No pressure drop through pipes and components
- Circulator inlet flow temperature = 80 °C
- Cooler inlet water temperature = 20 °C
- Cooler outlet water temperature = 45 °C
- Cooling water pressure = 300 kPa

Inputs

- TDL nominal Pressure = 9000 kPa (Reference [6-4])
- Cold leg Temperature = 659 °C (Reference [6-4])
- Hot leg Temperature = 900 °C (Reference [6-4])
- Mixed Temperature = 825 °C (Reference [6-4])
- Total mass flow equal to mass flow as calculated for 3 x 1.2 MW IHX A modules

The results of the steady state analyses are indicated on the PFD [MT-TLDR-TDL-02-0004] in Reference [6-8] and the calculations are shown in calculation sheet [MT-TLDR-CALC-T-0602] in Reference [6-8].

6.2.1.4 Hydrogen Production (HTSE process) (Reference [6-5])

One of the test requirements state that a process coupling heat exchanger for the High Temperature Steam Electrolysis process need to be tested. The HTSE heat exchanger is used to heat steam and air for the hydrogen production process. The steam and air inlet and outlet flow conditions as well as steam and air mass flows were given in the (Reference [6-5]) and were used as input into the model. The calculation was then used to determine if the TDL heating capacity (as specified for 3 x 1.2 MW IHX A test modules) will be adequate for the HTSE tests.

Assumptions

- Adiabatic flow conditions assumed in the TDL, no heat loss to surroundings.
- No pressure drop through pipes and components

Inputs

- TDL nominal helium pressure = 9000 kPa
The following test requirements were given (Reference [6-5]):
- Air inlet temperature = 176 °C
- Air inlet pressure = 5600 kPa
- Air outlet temperature = 870 °C
- Air outlet pressure = 5600 kPa
- Air mass flow = 0.76 kg/s
- Steam inlet temperature = 396 °C
- Steam inlet pressure = 5600 kPa
- Steam outlet temperature = 870 °C
- Steam outlet pressure = 5600 kPa
- Steam mass flow = 0.62 kg/s

From the calculations, shown in calculation sheet [MT-TLDR-CALC-T-0606] in Reference [6-12], the thermal requirement for the HTSE process heat exchanger was calculated to be 1.278 MW, indicating that the TDL heating capacity will be adequate to do HTSE process coupling heat exchanger tests.

6.2.1.5 Heat Transport System Hot Gas Duct

This section refers to the following test specification(s):
WEC-TS-PIP-009 in Reference [6-6]

The HTS HGD temperature was provided in a test specification [WEC-TS-PIP-009] in Reference [6-6] and was used as input into the model. The HGD tests do not indicate a required

mass flow and it was therefore assumed that the mass flow for HGD testing is equal to the mass flow required for 3 x 1.2 MW IHX A modules testing (3.65 kg/s). The TDL component thermal sizes were determined by means an energy balance. The auxiliary supply needs to the TDL were calculated as required for HGD testing.

Assumptions

- Adiabatic flow conditions assumed in the TDL, no heat loss to surroundings.
- Circulator outlet flow temperature = 85 °C (Assume isentropic efficiency $\approx$ 72.5%, Initial estimate to determine heat input into TDL for PFD's)
- Recuperator effectiveness assumed to be 80%
- Cooler is assumed to be water cooled shell and tube heat exchangers
- No pressure drop through pipes and components
- Circulator inlet flow temperature = 80 °C
- Cooler inlet water temperature = 20 °C
- Cooler outlet water temperature = 45 °C
- Cooling water pressure = 300 kPa

Inputs

- TDL nominal Pressure = 9000 kPa [WEC-TS-PIP-009] in Reference [6-6].
- HGD temperature conditions [WEC-TS-PIP-009] in Reference [6-6]
- Mass flow equal to mass flow as calculated for 3 x 1.2 MW IHX A modules

The results of the steady state analysis are indicated on the PFD [MT-TLDR-TDL-02-0003] in Reference [6-9] and the calculations are shown in calculation sheet [MT-TLDR-CALC-T-0603] in Reference [6-9].

6.2.1.6 Heating Ventilation and Air Conditioning Requirements

The objective of the calculation is to determine for a single TDL the heat loss to the atmosphere to serve as an input for the HVAC requirements specification given in Reference [6-26]. The calculation is only based on the “hot” section of a single TDL in the IHX test setup configuration. The “hot” section refers to all components not insulated on the outside as a result of the design assumptions and specification (where applicable). Both heaters are included in the calculation for a conservative approach (only one heater used while testing IHX). Assuming temperatures for the TDL components as well as the ambient temperature, heat transfer equations were used to calculate the heat loss from the TDL to the surrounding environment. The heat loss calculated for the TDL serves as input for the HVAC requirement. The results obtained are shown in Table 6-2.

Assumptions

- Building to be kept at 20 °C
- No heat loss from the cold pipes (perfect insulation)
- No heat loss from cooler and circulator vessels (perfect insulation)

- TDL HGD, IHX test vessel, heaters and recuperator pressure vessels' surface temperature are 200 °C
- TDL hot gas duct lengths as per initial component placement

Inputs

- IHX test vessel, heater and recuperator pressure vessel sizes
- TDL HGD lengths and diameters

*Results obtained***Table 6-2: The HVAC results for a single TDL**

Description	Unit	Value
TDL Hot Gas Ducts	kW	302
IHX test vessel	kW	228
Recuperator vessels	kW	251
Heaters	kW	208
Total	kW	989

The calculations are shown in calculation sheet [MT-TLDR-CALC-T-0604] in Reference [6-10].

6.2.1.7 Helium Inventory Control System requirements

In order to determine the HICS requirements, initial pipe diameters were calculated based on an average gas velocity of 20 m/s. Initial estimates of pipe lengths were made and the volume calculated accordingly. Initial estimates of component sizes and volumes were made based on engineering judgment. The total helium volume in the system was calculated and the requirement for the HICS determined. The results obtained for the primary and secondary loops are shown in Table 6-3 and Table 6-4 respectively.

Assumptions

- TDL configuration set up as for IHX tests.
- Initial pipe lengths as per initial component placement and component sizes as per engineering judgment
- TDL to remain at 20 °C when pressurized or depressurized
- Pressurization and depressurization between 10 kPa – 9600 kPa
- Pressurization and depressurization time $\approx$ 7200 s (2 hours)
- 1/3 of cooler shell volume is helium
- 1/3 of circulator vessel shell volume is helium
- 2/3 of recuperator shell volume is helium
- 2/3 of IHX vessel shell volume is helium

- Volume of IHX vessel is divided equally between primary and secondary heat transport capacity

Inputs

- Pipe diameters based on 20 m/s average gas velocity calculation
- Pipe lengths, and component sizes as per calculation sheet [MT-TLDR-CALC-T-0607] in Reference [6-13].

*Results obtained***Table 6-3: HICS Requirements Primary Loop**

Description	Unit	Value
$P_{\text{range he}}$	kPa	10 - 9000
$T_{\text{he in}}$	°C	20
$T_{\text{he out}}$	°C	80
$d_{\text{internal supply pipe}}$	m	0.02
m_{he}	kg/s	0.105
$m_{\text{he total}}$	kg	759

Table 6-4: HICS Requirements Secondary Loop

Description	Unit	Value
$P_{\text{range he}}$	kPa	10 - 9600
$T_{\text{he in}}$	°C	20
$T_{\text{he out}}$	°C	80
$d_{\text{internal supply pipe}}$	m	0.02
m_{he}	kg/s	0.064
$m_{\text{he total}}$	kg	459

The calculations are shown in calculation sheet [MT-TLDR-CALC-T-0607] in Reference [6-13].

6.2.1.8 Cooling Water Requirements

The cooling water requirements were obtained from the steady state analyses of the different test requirements. The cooling water is primarily used for the primary and secondary loop coolers and is shown in Table 6-5 and Table 6-6.

Table 6-5: Primary cooler water supply requirement

Description	Unit	Value
P_w	kPa	300
$T_{w \text{ in}}$	°C	20
$T_{w \text{ out}}$	°C	45
m_w	kg/s	79.5

Table 6-6: Secondary cooler water supply requirement

Description	Unit	Value
P_w	kPa	300
$T_{w \text{ in}}$	°C	20
$T_{w \text{ out}}$	°C	45
m_w	kg/s	45.9

6.2.1.9 Component Size and Auxiliary Interface Results

The results obtained from the steady state calculations were compared with each other in order to determine what the maximum system requirements for each TDL component would be. As mentioned before, the TDL components were oversized by $\approx 30\%$ to allow for future expansion of the TDL and to cater for other types of tests not listed yet. These component sizes and auxiliary interface requirements such as water, power supply, HICS, HVAC and HTSE steam and air requirements are shown on the component size and interface PFD [MT-TLDR-TDL-02-0001] in Reference [6-14]. These and other interface requirements are also given in [6-26].

6.2.2 System Breakdown Structure

Figure 6-1 shows a schematic of the TDL System Breakdown Structure (SBS).

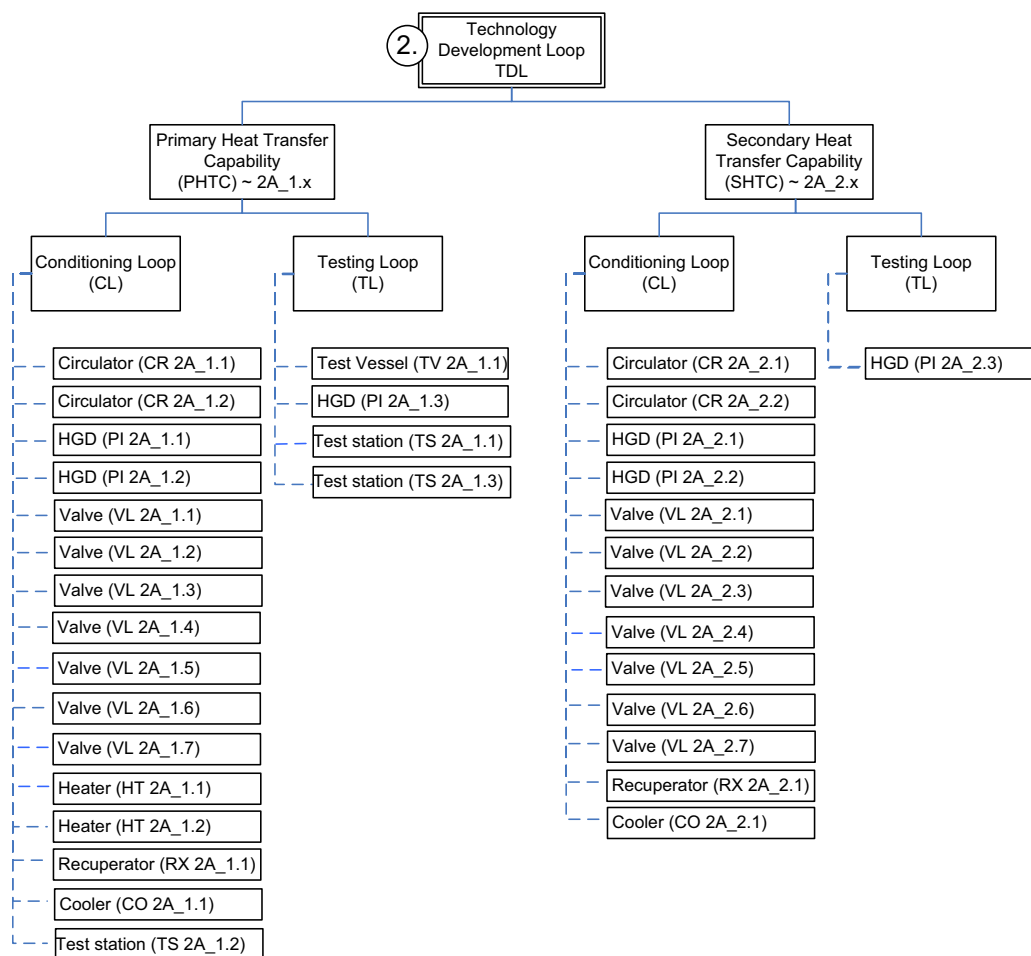


Figure 6-1: Schematic of the System breakdown structure.

A layout of the TDL and its components is shown later in this document (Figure 6-2) and its component sizes are indicated in the PFD [MT-TLDR-TDL-02-0001] in Reference [6-14].

6.2.3 Component Performance Specifications

The information obtained from the systems level process design is provided in this section and serves as input to the TDL component design.

6.2.3.1 Circulators

The system pressure drop was calculated and the calculation, assumptions and inputs are shown in calculation sheet [MT-TLDR-CALC-T-0605] in Reference [6-11].

Table 6-7: Primary loop circulator (CR 2A_1.1; CR 2A_1.2) performance specification

Description	Unit	Value
P_{he}	kPa	9000
$T_{he\ in}$	°C	80
ΔP_{system}	kPa	305
m_{he}	kg/s	4.75 (3.65)
Q_{th}	MW	0.122 (0.094)

Values in () indicate the component size without 30% safety margin. The primary loop circulator specification was obtained from the results of the 3 x 1.2 MW IHX A tests, this being the conservative case.

Table 6-8: Secondary loop circulator (CR 2A_2.1; CR 2A_2.2) performance specification

Description	Unit	Value
P_{he}	kPa	9600
$T_{he\ in}$	°C	80
ΔP_{system}	kPa	247
m_{he}	kg/s	4.75 (3.65)
Q_{th}	MW	0.0927 (0.0713)

Values in () indicate the component size without 30% safety margin. The secondary loop circulator specification was obtained from the results of the 3 x 1.2 MW IHX A tests, this being the conservative case.

It was decided to select one circulator that could be used in both the primary and secondary loop, this being based on the primary loop specifications.

6.2.3.2 Helium Transport System Cold Pipes

The TDL's HTS cold pipes are based on an average gas velocity of 20 m/s. Requirements are given in Table 6-9.

Table 6-9: HTS Cold pipes (PI 2A_1.1; PI 2A_2.1) performance specification

Description	Unit	Value
P_{he}	kPa	9600
$T_{he\ in}$	°C	417
$d_{internal}$	m	0.14
m_{he}	kg/s	3.65

The temperature was obtained from mixing chamber test results while the mass flow was obtained from the results of the 3 x 1.2 MW IHX A tests, these being the conservative cases.

6.2.3.3 Heat Transport System Hot Gas Ducts

The sizing of the TDL HGD was based on an average gas velocity of 20 m/s. The requirements are shown in Table 6-10.

Table 6-10: Heat Transport System Hot Gas Ducts (PI 2A_1.2; PI 2A_1.3; PI 2A_2.2; PI 2A_2.3) performance specification

Description	Unit	Value
P_{he}	kPa	9600
$T_{he\ in}$	°C	1000
$d_{internal\ liner}$	m	0.26
m_{he}	kg/s	3.65
$d_{pressure\ internal}$	m	0.5
$T_{pressure}$	°C	200

The temperature was obtained from the assumption that additional heating to achieve higher temperatures might be added in the future. The mass flow was obtained from the results of the 3 x 1.2 MW IHX A tests, these being the conservative cases.

6.2.3.4 Valves

The valves were divided into HTS control valves, HICS control valves and cooler water control valves. The valve requirements are presented in the tables below.

Table 6-11: HTS Control Valves performance specification

Description	Unit	Value
P_{he}	kPa	9600
$T_{he\ in}$	°C	85
$d_{internal\ pipe}$	m	0.14
m_{he}	kg/s	4.75 (3.65)
Values given relate to the following valves: (VL 2A_1.1; VL 2A_1.2; VL 2A_1.3; VL 2A_1.6; VL 2A_1.7; VL 2A_2.1; VL 2A_2.2; VL 2A_2.3; VL 2A_2.6; VL 2A_2.7)		

Values in () indicate the component size without 30% safety margin. The mass flow was obtained from the results of the 3 x 1.2 MW IHX A tests, this being the conservative case.

Table 6-12: HICS Valves performance specification

Description	Unit	Value
P_{he}	kPa	9600
$T_{he\ in}$	°C	85
$d_{internal\ pipe}$	m	0.02
m_{he}	kg/s	0.105
Values given relate to the following valves: VL 2A_1.4, VL 2A_2.4		

The HICS valve requirements were obtained from the HICS Requirements as given in the System Level Process Design above in Table 6-3 and Table 6-4.

Table 6-13: Cooler water control valves performance specification

Description	Unit	Value
P_w	kPa	300
$T_{w\ in}$	°C	20
$d_{internal\ pipe}$	m	0.07
m_w	kg/s	79.5
Values given relate to the following valves: VL 2A_1.5; VL 2A_2.5		

The cooler water control valve requirement was obtained from the component size PFD [MT-TLDR-TDL-02-0001] in Reference [6-14].

6.2.3.5 Heaters

The heater requirements are obtained from the systems level process design and are presented in the tables below.

Table 6-14: Primary loop heater 1 (HT 2A_1.1) performance specification

Description	Unit	Value
P_{he}	kPa	9000
$T_{he\ in}$	°C	625
$T_{he\ out}$	°C	950
m_{he}	kg/s	4.75 (3.65)
Q_{th}	MW	8.00 (6.16)
Q_e	MW	8.9

Values in () indicate the component size without 30% safety margin. The heater requirements were obtained from the results of the 3 x 1.2 MW IHX A tests, this being the conservative case. Q_e is the electrical input required, assuming 90% heat transfer efficiency.

Table 6-15: Primary loop heater 2 (HT 2A_1.2) performance specification

Description	Unit	Value
P_{he}	kPa	9000
$T_{he\ in}$	°C	85
$T_{he\ out}$	°C	659
m_{he}	kg/s	1.477 (1.136)
Q_{th}	MW	4.4 (3.38)
Q_e	MW	4.9

Values in () indicate the component size without 30% safety margin. The heater requirements were obtained from the results of the Mixing Chamber tests, this being the conservative case. Q_e is the electrical input required, assuming 90% heat transfer efficiency.

6.2.3.6 Recuperators

The primary and secondary loop recuperator requirements are obtained from the systems level process design and are presented in the tables below.

Table 6-16: Primary loop recuperator (RX 2A_1.1) performance specification

Description	Unit	Value
P_{he} (Hot side)	kPa	9000
$T_{he\ in}$ (Hot side)	°C	950
$T_{he\ out}$ (Hot side)	°C	258
m_{he} (Hot side)	kg/s	4.75 (3.65)
P_{he} (Cold side)	kPa	9000
$T_{he\ in}$ (Cold side)	°C	85
$T_{he\ out}$ (Cold side)	°C	777
m_{he} (Cold side)	kg/s	4.75 (3.65)
Q_{th}	MW	17.04 (13.11)

Values in () indicate the component size without 30% safety margin. The recuperator requirements were obtained from the results of the Hot Gas Duct tests, this being the conservative case.

Table 6-17: Secondary loop recuperator (RX 2A_2.1) performance specification

Description	Unit	Value
P_{he} (Hot side)	kPa	9600
$T_{he\ in}$ (Hot side)	°C	900
$T_{he\ out}$ (Hot side)	°C	275

Description	Unit	Value
m_{he} (Hot side)	kg/s	4.75 (3.65)
P_{he} (Cold side)	kPa	9600
$T_{he\ in}$ (Cold side)	°C	85
$T_{he\ out}$ (Cold side)	°C	737
m_{he} (Cold side)	kg/s	4.75 (3.65)
Q_{th}	MW	15.39 (11.84)

Values in () indicate the component size without 30% safety margin. The recuperator requirements were obtained from the results of the 3 x 1.2 MW IHX A tests, this being the conservative case.

6.2.3.7 Coolers

The primary and secondary loop cooler requirements are obtained from the systems level process design and are presented in the tables below.

Table 6-18: Primary loop cooler (CL 2A_1.1) performance specification

Description	Unit	Value
P_{he}	kPa	9000
$T_{he\ in}$	°C	417
$T_{he\ out}$	°C	80
m_{he}	kg/s	4.75 (3.65)
P_w	kPa	300
$T_{w\ in}$	°C	20
$T_{w\ out}$	°C	45
m_w	kg/s	79.5 (61.1)
Q_{th}	MW	8.307 (6.39)

Values in () indicate the component size without 30% safety margin. The primary loop cooler requirements were obtained from the results of the Mixing Chamber tests, this being the conservative case.

Table 6-19: Secondary loop cooler (CL 2A_2.1) performance specification

Description	Unit	Value
P_{he}	kPa	9600
$T_{he\ in}$	°C	275
$T_{he\ out}$	°C	80
m_{he}	kg/s	4.75 (3.65)
P_w	kPa	300
$T_{w\ in}$	°C	20

Description	Unit	Value
$T_{w \text{ out}}$	$^{\circ}\text{C}$	45
m_w	kg/s	45.9 (35.3)
Q_{th}	MW	4.8 (3.69)

Values in () indicate the component size without 30% safety margin. The secondary loop cooler requirements were obtained from the results of the 3 x 1.2 MW IHX A tests, this being the conservative case.

6.2.3.8 Intermediate Heat Exchanger Test Vessel

The IHX tests vessel requirements as obtained from the systems level process design are presented in the tables below.

Table 6-20: IHX test vessel (TV 2A_1.1) performance specification

Description	Unit	Value
P_{he}	kPa	9600
$T_{he \text{ in}}$	$^{\circ}\text{C}$	1000
$d_{\text{internal vessel}}$	m	3.29
$d_{\text{internal liner}}$	m	3
L_{vessel}	m	6.89
$L_{\text{vessel liner}}$	m	6.6
$C_{\text{connections}}$		4 (min)
$d_{\text{connections internal}}$	m	0.5

The IHX test vessel requirements were obtained from test specifications [WEC-TS-IHXA-016; WEC-TS-IHXA-034 and WEC-TS-IHXB-016] in Reference [6-6], which requires 3 x 1.2 MW IHX tests, this being the worst case.

6.3 TDL: Component Design

The component design of the various TDL components is discussed in this section. Figure 6-2 provides a first order representation of some of the TDL components and their relative layout and position to one another.

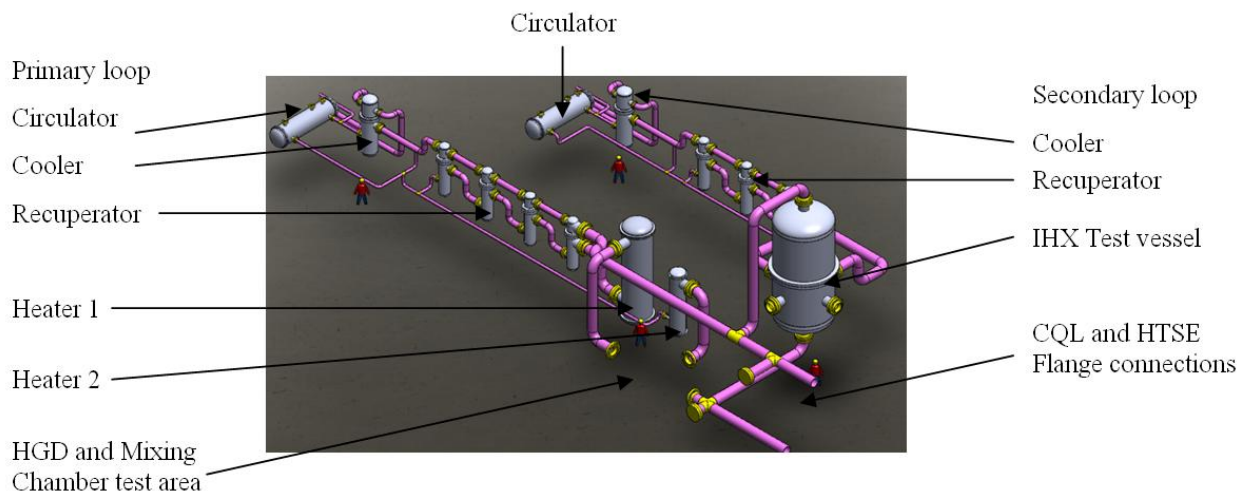


Figure 6-2: Components and layout of a TDL.

It was decided to use passive cooling for all the HTS components. The reason being that it simplifies the design, making it more robust and reduces the need for a backup cooling system as would be necessary with active cooling when the cooling system fails.

6.3.1 Technology Development Loop Circulator

This section refers to the following component(s): CR 2A_1.1; CR 2A_1.2; CR 2A_2.1; CR 2A_2.2.

No pressure drop for the TDL was calculated in the steady state analysis. The circulator design was however based on the assumption that the highest pressure drop over the system would be obtained when doing IHX relevant tests. The system pressure drop could then be calculated from initial pipe lengths and component pressure drops to obtain a circulator performance specification as shown in Table 6-21.

Since custom helium circulators are not freely available commercially, it was decided to use an “off the shelf” dynamic air circulator from GARDNER DENVER. For a first estimate the density ratio between air and helium was used to scale the circulator pressure rise and power, assuming that the volume flow through a dynamic machine will be the same for helium and air. The assumptions are given below and the inputs in Table 6-21.

Assumptions:

- Pressure rise scaled with density ratio between air and helium
- Power scaled with density ratio between air and helium
- Volume flow through machine to be the same in air and helium
- Air conditions = 20 °C @ 100 kPa
- Helium conditions = 80 °C @ 9000 kPa

Description	Unit	Value
P _{he}	kPa	9000
T _{he in}	°C	80
ΔP _{system}	kPa	305
m _{he}	kg/s	4.75 (3.65)
Q _{th}	MW	0.122 (0.094)

From the inputs and assumptions, an equivalent dynamic air circulator was selected with characteristics listed in Table 6-22. Figure 6-3 shows a schematic of the dynamic centrifugal circulator from GARDNER DENVER.

Description	Unit	Value
P _{air}	kPa	100
T _{air in}	°C	20
ΔP _{air}	kPa	30
V _{air}	m ³ /s	0.369
Q _e	kW	22.8



Using the density ratio between air and helium to scale the circulator the air circulator's performance in helium is predicted to be as shown in Table 6-23.

Table 6-23: Circulator performance in Helium

Description	Unit	Value
P_{he}	kPa	9000
$T_{he\ in}$	°C	80
ΔP_{he}	kPa	299
V_{he}	m ³ /s	0.369
m_{he}	kg/s	4.38
Q_e	kW	227

The machine has the capability to add additional stages to increase the pressure rise over the machine should this be required at a later stage.

Due to the high pressure level of the system, a large pressure differential would normally be present over the bearings and seals of the compressor-section on the circulator. It was decided to make use of a completely submerged motor concept, thus the complete circulator - including motor and compressor, would be placed inside a high-pressure vessel. The circulator and motor will have grease lubricated bearings, therefore no additional lubrication auxiliary is necessary. It is proposed that the circulator be operated at a low temperature (<80°C) so that no cooling auxiliary is required for the machine. Since this circulator is build for air conditions, it is recommended that a detailed analysis and immediate tests be done on the machine's mechanical strengths as well as performance when operated in helium. It is proposed that the same machine be used for both primary and the secondary circulator.

The pressure vessel which houses the circulator will have an internal diameter of 1.2 m and a length of 4 m. The vessel will have connections; one for the helium inlet and one for the helium outlet as well as connections where the power cables penetrate the vessel. Since the vessel does not contain hot helium, the shell temperature is expected to be below 100°C. The vessel shell thickness was calculated using ASME VIII Div 1. The proposed material is SA-516 GR.70 with a shell thickness of 58.4 mm. The data pack, which includes the component specification sheet [MT-TLDR-TDL-CMPT-05-0001] and calculation sheet [MT-TLDR-CALC-F-M-0608], are shown in [6-15]. Figure 6-4 shows the Circulator vessel and Figure 6-5 is a sectional-cut depiction of the circulator and circulator vessel.

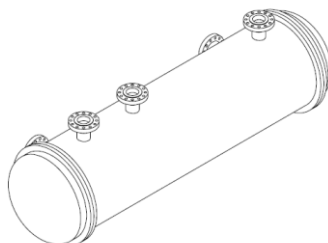


Figure 6-4: Circulator vessel.

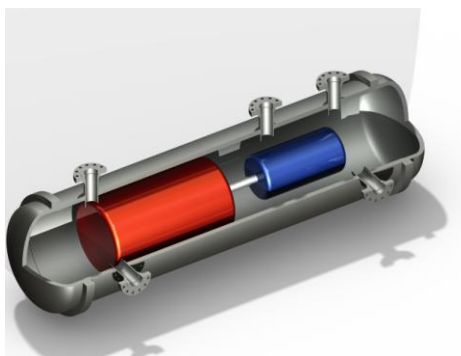


Figure 6-5: Cut-through of the proposed circulator and circulator vessel.

The circulator is a critical component and since failure of the circulator could lead to hot helium spreading to components in the TDL not designed for high temperatures, a standby/secondary circulator is recommended for both the primary and secondary loops. The secondary circulator will continue circulating helium when failure of the primary circulator occurs. This also allows routine maintenance to be carried out on a circulator whilst the TDL is operating, therefore not interrupting a test already in progress.

6.3.2 Helium Transport System “Cold Pipes”

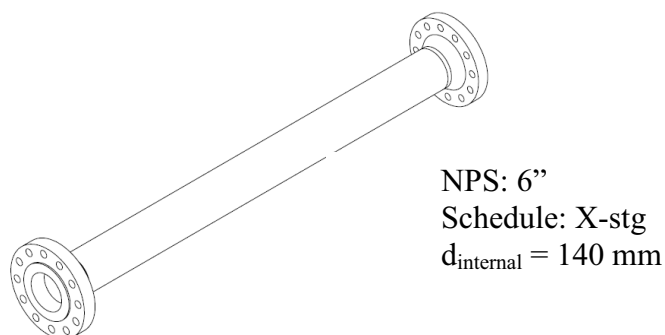
This Section refers to the following component(s): PI 2A_1.1; PI 2A_2.1

The HTS “Cold Pipes” are used in the conditioning loops where the gas temperatures are low. These pipes are insulated to prevent heat loss to the environment. The inputs from the component performance specifications are as shown in Table 6-24.

Table 6-24: Inputs from performance specification:

Description	Unit	Value
P_{he}	kPa	9600
$T_{he\ in}$	°C	417
$d_{internal}$	m	0.14
m_{he}	kg/s	3.65

Based on the thermo hydraulic inputs, the mechanical design was performed using ASME VIII Div 1 to do the pressure boundary calculations. The thickness of the pressure boundary was calculated to be 17 mm with the proposed material being SA-516 GR.70. The data pack, which includes the component specification sheet [MT-TLDR-TDL-CMPT-05-0002] and calculation sheet [MT-TLDR-CALC-F-M-0609], are shown in Reference [6-16]. Figure 6-6 shows the HTS “cold pipe”.

**Figure 6-6: HTS “Cold pipe”.**

6.3.3 Helium Transport System Hot Gas Duct

This section refers to the following component(s): PI 2A_1.2; PI 2A_1.3; PI 2A_2.2; PI 2A_2.3

The TDL’s HGD concept is used to convey high temperature high pressure helium between the TDL components. The hot gas is passed through an internal pipe (liner) surrounded by insulation to prevent the pressure boundary from getting excessively hot. The liner material needs to be able to withstand the high temperature, possibly Monel, but this and the thickness of this liner should be investigated further in future. The pressure boundary itself is used to contain the pressure. The pressure boundary is not insulated in order to lose heat to the surroundings preventing it from heating up to the internal gas temperature over a period of time.

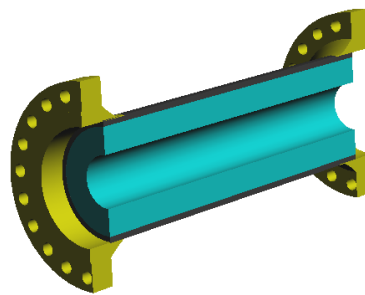
A general maximum gas velocity assumption for hot gas test systems is 60 m/s. The internal gas flow liner diameter was calculated based on a 20 m/s average gas velocity to be conservative and to allow for future expansion and flexibility of the TDL. The insulation thickness could then be determined, based on a conservative thermal conductivity of 0.5 W/mK, to give a pressure boundary outside temperature of 200 °C. The inside diameter of the pressure boundary could then be determined based on the insulation thickness. The inputs from the component performance specifications are as given in Table 6-25.

Table 6-25: Inputs from performance specification

Description	Unit	Value
P_{he}	kPa	9600
$T_{\text{he in}}$	°C	1000
$d_{\text{internal liner}}$	m	0.26
m_{he}	kg/s	3.65
$d_{\text{pressure internal}}$	m	0.5
T_{pressure}	°C	200
$t_{\text{insulation}}$	m	0.12

The gas temperature was assumed at 1000°C instead of 950 °C. This was done to allow for flexibility of the design for future requirements that might require higher temperatures.

Based on the thermo hydraulic inputs, the mechanical design was done using ASME VIII Div 1 to do the pressure boundary calculations. The liner was assumed to be 5mm thick and the insulation required to keep the pressure boundary below 200 °C 0.12m thick. The pressure boundary thickness was calculated to be 48 mm when SA-516 GR.70 material is the proposed material. The data pack, which includes the component specification sheet [MT-TLDR-TDL-CMPT-05-0003] and calculation sheet [MT-TLDR-CALC-F-M-0610], are shown in Reference [6-17]. Figure 6-7 shows a cut-through view of HTS HGD pressure boundary and internal insulation.



NPS: 24"
Schedule: 80
 $D_{\text{outer}} = 610 \text{ mm}$

Figure 6-7: Cut-through of the HTS HGD pressure boundary and internal insulation.

Further development of the HTS HGD is listed in future work and should address issues like expansion, insulation material, the effect of impurities on insulation material, temperature and pressure transients within the HGD as well as pressure boundary and liner materials and material thicknesses.

6.3.4 Control Valves

This section refers to the following component(s): VL 2A_1.1; VL 2A_1.2; VL 2A_1.3; VL 2A_1.6; VL 2A_1.7; VL 2A_2.1; VL 2A_2.2; VL 2A_2.3; VL 2A_2.6; VL 2A_2.7) and HICS Valves (VL 2A_1.4; VL 2A_2.4)

In a high pressure, -temperature and -purity helium environment, metallic components in contact with each other tend to diffuse (weld) together over a period of time. For this reason, all the control valves for the TDL are located in the “cold sections” (below 85 °C). The inputs from the component performance specifications are as given in Table 6-26 and Table 6-27.

Table 6-26: Control Valve inputs from performance specification:

Description	Unit	Value
P_{he}	kPa	9600
$T_{he\ in}$	°C	85
$d_{internal\ pipe}$	m	0.14
m_{he}	kg/s	4.75 (3.65)

Values in () indicate the component size without 30% safety margin.

Table 6-27: HICS Valve inputs from performance specification:

Description	Unit	Value
P_{he}	kPa	9600
$T_{he\ in}$	°C	85
$d_{internal\ pipe}$	m	0.02
m_{he}	kg/s	0.105

The valve manufacturer (VELAN) can supply the valve components in various types of materials which can be combined to “build up” the valve. Operating experience with VELAN valves was obtained in the Helium Test Facility (South Africa). The control valves component materials were chosen and are as follows:

Valve type: Parallel slide gate valve
 Valve body material: S/S, F304L, CF 3
 Disc seating surface: Stellite 6
 Seat surface: Stellite 6
 Stem: 316
 Valve nominal diameter: 150mm (6")

and for the HICS system the valves are as follows:

Valve type: Gate valve
 Valve body material: S/S, F304L, CF 3
 Disc seating surface: Stellite 6
 Seat surface: Stellite 6
 Stem: 316
 Valve nominal diameter: 20mm (3/4")

The data pack containing the component specification sheet [MT-TLDR-TDL-CMPT-05-0004] for the control valves and [MT-TLDR-TDL-CMPT-05-0005] for the HICS valves are given in Reference [6-18].

The valve sizes were selected based on the pipe diameters. The valve’s flow coefficient (CV) and actuators will be included in future work once a more detailed design and analysis of the TDL is available. The type of valve selected is parallel slide gate valves. This is however a first estimate and the valve type and actuator selection can be confirmed once more detail of the

TDL and the control thereof is available. Figure 6-8 shows a cut-through view of the parallel slide valve.

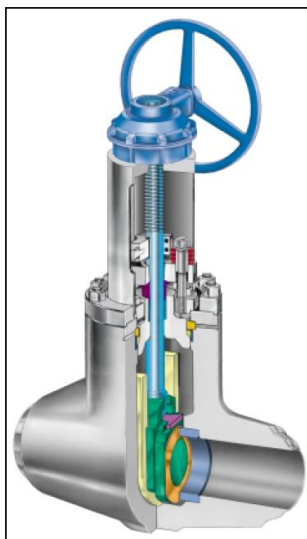


Figure 6-8: Cut section of the parallel slide valve.

6.3.5 Cooler Water Control Valves

This section refers to the following component(s): VL 2A_1.5; VL 2A_2.5

The primary and secondary loop cooler helium outlet temperature is controlled by varying the mass flow of the cooling water. The inputs from the component performance specifications are as given in Table 6-28.

Table 6-28: Cooler water control valve inputs from performance specification::

Description	Unit	Value
P_w	kPa	300
$T_{w \text{ in}}$	$^{\circ}\text{C}$	20
$d_{\text{internal pipe}}$	m	0.07
m_w	kg/s	79.5

For the preconceptual design, a gate valve was chosen from VELAN. The type of valve, valve CV and control actuator can be finalized once a more detailed design and analysis of the TDL is available. The valve diameter was selected based on the pipe diameter. The valve specifications are as follows:

Valve type:	Gate valve
Valve body material:	A105, WCB
Disc seating surface:	Stellite 6
Seat surface:	Stellite 6
Stem:	316

Valve nominal diameter: 65mm (2 1/2")
Flange: ASME PN 150

The data pack containing the component specification sheet [MT-TLDR-TDL-CMPT-05-0005] is given in Reference [6-19].

The valve sizes were selected based on the pipe diameters. The valve CV's and actuators will be included in future work once a more detailed design and analysis of the TDL is available. The type of valve selected is gate valves. This is however a first estimate and the valve type and actuator selection can be confirmed once more detail of the TDL and the control thereof is available. Figure 6-9 shows a cut-through section of the gate valve.

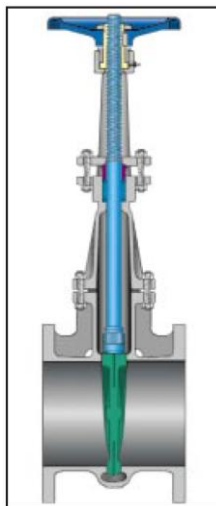


Figure 6-9: Cut section of the gate valve

6.3.6 Primary Loop Heater 1

This section refers to the following component(s): HT 2A_1.1

The inputs from the component performance specifications are as shown in Table 6-29.

Table 6-29: Primary loop heater 1 inputs from performance specification:

Description	Unit	Value
P_{he}	kPa	9000
$T_{he\ in}$	°C	625
$T_{he\ out}$	°C	950
m_{he}	kg/s	4.75 (3.65)
Q_{th}	MW	8.00 (6.16)
Q_c	MW	8.9

Values in () indicate the component size without 30% safety margin. Q_e is the electrical input required, assuming 90% heat transfer efficiency.

The TDL Heater 1 uses Graphite heating elements and assumes the power density of the HENDEL graphite heater from which the heater core volume is calculated. It was assumed that the TDL Heater has a similar “heater core geometric ratio” as the HENDEL test loop with which the core dimensions for the TDL Heater were calculated. The basis for this is that the HENDEL heater operated at 40bar, 4kg/s, 700°C to 1000°C, while the CTF TDL heater works at 90bar, 4.75kg/s, 625°C to 950°C. The pressure (therefore, higher density) in the CTF should enable better heat transfer and hence, a higher power density in the CTF TDL heater than in the HENDEL heater.

Additionally, the HENDEL element temperature was estimated to be 1300°C, while the experience with the HTTU (South Africa) is that the maximum continuous temperature for a graphite element is 1600°C. This supports the notion that the heater size could be reduced by using a higher heater power density. The diameter of the heater is 1.22 m and the length is 5.46 m. The heater core is insulated from the pressure boundary as was done with the HTS HGD. This prevents the pressure boundary from overheating and losing mechanical strength. The insulation thickness (0.3 m) was calculated based on a 200 °C pressure boundary outside shell temperature. The heater was oversized by 30 % to compensate for the heat loss to the environment and other unforeseen conditions and losses.

The pressure boundary calculations for the heater were done using ASME VIII Div 1. The heater vessel cylinder is 6 m long and has an outside diameter of 1.824 m. The vessel wall thickness is 88.9 mm when SA-516 GR.70 is selected as the preferred material. The vessel has a top and bottom flange to allow removal of the vessel heads to gain access to the vessel internals. The data pack containing the component specification sheet [MT-TLDR-TDL-CMPT-05-0007] and calculation sheet [MT-TLDR-CALC-F-M-0613] are shown in [6-20]. Figure 6-10 shows a depiction of a cut-through view of heater 1 and shows the graphite heating elements and pressure boundary insulation.

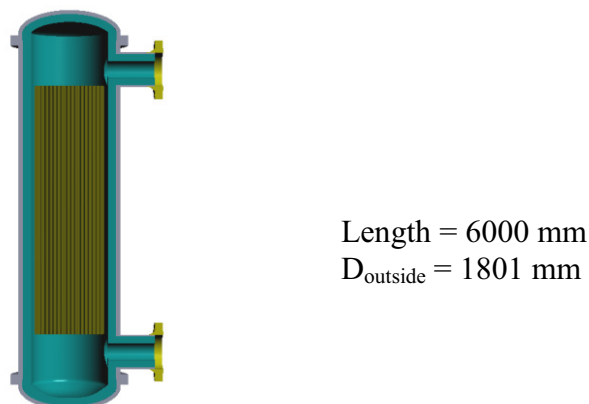


Figure 6-10: Cut through of heater 1 showing the pressure boundary, insulation and elements.

6.3.7 Primary Loop Heater 2

This section refers to the following component(s): HT 2A_1.2

The inputs from the component performance specifications are as shown in Table 6-30.

Table 6-30: Primary loop heater 2 inputs from performance specification:

Description	Unit	Value
P_{he}	kPa	9000
$T_{he\ in}$	°C	85
$T_{he\ out}$	°C	659
m_{he}	kg/s	1.477 (1.136)
Q_{th}	MW	4.4 (3.38)
Q_e	MW	4.9

Values in () indicate the component size without 30% safety margin. Q_e is the electrical input required, assuming 90% heat transfer efficiency.

The TDL Heater 2 uses Inconel heater elements and assumes the heat transfer per meter of Inconel wire to be 1 kW/m. With this as basis the required length of wire could be calculated. By selecting the pitch of the wire the size of the heater could be calculated. The diameter of the heater is 0.76 m and the length is 3.39 m. If required, the heat transfer per meter of the Inconel wire can be increased to 3 kW/m. The heater core is insulated from the pressure boundary as was done with the HTS HGD. This prevents the pressure boundary from overheating and losing mechanical strength. The insulation thickness (0.1 m) was calculated based on a 200 °C pressure boundary outside temperature.

The pressure boundary calculations for the heater were done using ASME VIII Div 1. The heater vessel cylinder is 4 m long and has an outside diameter of 0.96 m. The vessel wall thickness is 50.8 mm when SA-516 GR.70 material is used. The vessel has a top and bottom flange to allow removal of the vessel heads to gain access to the vessel internals. The data pack, which includes the component specification sheet [MT-TLDR-TDL-CMPT-05-0008] and calculation sheet [MT-TLDR-CALC-F-M-0614], are shown in Reference [6-21]. Figure 6-11 shows a schematic of heater 2 and its protrusions.

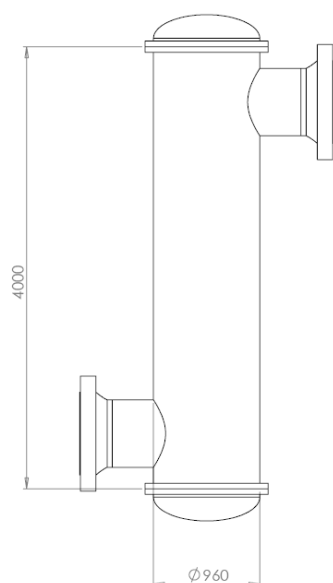


Figure 6-11: Schematic of heater 2 (dimensions in mm)

6.3.8 Primary Loop Recuperator and Secondary Loop Recuperator

This section refers to the following component(s): RX 2A_1.1, RX 2A_2.1

The recuperator is used to exchange thermal heat between the hot and cold helium streams. The recuperators are simple shell and tube heat exchangers with the hot helium stream passing thru the tubes and the colder stream passing thru the shell. The shell and tube heat exchanger was chosen due to its robustness. The inputs from the component performance specifications are as shown in Table 6-31 and Table 6-32.

Table 6-31: Primary loop recuperator inputs from performance specification

Description	Unit	Value
P_{he} (Hot side)	kPa	9000
$T_{he\ in}$ (Hot side)	°C	950
$T_{he\ out}$ (Hot side)	°C	258
m_{he} (Hot side)	kg/s	4.75 (3.65)
P_{he} (Cold side)	kPa	9000
$T_{he\ in}$ (Cold side)	°C	85
$T_{he\ out}$ (Cold side)	°C	777
m_{he} (Cold side)	kg/s	4.75 (3.65)
Q_{th}	MW	17.04 (13.11)

Values in () indicate the component size without 30% safety margin.

Table 6-32: Secondary loop recuperator inputs from performance specification:

Description	Unit	Value
P_{he} (Hot side)	kPa	9600
$T_{he\ in}$ (Hot side)	°C	900
$T_{he\ out}$ (Hot side)	°C	275
m_{he} (Hot side)	kg/s	4.75 (3.65)
P_{he} (Cold side)	kPa	9600
$T_{he\ in}$ (Cold side)	°C	85
$T_{he\ out}$ (Cold side)	°C	737
m_{he} (Cold side)	kg/s	4.75 (3.65)
Q_{th}	MW	15.39 (11.84)

Values in () indicate the component size without 30% safety margin.

The recuperators are standard units. Four recuperators are used in the primary loop and three for the secondary loop. This was done to minimize the material used in construction of the recuperators. The combined efficiency of the recuperators for the primary and secondary loops are 80% respectively. The recuperators consist of a shell and tube section as well as a pressure boundary. The pressure boundary is separated from the shell and tube section by means of a 100 mm gap filled with insulation. This is to prevent the pressure boundary from overheating and failing. It is proposed that the shell of the shell and tube section is made from Monel while the pressure boundary is 28 mm thick with an outside diameter of 688mm and is made from SA – 508 Gr. 3V. A single recuperator unit has a length of 3.64 m. The outside of the pressure boundary is not insulated to ensure that heat can be dissipated to the atmosphere, preventing the vessel from reaching the hot helium temperature inside the heat exchanger and thus overheating. The data pack containing the primary recuperator component specification sheet [MT-TLDR-TDL-CMPT-05-0009] and secondary recuperator component specification sheet [MT-TLDR-TDL-CMPT-05-0010] are shown in Reference [6-22]. Figure 6-12 shows a cut-through of a single recuperator unit and Figure 6-13 shows a layout of the recuperator vessel.

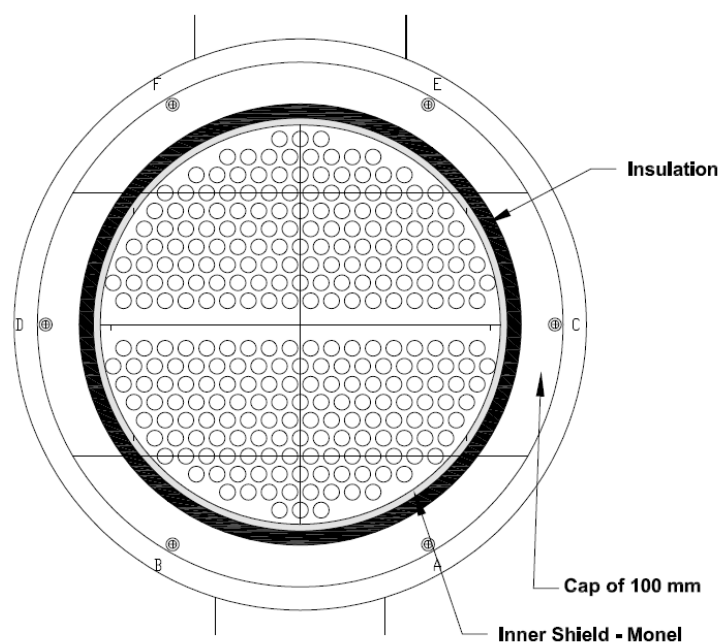


Figure 6-12: Cut through of the recuperator.

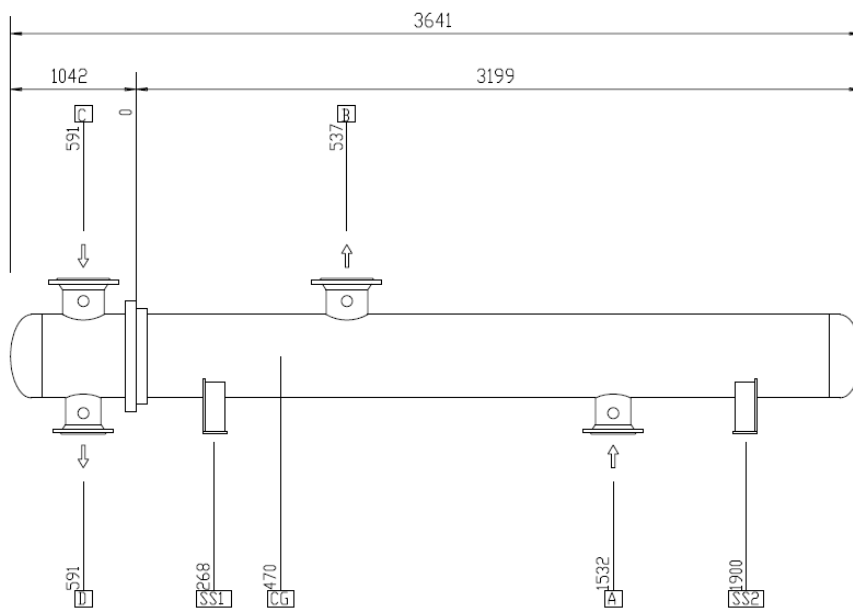


Figure 6-13: Layout of the recuperator vessel.

6.3.9 Primary Loop Cooler

This section refers to the following component(s): CL 2A_1.1

The primary loop cooler is used to reject heat from the primary loop helium stream before it enters the circulator. The circulator inlet temperature was limited to 80 °C which governed the cooler outlet temperature. A shell and tube cooler is proposed with the helium on the shell side and the water inside the tubes. The shell and tube heat exchanger was chosen due to its robustness. The inputs from the component performance specifications are as shown in Table 6-33.

Table 6-33: Primary loop cooler inputs from performance specification:

Description	Unit	Value
P_{he}	kPa	9000
$T_{he\ in}$	°C	417
$T_{he\ out}$	°C	80
m_{he}	kg/s	4.75 (3.65)
P_w	kPa	300
$T_{w\ in}$	°C	20
$T_{w\ out}$	°C	45
m_w	kg/s	79.5 (61.1)
Q_{th}	MW	8.307 (6.39)

Values in () indicate the component size without 30% safety margin.

The cooler is a single pass on the shell side and a two pass on the tube side heat exchanger. The shell has a diameter of 0.65 m, thickness of 44 mm and is made of SA-516 Gr 70 material. The shell has a length of 3.502 m. The data pack containing component specification sheet [MT-TLDR-TDL-CMPT-05-0011] is shown in Reference [6-23]. The cooler is placed upright to enable the internals to be lifted out by crane for cleaning or maintenance. A layout of the primary cooler is shown in Figure 6-14.

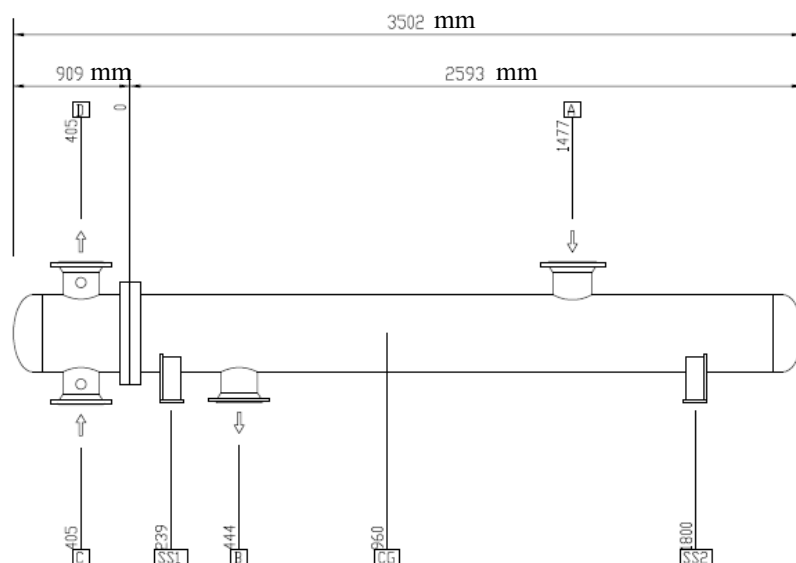


Figure 6-14: Layout of the primary cooler - refer to reference [6-23]

6.3.10 Secondary Loop Cooler

This section refers to the following component(s): CL 2A_2.1

The secondary loop cooler is used to reject heat from the secondary loop helium stream before it enters the circulator. The circulator inlet temperature was limited to 80 °C which governed the cooler outlet temperature. A shell and tube cooler was used with the helium on the shell side and the water inside the tubes. The shell and tube heat exchanger was chosen due to its robustness. The inputs from the component performance specifications are as shown in Table 6-34.

Table 6-34: Secondary loop cooler inputs from performance specification:

Description	Unit	Value
P_{he}	kPa	9600
$T_{he\ in}$	°C	275
$T_{he\ out}$	°C	80
m_{he}	kg/s	4.75 (3.65)
P_w	kPa	300
$T_{w\ in}$	°C	20
$T_{w\ out}$	°C	45
m_w	kg/s	45.9 (35.3)
Q_{th}	MW	4.8 (3.69)

Values in () indicate the component size without 30% safety margin.

The cooler is a single pass on the shell side and a two pass on the tube side heat exchanger. The shell has an outside diameter of 0.95 m, thickness of 51 mm and is made of SA-516 Gr 70 material. The shell has a length of 4.132 m. The data pack containing the component specification sheet [MT-TLDR-TDL-CMPT-05-0012] is shown in Reference [6-24]. The cooler is placed upright to enable the internals to be lifted out by crane for cleaning or maintenance. A layout of the secondary cooler is shown in Figure 6-15.

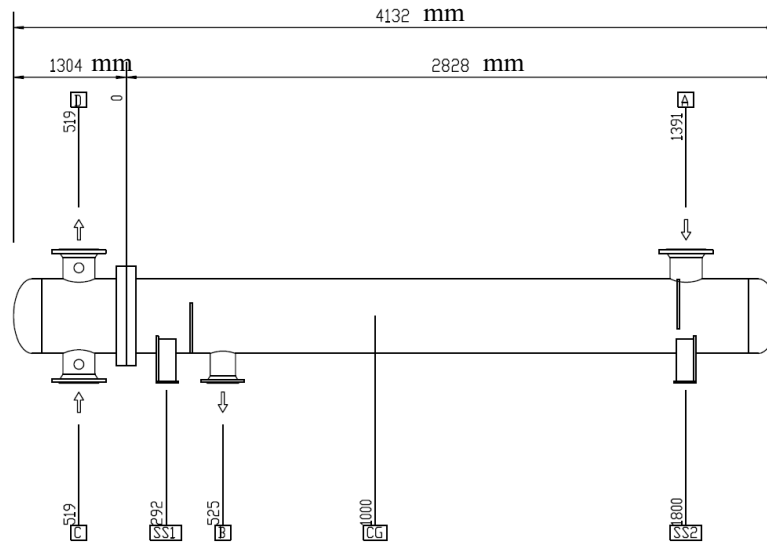


Figure 6-15: Layout of the secondary loop cooler – refer to reference [6-24]

6.3.11 Intermediate Heat Exchanger Test Vessel

This section refers to the following component(s): TV 2A_1.1

The TDL IHX test vessel originated from the requirement to test the heat transfer of 3 x 1.2 MW IHX modules coupled in some configuration. The test vessel was sized to a similar diameter and length in order to be able to simulate similar flow conditions to that of the proposed IHX A or B. The inputs from the component performance specifications are shown in Table 6-35.

Table 6-35: IHX test vessel inputs from performance specification:

Description	Unit	Value
P_{he}	kPa	9600
$T_{he\ in}$	°C	1000
$d_{internal\ vessel}$	m	3.29
$d_{internal\ liner}$	m	3.00
L_{vessel}	m	6.89
$L_{vessel\ liner}$	m	6.60
Connections		4.00 (min)
$d_{connections\ internal}$	m	0.50

The vessel's pressure boundary is passively cooled by means of insulation. The insulation is contained by means of a liner, possibly Monel, but the material and thickness of the liner needs to be confirmed in future work. Conservative insulation properties were obtained from operating experience at the Helium Test Facility (South Africa) and were used to calculate the insulation thickness to prevent the pressure boundary temperature from rising above 200 °C. this resulted in an insulation thickness of 145 mm. The vessel is not insulated on the outside of the pressure boundary to allow it to dissipate heat to the surroundings and prevent the vessel from reaching the internal gas temperature. The vessel is placed upright and split into two halves which are bolted together. This allows the top half to be removed for easy access to the equipment being tested. The vessel is equipped with four nozzles, equally spaced around the vessel's circumference and two additional nozzles, one at the top end one at the bottom of the vessel respectively. This nozzle placement allows for the testing of different configurations of IHX modules. Nozzles that are not being used will be blanked off.

The IHX test vessel has an outside diameter of 3.632 m and a wall thickness of 172 mm. the vessel has a length of 6m and is made from SA_240 material according to ASME Code VIII Div 1. The data pack containing the component specification sheet [MT-TLDR-TDL-CMPT-05-0013] and calculation sheet [MT-TLDR-CALC-F-M-0618] are shown in Reference [6-25]. Figure 6-16 shows the IHX test vessel and Figure 6-17 shows a cut-through view of the vessel and the proposed IHX test area within the vessel.

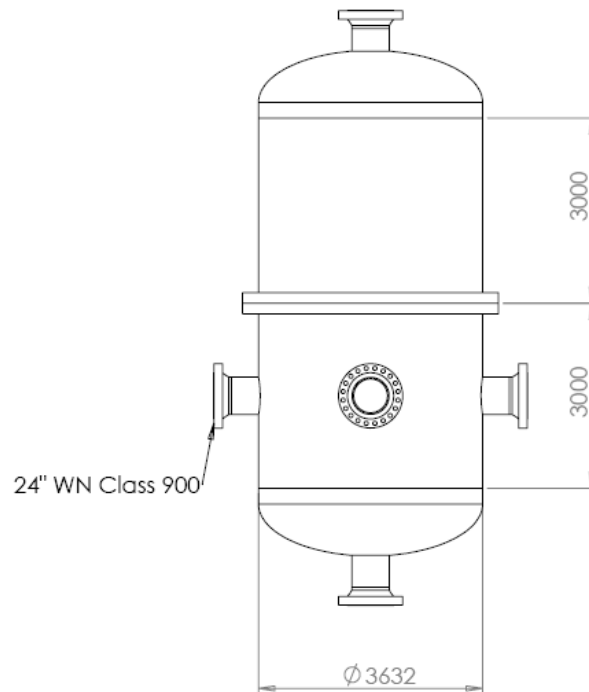


Figure 6-16: IHX test vessel (dimensions in mm)

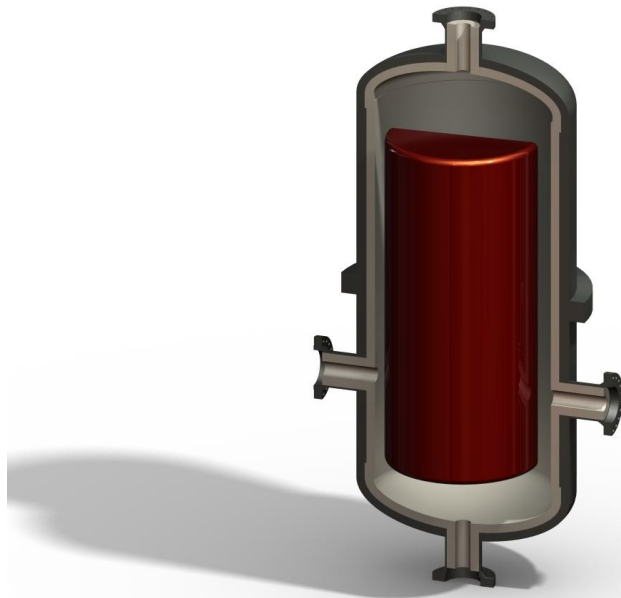


Figure 6-17: Cut through of the IHX vessel showing the proposed IHX test area.

6.3.12 Test Stations

This section refers to the following component(s): TS 2A_1.1; TS 2A_1.2; TS 2A_1.3

The test stations are flanged sections to facilitate the testing of various components. TS 2A_1.1 will initially be used for HGD and Mixing Chamber testing. The UUT can be connected to the flanges and the tests conducted with the required mass flow, pressure and temperature under measured conditions. TS 2A_1.2 will be used for the calibration of the TDL flow meters or other low mass flow meters and is instrumented for this purpose. TS 2A_1.3 will initially be used for HTSE process heat exchanger tests. These test stations can also be used for other types of tests as the need arises.

6.4 TDL: 3D Mechanical Layout

The mechanical layout of the TDL was driven by easy access to components and test stations. The primary and secondary loops are separated by 6 m to allow vehicle access between the two loops. This is done to allow easy uploading and unloading of equipment during maintenance and periods of altering the setup of test configurations. Figure 6-18 shows the access for vehicles between the primary and secondary loops.

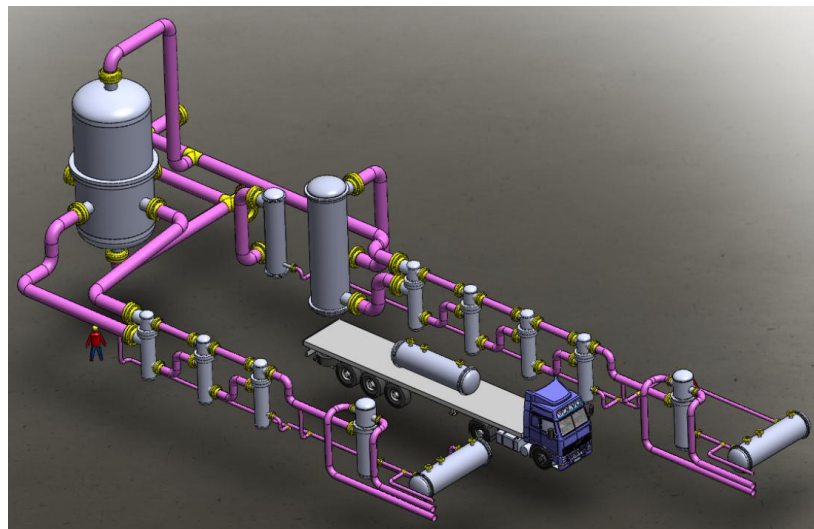


Figure 6-18: TDL layout showing access between primary and secondary loop.

The recuperators and coolers in both the primary and secondary loops as well as the heaters in the primary loop will be installed with their longitudinal axis upright. This will allow the internals of the equipment to be removed by lifting them out with a crane when maintenance or replacement is required.

The circulator test vessels are placed horizontally with two flanges on both ends of the vessels to allow easy access to the circulator and motor from different sides of the circulator vessel. Future work can be done to investigate the vertical placement of the circulator vessel and its internal components in order to use gravity to reduce the additional axial load on the circulator bearings due to higher forces experienced in the higher density helium environment.

The IHX test vessel is placed between the primary and secondary loops. This allows access to the vessel by means of a vehicle or a crane. The IHX vessel consists of two sections bolted together with a flange. The vessel is also placed upright to allow the top section to be removed, thus obtaining access to the vessel internals.

The test stations allow access by crane in order to install, remove or maintain equipment under test. The test stations are flanged sections and allow different types of setups to be tested.

There are no high temperature valves in the TDL and “blanks” are used to blank off sections and vessels which are not used while spool pieces are inserted to connect the vessels or test stations where testing will be conducted.

Flanges are also provided where the TDL will connect to the CQL1 hot and cold headers. The footprint of a single TDL is shown in Figure 6-19.

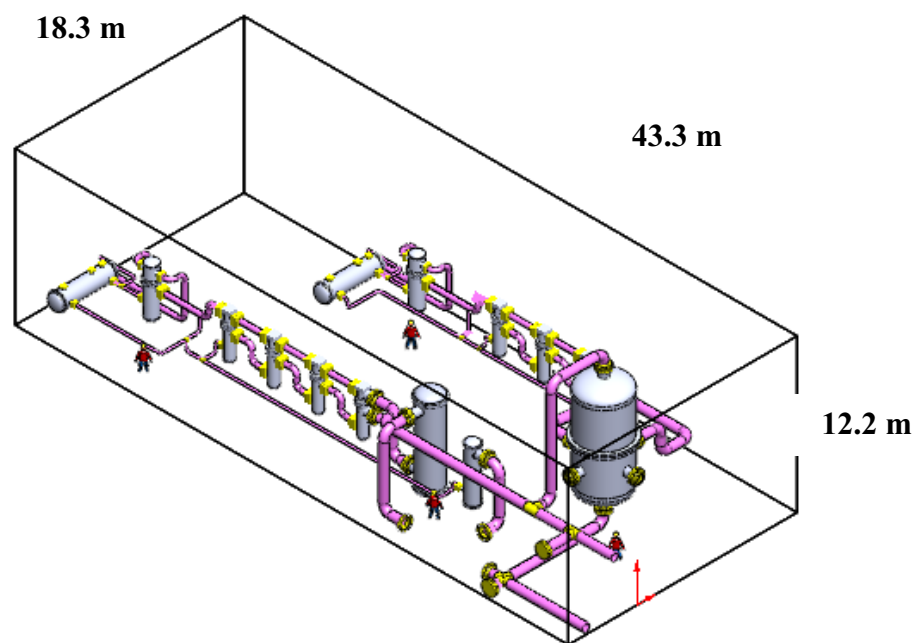


Figure 6-19: Footprint of a single TDL.

NOTE: A rotatable 3D layout drawing of the TDL is given in Reference [6-27].

6.5 TDL: Instrumentation & Control Design

This section will address the following:

- Typical modes and transitions
- Control loops
- Initial instrumentation specification

6.5.1 Typical Modes and Transitions

The modes and transitions of the TDL loops can be subdivided into the stream sequences', process sequences' and system sequences' modes and transitions respectively as discussed in the control and instrumentation philosophy. The sequences of the different tests will typically look the same especially on stream sequence level. Figure 6-20, Figure 6-21 and Figure 6-22 portray a stream, process and system sequence for a typical IHX test respectively.

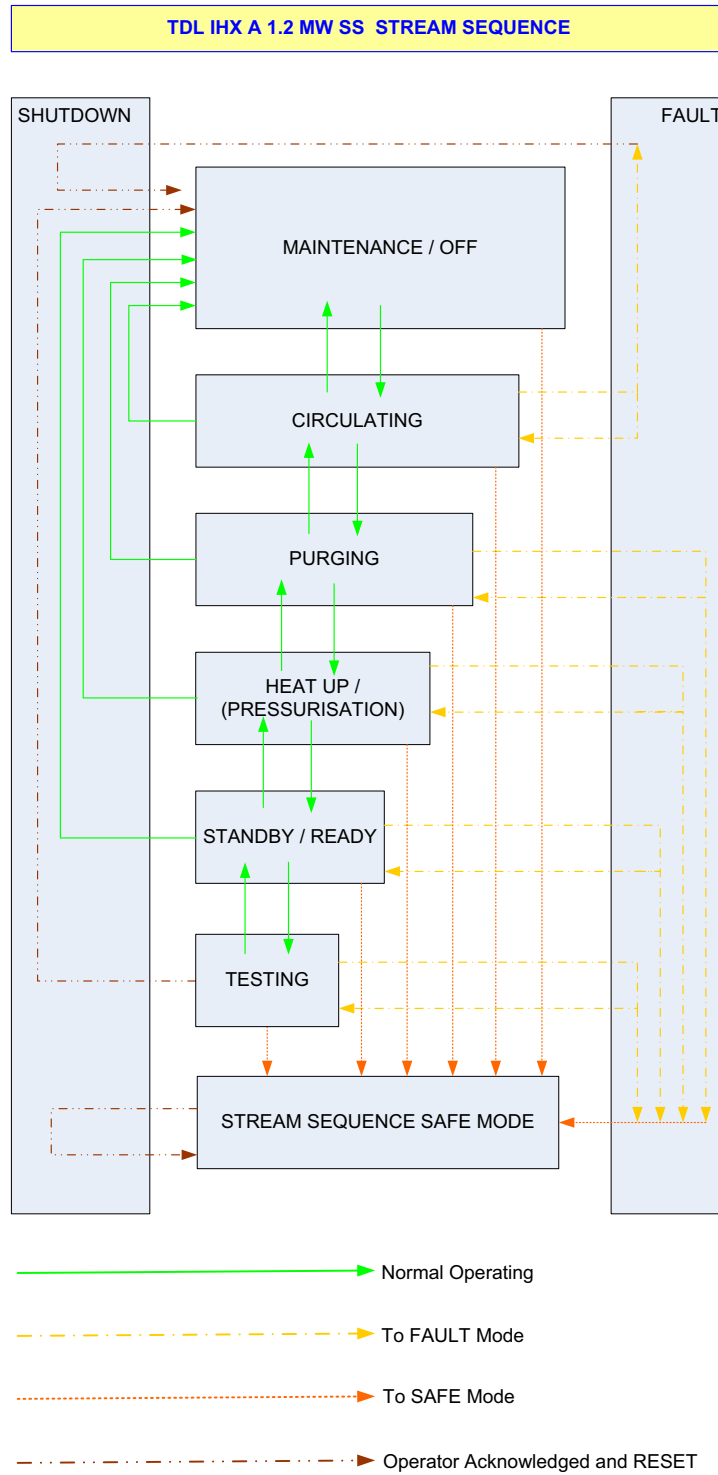


Figure 6-20: Typical TDL stream sequence

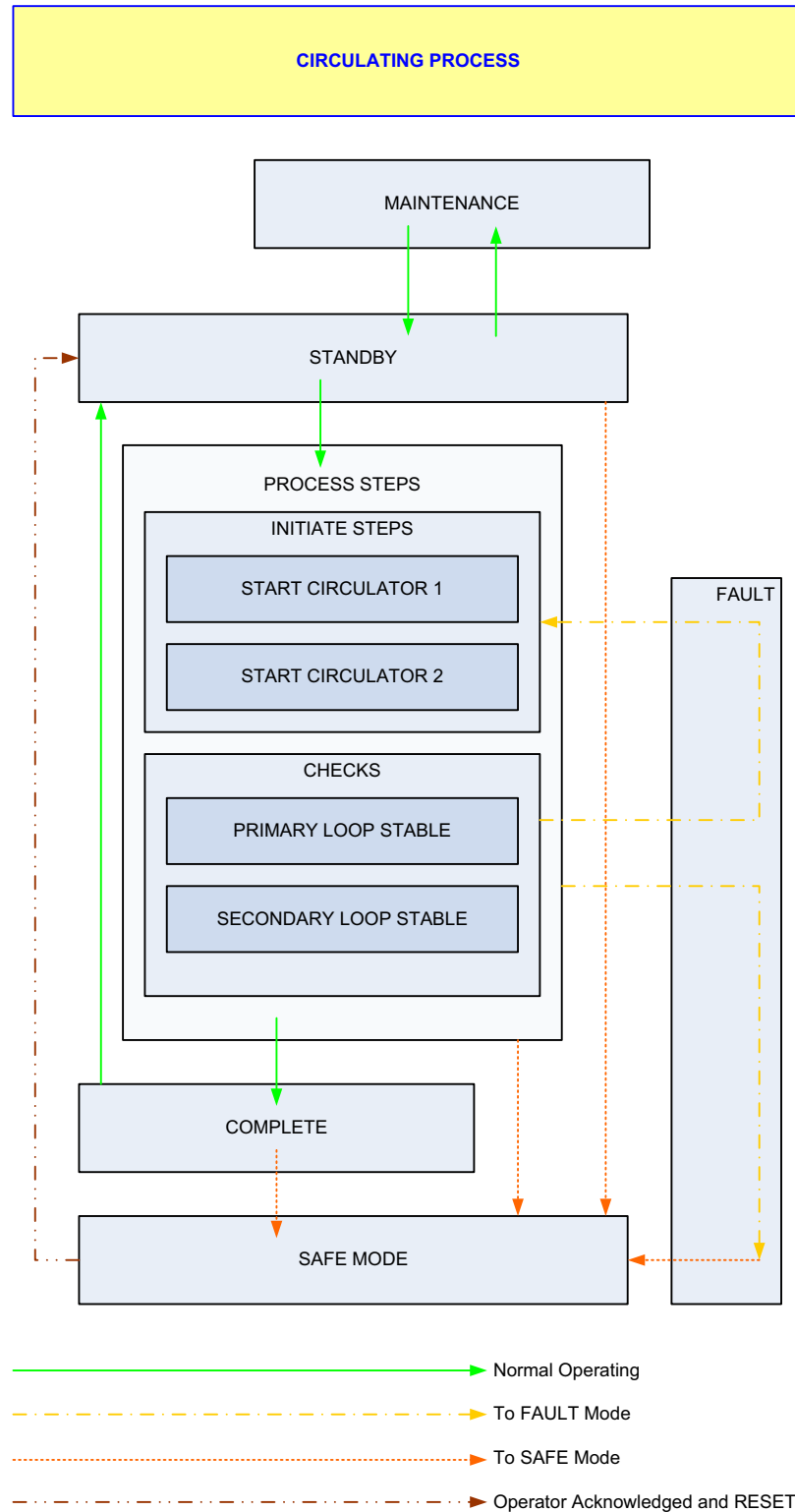


Figure 6-21: Typical TDL process sequence

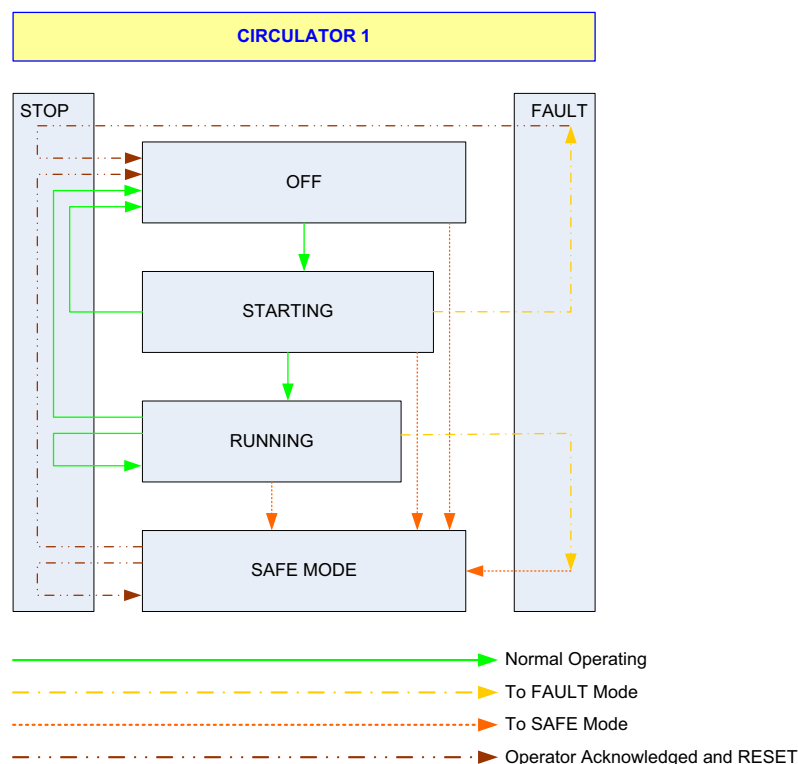


Figure 6-22: Typical TDL system sequence

6.5.2 Control Loops

With reference to the control P&ID's [MT-TLDR-TDL-03-0002] in Reference [6-14] the following types of controllers are discussed:

- Circulator surge control
- Temperature control
- Mass flow control
- Pressure control

6.5.2.1 Circulator surge control

The circulator surge control for the circulators (Primary loop CR 2A_1.1 and CR 2A_1.2; Secondary loop CR 2A_2.1 and CR 2A_2.2) will be achieved by adjusting the respective circulator speed and the bypass surge valve % opening (valve VL 2A_1.1 for circulator CR 2A_1.1 and valve VL 2A_2.1 for circulator CR 2A_2.1). The pressure drop over the circulator will be set (circulator set point) in order to obtain the required mass flow in the test loop. The control will be such that the ratio between the volumetric flow rate through the circulators and the circulator speeds (Q/N) will be a constant (surge line of the circulator).

The surge valve percentage opening will therefore continuously adjust to keep the (Q/N) ratio constant (keeping the circulator from surging) while the circulator speed will adjust to keep the pressure drop over the circulator (circulator set point) at the desired value. Figure 6-23 illustrates the control for CR 2A_1.1 which is similar for CR 2A_1.2 (standby circulator), CR 2A_2.1 and CR 2A_2.2 (standby circulator).

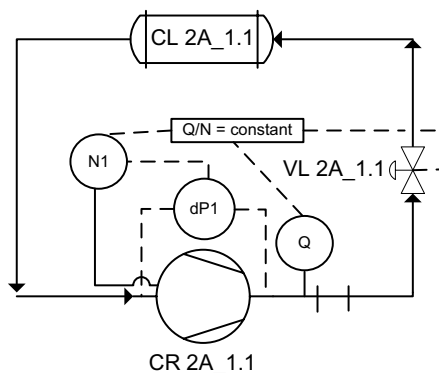


Figure 6-23: Circulator control.

6.5.2.2 Temperature control

The following temperatures will be controlled by adjusting the power supply to heater 1 (HT 2A_1.1) as illustrated in Figure 6-24:

- Temperature (T17) at the primary side of the intermediate heat exchangers (TS 2A_2.1)
- Temperature (T6) at the hot gas duct inlet (TS 2A_1.1)
- Temperature (T28) at the CQL1 flange when doing CQL1 tests
- Temperature (T6) at the primary inlet of the mixing chamber (TS 2A_1.1)

The following temperatures will be controlled by adjusting the power supply to heater 2 (HT 2A_1.2) as illustrated in Figure 6-24:

- Temperature (T7) at the secondary inlet of the mixing chamber (TS 2A_1.1)

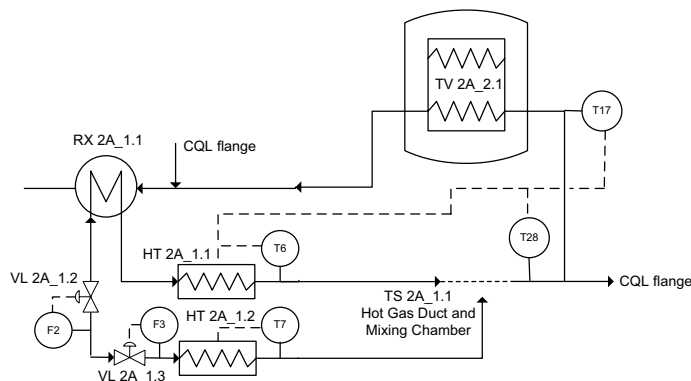


Figure 6-24: Primary loop temperature control.

Temperature (T10) at the inlet of the secondary side of the intermediate heat exchanger (TV 2A_2.1) will be controlled by adjusting the ratio between the % openings of valves 2 and 3 (VL 2A_2.2 and VL 2A_2.3) on the secondary loop, see Figure 6-25.

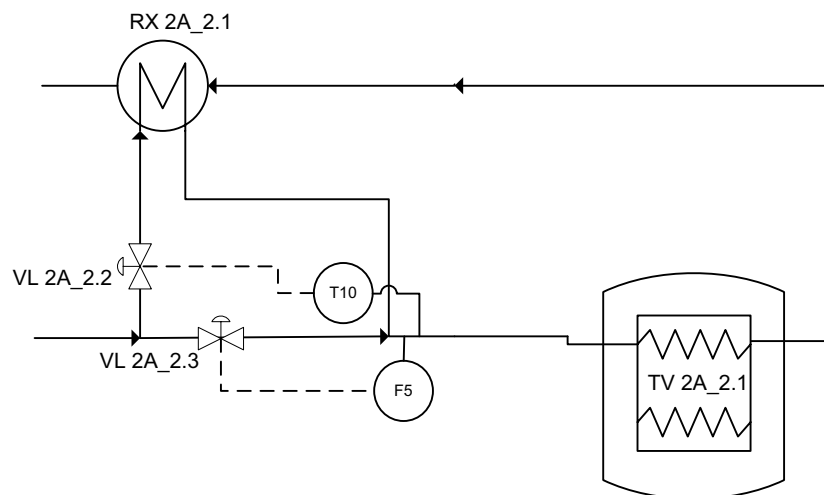


Figure 6-25: Secondary loop temperature and mass flow control.

The temperatures (T1 and T9) at the gas side outlets of both coolers (CL 2A_1.1 and CL 2A_2.1) will be controlled by adjusting the respective % valve openings in their water lines (valve VL 2A_1.5 for cooler CL 2A_1.1 and valve VL 2A_2.5 for cooler CL 2A_2.1). Figure 6-26 illustrates the control for CL 2A_1.1 which is similar for CL 2A_2.1.

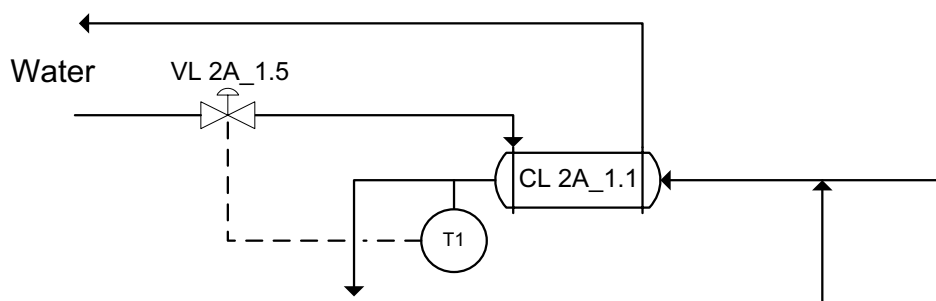


Figure 6-26: Cooler control.

6.5.2.3 Mass flow rate control

The following mass flow rates will be controlled by adjusting the percentage opening of the recuperator inlet valve (VL 2A_1.2) on the primary side as illustrated in Figure 6-24:

- Mass flow (F2) through the primary side of the intermediate heat exchangers (TS 2A_2.1)
- Mass flow (F2) through the hot gas duct (TS 2A_1.1)

- Mass flow (F2) through the CQL1 flange when doing CQL1 tests
- Mass flow (F2) to the primary inlet of the mixing chamber (TS 2A_1.1)

The following mass flows will be controlled by adjusting the percentage opening of the 2nd heater inlet valve (VL 2A_1.3) on the primary side as illustrated in Figure 6-24:

- Mass flow (F3) to the secondary inlet of the mixing chamber (TS 2A_1.1)

The mass flow (F5) at the inlet of the secondary side of the intermediate heat exchanger (TV 2A_2.1) will be controlled by adjusting the sum of the % openings of valves 2 and 3 (VL 2A_2.2, VL 2A_2.3) on the secondary loop as illustrated in Figure 6-25.

6.5.2.4 Pressure control

The pressures (P1 and P2) at the inlet to both circulators (CR 2A_1.1 and CR 2A_2.1) will be controlled by opening the valves in their respective auxiliary gas supply lines (valve VL 2A_1.4 for circulator CR 2A_1.1 and valve VL 2A_2.4 for circulator CR 2A_2.1). It is assumed that there will be helium available from the HICS auxiliary side at a higher or lower pressure (depending on if the plant is pressurized or depressurized) than the TDL pressure. Figure 6-27 illustrates the control for VL 2A_1.4 which is similar for VL 2A_2.4.

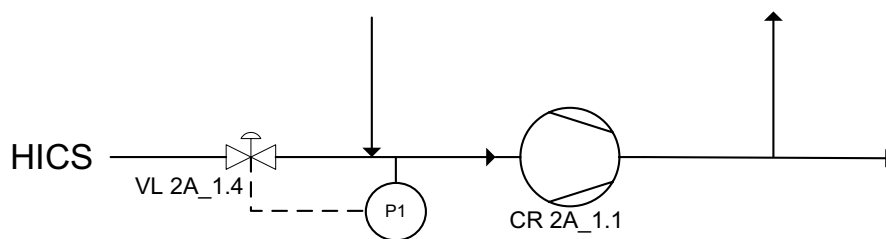


Figure 6-27: Pressure control.

6.5.3 Initial Instrumentation Specification

Table 6-36 shows the minimum instrument requirements with an indication of whether the instrument will be used for protection, control or validation and verification and whether it is required for a specific test specification. The instrumentation positions are indicated on the P&ID [MT-TLDR-TDL-03-0001] in [6-14]. The maximum nominal conditions at which each instrument will be operating are given. Preliminary operating ranges for each instrument were obtained from the maximum nominal conditions. These ranges will be updated according to the most conservative case scenarios' operating conditions.

Component	Instrument	Protection	Control	V&V	Test spec	Temperatures (°C)		Mass flows (kg/s)		Pressures (MPa)		Diff Press (kPa)		Other	
						Max nom	Range	Max nom	Range	Max nom	Range	Max nom	Range	Max nom	Range
CL 2A_1.1	dP11			x		417	0-500	3.65	0-5	9	0-10	6.58	10		
	T1	x	x			80	0-100	3.65	0-5	9	0-10				
	T21			x		417	0-500	3.65	0-5	9	0-10				
	FS1	x				20	0-40	45.9	0-60	0.3	0.5				
	VL 2_1.5		x			20	0-40	45.9	0-60	0.3	0.5				
	T23			x		20	0-40	45.9	0-60	0.3	0.5				
CL 2A_2.1	T24			x		45	0-60	45.9	0-60	0.3	0.5				
	dP12			x		508	0-600	3.65	0-5	9.6	0-11	9.17	15		
	T9	x	x			80	0-100	3.65	0-5	9.6	0-11				
	T22			x		508	0-600	3.65	0-5	9.6	0-11				
	FS2	x				20	0-40	79.5	0-100	0.3	0.5				
	VL 2_2.5		x			20	0-40	79.5	0-100	0.3	0.5				
CR 2A_1.1	T25			x		20	0-40	79.5	0-100	0.3	0.5				
	T26			x		45	0-60	79.5	0-100	0.3	0.5				
	dP1		x			85	0-100	3.65	0-5	9	0-10	300	400		
	F1	x	x		INL F&OR	85	0-100	3.65	0-5	9	0-10				
	N1		x											3550 RPM	4000 RPM
	P1	x	x			80	0-100	3.65	0-5	9	0-10				
CR 2A_2.1	T2		x			85	0-100	3.65	0-5	9	0-10				
	dP2		x			85	0-100	3.65	0-5	9.6	0-11	300	400		
	F4	x	x			85	0-100	3.65	0-5	9.6	0-11				
	N2		x											3550 RPM	4000 RPM
	P2	x	x			80	0-100	3.65	0-5	9.6	0-11				
	T8		x			85	0-100	3.65	0-5	9.6	0-11				
TS 2A_1.2	dP3				INL F&OR	85	0-100	3.65	0-5	9	0-10				
	dP4				INL F&OR	85	0-100	3.65	0-5	9	0-10				
	dP5				INL F&OR	85	0-100	3.65	0-5	9	0-10				
	T3				INL F&OR	85	0-100	3.65	0-5	9	0-10				
	T4				INL F&OR	85	0-100	3.65	0-5	9	0-10				
	T5				INL F&OR	85	0-100	3.65	0-5	9	0-10				
VL 2_1.1	VL 2_1.1	x	x			85	0-100	3.65	0-5	9	0-10				
VL 2_1.2	VL 2_1.2	x	x			85	0-100	3.65	0-5	9	0-10				
VL 2_1.3	VL 2_1.3	x	x			85	0-100	3.65	0-5	9	0-10				
VL 2_1.4	VL 2_1.4	x				80	0-100	0.105	0-0.2	9	0-10				
VL 2_2.1	VL 2_2.1	x	x			85	0-100	3.65	0-5	9.6	0-11				
VL 2_2.2	VL 2_2.2	x	x			85	0-100	3.65	0-5	9.6	0-11				
VL 2_2.3	VL 2_2.3	x	x			85	0-100	3.65	0-5	9.6	0-11				
VL 2_2.4	VL 2_2.4	x				80	0-100	0.105	0-0.2	9.6	0-11				
RX 2A_2.1	dP13			x		737	0-900	3.65	0-5	9.6	0-11	66.7	100		
	dP14			x		900	0-1100	3.65	0-5	9.6	0-11	38.7	60		
	T12	x				900	0-1100	3.65	0-5	9.6	0-11				
	T13			x		508	0-600	3.65	0-5	9.6	0-11				
	F6			x		85	0-100	3.65	0-5	9.6	0-11				
	T15			x		737	0-900	3.65	0-5	9.6	0-11				
RX 2A_1.1	dP16			x		625	0-800	3.65	0-5	9	0-10	109	150		
	dP15			x		760	0-900	3.65	0-5	9	0-10	56.6	100		
	T11	x				760	0-900	3.65	0-5	9	0-10				
	T14			x		220	0-400	3.65	0-5	9	0-10				
	T16		x	x		625	0-800	3.65	0-5	9	0-10				

Component	Instrument	Protection	Control	V&V	Test spec	Temperatures (°C)		Mass flows (kg/s)		Pressures (MPa)		Diff Press (kPa)		Other	
						Max nom	Range	Max nom	Range	Max nom	Range	Max nom	Range	Max nom	Range
VL 2_1.4	GA1	x			WEC-TS-IHXA-013 WEC-TS-IHXA-014 WEC-TS-IHXA-016 WEC-TS-IHXA-031 WEC-TS-IHXA-032 WEC-TS-IHXA-034 WEC-TS-IHXB-013 WEC-TS-IHXB-014 WEC-TS-IHXB-016	80	0-100	0.105	0-0.2	9	0-10			TBD	TBD
VL 2_2.4	GA2	x				80	0-100	0.105	0-0.2	9.6	0-11				
TV 2A_2.1	ε1	x				900	0-1100	3.65	0-5	9.6	0-11			TBD	TBD
	T17		x	x		950	0-1100	3.65	0-5	9	0-10				
	T18			x		760	0-900	3.65	0-5	9	0-10				
	T19			x		710	0-900	3.65	0-5	9.6	0-11				
	T20			x		900	0-1100	3.65	0-5	9.6	0-11				
	dP6			x		950	0-1100	3.65	0-5	9	0-10	118	150		
	dP7			x		900	0-1100	3.65	0-5	9.6	0-11	118	150		
	F5		x			710	0-900	3.65	0-5	9.6	0-11				
	T10		x			710	0-900	3.65	0-5	9.6	0-11				
	T27	x				900	0-1100	3.65	0-5	9.6	0-11				
	dP8	x				900	0-1100	3.65	0-5	9.6	0-11	TBD	TBD		
TV 2A_1.1	T28		x	x	WEC-TS-PIP-009 WEC-TS-MC-001 WEC-TS-MC-002 WEC-TS-MC-003	950	0-1100	3.65	0-5	9	0-10				
	A1			x		950	0-1100	3.65	0-5	9	0-10			TBD	TBD
	dP9			x		950	0-1100	3.65	0-5	9	0-10	TBD	TBD		
	dP10			x		950	0-1100	3.65	0-5	9	0-10	TBD	TBD		
HT 2_1.1	F2		x		WEC-TS-IHXA-001 WEC-TS-IHXA-002 WEC-TS-IHXA-003 WEC-TS-IHXB-001 WEC-TS-IHXB-002 WEC-TS-IHXB-003 WEC-TS-PIP-009 WEC-TS-MC-001 WEC-TS-MC-002 WEC-TS-MC-003	950	0-1100	3.65	0-5	9	0-10				
	T6	x	x			950	0-1100	3.65	0-5	9	0-10				
HT 2_1.2	F3		x			659	0-800	1.136	0-2	9	0-10				
	T7	x	x			659	0-800	1.136	0-2	9	0-10				
TV 2A_1.3	T29			x	TBD	950	0-1100	3.65	0-5	9	0-10				
	T30			x		950	0-1100	3.65	0-5	9	0-10				
	T31			x		870	0-1000	0.62	0-1	5.6	0-7				
	T32			x		870	0-1000	0.76	0-1	5.6	0-7				
	T33			x		396	0-500	0.62	0-1	5.6	0-7				
	T34			x		176	0-250	0.76	0-1	5.6	0-7				
	dP17			x		950	0-1100	3.65	0-5	9	0-10	TBD	TBD		
	dP18	x		x		396	0-500	0.62	0-1	5.6	0-7	TBD	TBD		
	dP19	x		x		176	0-250	0.76	0-1	5.6	0-7	TBD	TBD		

Table 6-36: TDL Initial Instrumentation Specification

6.6 TDL: Electrical Design

The electrical loads required by the TDL conditioning loop components were calculated from the steady state analysis of the test requirements. The components were oversized by $\approx 30\%$ as mentioned in the Systems Level Process Design above. Heaters were assumed to be 90% efficient in converting electrical power into heat transferred to the helium stream and the circulator power requirements were obtained from the circulator data sheet and scaled as discussed in TDL Component design. The electrical requirements per TDL are given in Table 6-37 below.

Table 6-37: Electrical requirements.

Description	Unit	Value
Heater 1 (HT 2A_1.1)	MW	8.9
Heater 2 (HT 2A_1.2)	MW	4.9
Primary Circulator (CR 2A_1.1)	MW	0.227
Primary Circulator (CR 2A_2.1)	MW	0.227
Total	MW	14.25

In addition to the above-mentioned requirements is the power requirement for the measurement instrumentation.

A one line electrical diagram [NGNP-CTF-E-WIR-001-1 and NGNP-CTF-E-WIR-001-2] by indicates the required voltages and interface requirements for each system.

6.7 TDL: Future Work

- Minimal information is available on the “Shell-side flow distribution and bypass leakage testing” requirement [WEC-TS-IHXA-015; WEC-TS-IHXA-033; WEC-TS-IHXB-015] as referenced in [6-6] of IHX A (Metallic and Ceramic) and IHX B and would have to be addressed once more detailed information is available on the measurement and testing procedure.
- Minimal information is available on the pressure and temperature transients as listed in the test requirements. This should be addressed once more detailed test specifications are available as well as a more detailed design of the TDL.
- The test specifications do not indicate what the helium quality for the specific tests should be. In the absence of a design and test specification requirements for the Helium Purification System (HPS), the HPS will have to be addressed at a later stage.

- Some of the test requirements listed indicates that helium with varied composition should be used. The test specifications currently do not have adequate information and this should be addressed at later stage once more detailed information regarding the tests and the helium composition is available. Future work should include an injection point in the TDL where impurities can be injected into the test loop under controlled conditions.
- Gasket materials and flange surface finishing should be investigated further to obtain a specification for these requirements.
- Since the Primary and secondary loop circulators are build for air conditions, it is recommended that a detailed analysis and test setup be done on the machines' mechanical strengths as well as performance when operated in a high pressure helium environment.
- Future work can be done to investigate the vertical placement of the circulator vessel and its internal components in order to use gravity to reduce the additional axial load on the circulator bearings due to higher forces experienced in the higher density helium environment.
- Since a full scale Mixing Chamber or HGD cannot be tested in the TDL due to the high mass flow required (not attainable with the TDL), future work can be done by testing scaled versions of Mixing Chambers and HGDs in the TDL. Simulation codes can then be verified and validated enable accurate simulations and calculations regarding the performance and behavior of a full-scale Mixing Chamber or HGD.
- Monel can possibly be used for vessel and HGD liner material. The suitability of this material and other materials should be investigated further to find an optimum solution. The optimal thickness of the liner material should also be investigated in future work.
- From experience, the thermal conductivity of insulation in the high temperature and pressure helium environment can be conservatively taken as 0.5 W/mK. The effect that helium, temperature and impurity ingress into the insulation has on the thermal conductivity of the insulation, should be investigated in future work. Pressure differentials across the liner might lead to liner failure and should also be addressed in future work. The detail design of the TDL HGD should cater for this to prevent unwanted pressure and temperature differentials developing in the HGD liner and insulation.

6.8 References

- [6-1] “HTGR Component Test Facility (CTF) Feasibility and Recommendations,” February 2008.
- [6-2] “NGNP Technology Development Road Mapping Report,” NNGNP-CTF MTECH-TDRM-004
- [6-3] “NGNP Technology Development Road Mapping Report,” NNGNP-CTF MTECH-TDRM-005
- [6-4] “NGNP Technology Development Road Mapping Report,” NNGNP-CTF MTECH-TDRM -007
- [6-5] HPS.000.S01.HTSE review package
- [6-6] “CTF NNGNP Technology Development Roadmapping,” NNGNP-CT MTECH-TDRM

6.9 Appendices: Supporting Documentation

The following files are associated with this document

- [6-7] Appendix A: IHX Systems Level Calculation
- [6-8] Appendix B: Mixing Chamber Systems Level Calculation
- [6-9] Appendix C: HGD Systems Level Calculation
- [6-10] Appendix D: HVAC Systems Level Calculation
- [6-11] Appendix E: System Pressure Loss Calculation
- [6-12] Appendix F: HTSE Systems Level Calculation
- [6-13] Appendix G: HICS Systems Level Calculation
- [6-14] Appendix H: TDL PFD and P&ID Drawings
- [6-15] Appendix I: Circulator Calculations
- [6-16] Appendix J: HTS Cold Pipe Calculations
- [6-17] Appendix K: HTS Hot Gas Duct Calculations

- [6-18] Appendix L: TDL Control Valves & HICS Valves Component Specification Sheet
- [6-19] Appendix M: TDL Water Control Valves Component Specification Sheet
- [6-20] Appendix N: Heater (HT 2A_1.1) Calculation
- [6-21] Appendix O: Heater (HT 2A_1.2) Calculation
- [6-22] Appendix P: TDL Primary Loop Recuperator Component Specification Sheet
- [6-23] Appendix Q: TDL Primary Loop Cooler Component Specification Sheet
- [6-24] Appendix R: TDL Secondary Loop Cooler Component Specification Sheet
- [6-25] Appendix S: IHX Vessel Calculation
- [6-26] Appendix T: Interface Requirements as calculated per TDL
- [6-27] Appendix U: 3D View of TDL

Appendix A



M - T e c h
i n d u s t r i a l

***Attachment to Section 6: Technology Development
Loop (TDL)
IHX Systems Level Calculation***

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Configuration Management

CHANGE HISTORY

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Change Forecast

The document format and contents have been approved.

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1. Objective

The objective of the calculation is to determine for the various IHX test specifications as listed in the TDRM [NGNP-CTF MTECH-TDRM-004 and NGNP-CTF MTECH-TDRM-005], the component flow conditions at the various component inlets and outlets as well as the auxiliary requirements such as cooling water, power supply and the HICS system. The results are also used to assist in component capacity selection. This model was used for the steady state energy balance for the conditions listed in the TDRM for 1.2 MW IHX A (Ceramic and metallic), 1.2 MW IHX B, 3 x 1.2 MW IHX A (Ceramic and metallic) and 3 x 1.2 MW IHX B modules.

2. Methodology

2.1 APPROACH

The IHX inlet and outlet flow conditions were given in the TDRM [NGNP-CTF MTECH-TDRM-004 and NGNP-CTF MTECH-TDRM-005] and was used as input into the model. The mass flow needed to give the desired heat transfer between the IHX primary and secondary side could then be calculated. The component sizes could then be determined by means of an energy balance. The auxiliary supply needs to the TDL could then be calculated. The calculation is shown in Attachment A.

2.2 COMPUTER PROGRAMS

The computer program used is EES

3. Inputs and Assumptions

3.1 ASSUMPTIONS

- Adiabatic flow conditions assumed in the TDL, no heat loss to surroundings.
- Circulator outlet flow temperature = 85 °C (Assume isentropic efficiency $\approx$ 72.5%, initial estimate to determine heat input into TDL for PFD's. This implies a temperature rise of 5°C.)
- Circulator inlet flow temperature = 80 °C
- Recuperator effectiveness assumed to be 80%
- Coolers are assumed to be water cooled shell and tube heat exchangers
- No pressure drop through pipes and components
- Cooler inlet water temperature = 20 °C
- Cooler outlet water temperature = 45 °C
- Cooling water pressure = 300 kPa

3.2 INPUTS

- Primary loop nominal Pressure = 9000 kPa [NGNP-CTF MTECH-TDRM-004 and NGNP-CTF MTECH-TDRM-005]
- Secondary loop nominal Pressure = 9600 kPa [NGNP-CTF MTECH-TDRM-004 and NGNP-CTF MTECH-TDRM-005]
- IHX Inlet and outlet temperature conditions [NGNP-CTF MTECH-TDRM-004 and NGNP-CTF MTECH-TDRM-005]

4. Equations Used and Calculations

The equations used are first law of Thermodynamic energy balance equations [Fundamentals of Thermodynamics, Sonntag et al, Fifth edition, 1998]

The Number of Transfer Units method was used for both primary and secondary recuperators [Heat and Mass Transfer, Incropera and De Witt, Fifth Edition, 2002]. In the calculations, positions are numbered according to the PDF [MT-TLDR-TDL-02-0001].

5. Results

The results are given in the following PFD's in Appendix A:

- 1.2 MW IHX A module [MT-TLDR-TDL-02-0005]
- 3 x 1.2 MW IHX A module [MT-TLDR-TDL-02-0006]
- 1.2 MW IHX B module [MT-TLDR-TDL-02-0007]
- 3 x 1.2 MW IHX B module [MT-TLDR-TDL-02-0008]

6. Conclusions

Energy balance and component sizes for conceptual design.

Attachment A

IHX EES Calculation Sheet

*IHX Calculation sheet**Attachment A of [MT-TLDR-CAL-T - 0601]**Positions are numbered in PFD [MT-TLDR-TDL⁻⁰²-0001-Rev A]*

$$Q_{\text{IHX}} = 1200 \cdot 3 \text{ [kW] From TDRM}$$

$$\dot{m} = \frac{Q_{\text{IHX}}}{h_7 - h_{10}} \text{ Mass flow}$$

*PRIMARY SIDE**Primary side Recuperator Size*

$$T_{10} = 760 \text{ [C] Temperature from IHX as per TDRM}$$

$$P_{10} = 9000 \text{ [kPa] Primary side nominal pressure}$$

$$h_{10} = h[\text{'Helium'}, T=T_{10}, P=P_{10}]$$

$$T_4 = 85 \text{ [C] Blower outlet temperature assuming 72.5% isentropic efficiency}$$

$$P_4 = 9000 \text{ [kPa]}$$

$$h_4 = h[\text{'Helium'}, T=T_4, P=P_4]$$

$$Q_{\text{rec,pr}} = 0.8 \cdot [\dot{m} - \dot{m}_{\text{heat},2}] \cdot [h_{10} - h_4] \text{ Assuming 80\% Recuperator efficiency, NTU method}$$

$$T_1 = T[\text{'Helium'}, P=P_1, h=h_1]$$

$$P_1 = 9000 \text{ [kPa]}$$

$$h_1 = h_{10} - \frac{Q_{\text{rec,pr}}}{\dot{m}} \text{ Energy balance over recuperator}$$

$$T_6 = T[\text{'Helium'}, P=P_6, h=h_6]$$

$$P_6 = 9000 \text{ [kPa]}$$

$$h_6 = \frac{Q_{\text{rec,pr}}}{\dot{m} - \dot{m}_{\text{heat},2}} + h_4 \text{ Energy balance over recuperator}$$

Primary side cooler

$$T_2 = 80 \text{ [C] Blower inlet temperature}$$

$$P_2 = 9000 \text{ [kPa]}$$

$$h_2 = h[\text{'Helium'}, T=T_2, P=P_2]$$

$$Q_{\text{cool,pr}} = \dot{m} \cdot [h_1 - h_2] \text{ Thermal heat removed from helium}$$

$$T_{\text{w,inlet}} = 20 \text{ [C] Assuming 20 C to be the worst case}$$

$$T_{\text{w,outlet}} = 45 \text{ [C] Assuming 45 C to be the worst case}$$

$$P_w = 300 \text{ [kPa]}$$

$$h_{w,inlet} = h \text{ ['Water' , } T = T_{w,inlet} \text{ , } P = P_w \text{]}$$

$$h_{w,outlet} = h \text{ ['Water' , } T = T_{w,outlet} \text{ , } P = P_w \text{]}$$

$$\dot{m}_{water,pr} = \frac{Q_{cool,pr}}{h_{w,outlet} - h_{w,inlet}} \text{ Auxiliary water needed for cooler}$$

Primary side heater 1

$$T_7 = 950 \text{ [C]} \text{ Temperature to IHX as per TDRM}$$

$$P_7 = 9000 \text{ [kPa]}$$

$$h_7 = h \text{ ['Helium' , } T = T_7 \text{ , } P = P_7 \text{]}$$

$$Q_{pr,heat,1} = [\dot{m} - \dot{m}_{heat,2}] \cdot [h_7 - h_6] \text{ Heater thermal input into helium}$$

Primary side heater 2, not used when testing IHX

$$\dot{m}_{heat,2} = 0 \text{ [kg/s]} \text{ Heater mass flow}$$

$$T_5 = 85 \text{ [C]} \text{ Temperature into heater from circulator}$$

$$P_5 = 9000 \text{ [kPa]}$$

$$h_5 = h \text{ ['Helium' , } T = T_5 \text{ , } P = P_5 \text{]}$$

$$T_8 = 659 \text{ [C]} \text{ Temperature into mixing chamber}$$

$$P_8 = 9000 \text{ [kPa]}$$

$$h_8 = h \text{ ['Helium' , } T = T_8 \text{ , } P = P_8 \text{]}$$

$$Q_{pr,heat,2} = \dot{m}_{heat,2} \cdot [h_8 - h_5] \text{ Heater thermal input into helium}$$

Primary side Circulator

$$Q_{pr,circ} = \dot{m} \cdot [h_4 - h_2] \text{ Flow work by circulator based on isentropic efficiency}$$

SECONDARY SIDE

Secondary side recuperator

$$T_{16} = 900 \text{ [C]} \text{ Temperature from IHX as per TDRM}$$

$$P_{16} = 9600 \text{ [kPa]} \text{ Secondary side nominal pressure}$$

$$h_{16} = h \text{ ['Helium' , } T = T_{16} \text{ , } P = P_{16} \text{]}$$

$$T_{12} = 85 \text{ [C]} \text{ Blower outlet temperature}$$

$$P_{12} = 9600 \text{ [kPa]}$$

$$h_{12} = h \text{ ['Helium' , } T = T_{12} \text{ , } P = P_{12} \text{]}$$

$$Q_{\text{rec,sec}} = 0.8 \cdot [\dot{m} - \dot{m}_{\text{cool,flow}}] \cdot [h_{16} - h_{12}] \quad \text{Assuming 80\% Recuperator efficiency, NTU method}$$

$$T_{17} = T[\text{'Helium'}, P=P_{17}, h=h_{17}]$$

$$P_{17} = 9600 \quad [\text{kPa}]$$

$$h_{17} = h_{16} - \frac{Q_{\text{rec,sec}}}{\dot{m}} \quad \text{Energy balance over recuperator}$$

$$T_{14} = T[\text{'Helium'}, P=P_{14}, h=h_{14}]$$

$$P_{14} = 9600 \quad [\text{kPa}]$$

$$h_{14} = \frac{Q_{\text{rec,sec}}}{\dot{m} - \dot{m}_{\text{cool,flow}}} + h_{12} \quad \text{Energy balance over recuperator}$$

Secondary side mixing point. Used to obtain correct IHX inlet temperature

$$T_{13} = 85 \quad [\text{C}] \quad \text{Blower outlet temperature}$$

$$P_{13} = 9600 \quad [\text{kPa}]$$

$$h_{13} = h[\text{'Helium'}, T=T_{13}, P=P_{13}]$$

$$T_{15} = 710 \quad [\text{C}] \quad \text{Temperature to IHX as per TDRM}$$

$$P_{15} = 9600 \quad [\text{kPa}]$$

$$h_{15} = h[\text{'Helium'}, T=T_{15}, P=P_{15}]$$

$$\dot{m} = \frac{\dot{m}_{\text{cool,flow}} \cdot h_{13} + [\dot{m} - \dot{m}_{\text{cool,flow}}] \cdot h_{14}}{h_{15}} \quad \text{Energy balance to determine the mass flow distribution through recuperator}$$

Secondary side cooler

$$T_{18} = 80 \quad [\text{C}] \quad \text{Blower inlet temperature}$$

$$P_{18} = 9600 \quad [\text{kPa}]$$

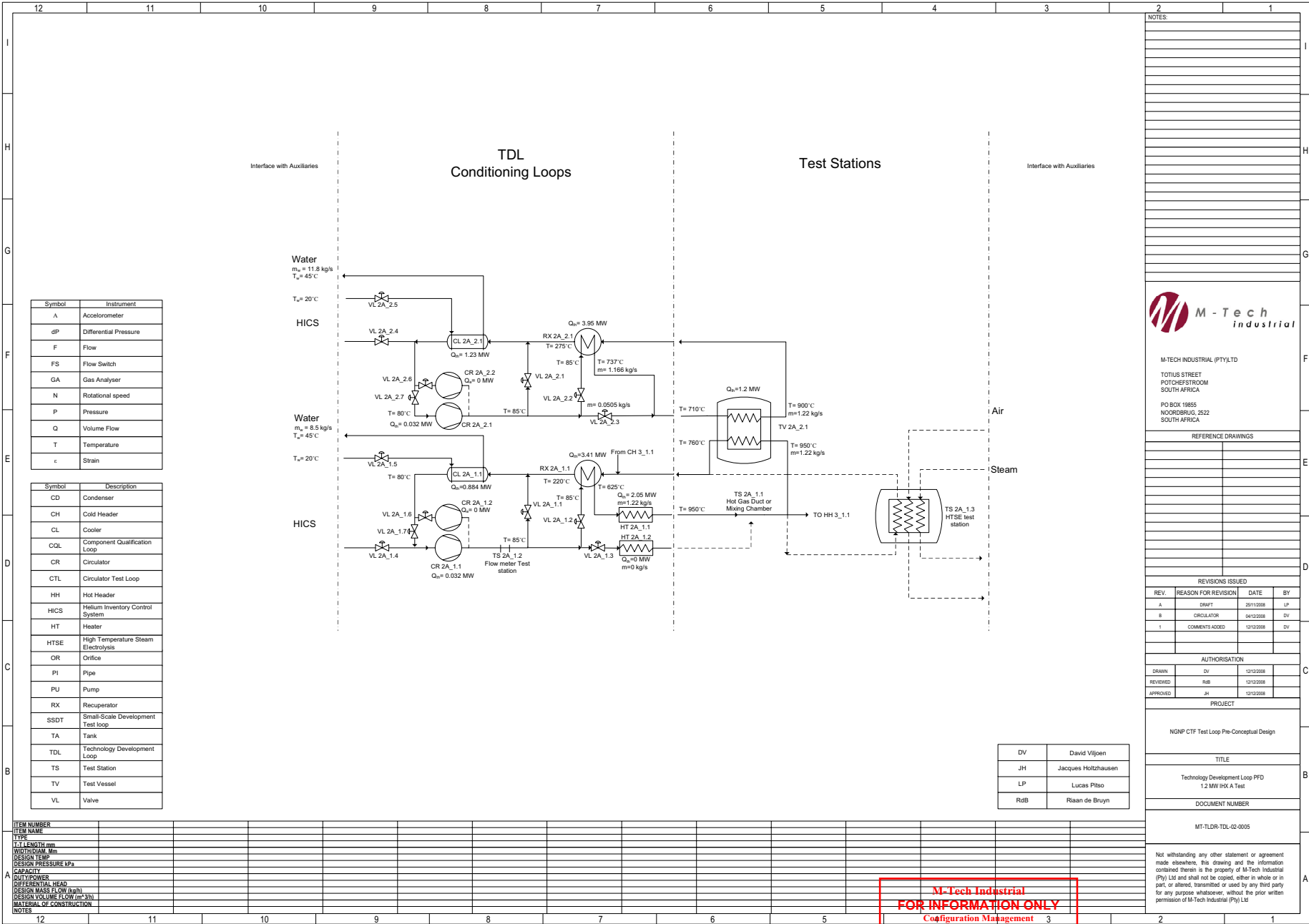
$$h_{18} = h[\text{'Helium'}, T=T_{18}, P=P_{18}]$$

$$Q_{\text{cool,sec}} = \dot{m} \cdot [h_{17} - h_{18}] \quad \text{Thermal heat removed from helium}$$

$$\dot{m}_{\text{water,sec}} = \frac{Q_{\text{cool,sec}}}{h_{\text{w,outlet}} - h_{\text{w,inlet}}} \quad \text{Auxiliary water needed for cooler}$$

Secondary side Circulator

$$Q_{\text{sec,circ}} = \dot{m} \cdot [h_{12} - h_{18}] \quad \text{Flow work by circulator based on isentropic efficiency}$$



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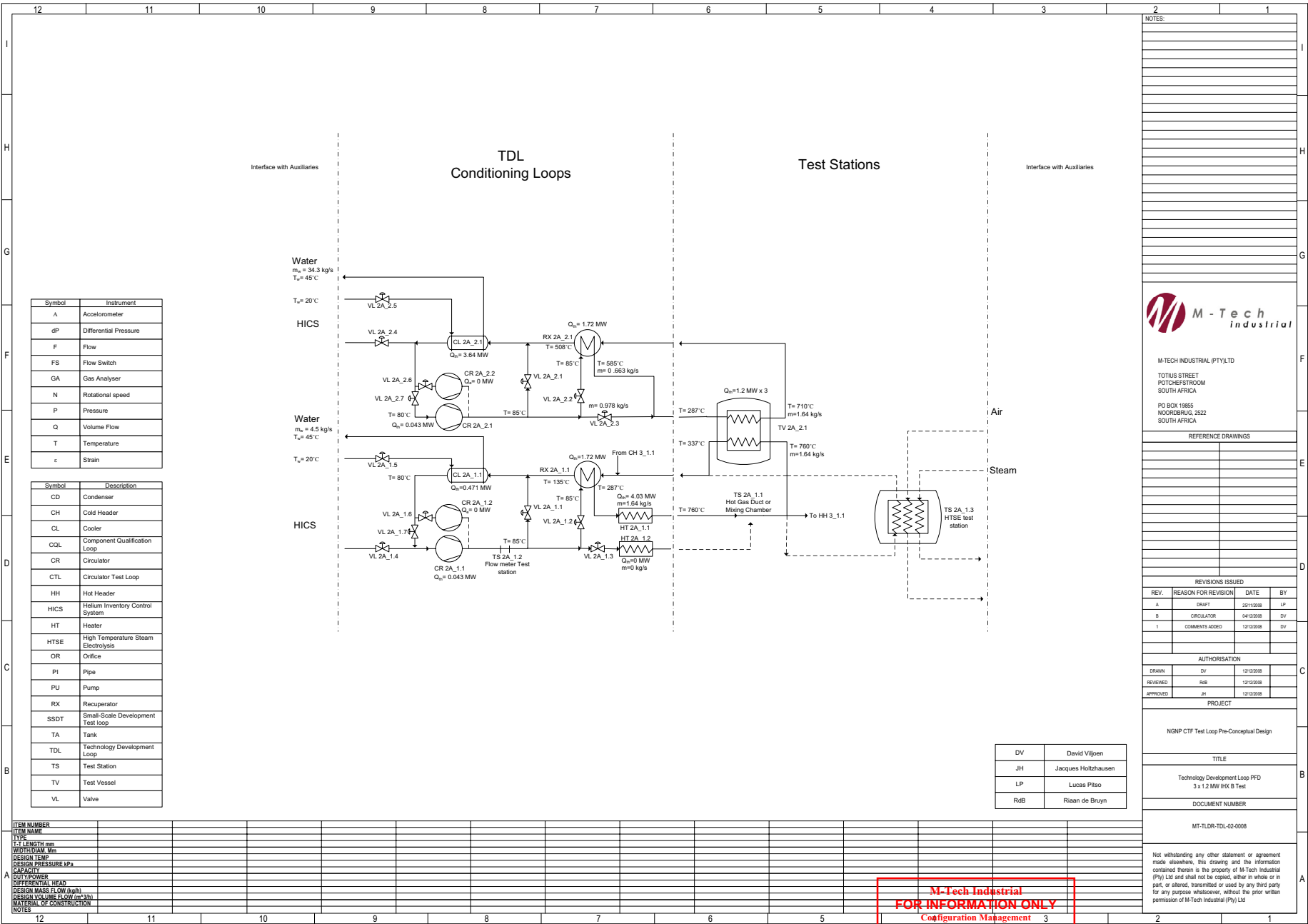
Technology Development Loop PFD
1.2 MW IHX A Test

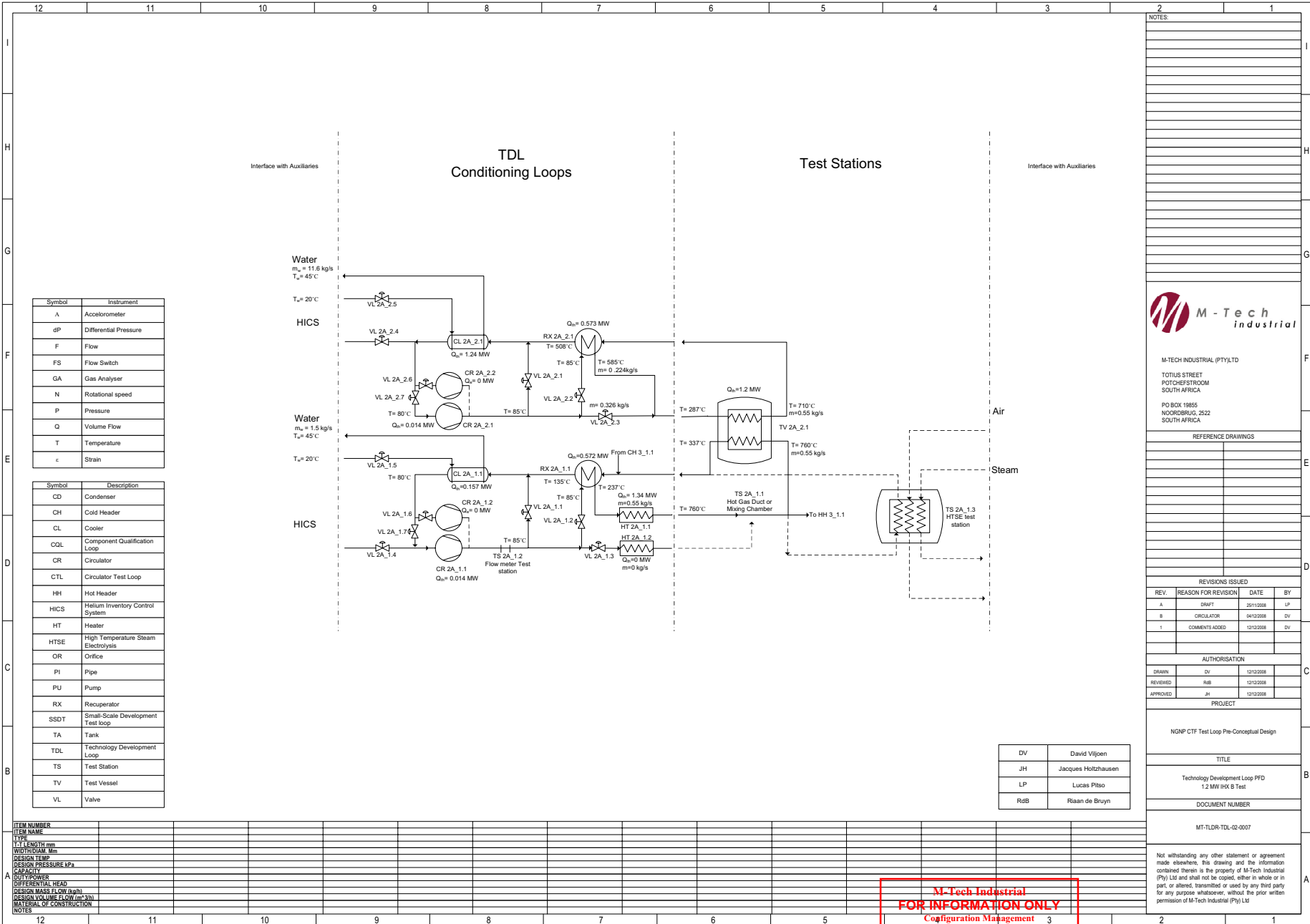
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Appendix B



M - T e c h
i n d u s t r i a l

***Attachment to Section 6: Technology Development
Loop (TDL)
Mixing Chamber Systems Level Calculation***

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Mixing Chamber EES Calculation	7

1. Objective

The objective of the calculation is to determine for the Mixing Chamber test specifications as listed in the TDRM [NGNP-CTF MTECH-TDRM-007], the component flow conditions of the TDL at the various component inlets and outlets as well as the auxiliary requirements such as cooling water, power supply and the HICS system. The results are also used to assist in component capacity selection.

2. Methodology

2.1. APPROACH

The Mixing Chamber temperatures were given in the TDRM [NGNP-CTF MTECH-TDRM-007] and were used as input into the model. The Mixing Chamber tests do not indicate a required mass flow and it was therefore assumed that the total mass flow for the Mixing Chamber tests are equal to the mass flow as required for 3 x 1.2 MW IHX A modules tests. An energy balance was done to determine the mass flows for the cold and hot leg inputs into the Mixing Chamber according to the specified cold and hot leg inlet temperatures and combined outlet temperature as specified in the test requirements. The TDL component thermal sizes could then be determined by means of an energy balance. The auxiliary supply needs of the TDL could then be calculated as required for mixing chamber testing. The calculation is shown in Attachment A.

2.2. COMPUTER PROGRAMS

The computer program used is EES.

3. Inputs and Assumptions

3.1. ASSUMPTIONS

- Adiabatic flow conditions assumed in the TDL, no heat loss to surroundings.
- Circulator outlet flow temperature = 85 °C (Assume isentropic efficiency $\approx$ 72.5%, Initial estimate to determine heat input into TDL for PFD's. This implies a fixed temperature rise of 5°C.)
- Circulator inlet flow temperature = 80 °C
- Recuperator effectiveness assumed to be 80%
- Cooler is assumed to be water cooled shell and tube heat exchangers
- No pressure drop through pipes and components
- Cooler inlet water temperature = 20 °C
- Cooler outlet water temperature = 45 °C
- Cooling water pressure = 300 kPa

3.2. INPUTS

- TDL nominal Pressure = 9000 kPa [NGNP-CTF MTECH-TDRM-007]
- Cold leg Temperature = 659 °C [NGNP-CTF MTECH-TDRM-007]
- Hot leg Temperature = 900 °C [NGNP-CTF MTECH-TDRM-007]
- Mixed Temperature = 825 °C [NGNP-CTF MTECH-TDRM-007]
- Total mass flow equal to mass flow as calculated for 3 x 1.2 MW IHX A modules

4. Equations Used and Calculations

The equations used are first law of Thermodynamic energy balance equations [Fundamentals of Thermodynamics, Sonntag et al, Fifth edition, 1998]

The Number of Transfer Units (NTU) method was used for the primary recuperator [Heat and Mass Transfer, Incropera and De Witt, Fifth Edition, 2002]

5. Results

The results are given in the following PFD in Appendix B:

- Mixing chamber PFD [MT-TLDR-TDL-02-0004]

6. Conclusions

Energy balance and component sizes for conceptual design.

Attachment A

Mixing Chamber EES Calculation

*Mixing Chamber tests**Attachment A of [MT-TLDR-CAL-T - 0602]**Positions are numbered in PFD [MT-TLDR-TDL- 02-0001-Rev A]*

$$\dot{m} = 3.651 \text{ [kg/s]} \text{ Assumed total mass flow as for } 1.2\text{MW} \times 3, \text{ IHX A}$$

*PRIMARY SIDE**Primary side Recuperator Size*

$$T_{10} = 825 \text{ [C]} \text{ Mixing chamber outlet temperature as per TDRM}$$

$$P_{10} = 9000 \text{ [kPa]} \text{ Nominal loop Pressure}$$

$$h_{10} = h \text{ ['Helium', } T=T_{10}, P=P_{10} \text{]}$$

$$T_4 = 85 \text{ [C]} \text{ Blower outlet temperature}$$

$$P_4 = 9000 \text{ [kPa]}$$

$$h_4 = h \text{ ['Helium', } T=T_4, P=P_4 \text{]}$$

$$Q_{\text{rec,pr}} = 0.8 \cdot [\dot{m} - \dot{m}_{\text{heat},2}] \cdot [h_{10} - h_4] \text{ Assuming 80\% Recuperator efficiency, NTU method}$$

$$T_1 = T \text{ ['Helium', } P=P_1, h=h_1 \text{]}$$

$$P_1 = 9000 \text{ [kPa]}$$

$$h_1 = h_{10} - \frac{Q_{\text{rec,pr}}}{\dot{m}} \text{ Energy balance over recuperator}$$

$$T_6 = T \text{ ['Helium', } P=P_6, h=h_6 \text{]}$$

$$P_6 = 9000 \text{ [kPa]}$$

$$h_6 = \frac{Q_{\text{rec,pr}}}{\dot{m} - \dot{m}_{\text{heat},2}} + h_4 \text{ Energy balance over recuperator}$$

Primary side cooler

$$T_2 = 80 \text{ [C]} \text{ Blower inlet temperature}$$

$$P_2 = 9000 \text{ [kPa]}$$

$$h_2 = h \text{ ['Helium', } T=T_2, P=P_2 \text{]}$$

$$Q_{\text{cool,pr}} = \dot{m} \cdot [h_1 - h_2] \text{ Thermal energy removed from cooler}$$

$$T_{\text{w,inlet}} = 20 \text{ [C]} \text{ Assuming 20 C to be the worst case}$$

$$T_{\text{w,outlet}} = 45 \text{ [C]}$$

$$P_w = 300 \text{ [kPa]}$$

$$h_{\text{w,inlet}} = h \text{ ['Water', } T=T_{\text{w,inlet}}, P=P_w \text{]}$$

$$h_{w,outlet} = h \left[\text{'Water'} , T = T_{w,outlet} , P = P_w \right]$$

$$\dot{m}_{water,pr} = \frac{Q_{cool,pr}}{h_{w,outlet} - h_{w,inlet}} \quad \text{Auxiliary water mass flow required for cooler}$$

Primary side heater 1

$$T_7 = 900 \quad [C] \quad \text{Mixing chamber hot leg inlet temperature}$$

$$P_7 = 9000 \quad [kPa]$$

$$h_7 = h \left[\text{'Helium'} , T = T_7 , P = P_7 \right]$$

$$Q_{pr,heat,1} = \left[\dot{m} - \dot{m}_{heat,2} \right] \cdot \left[h_7 - h_6 \right] \quad \text{Thermal heat input into helium}$$

Primary side heater 2

$$\dot{m}_{heat,2} = \frac{\dot{m} \cdot h_{10} - \left[\dot{m} - \dot{m}_{heat,2} \right] \cdot h_7}{h_8} \quad \text{Cold leg mass flow calculation}$$

$$T_5 = 85 \quad [C] \quad \text{Cold leg heater inlet temperature from circulator}$$

$$P_5 = 9000 \quad [kPa]$$

$$h_5 = h \left[\text{'Helium'} , T = T_5 , P = P_5 \right]$$

$$T_8 = 659 \quad [C] \quad \text{Mixing Chamber cold leg inlet temperature as per TDRM}$$

$$P_8 = 9000 \quad [kPa]$$

$$h_8 = h \left[\text{'Helium'} , T = T_8 , P = P_8 \right]$$

$$Q_{pr,heat,2} = \dot{m}_{heat,2} \cdot \left[h_8 - h_5 \right] \quad \text{Thermal heat input into helium}$$

Primary side Circulator

$$Q_{pr,circ} = \dot{m} \cdot \left[h_4 - h_2 \right] \quad \text{Circulatore flow work based on isentropic efficiency}$$

Appendix C



M - T e c h
i n d u s t r i a l

***Attachment to Section 6: Technology Development
Loop (TDL)
HGD Systems Level Calculation***

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HGD EES Calculation	7

1. Objective:

The objective of the calculation is to determine for the Hot Gas Duct (HGD) test specifications [WEC-TS-PIP-009], the component flow conditions of the TDL at the various component inlets and outlets as well as the auxiliary requirements such as cooling water, power supply and the HICS system. The results are also used to assist in component capacity selection.

2. Methodology:

2.1. APPROACH

The HGD temperature was given in test specification [WEC-TS-PIP-009] and was used as input into the model. The HGD tests do not indicate a required mass flow and it was therefore assumed that the mass flow for HGD testing is equal to the mass flow required for 3 x 1.2 MW IHX A modules testing. The TDL component thermal sizes could then be determined by means of an energy balance. The auxiliary supply needs to the TDL could then be calculated as required for HGD testing. The calculation is shown in Attachment A.

2.2. COMPUTER PROGRAMS

The computer program used is EES.

3. Inputs and Assumptions:

3.1. ASSUMPTIONS:

- Adiabatic flow conditions assumed in the TDL, no heat loss to surroundings.
- Circulator outlet flow temperature = 85 °C (Assume isentropic efficiency $\approx$ 72.5%, Initial estimate to determine heat input into TDL for PFD's. This implies a rise of 5°C over the circulator.)
- Circulator inlet flow temperature = 80 °C
- Recuperator effectiveness assumed to be 80%
- Cooler is assumed to be water cooled shell and tube heat exchangers
- No pressure drop through pipes and components
- Cooler inlet water temperature = 20 °C
- Cooler outlet water temperature = 45 °C
- Cooling water pressure = 300 kPa

3.2. INPUTS:

- TDL nominal Pressure = 9000 kPa [WEC-TS-PIP-009]
- HGD temperature conditions [WEC-TS-PIP-009]
- Mass flow equal to mass flow as calculated for 3 x 1.2 MW IHX A modules

4. Equations Used and Calculations:

The equations used are first law of Thermodynamic energy balance equations [Fundamentals of Thermodynamics, Sonntag et al, Fifth edition, 1998]

The Number of Transfer Units (NTU) method was used for the primary recuperator [Heat and Mass Transfer, Incropera and De Witt, Fifth Edition, 2002]. In the circulator, positions are numbered according to the PDF [MT-TLDR-TDL-02-0001].

5. Results:

The results are given in the following PFD:

- Hot gas duct PFD, [MT-TLDR-TDL-02-0003]

6. Conclusions:

Energy balance and component sizes for conceptual design.

Attachment A

HGD EES Calculation

*Hot Gas Duct test**Attachment A of [MT-TLDR-CAL-T - 0603]**Positions are numbered in PFD [MT-TLDR-TDL⁻⁰²-0001-Rev A]**PRIMARY SIDE*

$$\dot{m} = 3.651 \text{ [kg/s]} \text{ Assume mass flow as for 3 x 1.2 MW IHX A test modules}$$

Primary side Recuperator Size

$$T_{10} = 950 \text{ [C]} \text{ HGD outlet temperature}$$

$$P_{10} = 9600 \text{ [kPa]} \text{ Loop nominal pressure}$$

$$h_{10} = h \text{ ['Helium', } T = T_{10}, P = P_{10} \text{]}$$

$$T_4 = 85 \text{ [C]} \text{ Blower outlet temperature assuming 72.5 \% isentropic efficiency}$$

$$P_4 = 9600 \text{ [kPa]}$$

$$h_4 = h \text{ ['Helium', } T = T_4, P = P_4 \text{]}$$

$$Q_{\text{rec,pr}} = 0.8 \cdot [\dot{m} - \dot{m}_{\text{heat,2}}] \cdot [h_{10} - h_4] \text{ Assuming 80\% Recuperator efficiency, NTU method}$$

$$T_1 = T \text{ ['Helium', } P = P_1, h = h_1 \text{]}$$

$$P_1 = 9600 \text{ [kPa]}$$

$$h_1 = h_{10} - \frac{Q_{\text{rec,pr}}}{\dot{m}} \text{ Energy balance over recuperator}$$

$$T_6 = T \text{ ['Helium', } P = P_6, h = h_6 \text{]}$$

$$P_6 = 9600 \text{ [kPa]}$$

$$h_6 = \frac{Q_{\text{rec,pr}}}{\dot{m} - \dot{m}_{\text{heat,2}}} + h_4 \text{ Energy balance over recuperator}$$

Primary side cooler

$$T_2 = 80 \text{ [C]} \text{ Blower inlet temperature}$$

$$P_2 = 9600 \text{ [kPa]}$$

$$h_2 = h \text{ ['Helium', } T = T_2, P = P_2 \text{]}$$

$$Q_{\text{cool,pr}} = \dot{m} \cdot [h_1 - h_2] \text{ Heat transferd from helium}$$

$$T_{\text{w,inlet}} = 20 \text{ [C]} \text{ Assuming 20 C to be the worst case}$$

$$T_{\text{w,outlet}} = 45 \text{ [C]}$$

$$P_w = 300 \text{ [kPa]}$$

$$h_{\text{w,inlet}} = h \text{ ['Water', } T = T_{\text{w,inlet}}, P = P_w \text{]}$$

$$h_{w,outlet} = h \left[\text{'Water'} , T = T_{w,outlet} , P = P_w \right]$$

$$\dot{m}_{water,pr} = \frac{Q_{cool,pr}}{h_{w,outlet} - h_{w,inlet}} \quad \text{Cooling water auxiliary water supply mass flow}$$

Primary side heater 1

$$T_7 = 950 \quad [C] \quad \text{HGD inlet temperature}$$

$$P_7 = 9600 \quad [kPa]$$

$$h_7 = h \left[\text{'Helium'} , T = T_7 , P = P_7 \right]$$

$$Q_{pr,heat,1} = \left[\dot{m} - \dot{m}_{heat,2} \right] \cdot \left[h_7 - h_6 \right] \quad \text{Thermal heat transfered to helium}$$

Primary side heater 2

$$\dot{m}_{heat,2} = 0 \quad [kg/s] \quad \text{Heater not used when testing HGD}$$

$$T_5 = 85 \quad [C]$$

$$P_5 = 9600 \quad [kPa]$$

$$h_5 = h \left[\text{'Helium'} , T = T_5 , P = P_5 \right]$$

$$T_8 = 659 \quad [C] \quad \text{Mixing chamber inlet temperature}$$

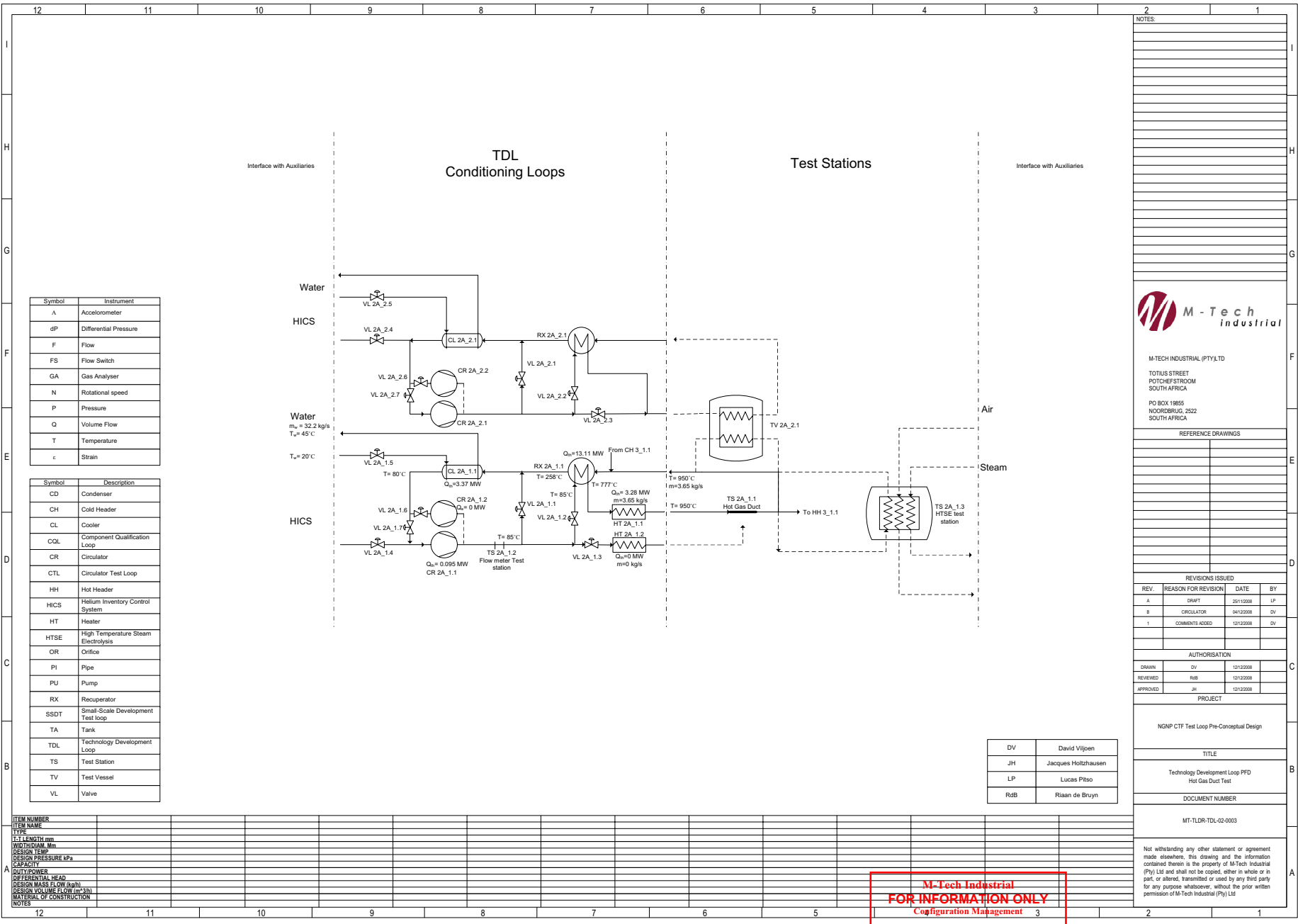
$$P_8 = 9600 \quad [kPa]$$

$$h_8 = h \left[\text{'Helium'} , T = T_8 , P = P_8 \right]$$

$$Q_{pr,heat,2} = \dot{m}_{heat,2} \cdot \left[h_8 - h_5 \right] \quad \text{Heat transfered to helium}$$

Primary side Circulator

$$Q_{pr,circ} = \dot{m} \cdot \left[h_4 - h_2 \right] \quad \text{Circulator flow power based on isentropic efficiency}$$



Appendix D



M - T e c h
i n d u s t r i a l

***Attachment to Section 6: Technology Development
Loop (TDL)
HVAC Systems Level Calculation***

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1. Objective:

The objective of the calculation is to determine for a single TDL the heat loss to the atmosphere in order to serve as an input for the HVAC specification.

2. Methodology:

2.1. APPROACH

The calculation is only based on the “hot” section of a single TDL in the IHX test set up configuration. Both heaters are included in the calculation for a conservative approach. Assuming temperatures for the TDL components as well as the ambient temperature, heat transfer equations could be used to calculate the heat loss from the TDL to the surrounding environment. The heat loss calculated for the TDL then serves as input for the HVAC requirement. The calculation is shown in Attachment A.

2.2. COMPUTER PROGRAMS

The computer program used is EES.

3. Inputs and Assumptions:

3.1. ASSUMPTIONS:

- Building to be kept at 20 °C
- No heat loss from the cold pipes (perfect insulation)
- No heat loss from cooler and blower vessels (perfect insulation)
- TDL hot gas ducts, IHX, heaters and recuperator pressure vessels' surface temperature are 200 °C
- TDL hot gas duct lengths as per initial component placement
- See Attachment A & B

3.2. INPUTS:

- IHX, heater and recuperator pressure vessel sizes as per [MT-TLDR-TDL-CMPT-05-0013, MT-TLDR-TDL-CMPT-05-0007, MT-TLDR-TDL-CMPT-05-0008, MT-TLDR-TDL-CMPT-05-0007, MT-TLDR-TDL-CMPT-05-0009, MT-TLDR-TDL-CMPT-05-0010]
- TDL Hot Gas Duct as per [MT-TLDR-TDL-CMPT-05-0003]
- See Attachment A & B

4. Equations Used and Calculations:

Heat transfer equations as per [Heat and Mass Transfer, Incropera and De Witt, Fifth Edition, 2002]

5. Results:

The results given are for a single TDL:

Description	Unit	Value
TDL Hot Gas Ducts	kW	302
IHX test vessel	kW	228
Recuperator vessels	kW	251
Heaters	kW	208
Total	kW	989

6. Conclusions:

The calculation provides HVAC requirements for conceptual design.

Attachment A

HVAC EES Calculation for HGD

*TDL HVAC requirements**Attachment A of [MT-TLDR-CAL-T - 0604]**Hot Gas Duct HVAC calculation**Assumptions*

=====

A passively cooled hot gas duct design is used $T_{\text{environment}} = 20 \text{ [C]}$ *Conservative assumption* $T_{\text{outer,surface}} = 200 \text{ [C]}$ *Depends on the steel type**Radiative heat transfer view factor from pipe surface to environment = 1**Radiative Area_{environment} is infinitely large**This simplifies the radiation heat transfer calculation**Inputs Units Reference*

=====

 $k = 0.5 \text{ [W/mK]}$ *Based on an assessment of current insulation materials, this is a conservative assumption**It agrees with results from the HENDEL tests:**Construction and Performance Tests of Helium Engineering Demonstration Loop
(HENDEL) for VHTR, Hishida et al., JAERI, 1984**IT also agrees with Helium Test Facility (South Africa) experience* $h_{\text{outside,convection}} = 10 \text{ [W/m}^2\text{K]}$ *Insulation data sheet* $d_{\text{HGD,Liner}} = 0.26 \text{ [m]}$ *TDL Calculations* $\text{emissivity}_{\text{outside}} = 0.9 \text{ [-]}$ *Typical for a painted surface* $L = 76 \text{ [m]}$ *Based on initial component placement for both primary and secondary heat transport capacity* $T_{\text{inside}} = 1000 \text{ [C]}$ *Equations*

=====

 $A_{\text{per,meter}} = \pi \cdot d_{\text{outside}} \cdot L$ *Outside area of a cylinder* $T1 = T_{\text{environment}} + 273$ $T2 = T_{\text{outer,surface}} + 273$

$$h_{\text{outside, radiation}} = 5.670\text{E-}08 \text{ [W/m}^2\text{-K}^4] \cdot [T_1 + T_2] \cdot \left[\frac{T_1^2 + T_2^2}{\frac{1 + \text{emissivity}_{\text{outside}}}{\text{emissivity}_{\text{outside}}} + 1} \right]$$

Heat and Mass Transfer, Incropera and De Witt, Fifth Edition, 2002

The following two simultaneous equations solve for the variables Q and d_{outside}

$$Q = [h_{\text{outside, convection}} + h_{\text{outside, radiation}}] \cdot A_{\text{per, meter}} \cdot [T_{\text{outer, surface}} - T_{\text{environment}}]$$

Heat and Mass Transfer, Incropera and De Witt, Fifth Edition, 2002

$$Q = k \cdot 2 \cdot \pi \cdot \frac{L}{\ln \left[\frac{d_{\text{outside}}}{d_{\text{HGD, Liner}}} \right]} \cdot [T_{\text{inside}} - T_{\text{outer, surface}}]$$

Heat and Mass Transfer, Incropera and De Witt, Fifth Edition, 2002



Attachment B

HVAC EES Calculation for IHX

*IHX test vessel HVAC calculation**Attachment B of [MT-TLDR-CAL-T - 0604]**IHX HVAC Calculation**Assumptions*

=====

A passively cooled pressure vessel is used

$$T_{\text{test}} = 1000 \text{ [C]}$$

$$T_{\text{amb}} = 20 \text{ [C]} \text{ Ambient temperature}$$

*It is assumed that there is a zero deltaT across the High-temperature vessel and across the polished cladding**Radiative heat transfer view factor from vessel surface to environment = 1**Radiative Area_{environment} is infinitely large**This simplifies the radiation heat transfer calculation**Material properties Units Reference*

=====

$$k_{\text{outer,insulation}} = 0.5 \text{ [W/mK]}$$

$$k_{\text{gap}} = k \text{ ['Helium', T = 80, P = 9000]}$$

$$k_{\text{steel}} = k \text{ ['Carbon_{steel,AISI1010'}, 80]}$$

$$\epsilon_{\text{ps clad}} = 0.3 \text{ Emissivity for polished stainless steel: Incropera}$$

$$\epsilon_{\text{ps pv,i}} = 0.8 \text{ Emissivity for lightly oxidised carbon steel: Incropera}$$

$$\epsilon_{\text{ps pv,o}} = 0.9 \text{ Emissivity for a painted surface: Incropera}$$

Geometry Units Reference

=====

$$R_{\text{test}} = 1.5 \text{ [m]} \text{ Radius of test section}$$

$$t_{\text{insulation}} = 0.145 \text{ [m]}$$

$$R_{\text{clad}} = R_{\text{test}} + t_{\text{insulation}} \text{ Radius of cladding}$$

$$L_{\text{gap}} = 0.0001 \text{ [m]} \text{ Gap between vessel and insulation}$$

$$R_{\text{pv,i}} = R_{\text{clad}} + L_{\text{gap}} \text{ Pressure vessel internal diameter}$$

$$L_{\text{pv}} = 0.05 \text{ Thickness of the pressure vessel wall}$$

$$R_{\text{pv,o}} = R_{\text{pv,i}} + L_{\text{pv}} \text{ Pressure vessel outside radius}$$

$$L_{\text{test}} = 6.6 \text{ [m] } \text{Length of test section}$$

$$A_{\text{pv,o}} = 2 \cdot \pi \cdot R_{\text{pv,o}} \cdot [L_{\text{test}} + 2 \cdot (R_{\text{pv,o}} - R_{\text{test}})] + 2 \cdot \pi \cdot R_{\text{pv,o}}^2$$

$$A_{\text{clad}} = 2 \cdot \pi \cdot R_{\text{clad}} \cdot [L_{\text{test}} + 2 \cdot (R_{\text{clad}} - R_{\text{test}})] + 2 \cdot \pi \cdot R_{\text{clad}}^2$$

$$L_{\text{pressurevessel}} = L_{\text{test}} + 2 \cdot [R_{\text{pv,i}} - R_{\text{test}}]$$

Equations

=====

$$Q_{\text{vessel}} = k_{\text{outer,insulation}} \cdot \left[2 \cdot \pi \cdot \frac{L_{\text{test}}}{\ln\left(\frac{R_{\text{clad}}}{R_{\text{test}}}\right)} + 2 \cdot \pi \cdot \left(\frac{R_{\text{clad}}^2}{R_{\text{clad}} - R_{\text{test}}}\right) \right] \cdot [T_{\text{test}} - T_{\text{clad}}]$$

$$h_{\text{gap,rad}} = 5.670\text{E-}08 \text{ [W/m}^2\text{-K}^4] \cdot [T_{\text{clad}} + 273 + T_{\text{pv,i}} + 273] \cdot \left[\frac{(T_{\text{clad}} + 273)^2 + (T_{\text{pv,i}} + 273)^2}{\frac{1 + \text{eps}_{\text{clad}}}{\text{eps}_{\text{clad}}} + 1 + \frac{1 + \text{eps}_{\text{pv,i}}}{\text{eps}_{\text{pv,i}}}} \right]$$

$$v_{\text{lam}} = 4.36$$

$$\frac{1}{h_{\text{gap,conv}}} = \frac{L_{\text{gap}}}{k_{\text{gap}} \cdot v_{\text{lam}}} + \frac{L_{\text{gap}}}{k_{\text{gap}} \cdot v_{\text{lam}}}$$

$$Q_{\text{vessel}} = [h_{\text{gap,rad}} + h_{\text{gap,conv}}] \cdot A_{\text{clad}} \cdot [T_{\text{clad}} - T_{\text{pv,i}}]$$

$$Q_{\text{vessel}} = k_{\text{steel}} \cdot \left[2 \cdot \pi \cdot \left(\frac{L_{\text{test}} + 2 \cdot [R_{\text{pv,i}} - R_{\text{test}}]}{\ln\left[\frac{R_{\text{pv,o}}}{R_{\text{pv,i}}}\right]} \right) + 2 \cdot \pi \cdot \frac{R_{\text{pv,o}}^2}{L_{\text{pv}}} \right] \cdot [T_{\text{pv,i}} - T_{\text{pv,o}}]$$

$$T1 = T_{\text{amb}} + 273$$

$$T2 = T_{\text{pv,o}} + 273$$

$$h_{\text{amb,conv}} = 10 \text{ [W/m}^2\text{K]} \text{ Insulation data sheet}$$

$$h_{\text{amb,rad}} = 5.670\text{E-}08 \text{ [W/m}^2\text{-K}^4] \cdot [T1 + T2] \cdot \left[\frac{T1^2 + T2^2}{\frac{1 + \text{eps}_{\text{pv,o}}}{\text{eps}_{\text{pv,o}}} + 1} \right]$$

Heat and Mass Transfer, Incropera and De Witt, Fifth Edition, 2002

$$Q_{\text{vessel}} = [h_{\text{amb,conv}} + h_{\text{amb,rad}}] \cdot A_{\text{pv,o}} \cdot [T_{\text{pv,o}} - T_{\text{amb}}]$$

Heat and Mass Transfer, Incropera and De Witt, Fifth Edition, 2002

Appendix E



M - T e c h
i n d u s t r i a l

***Attachment to Section 6: Technology Development
Loop (TDL)
System Pressure Loss Calculation***

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1. Objective:

The objective of the calculation is to determine the initial system pressure loss characteristic in order to serve as an input for the TDL circulator selection.

2. Methodology:

2.1. APPROACH

The mass flow in the TDL was based on the mass flow required for 3 x 1.2 MW IHX A module tests. Initial pipe diameters were calculated based on an average gas velocity of 20 m/s. Initial estimates of pipe lengths were made and the pressure loss calculated. Initial estimates of pressure loss over the different components were made based on engineering judgment. The total pressure loss in the system could then be calculated and the required fluid power to be supplied by the circulator determined. Pressure drop and flow characteristics as per "White".[Fluid Mechanics, White, fourth ed. 1999]

2.2. COMPUTER PROGRAMS

The computer program used is EES

3. Inputs and Assumptions:

3.1. ASSUMPTIONS:

- Adiabatic flow conditions assumed in the TDL, no heat loss to surroundings.
- Assume that the flow is fully developed turbulent flow
- Pipe roughness $\epsilon = 0.05$ mm
- Gas velocity in duct = 20 m/s
- Pressure loss over components not specified are based on engineering judgment [Attachment A]

3.2. INPUTS:

- Total mass flow equal to mass flow as calculated for 3 x 1.2 MW IHX A modules
- Pipe lengths as per initial component placement estimate [Attachment A]
- Pressure loss over IHX as per [Feasibility and recommendations study: IHX dP < 1.23% of the inlet pressure]
- Friction factor f as calculated form [Fluid Mechanics, White, fourth edition, 1999]
- Pipe diameters as per [Attachment A]
- Recuperator pressure loss as per [MT-TLDR-TDL-CMPT-05-0009, MT-TLDR-TDL-CMPT-05-0010]

- Cooler pressure loss as per [MT-TLDR-TDL-CMPT-05-0011, MT-TLDR-TDL-CMPT-05-0012]

4. Equations Used and Calculations:

Internal duct flow calculations were used to determine the pressure loss [Fluid Mechanics, White, fourth edition, 1999].

5. Results:

Primary side circulator (CR 2A_1.1)

Description	Unit	Value
P_{he}	kPa	9000
$T_{he\ in}$	°C	80
ΔP_{system}	kPa	305
m_{he}	kg/s	4.75 (3.65)
Q_{th}	MW	0.122 (0.094)
Q_e	MW	0.204

Values in () indicate the component size without 30% safety margin

Q_e is the electrical input assuming 60% efficiency from electrical input → flow output

Secondary loop circulator (CR 2A_2.1)

Description	Unit	Value
P_{he}	kPa	9600
$T_{he\ in}$	°C	80
ΔP_{system}	kPa	247
m_{he}	kg/s	4.75 (3.65)
Q_{th}	MW	0.0927 (0.0713)
Q_e	MW	0.154

Values in () indicate the component size without 30% safety margin

Q_e is the electrical input assuming 60% efficiency from electrical input → flow output

6. Conclusions:

Circulator sizes for conceptual design component selection.

Attachment A

System Pressure Drop EES Calculation

*Initial System Pressure Drop Calculation**Attachment A of [MT-TLDR-CAL-T - 0605]**Primary loop**Cold side*

$$\dot{m}_{pr} = 3.651 \text{ [kg/s]} \text{ Mass flow assumed to be as per 3 x 1.2 MW IHX A test modules}$$

$$v_{pr,cold} = 20 \text{ [m/s]} \text{ Conservative assumption based on engineering judgement}$$

$$f_{pr,cold} = 0.0155 \text{ White}$$

$$L_{pr,cold} = 42 \text{ [m]} \text{ Based on initial component placement estimates}$$

$$d_{pr,cold} = 0.14 \text{ [m]} \text{ As per hot gas duct pipe calculation}$$

$$T_{pr,cold} = 80 \text{ [C]}$$

$$P_{pr,cold} = 9000 \text{ [kPa]}$$

$$\rho_{pr,cold} = \rho[\text{'Helium'}, T = T_{pr,cold}, P = P_{pr,cold}]$$

$$K_{pr,cold} = f_{pr,cold} \cdot \frac{L_{pr,cold}}{d_{pr,cold}}$$

$$dP_{pr,cold} = K_{pr,cold} \cdot \frac{0.5 \cdot \rho_{pr,cold} \cdot v_{pr,cold}^2}{1000} \text{ Pressure loss in primary loop cold section pipes}$$

Hot side

$$v_{pr,hot} = 20 \text{ [m/s]} \text{ Conservative assumption based on engineering judgement}$$

$$f_{pr,hot} = 0.014 \text{ White}$$

$$L_{pr,hot} = 47 \text{ [m]} \text{ Based on initial component placement estimates}$$

$$d_{pr,hot} = 0.26 \text{ [m]} \text{ As per hot gas duct pipe calculation}$$

$$T_{pr,hot} = 760 \text{ [C]}$$

$$P_{pr,hot} = 9000 \text{ [kPa]}$$

$$\rho_{pr,hot} = \rho[\text{'Helium'}, T = T_{pr,hot}, P = P_{pr,hot}]$$

$$K_{pr,hot} = f_{pr,hot} \cdot \frac{L_{pr,hot}}{d_{pr,hot}}$$

$$dP_{pr,hot} = K_{pr,hot} \cdot \frac{0.5 \cdot \rho_{pr,hot} \cdot v_{pr,hot}^2}{1000} \text{ Pressure loss in primary loop hot section pipes}$$

Total Pressure loss Primary loop

$$dP_{pr,heater} = 10 \text{ [kPa]} \text{ Based on engineering judgment}$$

$$dP_{pr,rec} = 165 \text{ [kPa]} \text{ Both sides of the Recuperator, based on component data sheet}$$

$$dP_{pr,cooler} = 6.6 \text{ [kPa]} \text{ Based on component data sheet}$$

$$dP_{pr,IHXA} = 0.0123 \cdot 9000 \text{ [kPa]} \text{ Feasibility and recommendations study: IHX } dP < 1.23\% \text{ of the inlet pressure}$$

$$dP_{pr} = dP_{pr,cold} + dP_{pr,hot} + dP_{pr,heater} + dP_{pr,rec} + dP_{pr,cooler} + dP_{pr,IHXA}$$

$$V_{pr} = \frac{\dot{m}_{pr}}{\rho_{pr,cold}}$$

$$Q_{pr,circ} = V_{pr} \cdot dP_{pr} \text{ Fluid power to be supplied by secondary circulator}$$

Secondary loop

Cold side

$$\dot{m}_{sec} = 3.651 \text{ [kg/s]} \text{ Mass flow assumed to be as per 3 x 1.2 MW IHX A test modules}$$

$$v_{sec,cold} = 20 \text{ [m/s]} \text{ Conservative assumption based on engineering judgement}$$

$$f_{sec,cold} = 0.0155 \text{ White}$$

$$L_{sec,cold} = 42 \text{ [m]} \text{ Based on initial component placement estimates}$$

$$d_{sec,cold} = 0.14 \text{ [m]} \text{ As per hot gas duct pipe calculation}$$

$$T_{sec,cold} = 80 \text{ [C]}$$

$$P_{sec,cold} = 9600 \text{ [kPa]}$$

$$\rho_{sec,cold} = \rho[\text{'Helium'}, T = T_{sec,cold}, P = P_{sec,cold}]$$

$$K_{sec,cold} = f_{sec,cold} \cdot \frac{L_{sec,cold}}{d_{sec,cold}}$$

$$dP_{sec,cold} = K_{sec,cold} \cdot \frac{0.5 \cdot \rho_{sec,cold} \cdot v_{sec,cold}^2}{1000} \text{ Pressure loss in secondary loop cold section pipes}$$

Hot side

$$v_{sec,hot} = 20 \text{ [m/s]} \text{ Conservative assumption based on engineering judgement}$$

$$f_{sec,hot} = 0.014 \text{ White}$$

$$L_{sec,hot} = 29 \text{ [m]} \text{ Based on initial component placement estimates}$$

$$d_{sec,hot} = 0.26 \text{ [m]} \text{ As per hot gas duct pipe calculation}$$

$$T_{sec,hot} = 710 \text{ [C]}$$

$$P_{sec,hot} = 9600 \text{ [kPa]}$$

$$\rho_{sec,hot} = \rho[\text{'Helium'}, T = T_{sec,hot}, P = P_{sec,hot}]$$

$$K_{\text{sec,hot}} = f_{\text{sec,hot}} \cdot \frac{L_{\text{sec,hot}}}{d_{\text{sec,hot}}}$$

$$dP_{\text{sec,hot}} = K_{\text{sec,hot}} \cdot \frac{0.5 \cdot \rho_{\text{sec,hot}} \cdot v_{\text{sec,hot}}^2}{1000} \quad \text{Pressure loss in secondary loop hot section pipes}$$

Total Pressure secondary loop

$$dP_{\text{sec,rec}} = 106 \text{ [kPa]} \quad \text{Both sides of the Recuperator, based on component data sheet}$$

$$dP_{\text{sec,cooler}} = 9.2 \text{ [kPa]} \quad \text{Based on component data sheet}$$

$$dP_{\text{sec,IHXA}} = 0.0123 \cdot 9600 \text{ [kPa]} \quad \text{Feasibility and recommendations study: IHX } dP < 1.23\% \text{ of the inlet pressure}$$

$$dP_{\text{sec}} = dP_{\text{sec,cold}} + dP_{\text{sec,hot}} + dP_{\text{sec,rec}} + dP_{\text{sec,cooler}} + dP_{\text{sec,IHXA}}$$

$$V_{\text{sec}} = \frac{\dot{m}_{\text{sec}}}{\rho_{\text{sec,cold}}}$$

$$Q_{\text{sec,circ}} = V_{\text{sec}} \cdot dP_{\text{sec}} \quad \text{Fluid power to be supplied by secondary circulator}$$

Appendix F



M - T e c h
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***Attachment to Section 6: Technology Development
Loop (TDL)
HTSE Systems Level Calculation***

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HTSE EES Calculation	7

1. Objective:

The objective of the calculation is to determine for the High Temperature Steam Electrolysis (HTSE) process, the heat input required from the TDL. Due to the fact that only limited information is available on the HTSE heat exchanger, the calculation is not used to determine TDL component sizes but rather to verify that the TDL heating capacity is adequate for the HTSE process heat exchanger tests. The calculation is shown in Attachment A.

2. Methodology:

2.1. APPROACH

The HTSE heat exchanger steam and air inlet and outlet flow conditions as well as steam and air mass flows were given in the [HPS.000.S01.HTSE Review Package] and was used as input into the model. The calculation was then used to determine if the TDL heating capacity will be adequate for the HTSE tests

2.2. COMPUTER PROGRAMS

The computer program used is EES.

3. Inputs and Assumptions:

3.1. ASSUMPTIONS:

- Adiabatic flow conditions assumed in the TDL, no heat loss to surroundings.
- No pressure drop through pipes and components

3.2. INPUTS:

- TDL nominal helium pressure = 9000 kPa

The following are test inputs:

- Air inlet temperature = 176 °C
- Air inlet pressure = 5600 kPa
- Air outlet temperature = 870 °C
- Air outlet pressure = 5600 kPa
- Air mass flow = 0.76 kg/s
- Steam inlet temperature = 396 °C
- Steam inlet pressure = 5600 kPa
- Steam outlet temperature = 870 °C
- Steam outlet pressure = 5600 kPa
- Steam mass flow = 0.62 kg/s

4. Equations Used and Calculations:

The equations used are first law of Thermodynamic energy balance equations [Fundamentals of Thermodynamics, Sonntag et al, Fifth edition, 1998].

5. Results:

The model shows that the HTSE process heat exchanger transfers 1.278 MW from the helium to the air and steam. The thermal heating capacity of the TDL is 6.16 MW and is therefore adequate for the HTSE process heat exchanger tests.

6. Conclusions:

The TDL heating capacity is adequate to do HTSE heat exchanger tests.

Attachment A

HTSE EES Calculation

TDL test for High Temperature Steam Electrolysis

Attachment A of [MT-TLDR-CAL-T - 0606]

Positions are numbered in PFD [MT-TLDR-TDL- 02 -0001-Rev A]

Process heat exchangers

Air heat exchanger

$$T_9 = 176 \text{ [C]} \text{ Air inlet temperature}$$

$$P_9 = 5600 \text{ [kPa]} \text{ Air inlet pressure}$$

$$h_9 = h \text{ ['Air' , } T = T_9 \text{]}$$

$$T_{19} = 870 \text{ [C]} \text{ Air outlet temperature}$$

$$P_{19} = 5600 \text{ [kPa]} \text{ Air outlet pressure}$$

$$h_{19} = h \text{ ['Air' , } T = T_{19} \text{]}$$

$$\dot{m}_{\text{air}} = 0.76 \text{ [kg/s]} \text{ Air mass flow}$$

$$Q_{\text{air}} = \dot{m}_{\text{air}} \cdot [h_{19} - h_9] \text{ Heat transferred from helium to air}$$

Steam heat exchanger

$$T_{20} = 396 \text{ [C]} \text{ Steam inlet temperature}$$

$$P_{20} = 5600 \text{ [kPa]} \text{ Steam inlet pressure}$$

$$h_{20} = h \text{ ['Water' , } T = T_{20} \text{ , } P = P_{20} \text{]}$$

$$T_{21} = 870 \text{ [C]} \text{ Steam outlet temperature}$$

$$P_{21} = 5600 \text{ [kPa]} \text{ Steam outlet pressure}$$

$$h_{21} = h \text{ ['Water' , } T = T_{21} \text{ , } P = P_{21} \text{]}$$

$$\dot{m}_{\text{steam}} = 0.62 \text{ [kg/s]} \text{ Mass flow steam}$$

$$Q_{\text{steam}} = \dot{m}_{\text{steam}} \cdot [h_{21} - h_{20}] \text{ Heat transferred from helium to steam}$$

$$Q_{\text{PCHX}} = Q_{\text{steam}} + Q_{\text{air}} \text{ Heat removed from helium}$$

Appendix G



M - T e c h
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***Attachment to Section 6: Technology Development
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HICS Systems Level Calculation***

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HICS EES Calculation	7

1. Objective:

The objective of the calculation is to determine the initial system volume in order to serve as an input for the HICS requirements.

2. Methodology:

2.1. APPROACH

Initial pipe diameters were calculated based on an average gas velocity of 20 m/s. Initial estimates of pipe lengths were made and the volume calculate. Initial estimates of component sizes and volumes were made based on engineering judgment. The total helium volume in the system could then be calculated and the requirement for the HICS determined.

2.2. COMPUTER PROGRAMS

The computer program used is EES.

3. Inputs and Assumptions:

3.1. ASSUMPTIONS:

- TDL configuration set up as for IHX tests.
- Initial pipe lengths as per initial component placement and component sizes as per engineering judgment [Attachment A]
- TDL to remain at 20 °C when pressurized or depressurized
- Pressurization and depressurization between 10 kPa – 9600 kPa
- Pressurization and depressurization time $\approx$ 7200 s (2 hours)
- 1/3 of cooler shell volume is helium
- 1/3 of blower vessel shell volume is helium
- 2/3 of recuperator shell volume is helium
- 2/3 of IHX vessel shell volume is helium
- Volume of IHX vessel is divided equally between primary and secondary heat transport capacity

3.2. INPUTS:

- Pipe diameters based on 20 m/s average gas velocity calculation
- Pipe lengths, and component sizes as per [Attachment A]

4. Equations Used and Calculations:

Simple volume calculations.

5. Results:

HICS Primary Heat Transport Capacity

NGNP	CTF MTECH	TLDR
$P_{\text{range he}}$	kPa	10 - 9000
$T_{\text{he in}}$	°C	20
$T_{\text{he out}}$	°C	80
$d_{\text{internal pipe}}$	m	0.02
m_{he}	kg/s	0.105
$m_{\text{he total}}$	kg	759

HICS Secondary Heat Transport Capacity

NGNP	CTF MTECH	TLDR
$P_{\text{range he}}$	kPa	10 - 9600
$T_{\text{he in}}$	°C	20
$T_{\text{he out}}$	°C	80
$d_{\text{internal pipe}}$	m	0.02
m_{he}	kg/s	0.064
$m_{\text{he total}}$	kg	459

6. Conclusions:

HICS requirements for conceptual design.

Attachment A

HICS EES Calculation

Internal volume of TDL for HICS requirement

Attachment A of [MT-TLDR-CAL-T - 0607]

Assume fill time is 2 hours

$$t_{\text{fill}} = 7200 \text{ [s]}$$

Primary loop

Primary loop Pipes

$$L_{\text{pr,cold}} = 42 \text{ [m]} \text{ Based on initial component placement estimates}$$

$$d_{\text{pr,cold}} = 0.14 \text{ [m]} \text{ Based on gas duct diameter calculation}$$

$$V_{\text{pr,cold}} = L_{\text{pr,cold}} \cdot \pi \cdot \left[\frac{d_{\text{pr,cold}}}{2} \right]^2$$

$$L_{\text{pr,hot}} = 47 \text{ [m]} \text{ Based on initial component placement estimates}$$

$$d_{\text{pr,hot}} = 0.5 \text{ [m]} \text{ Based on gas duct diameter calculation}$$

$$V_{\text{pr,hot}} = L_{\text{pr,hot}} \cdot \pi \cdot \left[\frac{d_{\text{pr,hot}}}{2} \right]^2$$

Heaters

$$L_{\text{heater,1}} = 10 \text{ [m]} \text{ Based on initial component size estimates}$$

$$d_{\text{heater,1}} = 1.8 \text{ [m]}$$

$$V_{\text{heater,1}} = 2 / 3 \cdot L_{\text{heater,1}} \cdot \pi \cdot \left[\frac{d_{\text{heater,1}}}{2} \right]^2 \text{ Assume 2/3 of total volume is gas}$$

$$L_{\text{heater,2}} = 4.5 \text{ [m]} \text{ Based on initial component size estimates}$$

$$d_{\text{heater,2}} = 1 \text{ [m]}$$

$$V_{\text{heater,2}} = 2 / 3 \cdot L_{\text{heater,2}} \cdot \pi \cdot \left[\frac{d_{\text{heater,2}}}{2} \right]^2 \text{ Assume 2/3 of total volume is gas}$$

Primary loop Recuperator (4 units will be used in series)

$$L_{\text{pr,rec}} = 3.64 \text{ [m]} \text{ Based on initial component size estimates}$$

$$d_{\text{pr,rec}} = 0.63 \text{ [m]}$$

$$V_{\text{pr,rec}} = 4 \cdot 2 / 3 \cdot L_{\text{pr,rec}} \cdot \pi \cdot \left[\frac{d_{\text{pr,rec}}}{2} \right]^2 \text{ Assume 2/3 of total volume is gas}$$

Primary loop Cooler

$$L_{\text{pr,cool}} = 3.5 \text{ [m]} \text{ Based on initial component size estimates}$$

$$d_{pr,cool} = 0.56 \text{ [m]}$$

$$V_{pr,cool} = 1 / 3 \cdot L_{pr,cool} \cdot \pi \cdot \left[\frac{d_{pr,cool}}{2} \right]^2 \quad \text{Assume 1/3 of total volume is gas}$$

Primary side IHX vessel

Assume 1/2 of IHX vessel volume for Primary loop

$$L_{pr,IHX} = 6.89 \text{ [m]} \quad \text{Based on initial component size estimates}$$

$$d_{pr,IHX} = 3.29 \text{ [m]}$$

$$V_{pr,IHX} = 1 / 2 \cdot 2 / 3 \cdot L_{pr,IHX} \cdot \pi \cdot \left[\frac{d_{pr,IHX}}{2} \right]^2 \quad \text{Assume 2/3 of Primary loop IHX volume to be gas}$$

Primary loop Blower vessel

$$L_{pr,blow} = 4 \text{ [m]} \quad \text{Based on initial component size estimates}$$

$$d_{pr,blow} = 1.2 \text{ [m]}$$

$$V_{pr,blow} = 1 / 3 \cdot L_{pr,blow} \cdot \pi \cdot \left[\frac{d_{pr,blow}}{2} \right]^2 \quad \text{Assume 1/3 of total volume is gas}$$

Primary loop volume

$$V_{pr} = V_{pr,cold} + V_{pr,hot} + V_{heater,1} + V_{heater,2} + V_{pr,rec} + V_{pr,cool} + V_{pr,IHX} + V_{pr,blow}$$

$$\rho_{pr} = \rho[\text{'Helium'}, T=20, P=9000] \quad \text{Assume system temperature to remain 20 C}$$

$$m_{pr} = V_{pr} \cdot \rho_{pr}$$

$$\dot{m}_{pr} = \frac{m_{pr}}{t_{fill}} \quad \text{Mass flow rate required for primary side}$$

Secondary loop

Secondary loop Pipes

$$L_{sec,cold} = 42 \text{ [m]} \quad \text{Based on initial component placement estimates}$$

$$d_{sec,cold} = 0.14 \text{ [m]} \quad \text{Based on gas duct diameter calculation}$$

$$V_{sec,cold} = L_{sec,cold} \cdot \pi \cdot \left[\frac{d_{sec,cold}}{2} \right]^2$$

$$L_{sec,hot} = 29 \text{ [m]} \quad \text{Based on initial component placement estimates}$$

$$d_{sec,hot} = 0.5 \text{ [m]} \quad \text{Based on gas duct diameter calculation}$$

$$V_{sec,hot} = L_{sec,hot} \cdot \pi \cdot \left[\frac{d_{sec,hot}}{2} \right]^2$$

Secondary loop Recuperator (3 units will be used in series)

$$L_{\text{sec,rec}} = 3.64 \text{ [m]} \text{ Based on initial component size estimates}$$

$$d_{\text{sec,rec}} = 0.63 \text{ [m]}$$

$$V_{\text{sec,rec}} = 3 \cdot 2 / 3 \cdot L_{\text{sec,rec}} \cdot \pi \cdot \left[\frac{d_{\text{sec,rec}}}{2} \right]^2 \text{ Assume 2/3 of total volume is gas}$$

Secondary loop Cooler

$$L_{\text{sec,cool}} = 4.13 \text{ [m]} \text{ Based on initial component size estimates}$$

$$d_{\text{sec,cool}} = 0.848 \text{ [m]}$$

$$V_{\text{sec,cool}} = 1 / 3 \cdot L_{\text{sec,cool}} \cdot \pi \cdot \left[\frac{d_{\text{sec,cool}}}{2} \right]^2 \text{ Assume 1/3 of total volume is gas}$$

Secondary side IHX vessel

Assume 1/2 of IHX vessel volume for Secondary loop

$$L_{\text{sec,IHX}} = 6.89 \text{ [m]} \text{ Based on initial component size estimates}$$

$$d_{\text{sec,IHX}} = 3.29 \text{ [m]}$$

$$V_{\text{sec,IHX}} = 1 / 2 \cdot 2 / 3 \cdot L_{\text{sec,IHX}} \cdot \pi \cdot \left[\frac{d_{\text{sec,IHX}}}{2} \right]^2 \text{ Assume 2/3 of Secondary loop IHX volume to be gas}$$

Secondary loop Blower vessel

$$L_{\text{sec,blow}} = 4 \text{ [m]} \text{ Based on initial component size estimates}$$

$$d_{\text{sec,blow}} = 1.2 \text{ [m]}$$

$$V_{\text{sec,blow}} = 1 / 3 \cdot L_{\text{sec,blow}} \cdot \pi \cdot \left[\frac{d_{\text{sec,blow}}}{2} \right]^2 \text{ Assume 1/3 of total volume is gas}$$

Secondary loop volume

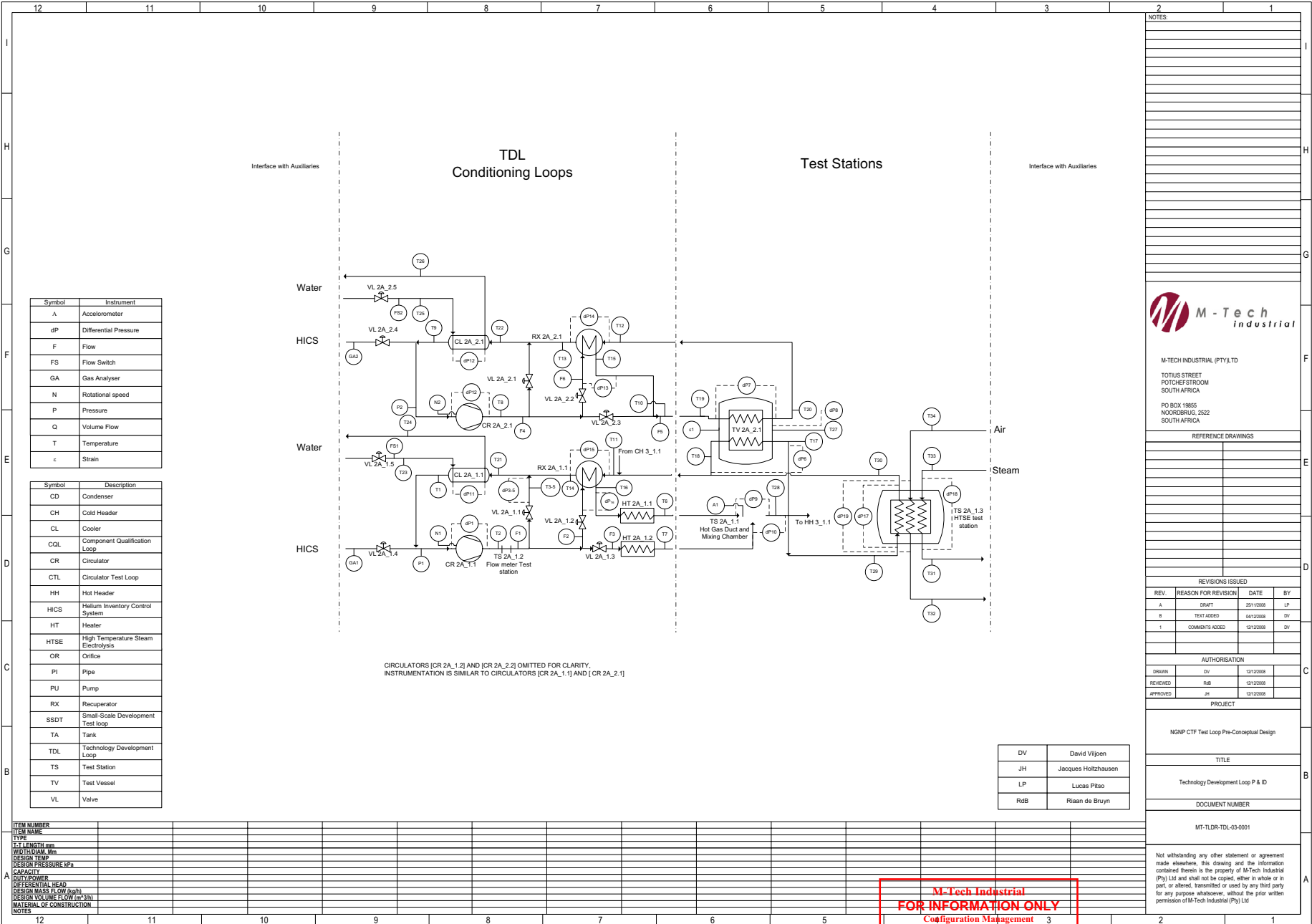
$$V_{\text{sec}} = V_{\text{sec,cold}} + V_{\text{sec,hot}} + V_{\text{sec,rec}} + V_{\text{sec,cool}} + V_{\text{sec,IHX}} + V_{\text{sec,blow}}$$

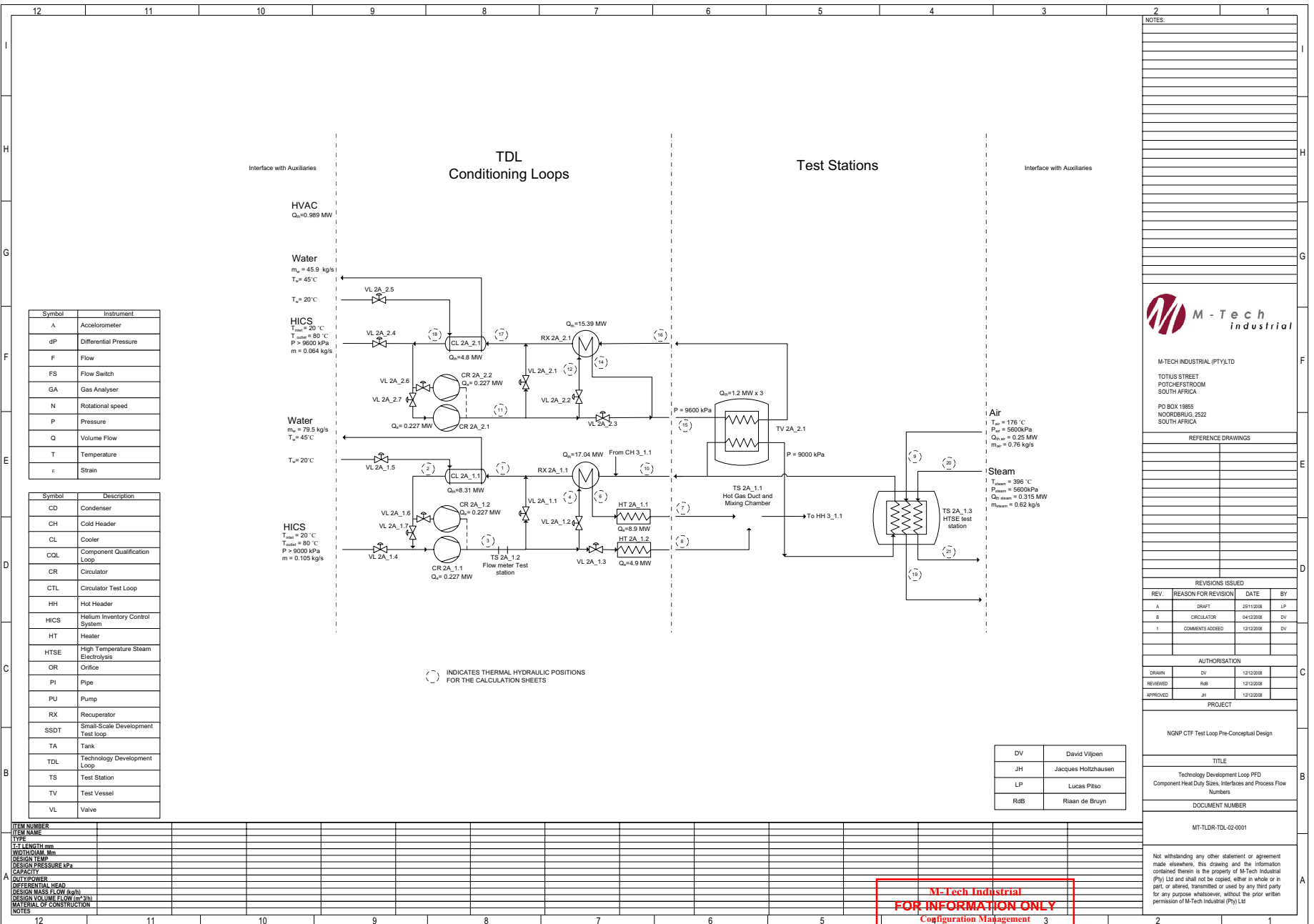
$$\rho_{\text{sec}} = \rho[\text{'Helium'}, T=20, P=9600] \text{ Assume system temperature to remain 20 C}$$

$$m_{\text{sec}} = V_{\text{sec}} \cdot \rho_{\text{sec}}$$

$$\dot{m}_{\text{sec}} = \frac{m_{\text{sec}}}{t_{\text{fill}}} \text{ Mass flow rate required for secondary side}$$

Appendix H





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REFERENCE DRAWINGS

REV.	REASON FOR REVISION	DATE	BY
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1	COMMENTS ADDED	12/10/2008	DV

REV.	REASON FOR REVISION	DATE	BY
A	DRAFT	2011/09/08	LP
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A	DRAFT	2011/09/08	LP
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AUTHORISATION

REV.	REASON FOR REVISION	DATE	BY
A	DRAFT	2011/09/08	LP
B	CIRCULATOR	04/10/2008	DV
1	COMMENTS ADDED	12/10/2008	DV

PROJECT

NGNP CTF Test Loop Pre-Conceptual Design

TITLE

Technology Development Loop PFD
Component Heat Duty Sizing, Interfaces and Process Flow
Numbers

DOCUMENT NUMBER

MT-TLDR-TDL-02-0001

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Configuration Management

Appendix I



M - T e c h
i n d u s t r i a l

***Attachment to Section 6: Technology Development
Loop (TDL)
Circulator Calculation***

Document number: MT-TLDR-CAL-F-M-0608

Revision: 1

Status: Approved

D.J. Viljoen

November 2008

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Configuration Management

CHANGE HISTORY

Configuration Control	
Client Name:	Westinghouse Electric Company
Project Number:	NGNP-CTF MTECH-TLDR
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Calculation Title:	Circulator Calculation
Calculation Identification Number:	MT-TLDR-CAL-F-M-0608
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Authorisation			
Action	Name	Signature	Date
Preparer	D J Viljoen	_____	November 26, 2008
Reviewer	H van Antwerpen	_____	November 28, 2008
Approver	R de Bruyn	_____	November 28, 2008

Original Signed Copy at CMC

Distribution					
Discipline	Name	Discipline	Name	Discipline	Name

Confirmation Required Status			
Calculation Page	Input/Assumption that Requires Confirmation	Preparer and Date Input/Assumption Confirmed	Reviewer and Date Input/Assumption Approved

Record of Changes	
Revision	Description of Changes
A	Initial Draft
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Change Forecast

The document format and contents have been approved.

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1. Objective:

The objective of the calculation is to select a blower based on requirements obtained from the system pressure loss calculation [MT-TLDR-CAL-T-0605] in Appendix E. The Mechanical design calculations and results for the circulator vessel are shown in Attachment A.

2. Methodology:

2.1. APPROACH

Since custom helium blowers are not freely available commercially it was decided to use an “off the shelf” dynamic air blower. For a first estimate the density ratio between air and helium was used to scale the blower pressure rise and power, assuming that the volume flow through a dynamic machine will be the same for helium and air.

2.2. COMPUTER PROGRAMS

The computer program used is Excel.

3. Inputs and Assumptions:

3.1. ASSUMPTIONS:

Thermo Hydraulic:

- Pressure rise scaled with density ratio between air and helium
- Power scaled with density ratio between air and helium
- Volume flow through machine to be the same in air and helium
- Air conditions = 20 °C @ 100 kPa
- Helium conditions = 80 °C @ 9000 kPa

Mechanical:

- All pressure boundary calculations are done using a MS Excel spreadsheet incorporating ASME Code VIII Div 1 2001, No Addenda
- No corrosion allowance was included
- All pressure boundary outside temperatures are taken as 200°C

3.2. INPUTS (THERMO HYDRAULIC):

Thermo Hydraulic:

- Air conditions = 20 °C @ 100 kPa [Appendix I]

Primary loop circulator (CR 2A_1.1; CR 2A_1.2)

Description	Unit	Value
P_{he}	kPa	9000
$T_{he\ in}$	°C	80
ΔP_{system}	kPa	305
m_{he}	kg/s	4.75 (3.65)

Values in () indicate the component size without 30% safety margin

Secondary loop circulator (CR 2A_2.1; CR 2A_2.2)

Description	Unit	Value
P_{he}	kPa	9600
$T_{he\ in}$	°C	80
ΔP_{system}	kPa	247
m_{he}	kg/s	4.75 (3.65)

Values in () indicate the component size without 30% safety margin.

Mechanical:

- Proposed material is SA-516 Gr.70
- Allowable stress was taken as 20 KSI at 204°C (400°F) from ASME material property database
- Internal pressures taken as 9.6 MPa
- All other related input can be found in the attached calculation spreadsheet and are included in sections: **Dimensions** and **Material and Conditions**

4. Equations Used and Calculations:

The density ratio between air and helium is:

$$\rho_{air} = 1.19 \text{ kg/m}^3 \text{ [20 °C @ 100 kPa]}$$

$$\rho_{he} = 11.86 \text{ kg/m}^3 \text{ [80 °C @ 9000 kPa]}$$

$$\text{Ratio} = \rho_{he} / \rho_{air} = 9.97$$

The requirement for an equivalent dynamic air blower based on the primary loop circulator requirements is:

$$\Delta P_{air} = \Delta P_{he} / \text{Ratio} = 305 / 9.97 = 30.6 \text{ kPa}$$

$$V_{air} = V_{he} = m_{he} / \rho_{he} = 3.65 / 11.86 = 0.308 \text{ m}^3/\text{s}$$

5. Results:

From the requirements a dynamic air blower was obtained with the following work point:

Description	Unit	Value
P_{air}	kPa	100
$T_{air\ in}$	°C	20
ΔP_{air}	kPa	30
V_{air}	m ³ /s	0.369
Q_e	kW	22.8

The machine's performance in helium at the same work point is predicted to be:

Description	Unit	Value
P_{he}	kPa	9000
$T_{he\ in}$	°C	80
ΔP_{he}	kPa	299
V_{he}	m ³ /s	0.369
m_{he}	kg/s	4.38
Q_e	kW	227

The mechanical design calculations and results for the circulator vessel are shown in Attachment A.

6. Conclusions:

The calculation provides the requirements for a dynamic air blower (to be used in helium) and predicts the performance of a selected dynamic air blower when used in helium.

Attachment A

Circulator Vessel Design Calculations

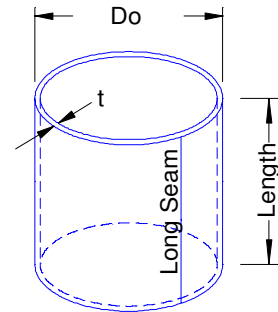
Pipe and Shell CR2A_1.1

ASME Code VIII Div I 2001 edition no addenda

ASME L-2.2.1 <- BM	1 <- BM Item #	1 <- BM Qty
Verification Calc #3 <- Vessel, description		

Dimensions:

6.625 <- Do - Outside Diameter
0.432 <- t - Nominal Wall Thickness
78.740 <- Length
0.000 <- Corr, Corrosion Allowance

**Material and Conditions:**

SA-516 <- Material	
20 000 <- S, Allowable Stress Level (psi)	
0.85 <- E1 - Longitudinal Efficiency (circ. stress)	
0.65 <- Ec - Circ. Connecting Efficiency (longitudinal stress)	
0.0% <- UTP, Undertolerance allowance (%)	1.19 <- Volume (cubic ft)
0.000 <- UTI, Undertolerance allowance (inch)	187.7 <- Material Weight (lbs cs)
1392.4 <- P, Interior Pressure	
0.0 <- Pa, Exterior Pressure	
1 <- B, From exterior pressure curve	0.004823 <- A (use to lookup B)

Variables:

UT = t*UTP+UTI	= 0.432*0+0	undertolerance	UT = 0.000
Ri = Do/2-t+corr	= 6.625/2-0.432+0	inside radius	Ri = 2.881
nt = t-Corr-UT	= 0.432-0-0	nominal thick	nt = 0.432
LDo = L/Do	= 78.74/6.625		LDo = 11.885
DoT = Do/nt	= 6.625/0.432		DoT = 15.336

Interior Pressure UG-27 (c) (1,2)

ta = P*Ri/(S*E1-0.6*P)	= 1392.4*2.881/(20000*0.85-0.6*1392.4)	ta = 0.248
tb = P*Ri/(2*S*Ec+0.4*P)	= 1392.4*2.881/(2*20000*0.65+0.4*1392.4)	tb = 0.151
tmin = Max(ta,tb) <= nt	Okay	tmin = 0.248
PMaxA = (S*E1*nt)/(Ri+0.6*nt)	= (20000*0.85*0.432)/(2.881+0.6*0.432)	PMaxA = 2339.1
PMaxB = (2*S*Ec*nt)/(Ri-0.4*nt)	= (2*20000*0.65*0.432)/(2.881-0.4*0.432)	PMaxB = 4148.2
PMax = Min(PMaxA,PMaxB)	Okay	PMax = 2339.1
tr1 = P*Ri/(S*1-0.6*P)	= 1392.4*2.881/(20000*1-0.6*1392.4)	tr1 = 0.209

Exterior Pressure UG-28 (c)

A = Interpolated from IID Part D Table G	A = 0.004823
PaMax = 4*B/(3*DoT)	Okay PaMax = 0.1
tre = (3*Do*Pa)/(4*B)	tre = 0.000

Shell stress relief -UCS-79(d), UNF-79(d), UHA-44(d)

Rf = (do-t)/2	= (6.625-0.432)/2	3.0965
% elong = (50*t/Rf)*(1-0)	= (50*0.432/3.097)*(1-0)	% elongation = 7.0

0.1% <- Max Elongation	
Yes <- Cold formed	7.0% <- Elongation
no <- Vessel carries lethal substances (Yes/no)	
no <- Impact testing is required (Yes/no)	
no <- Greater than 10% reduction in thickness	
no <- Formed between 250 and 900 Degrees F	
no <- Shell is greater than 5/8" thick before forming	

Required	Yes ?
no	no
no	no
no	no
no	no
no	no
no	no
Stress Relieve ?	no

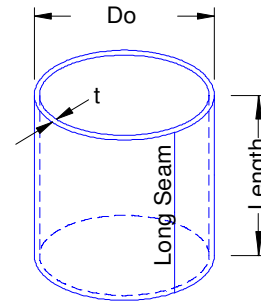
Pipe and Shell CR 2A_1.1

03-Dec-08 Page 1 of 1

ASME Code VIII Div I 2001 edition no addenda

www.pveng.com**ASME L-2.2.1** <- BM **1** <- BM Item #**1** <- BM Qty**Verification Calc #3** <- Vessel, description**Dimensions:**

47.240 <- Do - Outside Diameter
2.300 <- t - Nominal Wall Thickness
157.500 <- Length
0.000 <- Corr, Corrosion Allowance

**Material and Conditions:**

SA-516 <- Material
20 000 <- S, Allowable Stress Level (psi)
0.85 <- E1 - Longitudinal Efficiency (circ. stress)
0.65 <- Ec - Circ. Connecting Efficiency (longitudinal stress)
0.0% <- UTP, Undertolerance allowance (%) **130.16** <- Volume (cubic ft)
0.000 <- UTI, Undertolerance allowance (inch) **14 504.9** <- Material Weight (lbs cs)

1392.4 <- P, Interior Pressure
0.0 <- Pa, Exterior Pressure
1 <- B, From exterior pressure curve **0.003939** <- A (use to lookup B)

Variables:

UT = t*UTP+UTI	= 2.3*0+0	undertolerance	UT = 0.000
Ri = Do/2-t+corr	= 47.24/2-2.3+0	inside radius	Ri = 21.320
nt = t-Corr-UT	= 2.3-0-0	nominal thick	nt = 2.300
LDo = L/Do	= 157.5/47.24		LDo = 3.334
DoT = Do/nt	= 47.24/2.3		DoT = 20.539

Interior Pressure UG-27 (c) (1,2)

ta = P*Ri/(S*E1-0.6*P)	= 1392.4*21.32/(20000*0.85-0.6*1392.4)	ta = 1.836
tb = P*Ri/(2*S*Ec+0.4*P)	= 1392.4*21.32/(2*20000*0.65+0.4*1392.4)	tb = 1.118
tmin = Max(ta,tb) <= nt	Okay	tmin = 1.836
PMaxA = (S*E1*nt)/(Ri+0.6*nt)	= (20000*0.85*2.3)/(21.32+0.6*2.3)	PMaxA = 1722.5
PMaxB = (2*S*Ec*nt)/(Ri-0.4*nt)	= (2*20000*0.65*2.3)/(21.32-0.4*2.3)	PMaxB = 2931.4
PMax = Min(PMaxA,PMaxB)	Okay	PMax = 1722.5
tr1 = P*Ri/(S*1-0.6*P)	= 1392.4*21.32/(20000*1-0.6*1392.4)	tr1 = 1.549

Exterior Pressure UG-28 (c)

A = Interpolated from IID Part D Table G	A = 0.003939
PaMax = 4*B/(3*DoT)	Okay PaMax = 0.1
tre = (3*Do*Pa)/(4*B)	tre = 0.000

Shell stress relief -UCS-79(d), UNF-79(d), UHA-44(d)

Rf = (do-t)/2	= (47.24-2.3)/2	22.47
% elong = (50*t/Rf)*(1-0)	= (50*2.3/22.47)*(1-0)	% elongation = 5.1

0.1% <- Max Elongation**Yes** <- Cold formed **5.1%** <- Elongation**no** <- Vessel carries lethal substances (Yes/no)**no** <- Impact testing is required (Yes/no)**no** <- Greater than 10% reduction in thickness**no** <- Formed between 250 and 900 Degrees F**YES** <- Shell is greater than 5/8" thick before forming

Required	Yes ?
no	no
no	no
no	no
no	no
no	no
no	no
Stress Relieve ?	no

Elliptical Head CR2A_1.1

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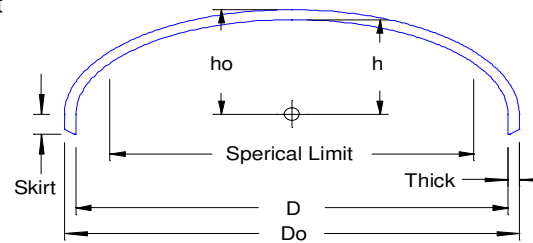
ASME Code VIII Div I 2001 no Addenda

<- BM <- BM Item # <- BM Qty

Heads <- Component

Dimensions:

47.240 <- Do, outside diameter
10.660 <- h
2.000 <- tb, thickness before forming
2.000 <- tf, thickness after forming
0.000 <- Corr, corrosion allowance
6.000 <- Skirt, straight skirt length

**Material and Conditions:**

SA-516 <- material
20 000 <- S, allowable stress level (psi)
1.00 <- E, efficiency
1392.4 <- P, interior pressure
0.0 <- Pa, exterior pressure
1 <- B, from exterior pressure curve

Calculated Properties:

63.0 <- Approximate blank diameter
1766.5 <- Approximate weight for steel, (lbs)
11.14 <- Volume (cuft, includes skirt)
34.59 <- Spherical Limit (0.8 * D)
0.00630 <- A value to lookup B

Variables:

D = Do-2*t = 47.24-2*2 = 43.24
 ho = h+t = 10.66+2 = 12.66
 D/2h = D/(2*h) = 43.24/(2*10.66) = 2.028
 Do/2ho = Do/(2*ho) = 47.24/(2*12.66) = 1.866
 K = Interpolated value from table 1-4.1 interior = 1.020
 Kone = Interpolated value from table UG-37 spherical = 0.913
 Kzero = Interpolated value from table UG-33.1 exterior = 0.840
 t = tf-corr = 2-0 = 2.000
 Ro = Ko*Do = 0.84*47.24 = 39.661

Interior Pressure App 1-4(c)(d), UG-37 1(a)

TMinl = (P*D*K)/(2*S*E-0.2*P) <= t
 TMinl (min thickness) = **1.546**
 = (1392.4*43.24*1.02)/(2*20000*1-0.2*1392.4) <= 2
 PMax = (2*S*E*t)/(K*D+0.2*t) >= P
 PMax = **1798**
 = (2*20000*1*2)/(1.02*43.24+0.2*2) >= 1392
 TSpl = (P*D*Kone)/(2*S*E-0.2*P)
 TSpl (required sphere zone thick) = **1.383**
 = (1392.4*43.24*0.913)/(2*20000*1-0.2*1392.4)

Exterior Pressure UG-33(d), UG-28(d)

A = 0.125/(Ro/t) = 0.125/(39.661/2) = 0.006303
 PaMax = B/(Ro/t) >= Pa = 1/(39.661/2) >= 0
 PaMax = **0.1**
 TMinE = (Ro*Pa)/B = (39.661*0)/1 = 0.000
 TMinE = **0.000**

Head stress relief UCS-79(d), UNF-79(d), UHA-44(d)

% elong = ((75*t)/h)*(1-0) = ((75*2)/10.66)*(1-0) = 14.1
 % elong = **14.1**

5.0% <- Max Elongation**Yes** <- Cold Formed **14.1%** <- Elongation**no** <- Vessel carries lethal substances(Yes/no)**no** <- Impact testing is required (Yes/no)**no** <- Formed between 250 and 900 Degrees F**no** <- Greater than 10% reduction in thickness**Yes** <- Head is greater than 5/8" thick before forming

Required	Yes ?
no	no
no	no
no	no
no	no
Yes ?	YES
Stress Relieve ?	YES

Appendix I

Component Specification Sheet

Company:	M-Tech Industrial (Pty) Ltd		
Location:	Potchefstroom, South Africa		
Document Number:	MT-TLDR-TDL-CMPT-05-0001		
Component:	TDL Circulators (CR 2A_1.1; CR 2A_1.2; CR 2A_2.1 and CR 2A_2.2)		
Date:	11 December 2008	Rev. No.:	2

Authorisation			
Action	Name	Signature	Date
Preparer	Bennie Nel		December 11, 2008
Reviewer	Herman van Antwerpen		December 11, 2008
Approver	Riaan de Bruyn		December 11, 2008

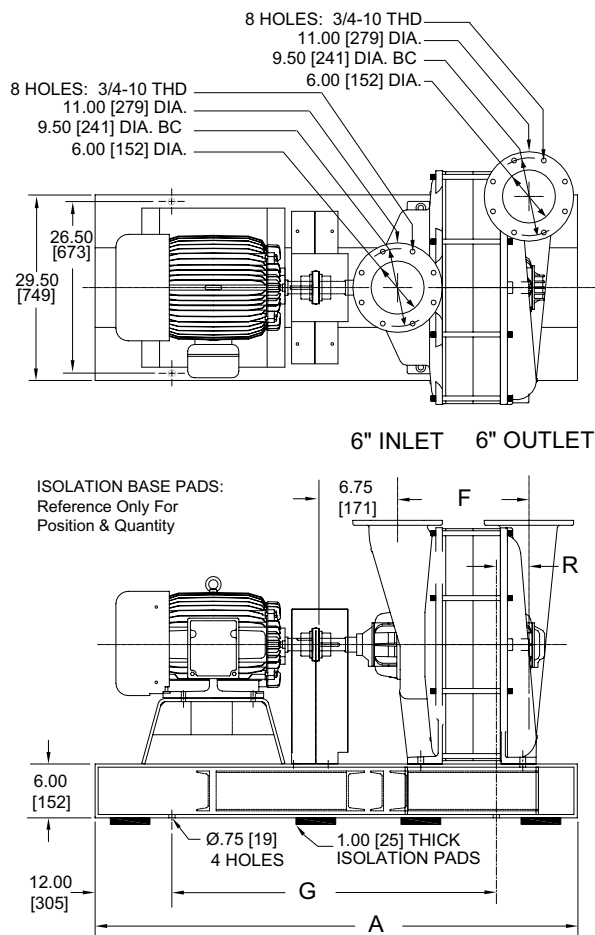
Record of Changes	
Revision	Description of Changes
A	Initial Draft
1	Document Approved
2	Configuration tables added

CR 2A_1.1; CR 2A_1.2; CR 2A_2.1; CR 2A_2.2
Component Specification Sheet

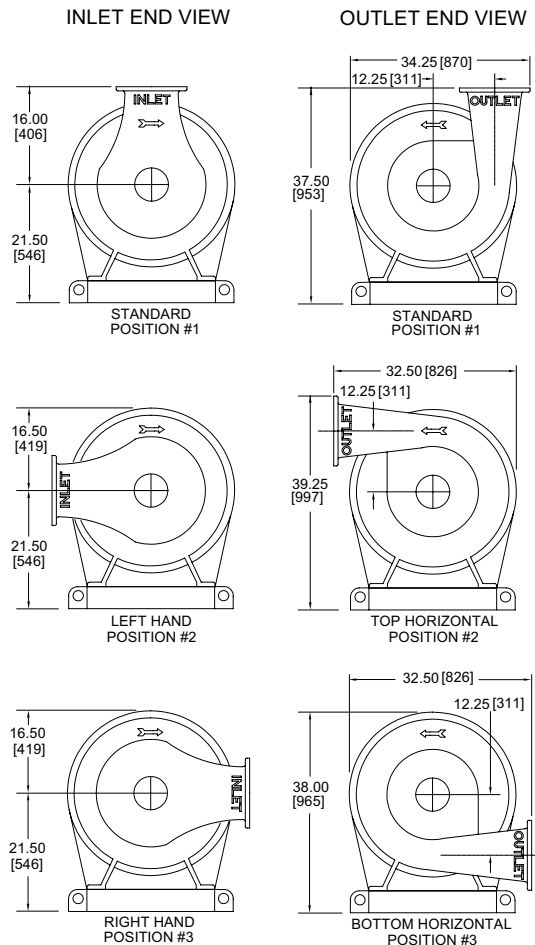
	<u>Value & Unit</u>	<u>Remarks</u>
P_{he} :	9 600 kPa	Nominal pressure.
$T_{he\ in}$:	80 °C	Inlet temperature.
ΔP_{he} :	299 kPa	Differential pressure across the circulator.
V_{he} :	0.369 m ³ /s	Volume flow rate.
m_{he} :	4.38 kg/s	
Q_e :	227 kW	Q_e is the electrical input.
Fluid:	Helium	
T_{design} :	80 °C	
P_{design} :	9 600 kPa	
<u>Shell:</u>		
Length:	4 000 mm	
Outside diameter:	1 200 mm	
Wall thickness:	58.42 mm	
Corrosion allowance:	0 mm	
<u>Nozzles:</u>		
No. of protrusions:	5	
Length:	2 000 mm	
Outside diameter:	168.3 mm	
Wall thickness:	11 mm	
<u>Elliptical Head:</u>		
Head ratio:	2 : 1	
Height:	270.76 mm	Height before and after forming
Wall thickness before:	50.8 mm	
Wall thickness after:	50.8 mm	
Skirt:	152.4 mm	
<u>Material:</u>		
Component material:	SA-516 Gr.70	

Allowable stress:	115.14 MPa	
Vessel Mass:	8 608 kg	Includes only the pressure boundary, excludes flanges.

GENERAL ARRANGEMENT



FLANGE ORIENTATIONS



DIMENSIONAL DATA – inches [millimeters]

FRAME	A	F	G	R
4201	48.75 [1238]	9.25 [235]	24.75 [629]	4.50 [114]
4202	60.75 [1543]	12.69 [322]	36.75 [933]	2.00 [51]
4203	60.75 [1543]	16.13 [410]	36.75 [933]	4.50 [114]
4204	72.75 [1848]	19.56 [497]	48.75 [1238]	2.00 [51]
4205	72.75 [1848]	23.00 [584]	48.75 [1238]	2.00 [51]
4206	72.75 [1848]	26.44 [672]	48.75 [1238]	4.50 [114]
4207	84.75 [2153]	29.88 [759]	60.75 [1543]	2.00 [51]
4208	84.75 [2153]	33.31 [846]	60.75 [1543]	2.00 [51]

WEIGHTS – lb [kg] & INERTIA – lb-ft² [kg-m²]

FRAME	PKG. LESS MOTOR	BARE UNIT	WK ²
4201	749 [340]	590 [268]	9 [0.38]
4202	925 [420]	760 [345]	18 [0.76]
4203	1103 [500]	930 [422]	27 [1.14]
4204	1294 [587]	1100 [499]	36 [1.53]
4205	1494 [678]	1300 [590]	46 [1.91]
4206	1666 [756]	1470 [667]	55 [2.29]
4207	1836 [833]	1640 [744]	64 [2.67]
4208	2035 [923]	1810 [821]	73 [3.06]

PRODUCT NOTES

- Information is approximate, subject to change without notice, and not for construction use unless certified
- Position #1 is standard inlet & outlet orientation
- A and G dimensions may vary depending on motor frame size

Gardner Denver Engineered Products Division

100 Gardner Park, Peachtree City, GA 30269
 Phone: 800-982-3009 / 770-632-5000
 Fax: 770-486-5628
 E-mail: blowersmktg@gardnerdenver.com
 Web: www.gardnerdenver.com

11/2006 Page 1 of 1 CF1496061 Vs 01



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DESIGN STANDARD

{ Offered }

Number of Stages	1-8 (60 & 50 Hz)
Inlet Connection	6" Flange, ANSI 125# Drilling
Outlet Connection	6" Flange, ANSI 125# Drilling
Operating Speed	3550 RPM (60 Hz), 2925 RPM (50 Hz)
Casing Pressure	25 PSIG (1.73 bar)
Air Seals	Carbon Ring Type
Bearings	Anti-friction Type, designed for extended L ₁₀ life
Lubrication	AEON® CF Grease {AEON® CF Oil}
Impeller	24.0 inches (610 millimeters) Diameter (statically balanced)
Impeller Tip Speed	372 feet/second (113 meters/second)
Drive Type	Direct Coupled (Inlet drive is standard)
Drive Shaft	1.625 inches (41.28 millimeters) Diameter
Vibration	.235 in/sec. (5.97 mm/sec.) Peak Velocity
Rotor	Factory Balanced Per ISO 1940, ANSI S2.19

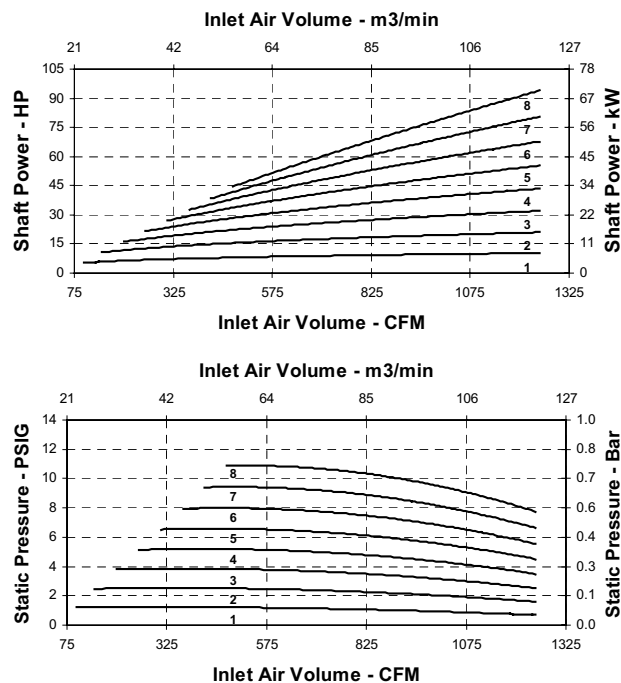
MATERIAL STANDARD

{ Offered }

Casing	ASTM A48 Class 30 Gray Cast Iron
Bearing Housings	ASTM A48 Class 30 Gray Cast Iron
Bearing Cap	ASTM A48 Class 30 Gray Cast Iron
Tie Rods	ASTM A307 Zinc Plated Threaded Rod
Carbon Ring Seal	ASTM C695 Fine Grain Molded Graphite
	ASTM A48 Class 30 Gray Cast Iron Housing
Joint Sealing	RTV Silicone Compound
Shaft	ASTM A108 Grade 1045 HRS {Stainless Steel}
Impeller	ASTM SC64C Sr-319 Cast Aluminum
Blower Base	ASTM A36 Hot Rolled Structural Steel
Motor Pedestal	ASTM A36 Hot Rolled Structural Steel
Isolation Base Pads	ASTM D2000 Neoprene 70 MC-2 11# Cork
Finish	Two Part Epoxy GDI 171 CF Blue

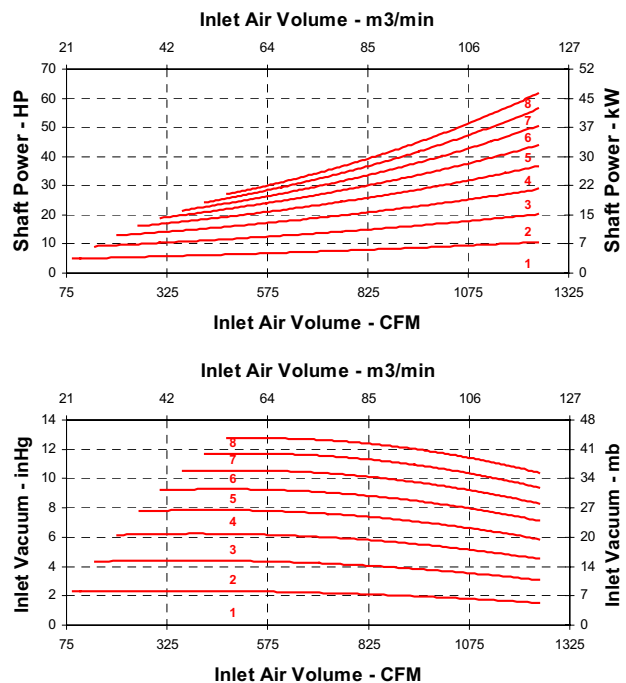
PRESSURE PERFORMANCE

14.7 PSIA [1 Bar], 68°F [20°C],
36% RH, Speed: 3550 RPM



VACUUM PERFORMANCE

29.9 inHg [1 Bar], 68°F [20°C],
36% RH, Speed: 3550 RPM



PRODUCT & PERFORMANCE NOTES

- Information is approximate and subject to change without notice
- Performances noted above are typical and not job specific
- Consult authorized Gardner Denver sales representative for job specific blower or exhauster performance sizing
- Factory ASME PTC-10 test offered for performance verification

Gardner Denver Engineered Products Division

100 Gardner Park, Peachtree City, GA 30269
Phone: 800-982-3009 / 770-632-5000
Fax: 770-486-5628
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Web: www.gardnerdenver.com

11/2006 Page 1 of 1 CF1496064 Vs 03



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Appendix J



M - T e c h
i n d u s t r i a l

***Attachment to Section 6: Technology Development
Loop (TDL)
HTS Cold Pipe Calculation***

Document number: MT-TLDR-CAL-M-0609

Revision: 1

Status: Approved

D.J. Viljoen

November 2008

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Configuration Management

CHANGE HISTORY

Configuration Control	
Client Name:	Westinghouse Electric Company
Project Number:	NGNP-CTF MTECH-TLDR
Project Name:	NGNP CTF Test Loop Preconceptual Design
Calculation Title:	HTS Cold Pipe Calculation
Calculation Identification Number:	MT-TLDR-CAL-M-0609
Quality Level:	3

Template No: MT-TLDR-CAL-REP rev 1

Authorisation			
Action	Name	Signature	Date
Preparer	D J Viljoen	_____	November 26, 2008
Reviewer	H van Antwerpen	_____	November 28, 2008
Approver	R de Bruyn	_____	November 28, 2008

Original Signed Copy at CMC

Distribution					
Discipline	Name	Discipline	Name	Discipline	Name

Confirmation Required Status			
Calculation Page	Input/Assumption that Requires Confirmation	Preparer and Date Input/Assumption Confirmed	Reviewer and Date Input/Assumption Approved

Record of Changes	
Revision	Description of Changes
A	Initial Draft
1	Document Approved

Reference to this document
NGNP-CTF MTECH-TLDR-0006

Change Forecast

The document format and contents have been approved.

Calculation Table of Contents

Calculation Table of Contents.....	4
1. Objective:.....	5
2. Methodology:.....	5
2.1. APPROACH.....	5
2.2. COMPUTER PROGRAMS	5
3. Inputs and Assumptions:	5
3.1. ASSUMPTIONS:	5
3.2. INPUTS:.....	5
4. Equations Used and Calculations:	6
5. Results:	6
6. Conclusions:	6
Attachment A	7
HTS Cold Pipe Calculation	7

1. Objective:

The objective of the calculation is to do the mechanical design for the HTS cold pipes. The mechanical design calculation and results are shown in Attachment A.

2. Methodology:

2.1. APPROACH

The Mechanical design calculations for the HTS cold pipes were done according to ASME VIII Div 1.

2.2. COMPUTER PROGRAMS

The computer program used is Excel.

3. Inputs and Assumptions:

3.1. ASSUMPTIONS:

- All pressure boundary calculations are done using a MS Excel spreadsheet incorporating ASME Code VIII Div 1 2001, No Addenda
- No corrosion allowance was included
- All pressure boundary outside temperatures are taken as 200°C

3.2. INPUTS:

- Proposed material is SA-516 Gr.70
- Allowable stress was taken as 20 KSI at 204°C (400°F) from ASME material property database
- Internal pressures taken as 9.6 MPa
- All other related input can be found in the attached calculation spreadsheet and are included in sections: **Dimensions** and **Material and Conditions**.

4. Equations Used and Calculations:

Equations and calculations used as per ASME VIII Div 1.

5. Results:

Results obtained are shown in the calculation in Attachment A.

6. Conclusions:

HTS Cold Pipe design as per ASME VIII Div 1.

Attachment A

HTS Cold Pipe Calculation

Pipe and Shell TDL

ASME Code VIII Div I 2001 edition no addenda

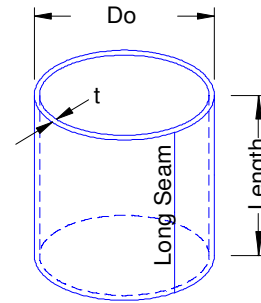
ASME L-2.2.1 <- BM **1** <- BM Item #

Verification Calc #3 <- Vessel, description

1 <- BM Qty

Dimensions:

6.625 <- Do - Outside Diameter
0.432 <- t - Nominal Wall Thickness
78.740 <- Length
0.000 <- Corr, Corrosion Allowance



Material and Conditions:

SA-516 <- Material
20 000 <- S, Allowable Stress Level (psi)
0.85 <- E1 - Longitudinal Efficiency (circ. stress)
0.65 <- Ec - Circ. Connecting Efficiency (longitudinal stress)
0.0% <- UTP, Undertolerance allowance (%) **1.19** <- Volume (cubic ft)
0.000 <- UTI, Undertolerance allowance (inch) **187.7** <- Material Weight (lbs cs)
1392.4 <- P, Interior Pressure
0.0 <- Pa, Exterior Pressure
1 <- B, From exterior pressure curve **0.004823** <- A (use to lookup B)

Variables:

UT = $t \cdot \text{UTP} + \text{UTI}$ = $0.432 \cdot 0 + 0$ undertolerance UT = **0.000**
 Ri = $\text{Do} / 2 - t + \text{corr}$ = $6.625 / 2 - 0.432 + 0$ inside radius Ri = **2.881**
 nt = $t - \text{Corr} - \text{UT}$ = $0.432 - 0 - 0$ nominal thick nt = **0.432**
 LDo = L / Do = $78.74 / 6.625$ LDo = **11.885**
 DoT = Do / nt = $6.625 / 0.432$ DoT = **15.336**

Interior Pressure UG-27 (c) (1,2)

ta = $P \cdot \text{Ri} / (S \cdot E1 - 0.6 \cdot P)$ = $1392.4 \cdot 2.881 / (20000 \cdot 0.85 - 0.6 \cdot 1392.4)$ ta = **0.248**
 tb = $P \cdot \text{Ri} / (2 \cdot S \cdot \text{Ec} + 0.4 \cdot P)$ = $1392.4 \cdot 2.881 / (2 \cdot 20000 \cdot 0.65 + 0.4 \cdot 1392.4)$ tb = **0.151**
 tmin = $\text{Max}(ta, tb)$ <= nt **Okay** tmin = **0.248**
 PMaxA = $(S \cdot E1 \cdot \text{nt}) / (\text{Ri} + 0.6 \cdot \text{nt})$ = $(20000 \cdot 0.85 \cdot 0.432) / (2.881 + 0.6 \cdot 0.432)$ PMaxA = **2339.1**
 PMaxB = $(2 \cdot S \cdot \text{Ec} \cdot \text{nt}) / (\text{Ri} - 0.4 \cdot \text{nt})$ = $(2 \cdot 20000 \cdot 0.65 \cdot 0.432) / (2.881 - 0.4 \cdot 0.432)$ PMaxB = **4148.2**
 PMax = $\text{Min}(\text{PMaxA}, \text{PMaxB})$ **Okay** PMax = **2339.1**
 tr1 = $P \cdot \text{Ri} / (S \cdot 1 - 0.6 \cdot P)$ = $1392.4 \cdot 2.881 / (20000 \cdot 1 - 0.6 \cdot 1392.4)$ tr1 = **0.209**

Exterior Pressure UG-28 (c)

A = Interpolated from IID Part D Table G A = **0.004823**
 PaMax = $4 \cdot B / (3 \cdot \text{DoT})$ = $4 \cdot 1 / (3 \cdot 15.336)$ **Okay** PaMax = **0.1**
 tre = $(3 \cdot \text{Do} \cdot \text{Pa}) / (4 \cdot B)$ = $(3 \cdot 6.625 \cdot 0) / (4 \cdot 1)$ tre = **0.000**

Shell stress relief -UCS-79(d), UNF-79(d), UHA-44(d)

Rf = $(\text{do} - t) / 2$ = $(6.625 - 0.432) / 2$
 % elong = $(50 \cdot t / \text{Rf}) \cdot (1 - 0)$ = $(50 \cdot 0.432 / 3.097) \cdot (1 - 0)$ % elongation = **7.0**
0.1% <- Max Elongation

Yes <- Cold formed **7.0%** <- Elongation

no <- Vessel carries lethal substances (Yes/no)

no <- Impact testing is required (Yes/no)

no <- Greater than 10% reduction in thickness

no <- Formed between 250 and 900 Degrees F

no <- Shell is greater than 5/8" thick before forming

Required	Yes ?
no	no
no	no
no	no
no	no
no	no
no	no
Stress Relieve ?	no

Appendix J

Component Specification Sheet

Company:	M-Tech Industrial (Pty) Ltd		
Location:	Potchefstroom, South Africa		
Document Number:	MT-TLDR-TDL-CMPT-05-0002		
Component:	HTS TDL Cold Piping (PI 2A_1.1; PI 2A_2.1)		
Date:	11 December 2008	Rev. No.:	2

Authorisation			
Action	Name	Signature	Date
Preparer	Bennie Nel		December 11, 2008
Reviewer	Herman van Antwerpen		December 11, 2008
Approver	Riaan de Bruyn		December 17, 2008

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Revision	Description of Changes
A	Initial Draft
1	Document Approved
2	Configuration tables added

CR 2A_1.1; CR 2A_1.2; CR 2A_2.1; CR 2A_2.2
Component Specification Sheet

	<u>Value & Unit</u>	<u>Remarks</u>
P _{he} :	9 600 kPa	Nominal pressure.
T _{he in} :	417 °C	Inlet temperature, obtained from mixing chamber test results (worst case).
d _{internal} :	0.14 m	Mass flow obtained from the 3 x 1.2 MW IHX A tests (worst case).
m _{he} :	3.65 kg/s	
Fluid:	Helium	
T _{design} :		
P _{design} :	9 600 kPa	
<u>Shell:</u>		
Length:	N / A	
Outside diameter:	168.3 mm	
Wall thickness:	11 mm	
Corrosion allowance:	0 mm	
<u>Nozzles:</u>	0	
<u>Material:</u>		
Component material:	SA-516 Gr.70	
Allowable stress:	115.14 MPa	
Vessel mass per meter:	42 kg/m	Includes only the pressure boundary, excludes flanges.

Appendix K



M - T e c h
i n d u s t r i a l

***Attachment to Section 6: Technology Development
Loop (TDL)
HTS Hot Gas Duct Calculation***

Document number: MT-TLDR-CAL-F-M-0610

Revision: 1

Status: Approved

D.J. Viljoen

November 2008

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Configuration Management

CHANGE HISTORY

Configuration Control	
Client Name:	Westinghouse Electric Company
Project Number:	NGNP-CTF MTECH-TLDR
Project Name:	NGNP CTF Test Loop Preconceptual Design
Calculation Title:	HTS Hot Gas Duct Calculation
Calculation Identification Number:	MT-TLDR-CAL-F-M-0610
Quality Level:	3

Template No: MT-TLDR-CAL-REP rev 1

Authorisation			
Action	Name	Signature	Date
Preparer	D J Viljoen	_____	November 26, 2008
Reviewer	H van Antwerpen	_____	November 28, 2008
Approver	R de Bruyn	_____	November 28, 2008

Original Signed Copy at CMC

Distribution					
Discipline	Name	Discipline	Name	Discipline	Name

Confirmation Required Status			
Calculation Page	Input/Assumption that Requires Confirmation	Preparer and Date Input/Assumption Confirmed	Reviewer and Date Input/Assumption Approved

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Revision	Description of Changes
A	Initial Draft
1	Document Approved

Reference to this document
NGNP-CTF MTECH-TLDR-0006

Change Forecast

The document format and contents have been approved.

Calculation Table of Contents

Calculation Table of Contents.....	4
1. Objective:.....	5
2. Methodology:.....	5
2.1. APPROACH.....	5
2.2. COMPUTER PROGRAMS	5
3. Inputs and Assumptions:	5
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6. Conclusions:	6
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HGD Thermo Hydraulic Calculation.....	7
Attachment B	8
HGD Mechanical Design Calculation	8

1. Objective:

The objective of the calculation is to determine the insulation thickness of a passively cooled hot gas duct and to determine the inside diameter of the pressure boundary. The Thermo Hydraulic design calculations are shown in Attachment A and the Mechanical design calculations in Attachment B.

2. Methodology:

2.1. APPROACH

The internal gas flow liner diameter was calculated based on a 20 m/s average gas velocity. The insulation thickness could then be determined to give a pressure boundary outside temperature of 200 °C. The inside diameter of the pressure boundary could then be determined. From these results the mechanical design could be done.

2.2. COMPUTER PROGRAMS

The computer program used is EES and Excel.

3. Inputs and Assumptions:

3.1. ASSUMPTIONS:

Thermo Hydraulic:

- See Attachment A

Mechanical design:

- All pressure boundary calculations are done using a MS Excel spreadsheet incorporating ASME Code VIII Div 1 2001, No Addenda
- No corrosion allowance was included
- All pressure boundary outside temperatures are taken as 200°C

3.2. INPUTS:

Thermo Hydraulic:

- See Attachment A

Mechanical design:

- Proposed material is SA-516 Gr.70
- Allowable stress was taken as 20 KSI at 204°C (400°F) from ASME material property database
- Internal pressures taken as 9.6 MPa

- All other related input can be found in the attached calculation spreadsheet and are included in sections: **Dimensions** and **Material and Conditions**.

4. Equations Used and Calculations:

- Heat transfer equations as per [Heat and Mass Transfer, Incropera and De Witt, Fifth Edition, 2002].
- The mechanical calculations were done according to ASME VIII Div 1.

5. Results:

The Results obtained from the Thermo Hydraulic design are as follows:

Hot gas ducts (PI 2A x.x)

Description	Unit	Value
P_{he}	kPa	9600
$T_{he\ in}$	°C	1000
$d_{internal\ liner}$	m	0.26
m_{he}	kg/s	3.65
$d_{pressure\ internal}$	m	0.5
$T_{pressure}$	°C	200

The Results for the Mechanical Design are shown in Attachment B.

6. Conclusions:

The results obtained serve as the Thermo Hydraulic and Mechanical design for the HTS HGD.

Attachment A

HGD Thermo Hydraulic Calculation



Attachment B

HGD Mechanical Design Calculation

HTS HGD insulation thickness and outsd temperature calculation

Attachment A to [MT-TLDR-CAL-F-M- 0610]

Assumptions

=====

A passively cooled hot gas duct design is used

$T_{\text{environment}} = 30 \text{ [C]}$ *Conservative assumption*

$T_{\text{outer,surface}} = 200 \text{ [C]}$ *Depends on the steel type*

Radiative heat transfer view factor from pipe surface to environment = 1

Radiative Area_{environment} is infinitely large

This simplifies the radiation heat transfer calculation

Inputs Units Reference

=====

$k = 0.5 \text{ [W/mK]}$ *Based on an assessment of current insulation materials, this is a conservative assumption*

It agrees with results from the HENDEL tests:

*Construction and Performance Tests of Helium Engineering Demonstration Loop
(HENDEL) for VHTR, Hishida et al., JAERI, 1984*

IT also agrees with Helium Test Facility (South Africa) experience

$h_{\text{outside,convection}} = 10 \text{ [W/m}^2\text{K]}$ *Insulation data sheet*

$d_{\text{HGD,Liner}} = 0.26 \text{ [m]}$ *TDL Calculations*

$\text{emissivity}_{\text{outside}} = 0.9 \text{ [-]}$ *Typical for a painted surface*

$L = 1 \text{ [m]}$ *Pipe section length*

$T_{\text{inside}} = 1000 \text{ [C]}$

Equations

=====

$A_{\text{per,meter}} = \pi \cdot d_{\text{outside}} \cdot L$ *Outside area of a cylinder*

$T1 = T_{\text{environment}} + 273$

$T2 = T_{\text{outer,surface}} + 273$

$h_{\text{outside,radiation}} = 5.670\text{E-}08 \text{ [W/m}^2\text{-K}^4] \cdot [T1 + T2] \cdot \left[\frac{T1^2 + T2^2}{\frac{1 + \text{emissivity}_{\text{outside}}}{\text{emissivity}_{\text{outside}}} + 1} \right]$

Heat and Mass Transfer, Incropera and De Witt, Fifth Edition, 2002

The following two simultaneous equations solve for the variables Q and d_{outside}

$$Q = [h_{\text{outside,convection}} + h_{\text{outside,radiation}}] \cdot A_{\text{per,meter}} \cdot [T_{\text{outer,surface}} - T_{\text{environment}}]$$

Heat and Mass Transfer, Incropera and De Witt, Fifth Edition, 2002

$$Q = k \cdot 2 \cdot \pi \cdot \frac{L}{\ln \left[\frac{d_{\text{outside}}}{d_{\text{HGD,Liner}}} \right]} \cdot [T_{\text{inside}} - T_{\text{outer,surface}}]$$

Heat and Mass Transfer, Incropera and De Witt, Fifth Edition, 2002

Pipe and Shell: Hot Gas Duct TDL

Page 1 of 1

ASME Code VIII Div I 2001 edition no addenda

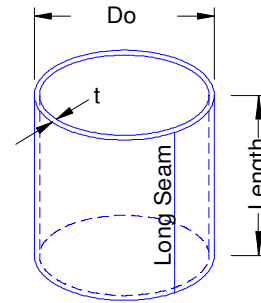
ASME L-2.2.1 <- BM **1** <- BM Item #

Verification Calc #3 <- Vessel, description

1 <- BM Qty

Dimensions:

24.000 <- Do - Outside Diameter
1.220 <- t - Nominal Wall Thickness
39.370 <- Length
0.000 <- Corr, Corrosion Allowance



Material and Conditions:

SA-516 <- Material
20 000 <- S, Allowable Stress Level (psi)
0.85 <- E1 - Longitudinal Efficiency (circ. stress)
0.65 <- Ec - Circ. Connecting Efficiency (longitudinal stress)
0.0% <- UTP, Undertolerance allowance (%) **8.32** <- Volume (cubic ft)
0.000 <- UTI, Undertolerance allowance (inch) **974.9** <- Material Weight (lbs cs)

1392.4 <- P, Interior Pressure
0.0 <- Pa, Exterior Pressure
1 <- B, From exterior pressure curve

0.009696 <- A (use to lookup B)

Variables:

UT = $t \cdot \text{UTP} + \text{UTI}$ = $1.22 \cdot 0 + 0$ undertolerance UT = **0.000**
 Ri = $\text{Do} / 2 - t - \text{corr}$ = $24 / 2 - 1.22 + 0$ inside radius Ri = **10.780**
 nt = $t - \text{Corr} - \text{UT}$ = $1.22 - 0 - 0$ nominal thick nt = **1.220**
 LDo = L / Do = $39.37 / 24$ LDo = **1.640**
 DoT = Do / nt = $24 / 1.22$ DoT = **19.672**

Interior Pressure UG-27 (c) (1,2)

$t_a = P \cdot R_i / (S \cdot E_1 - 0.6 \cdot P)$ = $1392.4 \cdot 10.78 / (20000 \cdot 0.85 - 0.6 \cdot 1392.4)$ $t_a = \mathbf{0.929}$
 $t_b = P \cdot R_i / (2 \cdot S \cdot E_c + 0.4 \cdot P)$ = $1392.4 \cdot 10.78 / (2 \cdot 20000 \cdot 0.65 + 0.4 \cdot 1392.4)$ $t_b = \mathbf{0.565}$
 $t_{\min} = \text{Max}(t_a, t_b) \leq nt$ **Okay** $t_{\min} = \mathbf{0.929}$
 $P_{\max A} = (S \cdot E_1 \cdot nt) / (R_i + 0.6 \cdot nt)$ = $(20000 \cdot 0.85 \cdot 1.22) / (10.78 + 0.6 \cdot 1.22)$ $P_{\max A} = \mathbf{1801.6}$
 $P_{\max B} = (2 \cdot S \cdot E_c \cdot nt) / (R_i - 0.4 \cdot nt)$ = $(2 \cdot 20000 \cdot 0.65 \cdot 1.22) / (10.78 - 0.4 \cdot 1.22)$ $P_{\max B} = \mathbf{3082.0}$
 $P_{\max} = \text{Min}(P_{\max A}, P_{\max B})$ **Okay** $P_{\max} = \mathbf{1801.6}$
 $tr_1 = P \cdot R_i / (S \cdot 1 - 0.6 \cdot P)$ = $1392.4 \cdot 10.78 / (20000 \cdot 1 - 0.6 \cdot 1392.4)$ $tr_1 = \mathbf{0.783}$

Exterior Pressure UG-28 (c)

A = Interpolated from IID Part D Table G A = **0.009696**
 $Pa_{\max} = 4 \cdot B / (3 \cdot DoT)$ = $4 \cdot 1 / (3 \cdot 19.672)$ **Okay** $Pa_{\max} = \mathbf{0.1}$
 $tre = (3 \cdot Do \cdot Pa) / (4 \cdot B)$ = $(3 \cdot 24 \cdot 0) / (4 \cdot 1)$ $tre = \mathbf{0.000}$

Shell stress relief -UCS-79(d), UNF-79(d), UHA-44(d)

$R_f = (do - t) / 2$ = $(24 - 1.22) / 2$
 $\% \text{ elong} = (50 \cdot t / R_f) \cdot (1 - 0)$ = $(50 \cdot 1.22 / 11.39) \cdot (1 - 0)$ $\% \text{ elongation} = \mathbf{5.4}$
0.1% <- Max Elongation

Yes <- Cold formed **5.4%** <- Elongation

no <- Vessel carries lethal substances (Yes/no)

no <- Impact testing is required (Yes/no)

no <- Greater than 10% reduction in thickness

no <- Formed between 250 and 900 Degrees F

YES <- Shell is greater than 5/8" thick before forming

Required	Yes ?
no	no
no	no
no	no
no	no
no	no
no	no
Stress Relieve ?	no

Appendix K

Component Specification Sheet

Company:	M-Tech Industrial (Pty) Ltd		
Location:	Potchefstroom, South Africa		
Document Number:	MT-TLDR-TDL-CMPT-05-0003		
Component:	HTS TDL Hot Gas Ducts (PI 2A_1.2; PI 2A_1.3; PI 2A_2.2; PI 2A_2.3)		
Date:	11 December 2008	Rev. No.:	2

Authorisation			
Action	Name	Signature	Date
Preparer	Bennie Nel		December 11, 2008
Reviewer	Herman van Antwerpen		December 11, 2008
Approver	Riaan de Bruyn		December 17, 2008

Record of Changes	
Revision	Description of Changes
A	Initial Draft
1	Document Approved
2	Configuration tables added

PI 2A_1.2; PI 2A_1.3; PI 2A_2.2; PI 2A_2.3
Component Specification Sheet

	<u>Value & Unit</u>	<u>Remarks</u>
P_{he} :	9 600 kPa	Nominal pressure.
$T_{he\ in}$:	1 000 °C	Inlet temperature, obtained from the assumption that additional heating might be added in the future to achieve higher temperatures (worst case).
$d_{internal\ liner}$:	0.26 m	Mass flow obtained from the 3 x 1.2 MW IHX A tests (worst case).
m_{he} :	3.65 kg/s	
$T_{pressure}$:	200 °C	
Fluid:	Helium	
T_{design} :		
P_{design} :	9 600 kPa	
<u>Shell:</u>		
Length:	N / A	
Outside diameter:	609.6 mm	
Wall thickness:	31 mm	
Corrosion allowance:	0 mm	
<u>Material:</u>		
Component material:	SA-516 Gr.70	
Allowable stress:	115.14 MPa	
Vessel mass per meter:	442.2 kg/m	Includes only the pressure boundary, excludes flanges.

Appendix L

Appendix L

Component Specification Sheet

Company:	M-Tech Industrial (Pty) Ltd		
Location:	Potchefstroom, South Africa		
Document Number:	MT-TLDR-TDL-CMPT-05-0004		
Component:	TDL Control Valves (VL 2A_1.1; VL 2A_1.2; VL 2A_1.3; VL 2A_1.6; VL 2A_1.7; VL 2A_2.1; VL 2A_2.2; VL 2A_2.3; VL 2A_2.6 and VL 2A_2.7)		
Date:	11 December 2008	Rev. No.:	2

Authorisation			
Action	Name	Signature	Date
Preparer	Bennie Nel		December 11, 2008
Reviewer	Herman van Antwerpen		December 11, 2008
Approver	Riaan de Bruyn		December 17, 2008

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1	Document Approved
2	Configuration tables added

VL 2A_1.1; VL 2A_1.2; VL 2A_1.3; VL 2A_1.6; VL 2A_1.7; VL 2A_2.1; VL 2A_2.2; VL 2A_2.3; VL 2A_2.6 and VL 2A_2.7

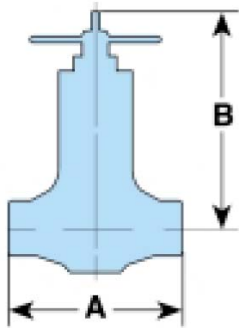
Component Specification Sheet

	<u>Value & Unit</u>	<u>Remarks</u>
P _{he} :	9 600 kPa	Nominal pressure.
T _{he in} :	85 °C	Inlet temperature.
d _{internal pipe} :	0.14 m	
m _{he} :	4.75 (3.65) kg/s	() indicates the size without 30% safety margin. Mass flow obtained from 3 x 1.2 MW IHX A tests (worst case).
Cv:		USGPM/sqrt(psi).
ΔP _{he} :	-	
Fluid:	Helium	
T _{design} :	100 °C	
P _{design} :	9 600 kPa	
<u>Physical:</u>		
Type:	Parallel slide gate valve	
Nominal diameter:	150 mm (6")	
<u>Material:</u>		
Body material:	S/S, F304L, CF 3	
Disc seating surface:	Stellite 6	
Seat surface:	Stellite 6	
Stem:	316 SS	
Connection:	Welded on	

Valve dimensions:

A = 508 mm

B = 920 mm



Flange dimensions are in accordance with
ASME B16.5.
Flanges are welded on.

Appendix L

Component Specification Sheet

Company:	M-Tech Industrial (Pty) Ltd		
Location:	Potchefstroom, South Africa		
Document Number:	MT-TLDR-TDL-CMPT-05-0005		
Component:	TDL HICS Valves (VL 2A_1.4; VL 2A_2.4)		
Date:	11 December 2008	Rev. No.:	2

Authorisation			
Action	Name	Signature	Date
Preparer	Bennie Nel		December 11, 2008
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Approver	Riaan de Bruyn		December 17, 2008

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A	Initial Draft
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2	Configuration tables added

VL 2A_1.4; VL 2A_2.4 Component Specification Sheet		
	<u>Value & Unit</u>	<u>Remarks</u>
P _{he} :	9 600 kPa	Nominal pressure.
T _{he in} :	85 °C	Inlet temperature.
d _{internal pipe} :	0.02 m	
m _{he} :	0.105 kg/s	
Cv:		USGPM/sqrt(psi).
ΔP _{he} :	-	
Fluid:	Helium	
T _{design} :	100 °C	
P _{design} :	9 600 kPa	
<u>Physical:</u>		
Type:	Gate valve	
Nominal diameter:	20 mm (3/4")	
<u>Material:</u>		
Body material:	S/S, F304L, CF 3	
Disc seating surface:	Stellite 6	
Seat surface:	Stellite 6	
Stem:	316 SS	
Connection:	Welded on	

Valve dimensions:

A = 18 mm

B = 152 mm

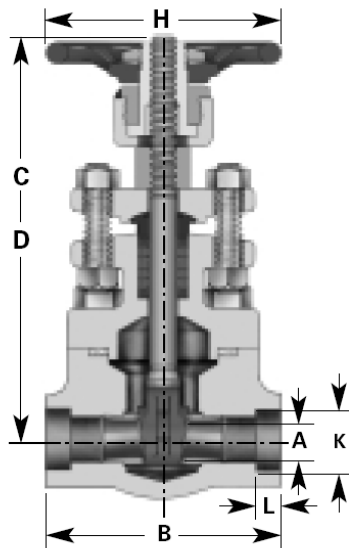
C = 231mm (Centre to top closed)

D = 244 mm (Centre to top open)

H = 127 mm

K = 27 mm

L = 13 mm



Appendix M

Appendix M

Component Specification Sheet

Company:	M-Tech Industrial (Pty) Ltd		
Location:	Potchefstroom, South Africa		
Document Number:	MT-TLDR-TDL-CMPT-05-0006		
Component:	TDL Water Control Valves (VL 2A_1.5; VL 2A_2.4)		
Date:	11 December 2008	Rev. No.:	2

Authorisation			
Action	Name	Signature	Date
Preparer	Bennie Nel		December 11, 2008
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Record of Changes	
Revision	Description of Changes
A	Initial Draft
1	Document Approved
2	Configuration tables added

VL 2A_1.5; VL 2A_2.4 Component Specification Sheet		
	<u>Value & Unit</u>	<u>Remarks</u>
P_w :	300 kPa	Nominal pressure.
$T_{w\text{ in}}$:	20 °C	Inlet temperature.
$d_{\text{internal pipe}}$:	0.07 m	
m_w :	79.5 kg/s	The cooler water control valve requirement was obtained from MTWH004-TDL-002-03_RevD.
C_v :		
ΔP_{he} :		
Fluid	Water	
T_{design} :		
P_{design} :		
<u>Physical:</u>		
Type:	Gate valve	
Nominal diameter:	65 mm (2 1/2")	
<u>Material:</u>		
Body material:	A105, WCB	
Disc seating surface:	Stellite 6	
Seat surface:	Stellite 6	
Stem:	316 SS	
Connection:	Flange ASME PN 150	

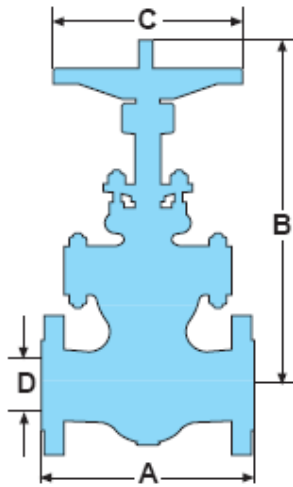
Valve Dimensions:

A = 191 mm

B = 400 mm

C = 203 mm

D = 64 mm



Appendix N



M - T e c h
i n d u s t r i a l

***Attachment to Section 6: Technology Development
Loop (TDL)
Heater (HT 2A_1.1) Calculation***

Document number: MT-TLDR-CAL-F-M-0613

Revision: 1

Status: Approved

D.J. Viljoen

November 2008

CHANGE HISTORY

Configuration Control	
Client Name:	Westinghouse Electric Company
Project Number:	NGNP-CTF MTECH-TLDR
Project Name:	NGNP CTF Test Loop Preconceptual Design
Calculation Title:	Heater (HT 2A_1.1) Calculation
Calculation Identification Number:	MT-TLDR-CAL-F-M-0613
Quality Level:	3

Template No: MT-TLDR-CAL-REP rev 1

Authorisation			
Action	Name	Signature	Date
Preparer	D J Viljoen	_____	November 26, 2008
Reviewer	H van Antwerpen	_____	November 28, 2008
Approver	R de Bruyn	_____	November 28, 2008

Original Signed Copy at CMC

Distribution					
Discipline	Name	Discipline	Name	Discipline	Name

Confirmation Required Status			
Calculation Page	Input/Assumption that Requires Confirmation	Preparer and Date Input/Assumption Confirmed	Reviewer and Date Input/Assumption Approved

Record of Changes	
Revision	Description of Changes
A	Initial Draft
1	Document Approved

Reference to this document
NGNP-CTF MTECH-TLDR-0006

Change Forecast

The document format and contents have been approved.

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2.2. COMPUTER PROGRAMS	5
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5. Results:	6
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Attachment B	7
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1. Objective:

The objective of the calculation is to determine the heater dimensions as well as the diameter of the heater. The heater Thermo Hydraulic design calculation is shown in Attachment A and the Mechanical design in Attachment B.

2. Methodology:

2.1. APPROACH

The TDL Heater 1 uses Graphite heater elements and assumes the power density of the HENDEL graphite heater and calculates the heater core volume. The heater core geometric ratio of the HENDEL test loop was then assumed and the core dimensions calculated for the TDL heater.

The basis for this is that the HENDEL heater operated at 40bar, 4kg/s, 700°C to 1000°C, while the CTF TDL heater works at 90bar, 4.75kg/s, 625°C to 950°C. The pressure (therefore, higher density) in the CTF should enable better heat transfer and hence, a higher power density in the CTF TDL heater than in the HENDEL heater. Additionally, the HENDEL element temperature was estimated to be 1300°C, while the experience with HTTU (South Africa) is that the maximum continuous temperature for a graphite element is 1600°C. This supports the notion that the heater size could be reduced by using a higher heater power density.

2.2. COMPUTER PROGRAMS

The computer programs used are EES and Excel.

3. Inputs and Assumptions:

3.1. ASSUMPTIONS:

Thermo hydraulic:

- See Attachment A

Mechanical Design:

- All pressure boundary calculations are done using a MS Excel spreadsheet incorporating ASME Code VIII Div 1 2001, No Addenda
- No corrosion allowance was included
- All pressure boundary outside temperatures are taken as 200°C

3.2. INPUTS:

Thermo hydraulic:

- See Attachment A

Mechanical Design:

- Proposed material is SA-516 Gr.70
- Allowable stress was taken as 20 KSI at 204°C (400°F) from ASME material property database
- Internal pressures taken as 9.6 MPa
- All other related input can be found in the attached calculation spreadsheet and are included in sections: **Dimensions** and **Material and Conditions**

4. Equations Used and Calculations:

- Heat transfer equations as per [Heat and Mass Transfer, Incropera and De Witt, Fifth Edition, 2002].
- The mechanical calculations were done according to ASME VIII Div 1.

5. Results:

The Results obtained from the Thermo Hydraulic design are as follows:

Description	Unit	Value
D _{heater}	m	1.22
L _{heater}	m	5.46
D _{vessel}	m	1.82
L _{vessel}	m	10.07
Power density	kW/m ³	1245

The Results for the Mechanical Design are shown in Attachment B.

6. Conclusions:

The results obtained serve as the Thermo Hydraulic and Mechanical design for Heater (HT 2A_1.1).

Attachment A

Heater (HT 2A_1.1) Thermo Hydraulic Calculation

Attachment B

Heater (HT 2A_1.1) Mechanical Design Calculation

CTF TDL Heater 1 calculation

Graphite heater

Attachment A to [MT-TLDR-CAL-F-M⁰⁶¹³]

Assumptions

=====

$$T_{\text{environment}} = 30 \text{ [C]}$$

$$T_{\text{outer,surface}} = 200 \text{ [C]} \text{ Depends on the steel type}$$

Radiative heat transfer view factor from pipe surface to environment = 1

Radiative Area_{environment} is infinitely large

This simplifies the radiation heat transfer calculation

$$H_{\text{heating}} = 5 \text{ [m]}$$

Height of heater internals

$$L_{\text{insulation}} = 0.3 \text{ [m]}$$

Insulation thickness, found adequate for the hot gas duct at 950C, wall temperature of ~200C

$$L_{\text{endspace}} = \frac{9.074 - 4.46}{2} - L_{\text{insulation}}$$

[m]

Distance of header volume at end of heater, based on HENDEL

Inputs Units Reference

=====

$$k = 0.5 \text{ [W/mK]}$$

Based on an assessment of current insulation materials, this is a conservative assumption

It agrees with results from the HENDEL tests:

*Construction and Performance Tests of Helium Engineering Demonstration Loop
(HENDEL) for VHTR, Hishida et al., JAERI, 1984*

$$h_{\text{outside,convection}} = 10 \text{ [W/m}^2\text{K]} \text{ General Engineering Experience}$$

$$\text{emissivity}_{\text{outside}} = 0.9 \text{ [-]} \text{ Typical for a painted surface}$$

$$T_{\text{inside}} = 1000 \text{ [C]}$$

$$T_{\text{inlet}} = 625 \text{ [C]} \text{ HT 2A}_{1.1} \text{ Specification sheet}$$

$$T_{\text{outlet}} = 950 \text{ [C]} \text{ HT 2A}_{1.1} \text{ Specification sheet}$$

$$Q_{\text{gas}} = 8000 \text{ [kW]}$$

HT 2A_{1,1} Specification sheet, includes 90% heater efficiency from HENDEL experience

$$\dot{m}_{\text{total}} = 4.75$$

$$\text{Powerdensity}_{\text{HENDEL}} = \frac{4360}{4.46 \cdot \pi \cdot \frac{1^2}{4}} \text{ [kW/m]}$$

$$\text{Ratio} = \frac{4.46}{1}$$

Geometric ratio from HENDEL heater H32 using Graphite elements

$$\text{Number}_{\text{elements,HENDEL}} = 36$$

$$\text{Power}_{\text{per,rod}} = \frac{4360}{\text{Number}_{\text{elements,HENDEL}}}$$

$$\text{Power}_{\text{per,m,HENDEL}} = \frac{\text{Power}_{\text{per,rod}}}{4.46}$$

$$L_{\text{HTTU}} = 9 \cdot 1.296$$

$$\text{Power}_{\text{per,m,HTTU}} = \frac{350}{L_{\text{HTTU}}}$$

Equations

=====

$$\text{Ratio} = \frac{H_{\text{heating}}}{D_{\text{heating}}}$$

$$\text{Powerdensity}_{\text{HENDEL}} = \frac{Q_{\text{gas}}}{H_{\text{heating}} \cdot \pi \cdot \frac{D_{\text{heating}}^2}{4}}$$

$$D_{\text{pressurevessel}} = D_{\text{heating}} + 2 \cdot L_{\text{insulation}}$$

$$H_{\text{pressurevessel}} = H_{\text{heating}} + 2 \cdot L_{\text{endspace}} + 2 \cdot L_{\text{insulation}}$$

Pipe and Shell HT 2A_1.1

Page 1 of 1

ASME Code VIII Div I 2001 edition no addenda

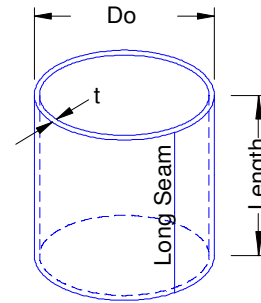
ASME L-2.2.1 <- BM 1 <- BM Item #

Verification Calc #3 <- Vessel, description

1 <- BM Qty

Dimensions:

24.000 <- Do - Outside Diameter
 1.220 <- t - Nominal Wall Thickness
 39.370 <- Length
 0.000 <- Corr, Corrosion Allowance

**Material and Conditions:**

SA-516 <- Material
 20 000 <- S, Allowable Stress Level (psi)
 0.85 <- E1 - Longitudinal Efficiency (circ. stress)
 0.65 <- Ec - Circ. Connecting Efficiency (longitudinal stress)
 0.0% <- UTP, Undertolerance allowance (%) 8.32 <- Volume (cubic ft)
 0.000 <- UTI, Undertolerance allowance (inch) 974.9 <- Material Weight (lbs cs)

1392.4 <- P, Interior Pressure
 0.0 <- Pa, Exterior Pressure
 1 <- B, From exterior pressure curve

0.009696 <- A (use to lookup B)

Variables:

UT = t*UTP+UTI = 1.22*0+0 undertolerance UT = 0.000
 Ri = Do/2-t+corr = 24/2-1.22+0 inside radius Ri = 10.780
 nt = t-Corr-UT = 1.22-0-0 nominal thick nt = 1.220
 LDo = L/Do = 39.37/24 LDo = 1.640
 DoT = Do/nt = 24/1.22 DoT = 19.672

Interior Pressure UG-27 (c) (1,2)

ta = P*Ri/(S*E1-0.6*P) = 1392.4*10.78/(20000*0.85-0.6*1392.4) ta = 0.929
 tb = P*Ri/(2*S*Ec+0.4*P) = 1392.4*10.78/(2*20000*0.65+0.4*1392.4) tb = 0.565
 tmin = Max(ta,tb) <= nt Okay tmin = 0.929
 PMaxA = (S*E1*nt)/(Ri+0.6*nt) = (20000*0.85*1.22)/(10.78+0.6*1.22) PMaxA = 1801.6
 PMaxB = (2*S*Ec*nt)/(Ri-0.4*nt) = (2*20000*0.65*1.22)/(10.78-0.4*1.22) PMaxB = 3082.0
 PMax = Min(PMaxA, PMaxB) Okay PMax = 1801.6
 tr1 = P*Ri/(S*1-0.6*P) = 1392.4*10.78/(20000*1-0.6*1392.4) tr1 = 0.783

Exterior Pressure UG-28 (c)

A = Interpolated from IID Part D Table G A = 0.009696
 PaMax = 4*B/(3*DoT) = 4*1/(3*19.672) Okay PaMax = 0.1
 tre = (3*Do*Pa)/(4*B) = (3*24*0)/(4*1) tre = 0.000

Shell stress relief -UCS-79(d), UNF-79(d), UHA-44(d)

Rf = (do-t)/2 = (24-1.22)/2 11.39
 % elong = (50*t/Rf)*(1-0) = (50*1.22/11.39)*(1-0) % elongation = 5.4

0.1% <- Max Elongation

Yes <- Cold formed 5.4% <- Elongation

no <- Vessel carries lethal substances (Yes/no)

no <- Impact testing is required (Yes/no)

no <- Greater than 10% reduction in thickness

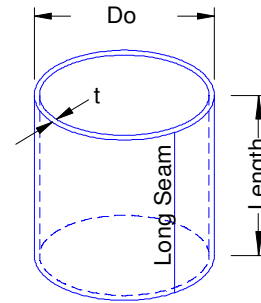
no <- Formed between 250 and 900 Degrees F

YES <- Shell is greater than 5/8" thick before forming

Required	Yes ?
no	no
no	no
no	no
no	no
no	no
no	no
Stress Relieve ?	no

Pipe and Shell HT 2A_1.1

ASME Code VIII Div I 2001 edition no addenda

ASME L-2.2.1 <- BM **1** <- BM Item #**Verification Calc #3** <- Vessel, description**1** <- BM Qty**Dimensions:****70.900** <- Do - Outside Diameter**3.500** <- t - Nominal Wall Thickness**236.000** <- Length**0.000** <- Corr, Corrosion Allowance**Material and Conditions:****SA-516** <- Material**20 000** <- S, Allowable Stress Level (psi)**0.85** <- E1 - Longitudinal Efficiency (circ. stress)**0.65** <- Ec - Circ. Connecting Efficiency (longitudinal stress)**0.0%** <- UTP, Undertolerance allowance (%)**437.99** <- Volume (cubic ft)**0.000** <- UTI, Undertolerance allowance (inch)**49 603.6** <- Material Weight (lbs cs)**1392.4** <- P, Interior Pressure**0.0** <- Pa, Exterior Pressure**1** <- B, From exterior pressure curve**0.004014** <- A (use to lookup B)**Variables:**

UT = t*UTP+UTI = 3.5*0+0

undertolerance UT = **0.000**

Ri = Do/2-t+corr = 70.9/2-3.5+0

inside radius Ri = **31.950**

nt = t-Corr-UT = 3.5-0-0

nominal thick nt = **3.500**

LDo = L/Do = 236/70.9

LDo = **3.329**

DoT = Do/nt = 70.9/3.5

DoT = **20.257****Interior Pressure** UG-27 (c) (1,2)

ta = P*Ri/(S*E1-0.6*P) = 1392.4*31.95/(20000*0.85-0.6*1392.4)

ta = **2.752**

tb = P*Ri/(2*S*Ec+0.4*P) = 1392.4*31.95/(2*20000*0.65+0.4*1392.4)

tb = **1.675**

tmin = Max(ta,tb) <= nt

Okaytmin = **2.752**

PMaxA = (S*E1*nt)/(Ri+0.6*nt) = (20000*0.85*3.5)/(31.95+0.6*3.5)

PMaxA = **1747.4**

PMaxB = (2*S*Ec*nt)/(Ri-0.4*nt) = (2*20000*0.65*3.5)/(31.95-0.4*3.5)

PMaxB = **2978.7**

PMax = Min(PMaxA,PMaxB)

OkayPMax = **1747.4**

tr1 = P*Ri/(S*1-0.6*P) = 1392.4*31.95/(20000*1-0.6*1392.4)

tr1 = **2.321****Exterior Pressure** UG-28 (c)

A = Interpolated from IID Part D Table G

A = **0.004014**

PaMax = 4*B/(3*DoT) = 4*1/(3*20.257)

OkayPaMax = **0.1**

tre = (3*Do*Pa)/(4*B) = (3*70.9*0)/(4*1)

tre = **0.000****Shell stress relief** -UCS-79(d), UNF-79(d), UHA-44(d)

Rf = (do-t)/2 = (70.9-3.5)/2

33.7

% elong = (50*t/Rf)*(1-0) = (50*3.5/33.7)*(1-0)

% elongation = **5.2****0.1%** <- Max Elongation**Yes** <- Cold formed**5.2%** <- Elongation**no** <- Vessel carries lethal substances (Yes/no)**no** <- Impact testing is required (Yes/no)**no** <- Greater than 10% reduction in thickness**no** <- Formed between 250 and 900 Degrees F**YES** <- Shell is greater than 5/8" thick before formingRequired **Yes ?****no** **no****no** **no****no** **no****no** **no****no** **no****Stress Relieve ?** **no**

Elliptical Head HT2A_1.1

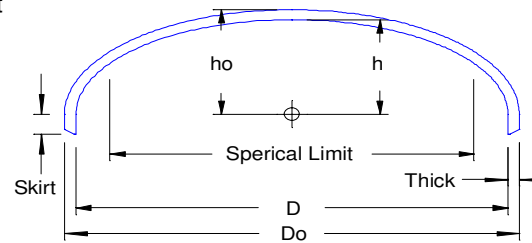
Page 1 of 1

ASME Code VIII Div I 2001 no Addenda

Heads	<- BM	<- BM Item #	<- BM Qty
	<- Component		

Dimensions:

70.900	<- Do, outside diameter
16.725	<- h
2.800	<- tb, thickness before forming
2.800	<- tf, thickness after forming
0.000	<- Corr, corrosion allowance
5.000	<- Skirt, straight skirt length

**Material and Conditions:**

SA-516	<- material
20 000	<- S, allowable stress level (psi)
1.00	<- E, efficiency
1392.4	<- P, interior pressure
0.0	<- Pa, exterior pressure
1	<- B, from exterior pressure curve

Calculated Properties:

87.9	<- Approximate blank diameter
4821.5	<- Approximate weight for steel, (lbs)
31.30	<- Volume (cuft, includes skirt)
52.24	<- Spherical Limit (0.8 * D)
0.00604	<- A value to lookup B

Variables:

D = Do-2*t	= 70.9-2*2.8	D = 65.30
ho = h+t	= 16.725+2.8	ho = 19.53
D/2h = D/(2*h)	= 65.3/(2*16.725)	D/2h = 1.952
Do/2ho = Do/(2*ho)	= 70.9/(2*19.525)	Do/2ho = 1.816
K = Interpolated value from table 1-4.1	interior	K = 0.967
Kone = Interpolated value from table UG-37	spherical	Kone = 0.878
Kzero = Interpolated value from table UG-33.1	exterior	Kzero = 0.817
t = tf-corr	= 2.8-0	t = 2.800
Ro = Ko*Do	= 0.817*70.9	Ro = 57.927

Interior Pressure App 1-4(c)(d), UG-37 1(a)

TMinl = (P*D*K)/(2*S*E-0.2*P) <= t	TMinl (min thickness) =	2.212
= (1392.4*65.3*0.967)/(2*20000*1-0.2*1392.4) <= 2.8		Okay
PMax = (2*S*E*t)/(K*D+0.2*t) >= P	PMax =	1759
= (2*20000*1*2.8)/(0.967*65.3+0.2*2.8) >= 1392		Okay
TSpl = (P*D*Kone)/(2*S*E-0.2*P)	TSpl (required sphere zone thick) =	2.011
= (1392.4*65.3*0.878)/(2*20000*1-0.2*1392.4)		

Exterior Pressure UG-33(d), UG-28(d)

A = 0.125/(Ro/t)	= 0.125/(57.927/2.8)	A = 0.006042
PaMax = B/(Ro/t) >= Pa	= 1/(57.927/2.8) >= 0	PaMax = 0.0
TMinE = (Ro*Pa)/B	= (57.927*0)/1	TMinE = 0.000

Head stress relief UCS-79(d), UNF-79(d), UHA-44(d)

% elong = ((75*t)/h)*(1-0)	= ((75*2.8)/16.725)*(1-0)	% elong = 12.6

5.0%	<- Max Elongation	12.6%	<- Elongation
Yes	<- Cold Formed		
no	<- Vessel carries lethal substances(Yes/no)		
no	<- Impact testing is required (Yes/no)		
no	<- Formed between 250 and 900 Degrees F		
no	<- Greater than 10% reduction in thickness		
Yes	<- Head is greater than 5/8" thick before forming		

Required	Yes ?
no	no
no	no
no	no
no	no
Yes ?	YES
Stress Relieve ?	YES

Appendix N

Component Specification Sheet

Company:	M-Tech Industrial (Pty) Ltd		
Location:	Potchefstroom, South Africa		
Document Number:	MT-TLDR-TDL-CMPT-05-0007		
Component:	TDL Primary Heater 1 (HT 2A_1.1)		
Date:	11 December 2008	Rev. No.:	2

Authorisation			
Action	Name	Signature	Date
Preparer	Bennie Nel		December 11, 2008
Reviewer	Herman van Antwerpen		December 11, 2008
Approver	Riaan de Bruyn		December 17, 2008

Record of Changes	
Revision	Description of Changes
A	Initial Draft
1	Document Approved
2	Configuration tables added

HT 2A_1.1		
Component Specification Sheet		
	<u>Value & Unit</u>	<u>Remarks</u>
P_{he} :	9 000 kPa	Nominal pressure.
$T_{he\ in}$:	$T_{ambient} - 625\ ^\circ C$	Inlet temperature.
$T_{he\ out}$:	950 $^\circ C$	
m_{he} :	4.75 (3.65) kg/s	Values in () indicate the component size without 30% safety margin.
Q_{th} :	8.0 (6.16) MW	The heater requirements obtained from the 3 x 1.2 MW IHX A tests (worst case).
Q_e :	8.9 MW	Q_e is the electrical input, assuming $\eta = 90\ \%$.
Fluid:	Helium	
T_{design} :	950 $^\circ C$	Heating elements are manufactured from graphite.
P_{design} :	9 600 kPa	
<u>Shell:</u>		
Length:	6 000 mm	
Outside diameter:	1 801 mm	
Wall thickness:	88.9 mm	
Corrosion allowance:	0 mm	
<u>Nozzles:</u>		
No. of protrusions:	2	Electrical protrusions to be added during detail design.
Length:	1 000 mm	
Outside diameter:	609.6 mm	
Wall thickness:	31 mm	
<u>Elliptical Head:</u>		
Head ratio:	2 : 1	
Height:	424.82 mm	Height before and after forming.
Wall thickness before:	71.12 mm	
Wall thickness after:	71.12 mm	
Skirt:	127 mm	

<u>Material:</u>		
Component material:	SA-516 Gr.70	
Allowable stress:	115.14 MPa	
Vessel mass:	27 759 kg	Includes only the pressure boundary, excludes flanges.

Appendix O



M - T e c h
i n d u s t r i a l

***Attachment to Section 6: Technology Development
Loop (TDL)
Heater (HT 2A_1.2) Calculation***

Document number: MT-TLDR-CAL-F-M-0614

Revision: 1

Status: Approved

D.J. Viljoen

November 2008

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Configuration Management

CHANGE HISTORY

Configuration Control	
Client Name:	Battelle Energy Alliance
Project Number:	NGNP-CTF MTECH-TLDR
Project Name:	NGNP CTF Test Loop Pre-Conceptual Design
Calculation Title:	Heater (HT 2A_1.2) Calculation
Calculation Identification Number:	MT-TLDR-CAL-F-M-0614
Quality Level:	3

Template No: MT-TLDR-CAL-REP rev 1

Authorisation			
Action	Name	Signature	Date
Preparer	D.J. Viljoen	_____	November 26, 2008
Reviewer	H. van Antwerpen	_____	November 28, 2008

Original Signed Copy at CMC

Distribution					
Discipline	Name	Discipline	Name	Discipline	Name

Confirmation Required Status			
Calculation Page	Input/Assumption that Requires Confirmation	Preparer and Date Input/Assumption Confirmed	Reviewer and Date Input/Assumption Approved

Record of Changes	
Revision	Description of Changes
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1	Document Approved

Reference to this document
Paragraph 6.3.7

Change Forecast

The document format and contents have been approved.

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1. Objective:

The objective of the calculation is to determine the heater dimensions as well as the diameter of the heater. The heater Thermo Hydraulic design calculation is shown in Attachment A and the Mechanical design in Attachment B.

2. Methodology:

2.1. APPROACH

The TDL Heater 2 uses Inconel heater elements and assumes the heat transfer per meter Inconel wire to be 1 kW/m. With this as basis the required length of wire could be calculated. By selecting the pitch of the wire the size of the heater could be calculated. The Mechanical calculations for the heater vessel could then be done using ASME VIII Div 1.

2.2. COMPUTER PROGRAMS

The computer programs used are EES and Excel.

3. Inputs and Assumptions:

3.1. ASSUMPTIONS:

Thermo Hydraulic:

- See Attachment A

Mechanical Design:

- All pressure boundary calculations are done using a MS Excel spreadsheet incorporating ASME Code VIII Div 1 2001, No Addenda
- No corrosion allowance was included
- All pressure boundary outside temperatures are taken as 200°C

3.2. INPUTS:

Thermo Hydraulic:

- See Attachment A

Mechanical Design:

- Proposed material is SA-516 Gr.70
- Allowable stress was taken as 20 KSI at 204°C (400°F) from ASME material property database
- Internal pressures taken as 9.6 MPa

- All other related input can be found in the attached calculation spreadsheet and are included in sections: **Dimensions** and **Material and Conditions**

4. Equations Used and Calculations:

- Heat transfer equations as per [Heat and Mass Transfer, Incropera and De Witt, Fifth Edition, 2002].
- The mechanical calculations were done according to ASME VIII Div 1.

5. Results:

The Results obtained from the Thermo Hydraulic design are as follows:

Description	Unit	Value
D _{heater}	m	0.76
L _{heater}	m	3.39
D _{vessel}	m	0.96
L _{vessel}	m	4.59
Power density	kW/m ³	2500

The Results for the Mechanical Design are shown in Attachment B.

6. Conclusions:

The results obtained serve as the Thermo Hydraulic and Mechanical design for Heater (HT 2A_1.2).

Attachment A

Heater (HT 2A_1.2) Thermo Hydraulic Calculation

Attachment B

Heater (HT 2A_1.2) Mechanical Design Calculation

*TDL Heater 2 calculation**Inconel wire heater**Attachment A to [MT-TLDR-CAL-F-M⁰⁶¹⁴]**Assumptions*

=====

A passively cooled hot gas duct design is used

$$T_{\text{environment}} = 30 \text{ [C]}$$

$$T_{\text{outer,surface}} = 200 \text{ [C]} \text{ Depends on the steel type}$$

*Radiative heat transfer view factor from pipe surface to environment = 1**Radiative Area_{environment} is infinitely large**This simplifies the radiation heat transfer calculation*

$$H_{\text{heating}} = 5 \text{ [m]}$$

Height of heater internals

$$\text{Pitch} = 0.02 \text{ [m]} \text{ Average distance between rows and columns of wires}$$

$$L_{\text{endspace}} = 0.5 \text{ [m]} \text{ Distance of header volume at end of heater}$$

$$L_{\text{insulation}} = 0.1 \text{ [m]}$$

*Insulation thickness, found adequate for the hot gas duct at 950C, wall temperature of ~200C**Inputs Units Reference*

=====

$$k = 0.5 \text{ [W/mK]}$$

*Based on an assessment of current insulation materials, this is a conservative assumption**It agrees with results from the HENDEL tests:**Construction and Performance Tests of Helium Engineering Demonstration Loop (HENDEL) for VHTR, Hishida et al., JAERI, 1984*

$$h_{\text{outside,convection}} = 10 \text{ [W/m}^2\text{K]} \text{ General Engineering Experience}$$

$$\text{emissivity}_{\text{outside}} = 0.9 \text{ [-]} \text{ Typical for a painted surface}$$

$$T_{\text{inside}} = 950 \text{ [C]}$$

$$T_{\text{inlet}} = 85 \text{ [C]} \text{ HT 2A}_{1,2} \text{ Specification sheet}$$

$$T_{\text{outlet}} = 660 \text{ [C]} \text{ HT 2A}_{1,2} \text{ Specification sheet}$$

$$Q_{\text{gas}} = 4900 \text{ [kW]}$$

HT 2A_{1,2} Specification sheet, includes 90% heater efficiency from HENDEL experience

$Q_{\text{per,meter}} = 1$ [kW/m] Heating density for 4mm Inconel wire heating element,

Westinghouse SA Experience from HTF Heaters

Can be increased when operating at lower temperatures

Results in approximately 100C dT between wire and gas, 50C dt between heating enclosure and gas

Equations

=====

$$\text{Wire}_{\text{length}} = \frac{Q_{\text{gas}}}{Q_{\text{per,meter}}}$$

$$\text{Number}_{\text{wires}} = \frac{\text{Wire}_{\text{length}}}{H_{\text{heating}}}$$

Assuming a square arrangement of wires

$$\text{Number}_{\text{rows}} = \sqrt{\text{Number}_{\text{wires}}}$$

$$L_{\text{row}} = \text{Number}_{\text{rows}} \cdot \text{Pitch}$$

$$D_{\text{pressurevessel}} = L_{\text{row}} + 2 \cdot L_{\text{insulation}}$$

$$H_{\text{pressurevessel}} = H_{\text{heating}} + 2 \cdot L_{\text{endspace}} + 2 \cdot L_{\text{insulation}}$$

$$\text{Ratio} = \frac{2.3}{11}$$

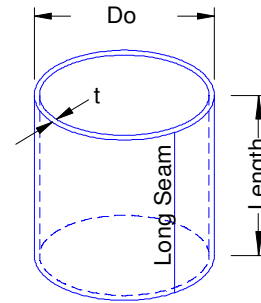
$$\text{Ratio} = \frac{D_{\text{pressurevessel}}}{H_{\text{pressurevessel}}}$$

$$\text{Powerdensity} = \frac{Q_{\text{gas}}}{L_{\text{row}}^2 \cdot H_{\text{heating}}}$$

$$\text{Powerdensity}_{\text{HTF}} = \frac{100}{0.4 \cdot 0.4 \cdot 0.5}$$

Pipe and Shell HT2A_1.2

ASME Code VIII Div I 2001 edition no addenda

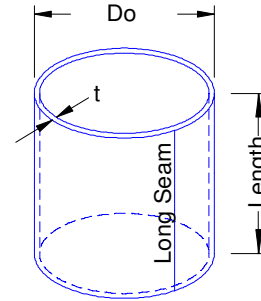
ASME L-2.2.1 <- BM **1** <- BM Item #**Verification Calc #3** <- Vessel, description**1** <- BM Qty**Dimensions:****24.000** <- Do - Outside Diameter**1.220** <- t - Nominal Wall Thickness**39.370** <- Length**0.000** <- Corr, Corrosion Allowance**Material and Conditions:****SA-516** <- Material**20 000** <- S, Allowable Stress Level (psi)**0.85** <- E1 - Longitudinal Efficiency (circ. stress)**0.65** <- Ec - Circ. Connecting Efficiency (longitudinal stress)**0.0%** <- UTP, Undertolerance allowance (%)**0.000** <- UTI, Undertolerance allowance (inch)**8.32** <- Volume (cubic ft)**974.9** <- Material Weight (lbs cs)**1392.4** <- P, Interior Pressure**0.0** <- Pa, Exterior Pressure**1** <- B, From exterior pressure curve**0.009696** <- A (use to lookup B)**Variables:**UT = $t \cdot \text{UTP} + \text{UTI}$ = $1.22 \cdot 0 + 0$ undertolerance UT = **0.000**Ri = $\text{Do} / 2 - t + \text{corr}$ = $24 / 2 - 1.22 + 0$ inside radius Ri = **10.780**nt = $t - \text{Corr} - \text{UT}$ = $1.22 - 0 - 0$ nominal thick nt = **1.220**LDo = L / Do = $39.37 / 24$ LDo = **1.640**DoT = Do / nt = $24 / 1.22$ DoT = **19.672****Interior Pressure** UG-27 (c) (1,2)ta = $P \cdot Ri / (S \cdot E1 - 0.6 \cdot P)$ = $1392.4 \cdot 10.78 / (20000 \cdot 0.85 - 0.6 \cdot 1392.4)$ ta = **0.929**tb = $P \cdot Ri / (2 \cdot S \cdot Ec + 0.4 \cdot P)$ = $1392.4 \cdot 10.78 / (2 \cdot 20000 \cdot 0.65 + 0.4 \cdot 1392.4)$ tb = **0.565**tmin = $\text{Max}(ta, tb) \leq nt$ **Okay**tmin = **0.929**PMaxA = $(S \cdot E1 \cdot nt) / (Ri + 0.6 \cdot nt)$ = $(20000 \cdot 0.85 \cdot 1.22) / (10.78 + 0.6 \cdot 1.22)$ PMaxA = **1801.6**PMaxB = $(2 \cdot S \cdot Ec \cdot nt) / (Ri - 0.4 \cdot nt)$ = $(2 \cdot 20000 \cdot 0.65 \cdot 1.22) / (10.78 - 0.4 \cdot 1.22)$ PMaxB = **3082.0**PMax = $\text{Min}(\text{PMaxA}, \text{PMaxB})$ **Okay**PMax = **1801.6**tr1 = $P \cdot Ri / (S \cdot 1 - 0.6 \cdot P)$ = $1392.4 \cdot 10.78 / (20000 \cdot 1 - 0.6 \cdot 1392.4)$ tr1 = **0.783****Exterior Pressure** UG-28 (c)

A = Interpolated from IID Part D Table G

A = **0.009696**PaMax = $4 \cdot B / (3 \cdot \text{DoT})$ = $4 \cdot 1 / (3 \cdot 19.672)$ **Okay**PaMax = **0.1**tre = $(3 \cdot \text{Do} \cdot Pa) / (4 \cdot B)$ = $(3 \cdot 24 \cdot 0) / (4 \cdot 1)$ tre = **0.000****Shell stress relief** -UCS-79(d), UNF-79(d), UHA-44(d)Rf = $(\text{do} - t) / 2$ = $(24 - 1.22) / 2$ **11.39**% elong = $(50 \cdot t / Rf) \cdot (1 - 0)$ = $(50 \cdot 1.22 / 11.39) \cdot (1 - 0)$ % elongation = **5.4****0.1%** <- Max Elongation**Yes** <- Cold formed**5.4%** <- Elongation**no** <- Vessel carries lethal substances (Yes/no)**no** <- Impact testing is required (Yes/no)**no** <- Greater than 10% reduction in thickness**no** <- Formed between 250 and 900 Degrees F**YES** <- Shell is greater than 5/8" thick before formingRequired **Yes ?****no** **no****no** **no****no** **no****no** **no****no** **no****Stress Relieve ?** **no**

Pipe and Shell HT 2A_1.2

ASME Code VIII Div I 2001 edition no addenda

ASME L-2.2.1 <- BM **1** <- BM Item #**Verification Calc #3** <- Vessel, description**1** <- BM Qty**Dimensions:****37.800** <- Do - Outside Diameter**2.000** <- t - Nominal Wall Thickness**157.500** <- Length**0.000** <- Corr, Corrosion Allowance**Material and Conditions:****SA-516** <- Material**20 000** <- S, Allowable Stress Level (psi)**0.85** <- E1 - Longitudinal Efficiency (circ. stress)**0.65** <- Ec - Circ. Connecting Efficiency (longitudinal stress)**0.0%** <- UTP, Undertolerance allowance (%)**81.78** <- Volume (cubic ft)**0.000** <- UTI, Undertolerance allowance (inch)**10 047.7** <- Material Weight (lbs cs)**1392.4** <- P, Interior Pressure**0.0** <- Pa, Exterior Pressure**1** <- B, From exterior pressure curve**0.003986** <- A (use to lookup B)**Variables:**

UT = t*UTP+UTI = 2*0+0

undertolerance UT = **0.000**

Ri = Do/2-t+corr = 37.8/2-2+0

inside radius Ri = **16.900**

nt = t-Corr-UT = 2-0-0

nominal thick nt = **2.000**

LDo = L/Do = 157.5/37.8

LDo = **4.167**

DoT = Do/nt = 37.8/2

DoT = **18.900****Interior Pressure** UG-27 (c) (1,2)

ta = P*Ri/(S*E1-0.6*P) = 1392.4*16.9/(20000*0.85-0.6*1392.4)

ta = **1.456**

tb = P*Ri/(2*S*Ec+0.4*P) = 1392.4*16.9/(2*20000*0.65+0.4*1392.4)

tb = **0.886**

tmin = Max(ta,tb) <= nt

Okay

tmin = **1.456**

PMaxA = (S*E1*nt)/(Ri+0.6*nt) = (20000*0.85*2)/(16.9+0.6*2)

PMaxA = **1878.5**

PMaxB = (2*S*Ec*nt)/(Ri-0.4*nt) = (2*20000*0.65*2)/(16.9-0.4*2)

PMaxB = **3229.8**

PMax = Min(PMaxA,PMaxB)

Okay

PMax = **1878.5**

tr1 = P*Ri/(S*1-0.6*P) = 1392.4*16.9/(20000*1-0.6*1392.4)

tr1 = **1.228****Exterior Pressure** UG-28 (c)

A = Interpolated from IID Part D Table G

A = **0.003986**

PaMax = 4*B/(3*DoT) = 4*1/(3*18.9)

Okay

PaMax = **0.1**

tre = (3*Do*Pa)/(4*B) = (3*37.8*0)/(4*1)

tre = **0.000****Shell stress relief** -UCS-79(d), UNF-79(d), UHA-44(d)

Rf = (do-t)/2 = (37.8-2)/2

17.9

% elong = (50*t/Rf)*(1-0) = (50*2/17.9)*(1-0)

% elongation = **5.6****0.1%** <- Max Elongation**Yes** <- Cold formed**5.6%** <- Elongation**no** <- Vessel carries lethal substances (Yes/no)**no** <- Impact testing is required (Yes/no)**no** <- Greater than 10% reduction in thickness**no** <- Formed between 250 and 900 Degrees F**YES** <- Shell is greater than 5/8" thick before forming

Required	Yes ?
no	no
no	no
no	no
no	no
no	no
no	no
Stress Relieve ?	no

Elliptical Head HT2A_1.2

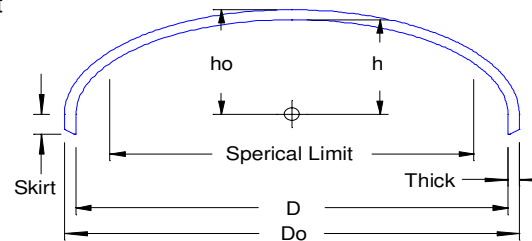
Page 1 of 1

ASME Code VIII Div I 2001 no Addenda

	<- BM	<- BM Item #	<- BM Qty
Heads	<- Component		

Dimensions:

37.800	<- Do, outside diameter
8.450	<- h
1.500	<- tb, thickness before forming
2.000	<- tf, thickness after forming
0.000	<- Corr, corrosion allowance
3.000	<- Skirt, straight skirt length

**Material and Conditions:**

SA-516	<- material
20 000	<- S, allowable stress level (psi)
1.00	<- E, efficiency
1392.4	<- P, interior pressure
0.0	<- Pa, exterior pressure
1	<- B, from exterior pressure curve

Calculated Properties:

46.0	<- Approximate blank diameter
707.6	<- Approximate weight for steel, (lbs)
4.48	<- Volume (cuft, includes skirt)
27.04	<- Spherical Limit (0.8 * D)
0.00813	<- A value to lookup B

Variables:

D = Do-2*t	= 37.8-2*2	D = 33.80
ho = h+t	= 8.45+2	ho = 10.45
D/2h = D/(2*h)	= 33.8/(2*8.45)	D/2h = 2.000
Do/2ho = Do/(2*ho)	= 37.8/(2*10.45)	Do/2ho = 1.809
K = Interpolated value from table 1-4.1	interior	K = 1.000
Kone = Interpolated value from table UG-37	spherical	Kone = 0.900
Kzero = Interpolated value from table UG-33.1	exterior	Kzero = 0.814
t = tf-corr	= 2-0	t = 2.000
Ro = Ko*Do	= 0.814*37.8	Ro = 30.764

Interior Pressure App 1-4(c)(d), UG-37 1(a)

TMinl = (P*D*K)/(2*S*E-0.2*P) <= t	TMinl (min thickness) = 1.185
= (1392.4*33.8*1)/(2*20000*1-0.2*1392.4) <= 2	Okay
PMax = (2*S*E*t)/(K*D+0.2*t) >= P	PMax = 2339
= (2*20000*1*2)/(1*33.8+0.2*2) >= 1392	Okay
TSpl = (P*D*Kone)/(2*S*E-0.2*P)	TSpl (required sphere zone thick) = 1.066
= (1392.4*33.8*0.9)/(2*20000*1-0.2*1392.4)	

Exterior Pressure UG-33(d), UG-28(d)

A = 0.125/(Ro/t)	= 0.125/(30.764/2)	A = 0.008126
PaMax = B/(Ro/t) >= Pa	= 1/(30.764/2) >= 0	PaMax = 0.1
TMinE = (Ro*Pa)/B	= (30.764*0)/1	TMinE = 0.000

Head stress relief UCS-79(d), UNF-79(d), UHA-44(d)

% elong = ((75*t)/h)*(1-0)	= ((75*2)/8.45)*(1-0)	% elong = 13.3

5.0%	<- Max Elongation	13.3%	<- Elongation
Yes	<- Cold Formed		
no	<- Vessel carries lethal substances(Yes/no)		
no	<- Impact testing is required (Yes/no)		
no	<- Formed between 250 and 900 Degrees F		
no	<- Greater than 10% reduction in thickness		
Yes	<- Head is greater than 5/8" thick before forming		

Required	Yes ?
no	no
no	no
no	no
no	no
Yes ?	YES
Stress Relieve ?	YES

Appendix O

Component Specification Sheet

Company:	M-Tech Industrial (Pty) Ltd		
Location:	Potchefstroom, South Africa		
Document Number:	MT-TLDR-TDL-CMPT-05-0008		
Component:	TDL Primary Heater 2 (HT 2A_1.2)		
Date:	11 December 2008	Rev. No.:	2

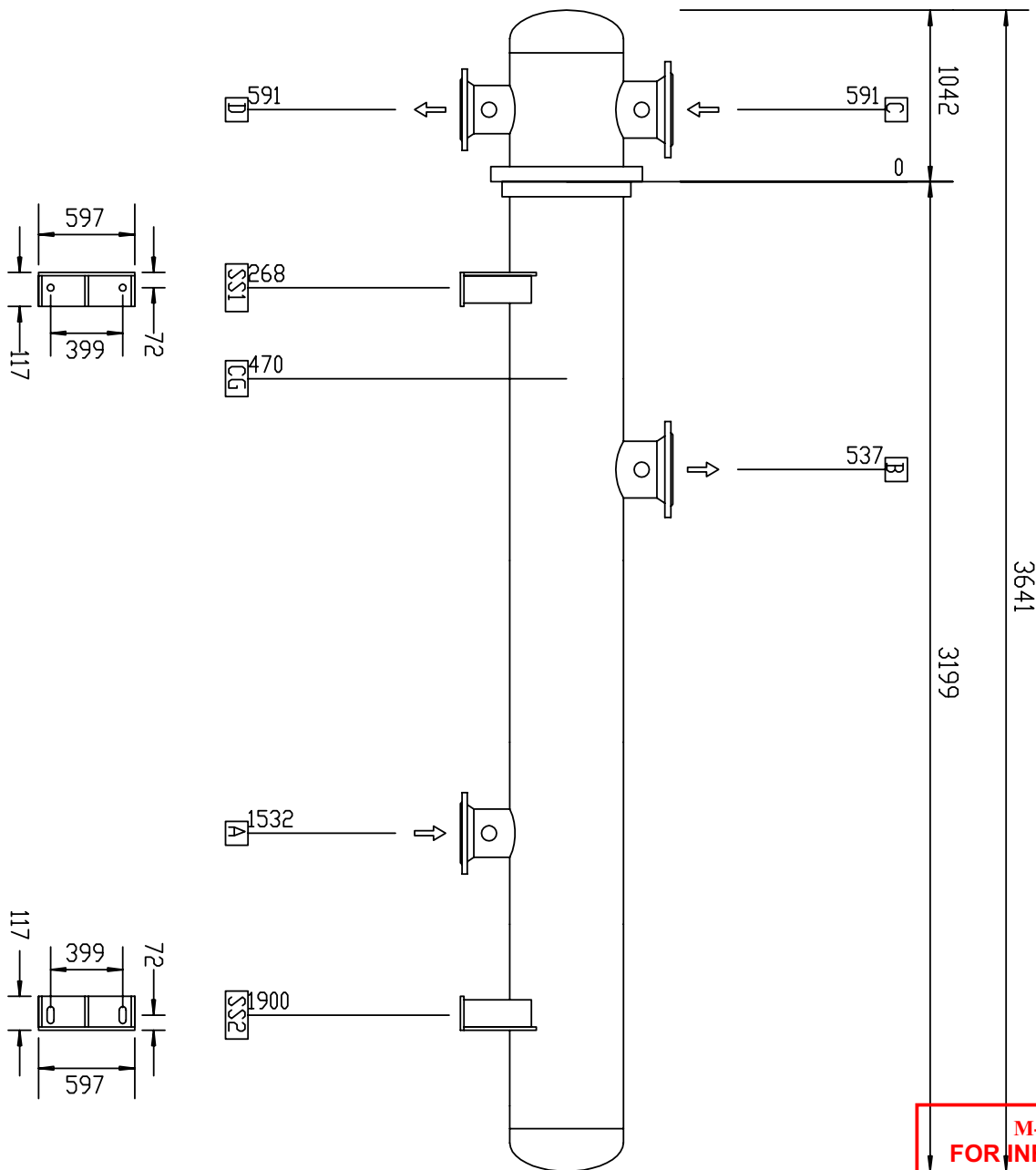
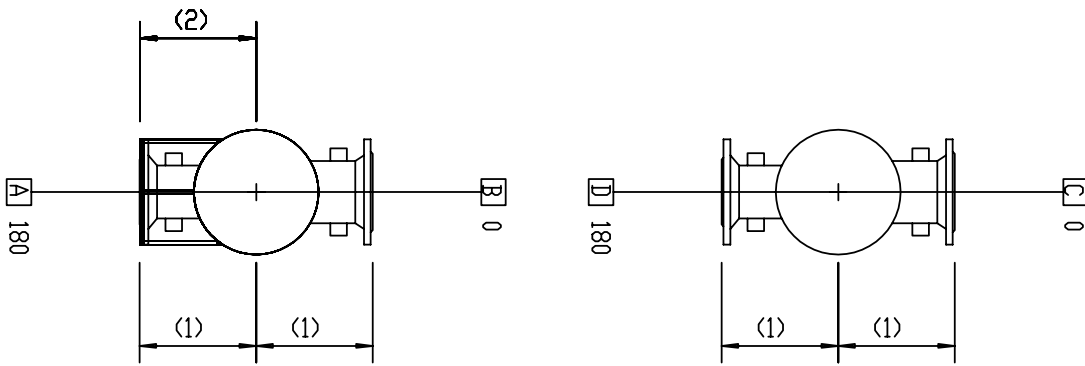
Authorisation			
Action	Name	Signature	Date
Preparer	Bennie Nel		December 11, 2008
Reviewer	Herman van Antwerpen		December 11, 2008
Approver	Riaan de Bruyn		December 17, 2008

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A	Initial Draft
1	Document Approved
2	Configuration tables added

HT 2A_1.2 Component Specification Sheet		
	<u>Value & Unit</u>	<u>Remarks</u>
P _{he} :	9 000 kPa	Nominal pressure.
T _{he in} :	T _{ambient} - 85 °C	Inlet temperature.
T _{he out} :	659 °C	
m _{he} :	1.477 (1.136) kg/s	Values in () indicate the component size without 30% safety margin.
Q _{th} :	4.4 (3.38) MW	The heater requirements obtained from the 3 x 1.2 MW IHX A tests (worst case).
Q _e :	4.9 MW	Q _e is the electrical input, assuming $\eta = 90 \%$.
Fluid:	Helium	
T _{design} :	659 °C	Heating elements manufactured from Kanthal.
P _{design} :	9 600 kPa	
<u>Shell:</u>		
Length:	4 000 mm	
Outside diameter:	960 mm	
Wall thickness	50.8 mm	
Corrosion allowance:	0 mm	
<u>Nozzles:</u>		
No. of protrusions:	2	Electrical protrusions to be added during detail design.
Length:	1 000 mm	
Outside diameter:	609.6 mm	
Wall thickness:	31 mm	
<u>Elliptical Head:</u>		
Head ratio:	2 : 1	
Height:	214.63 mm	Height before and after forming.
Wall thickness before:	38.1 mm	
Wall thickness after:	50.8 mm	
Skirt:	76.2 mm	

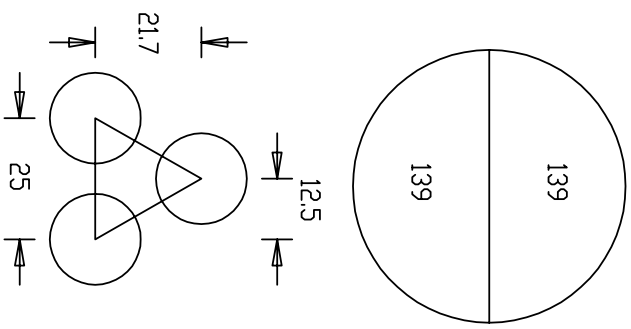
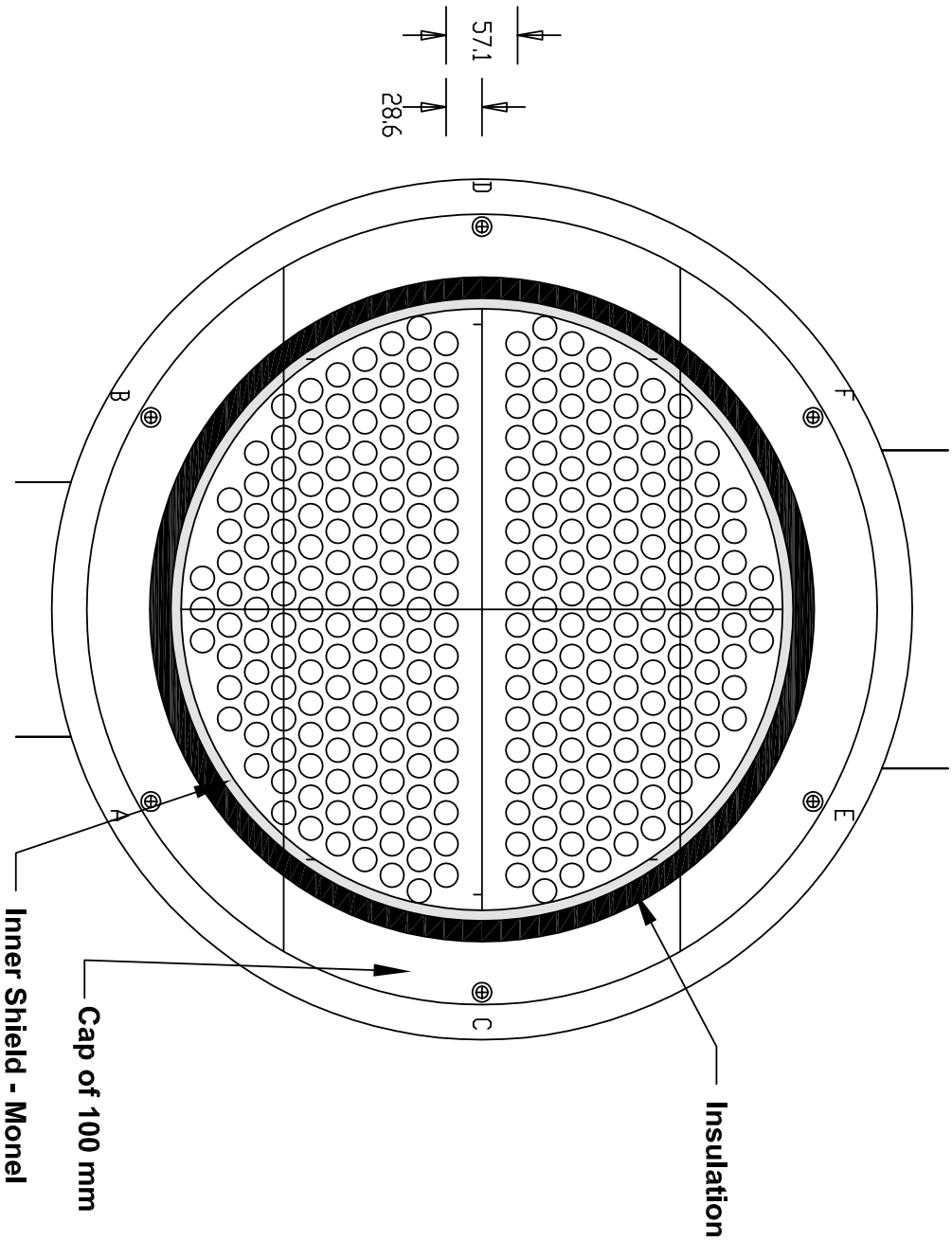
<u>Material:</u>		
Component material:	SA-516 Gr.70	
Allowable stress:	115.14 MPa	
Vessel mass:	6 084 kg	Includes only the pressure boundary, excludes flanges.

Appendix P



M-Tech Industrial
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 Configuration Management

Row	Holes
20	3
19	8
18	11
17	14
16	15
15	16
14	17
13	18
12	19
11	18
10	18
9	19
8	18
7	17
6	16
5	15
4	14
3	11
2	8
1	3
	278



Shell ID 632 mm
 D.T.L. 480.9 mm
 Baffle cut to C/158.5 mm

Component	D.D.	Thk.	Materials of Construction
Nozzle A Inlet	292.1	44.5	1500 # ANSI L.W.N.FF Flg SA-508 on SA-508 Carbon Steel Forg
Nozzle B Outlet	368.3	57.1	1500 # ANSI L.W.N.FF Flg SA-508 on SA-508 Carbon Steel Forg
Nozzle C Inlet	368.3	57.1	1500 # ANSI L.W.N.FF Flg SA-508 on SA-508 Carbon Steel Forg
Nozzle D Outlet	292.1	44.5	1500 # ANSI L.W.N.FF Flg SA-508 on SA-508 Carbon Steel Forg
Shell Cylinder	688	28.0	SA-508 Forgings Gr. 3V K31830
Fr Hd Cylinder	654	27.0	SA-508 Forgings Gr. 3V K31830
Fr Hd Cover	652	26.0	SA-508 Forgings Gr. 3V K31830 (Ellipsoidal Cover)
Shell Cover	688	27.0	SA-508 Forgings Gr. 3V K31830 (Ellipsoidal Cover)
Front TubSh	947	159.0	SB-564 N08800 (Ann) Ni Alloy Forg
Fr Hd Flng TubSh	947	177.0	SA-508 Forgings Gr. 3V K31830
Fr Hd Gskt TubSh	712	1.6	Comp Fiber 1/16 in. thk (Periph. Width 53.0 mm)
Re Hd Gskt TubSh			Comp Fiber 1/16 in. thk (Periph. Width 0.0 mm)
Fr Hd Gskt Cover			Comp Fiber 1/16 in. thk (Periph. Width 0.0 mm)
Fr Hd Bits TubSh	64		SA-193 B7 Steel Bit (16 Bolts on 826.0 mm B.C.)
Re Hd Bits TubSh			SA-193 B7 Steel Bit (0 Bolts on 0.0 mm B.C.)
Fr Hd Bits Cover			SA-193 B7 Steel Bit (0 Bolts on 0.0 mm B.C.)
Tubes	19.05	2.77	SB-163 N04400 (Ann) SmI 67Ni-30Cu Tube (Plain Tubes)
Baffles	628	5.0	Monel
Shell Supports		13.0	SA-285 Gr C Steel Plt

Appendix P

Component Specification Sheet

Company:	M-Tech Industrial (Pty) Ltd		
Location:	Potchefstroom, South Africa		
Document Number:	MT-TLDR-TDL-CMPT-05-0009		
Component:	TDL Primary Loop Recuperator (RX 2A_2.1)		
Date:	11 December 2008	Rev. No.:	2

Authorisation			
Action	Name	Signature	Date
Preparer	Bennie Nel		December 11, 2008
Reviewer	Herman van Antwerpen		December 11, 2008
Approver	Riaan de Bruyn		December 17, 2008

Record of Changes	
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A	Initial Draft
1	Document Approved
2	Configuration tables added

RX 2A_1.1 (Made up of 4 Recuperators in series)
Component Specification Sheet

<u>Shell side:</u>	<u>Value & Unit</u>	<u>Remarks</u>
Fluid:	Helium	
P_{he} :	9 000 kPa	Nominal pressure.
$T_{he\ in}$:	85 °C	Inlet temperature.
$T_{he\ out}$:	777 °C	Outlet temperature.
ΔP_{he} :	109 kPa	Pressure loss (Shell side).
V_{he} :	13.62 m/s	Velocity.
m_{he} :	219 kg/min	Converted from 3.65 kg/s.
Passes:	1	
T_{design} :	816 °C	
P_{design} :	9 790 kPa	
<u>Tube side:</u>		
Fluid:	Helium	
P_{he} :	9 000 kPa	Nominal pressure.
$T_{he\ in}$:	950 °C	Inlet temperature.
$T_{he\ out}$:	258 °C	Outlet temperature.
ΔP_{he} :	56.357 kPa	Pressure loss.
V_{he} :	28.24 m/s	Velocity.
m_{he} :	219 kg/min	Converted from 3.65 kg/s.
Passes:	2	
T_{design} :	988 °C	
P_{design} :	9 790 kPa	
Q:	13.208 MW	Heat Exchanged.
<u>Tubes:</u>		
No. of tubes:	139 U's	Per unit.
Outside diameter:	19.05 mm	
Thickness _{avg} :	2.6 mm	

Length:	2 000 mm	
Pitch:	25 mm	
<u>Body Shell:</u>		
Length:	3 641 mm	Total length, head to head.
Outside diameter:	688 mm	Diameter of a single vessel.
Wall thickness:		
Corrosion allowance:		
<u>Nozzles:</u>		
No. of protrusions:	4	
Connections:	Flanged	
Length:		
Nominal diameter:		
Wall thickness:		
<u>Elliptical Head:</u>		
Head ratio:		
Height:		
Wall thickness before:		
Wall thickness after:		
Skirt:		
<u>Material:</u>		
Shell material:	SA-508 Forgings Gr.3V K31830	The tubes will be surrounded by an Inner Shield of Monel, thereafter a layer of insulation.
Tube material:	SB-163 N04400 (Ann.)	67Ni-30Cu Tube.
Vessel and internals mass:	36 902 kg	

Information given on Specification Sheet equals combined total of 4 units.

Appendix P

Component Specification Sheet

Company:	M-Tech Industrial (Pty) Ltd		
Location:	Potchefstroom, South Africa		
Document Number:	MT-TLDR-TDL-CMPT-05-0010		
Component:	TDL Secondary Loop Recuperator (RX 2A_2.1)		
Date:	11 December 2008	Rev. No.:	2

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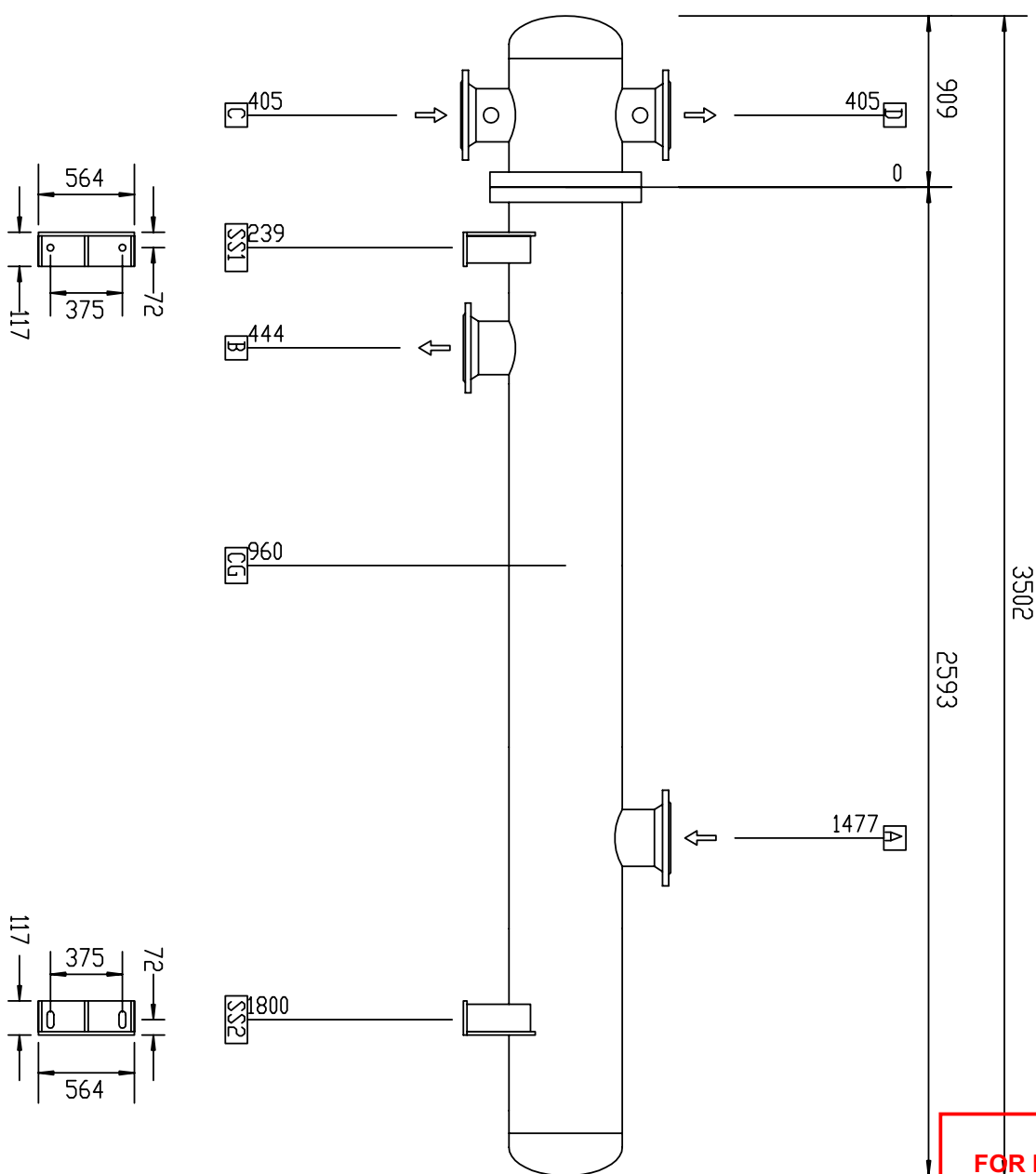
RX 2A_2.1 (Made up of 3 Recuperators in series)
Component Specification Sheet

<u>Shell side:</u>	<u>Value & Unit</u>	<u>Remarks</u>
Fluid:	Helium	
P_{he} :	9 600 kPa	Nominal pressure.
$T_{he\ in}$:	85 °C	Inlet temperature.
$T_{he\ out}$:	710 °C	Outlet temperature.
ΔP_{he} :	67 kPa	Pressure loss (Shell side).
V_{he} :	13.21 m/s	Velocity.
m_{he} :	219 kg/min	Converted from 3.65 kg/s.
Passes:	1	
T_{design} :	743 °C	
P_{design} :	10 480 kPa	
<u>Tube side:</u>		
Fluid:	Helium	
P_{he} :	9 600 kPa	Nominal pressure.
$T_{he\ in}$:	900 °C	Inlet temperature.
$T_{he\ out}$:	275 °C	Outlet temperature.
ΔP_{he} :	39 kPa	Pressure loss.
V_{he} :	25.9 m/s	Velocity.
m_{he} :	219 kg/min	Converted from 3.65 kg/s.
Passes:	2	
T_{design} :	937 °C	
P_{design} :	10 480 kPa	
Q:	11.925 MW	Heat Exchanged.
<u>Tubes:</u>		
No. of tubes:	139 U's	Per unit.
Outside diameter:	19.05 mm	
Thickness _{avg} :	2.6 mm	

Length:	2 000 mm	
Pitch:	25 mm	
<u>Body Shell:</u>		
Length:	3 641 mm	Total length, head to head.
Outside diameter:	688 mm	Diameter of a single vessel.
Wall thickness:		
Corrosion allowance:		
<u>Nozzles:</u>		
No. of protrusions:	4	
Connections:	Flanged	
Length:		
Nominal diameter:		
Wall thickness:		
<u>Elliptical Head:</u>		
Head ratio:		
Height:		
Wall thickness before:		
Wall thickness after:		
Skirt:		
<u>Material:</u>		
Shell material:	SA-508 Forgings Gr.3V K31830	The tubes will be surrounded by an Inner Shield of Monel, thereafter a layer of insulation.
Tube material:	SB-163 N04400 (Ann.)	67Ni-30Cu Tube.
Vessel and internals mass:	38 027 kg	

Information given on Specification Sheet equals combined total of 3 units.

Appendix Q

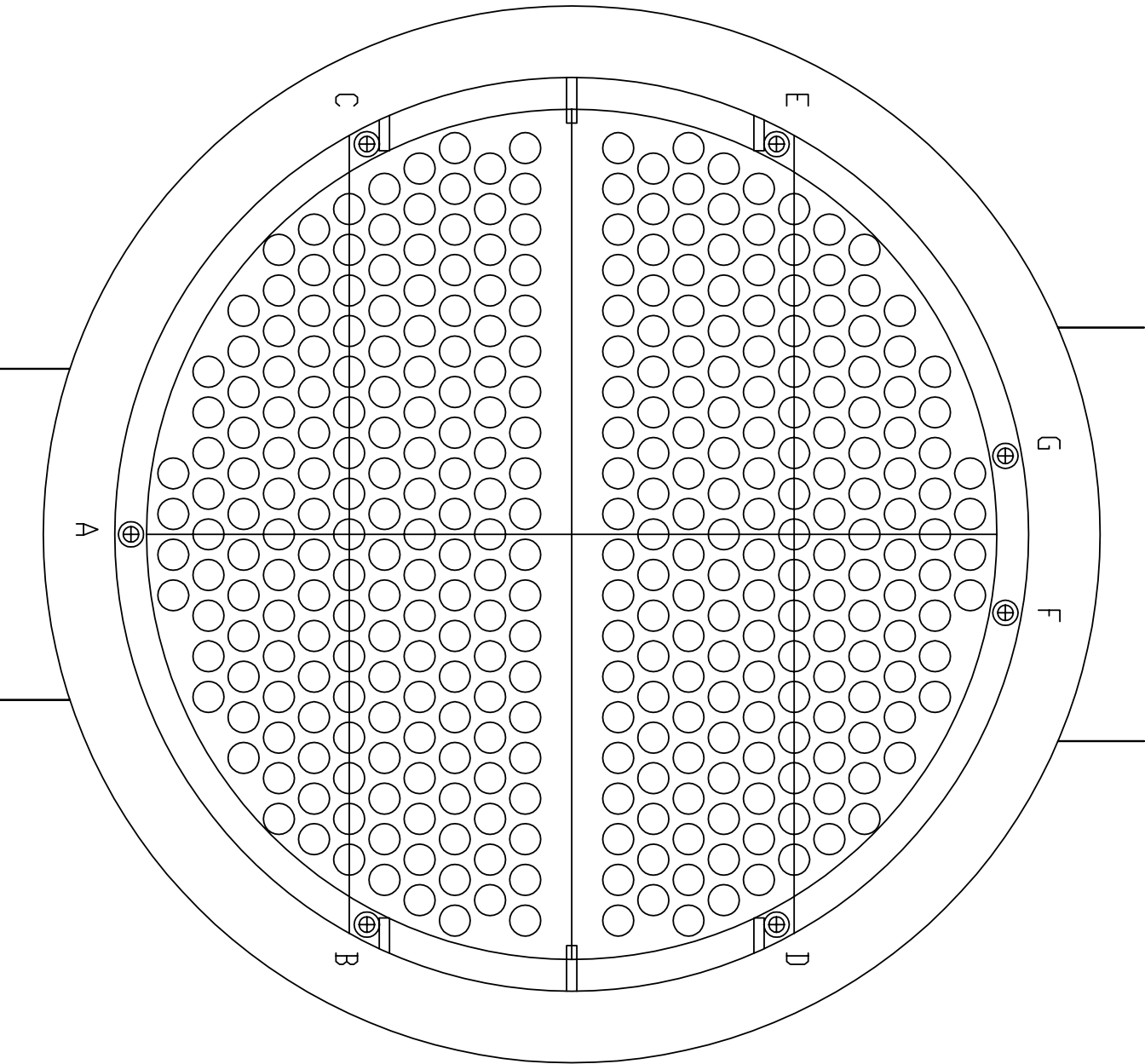
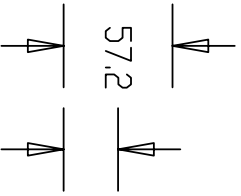


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Row

Holes

22	4
21	9
20	12
19	15
18	16
17	17
16	18
15	19
14	20
13	19
12	20
11	20
10	19
9	20
8	19
7	18
6	17
5	16
4	15
3	12
2	9
1	4
338	



Appendix Q

Component Specification Sheet

Company:	M-Tech Industrial (Pty) Ltd		
Location:	Potchefstroom, South Africa		
Document Number:	MT-TLDR-TDL-CMPT-05-0011		
Component:	TDL Primary Loop Cooler (CL 2A_1.1)		
Date:	11 December 2008	Rev. No.:	2

Authorisation			
Action	Name	Signature	Date
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CL 2A_1.1 Component Specification Sheet		
<u>Shell side:</u>	<u>Value & Unit</u>	<u>Remarks</u>
Fluid:	Helium	
P_{he} :	9 000 kPa	Nominal pressure.
$T_{he\ in}$:	417 °C	Inlet temperature.
$T_{he\ out}$:	80 °C	Outlet temperature.
ΔP_{he} :	6.58 kPa	Pressure loss.
V_{he} :	5.04 m/ s	Velocity.
m_{he} :	3.65 kg/s	
Passes:	1	
T_{design} :	454.4 °C	
P_{design} :	9 790 kPa	
<u>Tube side:</u>		
Fluid:	Water	
P_w :	300 kPa	Nominal pressure.
$T_{w\ in}$:	20 °C	Inlet temperature.
$T_{w\ out}$:	45.1 °C	Outlet temperature.
ΔP_w :	24.8 kPa	Pressure loss.
V_w :	2.4 m/ s	Velocity.
m_w :	61.1 kg/s	
Passes:	2	
T_{design} :	82 °C	
P_{design} :	517 kPa	
Q:	6.343 MW	Heat Exchanged.
<u>Tubes:</u>		
No. of tubes:	169 U's	
Outside diameter:	19.05 mm	
Thickness _{avg} :	2.6 mm	

Length:	2 000 mm	
Pitch:	25 mm	
<u>Body Shell:</u>		
Length:	3 502 mm	Total length, head to head.
Outside diameter:	650 mm	
Wall thickness:	44 mm	
Corrosion allowance:		
<u>Nozzles:</u>		
No. of protrusions:	4	
Connections:	Flanged	
Length:		
Outside diameter:		
Wall thickness:		
<u>Elliptical Head:</u>		
Head ratio:		
Height:		
Wall thickness before:		
Wall thickness after:		
Skirt:		
<u>Material:</u>		
Shell material:	SA-516 Gr.70	
Tube material:	SA-214 Wld Tube	
Vessel and internals mass:	5 635 kg	

Component	I.D.	Thk.	Materials of Construction
Nozzle A Inlet	374.6	60.3	2500 # ANSI L.W.N.F.F Flg SA-105 on SA-105 Carbon Steel Forg
Nozzle B Outlet	304.8	50.8	2500 # ANSI L.W.N.F.F Flg SA-105 on SA-105 Carbon Steel Forg
Nozzle C Inlet	304.8	25.4	150 # ANSI L.W.N.F.F Flg SA-105 on SA-105 Carbon Steel Forg
Nozzle D Outlet	304.8	25.4	150 # ANSI L.W.N.F.F Flg SA-105 on SA-105 Carbon Steel Forg
Shell Cylinder	650	44.0	SA-516 Gr 70 Steel Plt
Fr Hd Cylinder	650	8.0	SA-516 Gr 70 Steel Plt
Fr Hd Cover	650	8.0	SA-516 Gr 70 Steel Plt (Ellipsoidal Cover)
Shell Cover	650	42.0	SA-516 Gr 70 Steel Plt (Ellipsoidal Cover)
Front TubSh	884	130.0	SA-516 Gr 70 Steel Plt
Fr Hd Flng TubSh	884	63.0	SA-266 Grade 2 Forgings (Hub Flange)
Fr Hd Gskt TubSh	668	1.6	Comp Fiber 1/16 in. thk (Periph. Width 130 mm)
Fr Hd Gskt Cover			Comp Fiber 1/16 in. thk (Periph. Width 0.0 mm)
Fr Hd Blts TubSh	16		SA-193 B7 Steel Blt (24 Bolts on 845.0 mm B.C.)
Fr Hd Blts Cover			SA-193 B7 Steel Blt (0 Bolts on 0.0 mm B.C.)
Tubes	19.05	2.6	SA-214 Wld Tube (Plain Tubes)
Baffles	558	10.0	SA-285 Gr C Steel Plt
Shell Supports		13.0	SA-285 Gr C Steel Plt

Appendix R

Appendix R

Component Specification Sheet

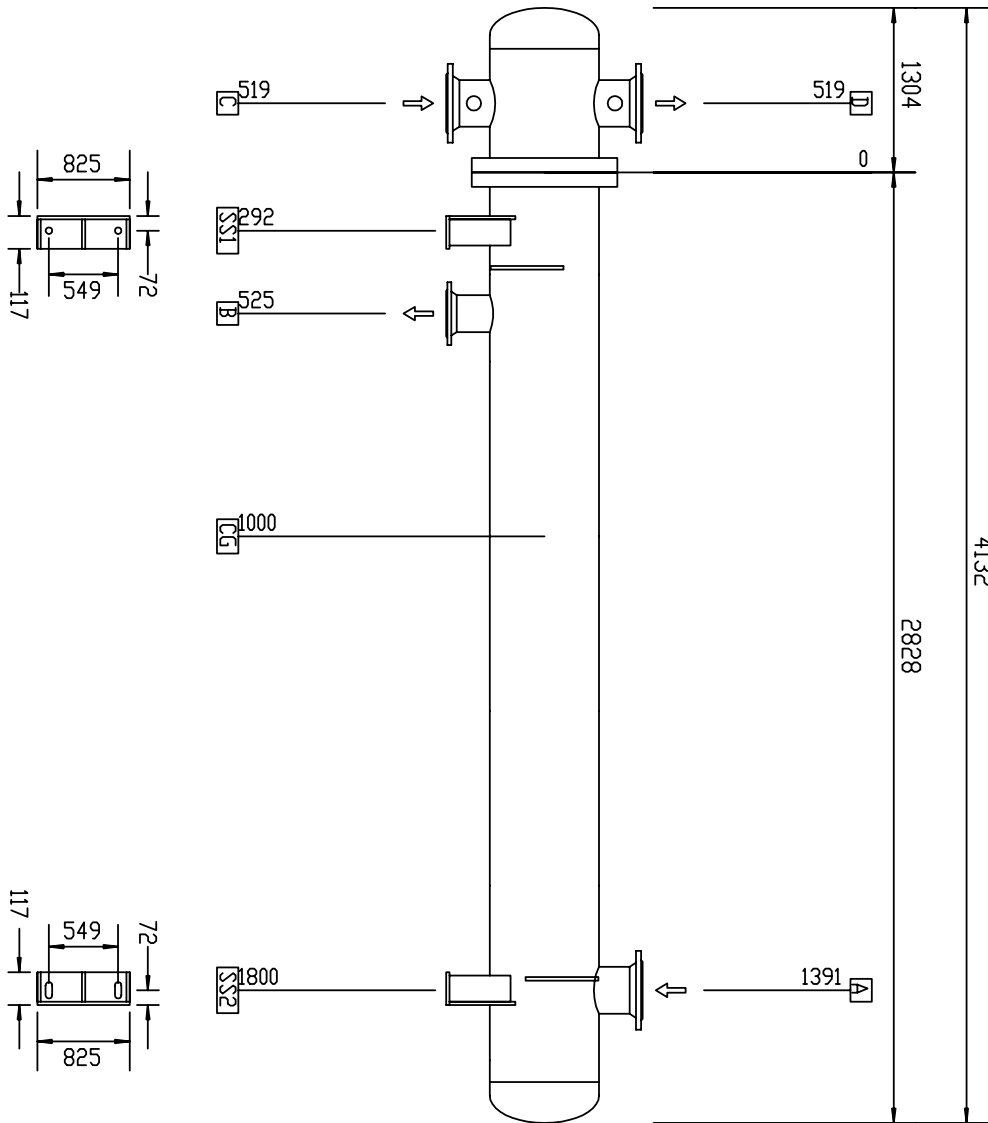
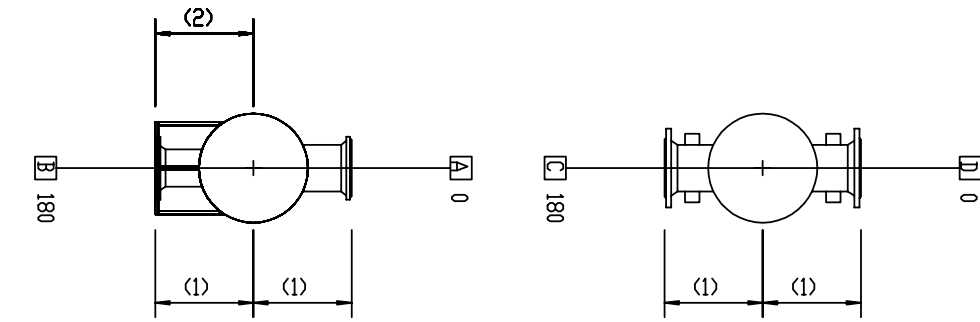
Company:	M-Tech Industrial (Pty) Ltd		
Location:	Potchefstroom, South Africa		
Document Number:	MT-TLDR-TDL-CMPT-05-0012		
Component:	TDL Secondary Loop Cooler (CL 2A_2.1)		
Date:	11 December 2008	Rev. No.:	2

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Action	Name	Signature	Date
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Approver	Riaan de Bruyn		December 17, 2008

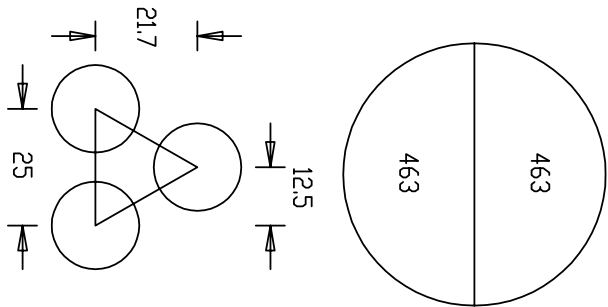
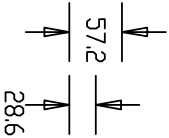
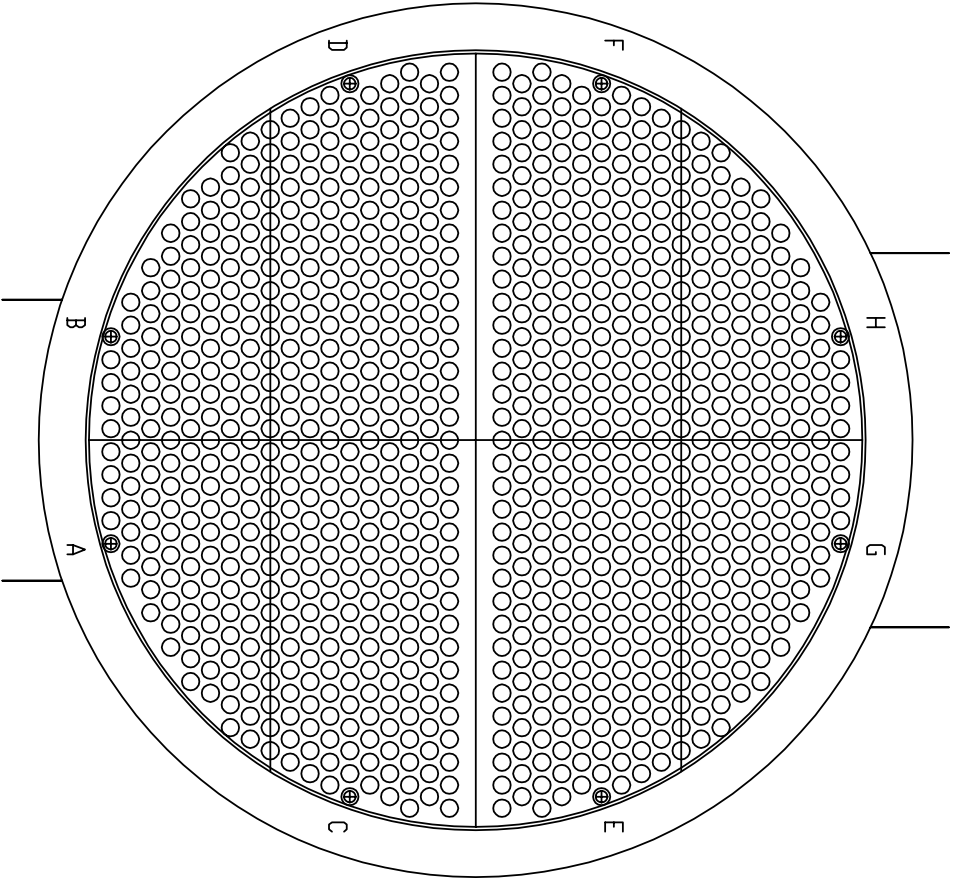
Record of Changes	
Revision	Description of Changes
A	Initial Draft
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CL 2A_2.1 Component Specification Sheet		
<u>Shell side:</u>	<u>Value & Unit</u>	<u>Remarks</u>
Fluid:	Helium	
P_{he} :	9 600 kPa	Nominal pressure.
$T_{he\ in}$:	275 °C	Inlet temperature.
$T_{he\ out}$:	80 °C	Outlet temperature.
ΔP_{he} :	9.17 kPa	Pressure loss.
V_{he} :	6.03 m/ s	Velocity.
m_{he} :	3.65 kg/s	
Passes:	1	
T_{design} :	310 °C	
P_{design} :	10 480 kPa	
<u>Tube side:</u>		
Fluid	Water	
P_w :	300 kPa	Nominal pressure.
$T_{w\ in}$:	20 °C	Inlet temperature.
$T_{w\ out}$:	45.2 °C	Outlet temperature.
ΔP_w :	19.32 kPa	Pressure loss.
V_w :	2.1 m/ s	Velocity.
m_w :	35.3 kg/s	
Passes:	2	
T_{design} :	82 °C	
P_{design} :	517 kPa	
Q:	3.725 MW	Heat Exchanged.
<u>Tubes:</u>		
No. of tubes:	112 U's	
Outside diameter:	19.05 mm	
Thickness _{avg} :	2.6 mm	

Length:	2 000 mm	
Pitch:	25 mm	
<u>Body Shell:</u>		
Length:	4 132 mm	Total length, head to head.
Outside diameter:	950 mm	
Wall thickness:	51 mm	
Corrosion allowance:		
<u>Nozzles:</u>		
No. of protrusions:	4	
Connections:	Flanged	
Length:		
Outside diameter:		
Wall thickness:		
<u>Elliptical Head:</u>		
Head ratio:		
Height:		
Wall thickness before:		
Wall thickness after:		
Skirt:		
<u>Material:</u>		
Shell material:	SA-516 Gr.70	
Tube material:	SA-214 Wld Tube	
Vessel and internals mass:	2 701 kg	



Shell ID 848 mm
D.T.L. 840.9 mm
Baffle cut to C/P23.4 mm



Appendix S



M - T e c h
i n d u s t r i a l

***Attachment to Section 6: Technology Development
Loop (TDL)
IHX Vessel Calculation***

Document number: MT-TLDR-CAL-F-M-0618

Revision: 1

Status: Approved

D.J. Viljoen

November 2008

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Configuration Management

CHANGE HISTORY

Configuration Control	
Client Name:	Battelle Energy Alliance
Project Number:	NGNP-CTF MTECH-TLDR
Project Name:	NGNP CTF Test Loop Pre-Conceptual Design
Calculation Title:	IHX Vessel Calculation
Calculation Identification Number:	MT-TLDR-CAL-F-M-0618
Quality Level:	3

Template No: MT-TLDR-CAL-REP rev 1

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Preparer	D J Viljoen	_____	November 26, 2008
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Approver	R de Bruyn	_____	November 28, 2008

Original Signed Copy at CMC

Distribution					
Discipline	Name	Discipline	Name	Discipline	Name

Confirmation Required Status			
Calculation Page	Input/Assumption that Requires Confirmation	Preparer and Date Input/Assumption Confirmed	Reviewer and Date Input/Assumption Approved

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A	Initial Draft
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Reference to this document
NGNP-CTF MTECH-TLDR-0006

Change Forecast

The document format and contents have been approved.

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2. Methodology:.....	5
2.1. APPROACH.....	5
2.2. COMPUTER PROGRAMS	5
3. Inputs and Assumptions:	5
3.1. ASSUMPTIONS:	5
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1. Objective:

The objective of the calculation is to determine the insulation thickness of the passively cooled IHX test vessel and to determine the inside diameter of the pressure boundary. The Thermal Hydraulic calculation is shown in Attachment A and the Mechanical design in Attachment B.

2. Methodology:

2.1. APPROACH

The internal gas flow liner diameter was calculated based on a on the component size to be tested. The insulation thickness could then be determined to give a pressure boundary outside temperature of 200 °C. The inside diameter of the pressure boundary could then be determined and the Mechanical design completed in conjunction with ASME VIII Div 1.

2.2. COMPUTER PROGRAMS

The computer programs used are EES and Excel.

3. Inputs and Assumptions:

3.1. ASSUMPTIONS:

Thermo Hydraulic:

- See Attachment A

Mechanical:

- All pressure boundary calculations are done using a MS Excel spreadsheet incorporating ASME Code VIII Div 1 2001, No Addenda
- No corrosion allowance was included
- All pressure boundary outside temperatures are taken as 200°C

3.2. INPUTS:

Thermo Hydraulic:

- See Attachment A

Mechanical:

- Proposed material is SA-516 Gr.70
- Allowable stress was taken as 20 KSI at 204°C (400°F) from ASME material property database
- Internal pressures taken as 9.6 MPa

All other related input can be found in the attached calculation spreadsheet and are included in sections: **Dimensions** and **Material and Conditions**

4. Equations Used and Calculations:

- Heat transfer equations as per [Heat and Mass Transfer, Incropera and De Witt, Fifth Edition, 2002].
- The mechanical calculations are done according to ASME VIII Div 1.

5. Results:

The thermo Hydraulic calculation results are as follows:

Description	Unit	Value
P_{he}	kPa	9600
$T_{he\ in}$	°C	1000
$d_{internal\ vessel}$	m	3.29
$d_{internal\ liner}$	m	3
L_{vessel}	m	6.89
$L_{vessel\ liner}$	m	6.6

The Mechanical calculation results are shown in Attachment B.

6. Conclusions:

The results serve as the mechanical design as well as thermal hydraulic design of the IHX test vessel.

Attachment A

IHX Test Vessel Thermo Hydraulic Calculation

Attachment B

IHX Test Vessel Mechanical Design Calculation

*IHX Test Vessel outside temperature and heat loss calculation**Attachment A to [MT-TLDR-CAL-F-M⁰⁶¹⁸]**Assumptions*

=====

A passively cooled pressure vessel is used

$$T_{\text{test}} = 1000 \text{ [C]}$$

$$T_{\text{amb}} = 30 \text{ [C]} \text{ Ambient temperature}$$

*It is assumed that there is a zero deltaT across the High-temperature vessel and across the polished cladding**Radiative heat transfer view factor from vessel surface to environment = 1**Radiative Area_{environment} is infinitely large**This simplifies the radiation heat transfer calculation**Material properties Units Reference*

=====

$$k_{\text{outer,insulation}} = 0.5 \text{ [W/mK]}$$

$$k_{\text{gap}} = k \text{ ['Helium' , T = 80 , P = 9000]}$$

$$k_{\text{steel}} = k \text{ ['Carbon_{steel,AISI1010}' , 80]}$$

$$\epsilon_{\text{ps clad}} = 0.3 \text{ Emissivity for polished stainless steel: Incropera}$$

$$\epsilon_{\text{ps pv,i}} = 0.8 \text{ Emissivity for lightly oxidised carbon steel: Incropera}$$

$$\epsilon_{\text{ps pv,o}} = 0.9 \text{ Emissivity for a painted surface: Incropera}$$

Geometry Units Reference

=====

$$R_{\text{test}} = 1.5 \text{ [m]} \text{ Radius of test section}$$

$$t_{\text{insulation}} = 0.145 \text{ [m]}$$

$$R_{\text{clad}} = R_{\text{test}} + t_{\text{insulation}} \text{ Radius of cladding}$$

$$L_{\text{gap}} = 0.0001 \text{ [m]} \text{ Gap between vessel and insulation}$$

$$R_{\text{pv,i}} = R_{\text{clad}} + L_{\text{gap}} \text{ Pressure vessel internal diameter}$$

$$L_{\text{pv}} = 0.05 \text{ Thickness of the pressure vessel wall}$$

$$R_{\text{pv,o}} = R_{\text{pv,i}} + L_{\text{pv}} \text{ Pressure vessel outside radius}$$

$$L_{\text{test}} = 6.6 \text{ [m]} \text{ Length of test section}$$

$$A_{pv,o} = 2 \cdot \pi \cdot R_{pv,o} \cdot [L_{test} + 2 \cdot (R_{pv,o} - R_{test})] + 2 \cdot \pi \cdot R_{pv,o}^2$$

$$A_{clad} = 2 \cdot \pi \cdot R_{clad} \cdot [L_{test} + 2 \cdot (R_{clad} - R_{test})] + 2 \cdot \pi \cdot R_{clad}^2$$

$$L_{pressurevessel} = L_{test} + 2 \cdot [R_{pv,i} - R_{test}]$$

Equations

=====

$$Q_{vessel} = k_{outer,insulation} \cdot \left[2 \cdot \pi \cdot \frac{L_{test}}{\ln\left(\frac{R_{clad}}{R_{test}}\right)} + 2 \cdot \pi \cdot \left(\frac{R_{clad}^2}{R_{clad} - R_{test}}\right) \right] \cdot [T_{test} - T_{clad}]$$

$$h_{gap,rad} = 5.670E-08 \text{ [W/m}^2\text{-K}^4] \cdot [T_{clad} + 273 + T_{pv,i} + 273] \cdot \left[\frac{(T_{clad} + 273)^2 + (T_{pv,i} + 273)^2}{\frac{1 + \epsilon_{ps_{clad}}}{\epsilon_{ps_{clad}}} + 1 + \frac{1 + \epsilon_{ps_{pv,i}}}{\epsilon_{ps_{pv,i}}}} \right]$$

$$v_{lam} = 4.36$$

$$\frac{1}{h_{gap,conv}} = \frac{L_{gap}}{k_{gap} \cdot v_{lam}} + \frac{L_{gap}}{k_{gap} \cdot v_{lam}}$$

$$Q_{vessel} = [h_{gap,rad} + h_{gap,conv}] \cdot A_{clad} \cdot [T_{clad} - T_{pv,i}]$$

$$Q_{vessel} = k_{steel} \cdot \left[2 \cdot \pi \cdot \left(\frac{L_{test} + 2 \cdot [R_{pv,i} - R_{test}]}{\ln\left[\frac{R_{pv,o}}{R_{pv,i}}\right]} \right) + 2 \cdot \pi \cdot \frac{R_{pv,o}^2}{L_{pv}} \right] \cdot [T_{pv,i} - T_{pv,o}]$$

$$T1 = T_{amb} + 273$$

$$T2 = T_{pv,o} + 273$$

$$h_{amb,conv} = 10 \text{ [W/m}^2\text{K]} \text{ Insulation data sheet}$$

$$h_{amb,rad} = 5.670E-08 \text{ [W/m}^2\text{-K}^4] \cdot [T1 + T2] \cdot \left[\frac{T1^2 + T2^2}{\frac{1 + \epsilon_{ps_{pv,o}}}{\epsilon_{ps_{pv,o}}} + 1} \right]$$

Heat and Mass Transfer, Incropera and De Witt, Fifth Edition, 2002

$$Q_{vessel} = [h_{amb,conv} + h_{amb,rad}] \cdot A_{pv,o} \cdot [T_{pv,o} - T_{amb}]$$

Heat and Mass Transfer, Incropera and De Witt, Fifth Edition, 2002

Pipe and Shell TV2A_2.1

ASME Code VIII Div I 2001 edition no addenda

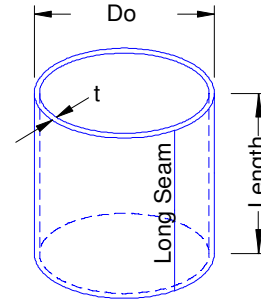
ASME L-2.2.1 <- BM 1 <- BM Item #

Verification Calc #3 <- Vessel, description

1 <- BM Qty

Dimensions:

24.000 <- Do - Outside Diameter
 1.220 <- t - Nominal Wall Thickness
 39.370 <- Length
 0.000 <- Corr, Corrosion Allowance

**Material and Conditions:**

SA-516 <- Material
 20 000 <- S, Allowable Stress Level (psi)
 0.85 <- E1 - Longitudinal Efficiency (circ. stress)
 0.65 <- Ec - Circ. Connecting Efficiency (longitudinal stress)
 0.0% <- UTP, Undertolerance allowance (%) 8.32 <- Volume (cubic ft)
 0.000 <- UTI, Undertolerance allowance (inch) 974.9 <- Material Weight (lbs cs)

1392.4 <- P, Interior Pressure
 0.0 <- Pa, Exterior Pressure
 1 <- B, From exterior pressure curve 0.009696 <- A (use to lookup B)

Variables:

UT = t*UTP+UTI = 1.22*0+0 undertolerance UT = 0.000
 Ri = Do/2-t+corr = 24/2-1.22+0 inside radius Ri = 10.780
 nt = t-Corr-UT = 1.22-0-0 nominal thick nt = 1.220
 LDo = L/Do = 39.37/24 LDo = 1.640
 DoT = Do/nt = 24/1.22 DoT = 19.672

Interior Pressure UG-27 (c) (1,2)

ta = P*Ri/(S*E1-0.6*P) = 1392.4*10.78/(20000*0.85-0.6*1392.4) ta = 0.929
 tb = P*Ri/(2*S*Ec+0.4*P) = 1392.4*10.78/(2*20000*0.65+0.4*1392.4) tb = 0.565
 tmin = Max(ta,tb) <= nt Okay tmin = 0.929
 PMaxA = (S*E1*nt)/(Ri+0.6*nt) = (20000*0.85*1.22)/(10.78+0.6*1.22) PMaxA = 1801.6
 PMaxB = (2*S*Ec*nt)/(Ri-0.4*nt) = (2*20000*0.65*1.22)/(10.78-0.4*1.22) PMaxB = 3082.0
 PMax = Min(PMaxA, PMaxB) Okay PMax = 1801.6
 tr1 = P*Ri/(S*1-0.6*P) = 1392.4*10.78/(20000*1-0.6*1392.4) tr1 = 0.783

Exterior Pressure UG-28 (c)

A = Interpolated from IID Part D Table G A = 0.009696
 PaMax = 4*B/(3*DoT) = 4*1/(3*19.672) Okay PaMax = 0.1
 tre = (3*Do*Pa)/(4*B) = (3*24*0)/(4*1) tre = 0.000

Shell stress relief -UCS-79(d), UNF-79(d), UHA-44(d)

Rf = (do-t)/2 = (24-1.22)/2 11.39
 % elong = (50*t/Rf)*(1-0) = (50*1.22/11.39)*(1-0) % elongation = 5.4

0.1% <- Max Elongation

Yes <- Cold formed 5.4% <- Elongation

no <- Vessel carries lethal substances (Yes/no)

no <- Impact testing is required (Yes/no)

no <- Greater than 10% reduction in thickness

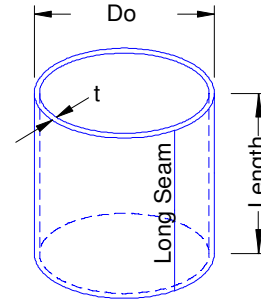
no <- Formed between 250 and 900 Degrees F

YES <- Shell is greater than 5/8" thick before forming

Required	Yes ?
no	no
no	no
no	no
no	no
no	no
Stress Relieve ?	no

Pipe and Shell TV2A_2.1

ASME Code VIII Div I 2001 edition no addenda

ASME L-2.2.1 <- BM **1** <- BM Item #**Verification Calc #3** <- Vessel, description**1** <- BM Qty**Dimensions:****143.000** <- Do - Outside Diameter**6.760** <- t - Nominal Wall Thickness**118.110** <- Length**0.000** <- Corr, Corrosion Allowance**Material and Conditions:****SA-516** <- Material**20 000** <- S, Allowable Stress Level (psi)**0.85** <- E1 - Longitudinal Efficiency (circ. stress)**0.65** <- Ec - Circ. Connecting Efficiency (longitudinal stress)**0.0%** <- UTP, Undertolerance allowance (%)**0.000** <- UTI, Undertolerance allowance (inch)**899.99** <- Volume (cubic ft)**96 919.5** <- Material Weight (lbs cs)**1392.4** <- P, Interior Pressure**0.0** <- Pa, Exterior Pressure**1** <- B, From exterior pressure curve**0.018748** <- A (use to lookup B)**Variables:**

UT = $t \cdot \text{UTP} + \text{UTI}$	= $6.76 \cdot 0 + 0$	undertolerance	UT = 0.000
Ri = $\text{Do} / 2 - t + \text{corr}$	= $143 / 2 - 6.76 + 0$	inside radius	Ri = 64.740
nt = $t - \text{Corr} - \text{UT}$	= $6.76 - 0 - 0$	nominal thick	nt = 6.760
LDo = L / Do	= $118.11 / 143$		LDo = 0.826
DoT = Do / nt	= $143 / 6.76$		DoT = 21.154

Interior Pressure UG-27 (c) (1,2)

ta = $P \cdot Ri / (S \cdot E1 - 0.6 \cdot P)$	= $1392.4 \cdot 64.74 / (20000 \cdot 0.85 - 0.6 \cdot 1392.4)$	ta = 5.577
tb = $P \cdot Ri / (2 \cdot S \cdot Ec + 0.4 \cdot P)$	= $1392.4 \cdot 64.74 / (2 \cdot 20000 \cdot 0.65 + 0.4 \cdot 1392.4)$	tb = 3.394
tmin = $\text{Max}(ta, tb) \leq nt$	Okay	tmin = 5.577
PMaxA = $(S \cdot E1 \cdot nt) / (Ri + 0.6 \cdot nt)$	= $(20000 \cdot 0.85 \cdot 6.76) / (64.74 + 0.6 \cdot 6.76)$	PMaxA = 1670.4
PMaxB = $(2 \cdot S \cdot Ec \cdot nt) / (Ri - 0.4 \cdot nt)$	= $(2 \cdot 20000 \cdot 0.65 \cdot 6.76) / (64.74 - 0.4 \cdot 6.76)$	PMaxB = 2833.2
PMax = $\text{Min}(PMaxA, PMaxB)$	Okay	PMax = 1670.4
tr1 = $P \cdot Ri / (S \cdot 1 - 0.6 \cdot P)$	= $1392.4 \cdot 64.74 / (20000 \cdot 1 - 0.6 \cdot 1392.4)$	tr1 = 4.704

Exterior Pressure UG-28 (c)

A = Interpolated from IID Part D Table G	A = 0.018748
PaMax = $4 \cdot B / (3 \cdot \text{DoT})$	Okay PaMax = 0.1
tre = $(3 \cdot \text{Do} \cdot Pa) / (4 \cdot B)$	tre = 0.000

Shell stress relief -UCS-79(d), UNF-79(d), UHA-44(d)

Rf = $(\text{do} - t) / 2$	= $(143 - 6.76) / 2$	68.12
% elong = $(50 \cdot t / Rf) \cdot (1 - 0)$	= $(50 \cdot 6.76 / 68.12) \cdot (1 - 0)$	% elongation = 5.0

0.1% <- Max Elongation**Yes** <- Cold formed **5.0%** <- Elongation**no** <- Vessel carries lethal substances (Yes/no)**no** <- Impact testing is required (Yes/no)**no** <- Greater than 10% reduction in thickness**no** <- Formed between 250 and 900 Degrees F**YES** <- Shell is greater than 5/8" thick before forming

Required	Yes ?
no	no
no	no
no	no
no	no
no	no
no	no
Stress Relieve ?	no

Elliptical Head TV2A_2.1

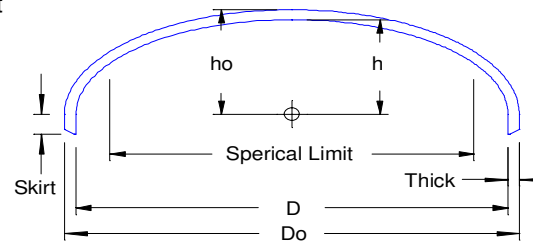
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ASME Code VIII Div I 2001 no Addenda

Heads	<- BM	<- BM Item #	<- BM Qty
	<- Component		

Dimensions:

143.000	<- Do, outside diameter
33.100	<- h
1.500	<- tb, thickness before forming
5.600	<- tf, thickness after forming
0.000	<- Corr, corrosion allowance
10.000	<- Skirt, straight skirt length

**Material and Conditions:**

SA-516	<- material
20 000	<- S, allowable stress level (psi)
1.00	<- E, efficiency
1392.4	<- P, interior pressure
0.0	<- Pa, exterior pressure
1	<- B, from exterior pressure curve

Calculated Properties:

176.3	<- Approximate blank diameter
10383.0	<- Approximate weight for steel, (lbs)
253.18	<- Volume (cuft, includes skirt)
105.44	<- Spherical Limit (0.8 * D)
0.00589	<- A value to lookup B

Variables:

D = Do-2*t	= 143-2*5.6	D = 131.80
ho = h+t	= 33.1+5.6	ho = 38.70
D/2h = D/(2*h)	= 131.8/(2*33.1)	D/2h = 1.991
Do/2ho = Do/(2*ho)	= 143/(2*38.7)	Do/2ho = 1.848
K = Interpolated value from table 1-4.1	interior	K = 0.994
Kone = Interpolated value from table UG-37	spherical	Kone = 0.896
Kzero = Interpolated value from table UG-33.1	exterior	Kzero = 0.831
t = tf-corr	= 5.6-0	t = 5.600
Ro = Ko*Do	= 0.831*143	Ro = 118.890

Interior Pressure App 1-4(c)(d), UG-37 1(a)

TMinl = (P*D*K)/(2*S*E-0.2*P) <= t	TMinl (min thickness) =	4.591
= (1392.4*131.8*0.994)/(2*20000*1-0.2*1392.4) <= 5.6		Okay
PMax = (2*S*E*t)/(K*D+0.2*t) >= P	PMax =	1696
= (2*20000*1*5.6)/(0.994*131.8+0.2*5.6) >= 1392		Okay
TSpl = (P*D*Kone)/(2*S*E-0.2*P)	TSpl (required sphere zone thick) =	4.139
= (1392.4*131.8*0.896)/(2*20000*1-0.2*1392.4)		

Exterior Pressure UG-33(d), UG-28(d)

A = 0.125/(Ro/t)	= 0.125/(118.89/5.6)	A = 0.005888
PaMax = B/(Ro/t) >= Pa	= 1/(118.89/5.6) >= 0	PaMax = 0.0
TMinE = (Ro*Pa)/B	= (118.89*0)/1	TMinE = 0.000

Head stress relief UCS-79(d), UNF-79(d), UHA-44(d)

% elong = ((75*t)/h)*(1-0)	= ((75*5.6)/33.1)*(1-0)	% elong = 3.4

5.0%	<- Max Elongation	3.4%	<- Elongation
Yes	<- Cold Formed		
no	<- Vessel carries lethal substances(Yes/no)		
no	<- Impact testing is required (Yes/no)		
no	<- Formed between 250 and 900 Degrees F		
no	<- Greater than 10% reduction in thickness		
Yes	<- Head is greater than 5/8" thick before forming		

Required	no
no	no
no	no
no	no
no	no
Yes ?	no
Stress Relieve ?	no

Appendix S

Component Specification Sheet

Company:	M-Tech Industrial (Pty) Ltd		
Location:	Potchefstroom, South Africa		
Document Number:	MT-TLDR-TDL-CMPT-05-0013		
Component:	TDL IHX Test Vessel (TV 2A_1.1)		
Date:	11 December 2008	Rev. No.:	2

Authorisation			
Action	Name	Signature	Date
Preparer	Bennie Nel		December 11, 2008
Reviewer	Herman van Antwerpen		December 11, 2008
Approver	Riaan de Bruyn		December 17, 2008

Record of Changes	
Revision	Description of Changes
A	Initial Draft
1	Document Approved
2	Configuration tables added

TV 2A_1.1 Component Specification Sheet		
	<u>Value & Unit</u>	<u>Remarks</u>
P _{he} :	9 600 kPa	Nominal pressure.
T _{he in} :	950 °C	Inlet temperature.
d _{internal vessel} :	3.29 m	The IHX test vessel requirements obtained from 3 x 1.2 MW IHX tests (worst case).
d _{internal liner} :	3 m	
L _{vessel}	6.89 m	
L _{vessel liner}	6.6 m	
Fluid:	Helium	
T _{design} :	1 000 °C	
P _{design} :	9 600 kPa	
<u>Shell:</u>		
Length:	2 x 3 000 mm	There are two domes with a total length of 6000 mm.
Outside diameter:	3 632 mm	
Wall thickness:	171.7 mm	
Corrosion allowance:	0 mm	
<u>Nozzles:</u>		
No. of protrusions:	6	
Length:	1 000 mm	
Outside diameter:	609.6 mm	
Wall thickness:	31 mm	
<u>Elliptical Head:</u>		
Head ratio:	2 : 1	
Height:	840.74 mm	Height before and after forming.
Wall thickness before:	38.1 mm	
Wall thickness after:	142.24 mm	
Skirt:	254 mm	
<u>Material:</u>		

Component material:	SA-516 Gr.70	
Allowable stress:	115.14 MPa	
Vessel mass:	54 266 kg	Only includes pressure boundary, excludes flanges.

Appendix U

Appendix T gives the interface requirements as calculated per TDL:

Handling/Building interface

A single TDL has the following footprint:

Height: 12.2 m
Width: 18.3 m
Length: 43.3 m

Crane capacity should allow height clearance according to the TDL footprint. The heaviest component is the IHX test vessel which has a mass of 54 266 kg excluding the vessel internals, insulation, flanges and tested components.

Initial mass calculations for a TDL indicate that the mass of the pressure boundary, excluding insulation, flanges and vessel internals are as shown in the Table below. The mass indicated for the recuperators and coolers are the total component mass.

Table T-1: Initial calculation of pressure boundary mass for a TDL.

Description	Unit	Value
HTS Cold pipes	kg/m	42
HTS HGD	kg/m	442
Primary Circulator vessel	kg	8 608
Secondary Circulator vessel	kg	8 608
Primary Recuperators	kg	36 902
Secondary Recuperators	kg	38 027
Heater 1	kg	27 759
Heater 2	kg	6 083
IHX test vessel	kg	54 266
Primary loop cooler	kg	5 635
Secondary loop cooler	kg	2 701

HICS

The HICS requirements for a single TDL is as follows:

Table T-2: HICS Primary Heat Transport Capacity

Description	Unit	Value
$P_{\text{range he}}$	kPa	10 - 9000
$T_{\text{he in}}$	°C	20
$T_{\text{he out}}$	°C	80
$d_{\text{internal pipe}}$	m	0.02
m_{he}	kg/s	0.105
$m_{\text{he total}}$	kg	759

Table T-3: HICS Secondary Heat Transport Capacity

Description	Unit	Value
$P_{\text{range he}}$	kPa	10 - 9600
$T_{\text{he in}}$	°C	20
$T_{\text{he out}}$	°C	80
$d_{\text{internal pipe}}$	m	0.02
m_{he}	kg/s	0.064
$m_{\text{he total}}$	kg	459

HICS – Helium Purification System

The test specifications do not indicate what the helium quality for the specific tests should be. In the absence of a design and test specification requirements for the HPS, the HPS will have to be addressed at a later stage.

*HVAC***Table T-4: The results given are for a single TDL:**

Description	Unit	Value
TDL Hot Gas Ducts	kW	302
IHX test vessel	kW	228
Recuperator vessels	kW	251
Heaters	kW	208
Total	kW	989

*Cooling water requirements***Table T-5: Primary cooler water supply requirement**

Description	Unit	Value
P_w	kPa	300
$T_{w \text{ in}}$	°C	20
$T_{w \text{ out}}$	°C	45
m_w	kg/s	79.5

Table T-6: Secondary cooler water supply requirement

Description	Unit	Value
P_w	kPa	300
$T_{w \text{ in}}$	°C	20
$T_{w \text{ out}}$	°C	45
m_w	kg/s	45.9

HTSE steam and air requirements

From the test specifications for the HTSE tests [HPS.000.S01.HTSE review package], there are additional steam and air requirements. These are as follows:

Table T-7: HTSE Steam requirements

Description	Unit	Value
P _{steam}	kPa	5600
T _{steam}	°C	396
m _{steam}	kg/s	0.62

Table T-8: HTSE Air requirements

Description	Unit	Value
P _{air}	kPa	5600
T _{air}	°C	176
m _{air}	kg/s	0.76

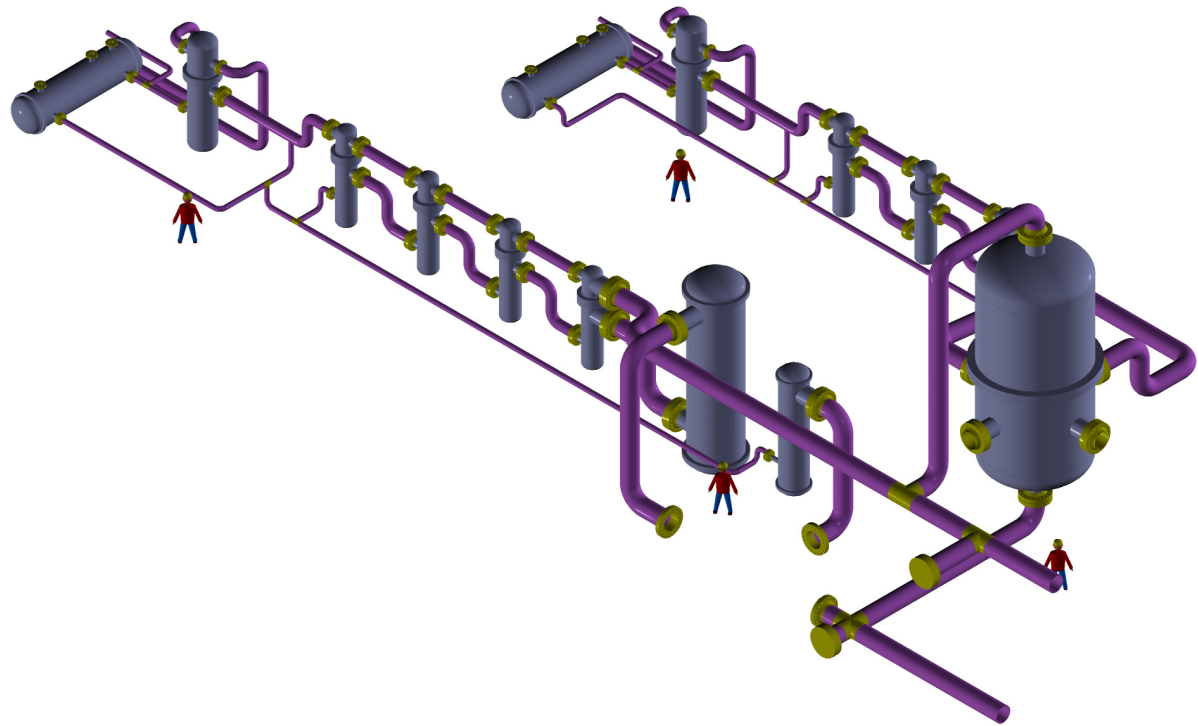
Electrical requirements

A one line electrical diagram [NGNP-CTF-E-WIR-001-1 and NGNP-CTF-E-WIR-001-2] by SHAW indicates the required voltages and interface requirements for each system.

Table T-9: Electrical requirements

Description	Unit	Value
Heater 1 (HT 2A_1.1)	MW	8.9
Heater 2 (HT 2A_1.2)	MW	4.9
Primary Circulator (CR 2A_1.1)	MW	0.227
Primary Circulator (CR 2A_2.1)	MW	0.227
Total	MW	14.25

Appendix U

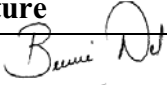
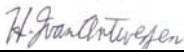


NGNP and Hydrogen Production Conceptual Design Study

NGNP CTF Test Loop Preconceptual Design Report

Section 7: Component Qualification Loop 1 (CQL1)

APPROVALS

Function	Printed Name and Signature	Date
Author	Name: Bennie Nel Company: M-Tech Industrial (Pty) Ltd 	November 21, 2008
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BACKGROUND INTELLECTUAL PROPERTY CONTENT

Section	Title	Description
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A	Bennie Nel	M-Tech internal review	November 21, 2008
B	Bennie Nel	First release to BEA	November 26, 2008
C	Bennie Nel	Updated release to BEA	November 29, 2008
D	Bennie Nel	Document updated following BEA review and 90 % review meeting; December 02, 2008	December 08, 2008
E	Bennie Nel	Updated for consistency with regards to references and nomenclature	December 11, 2008
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ACRONYMS

Abbreviation or Acronym	Definition
A	Accelerometer
A-E-C	Architecture – Engineering -Construction
AGR	Advanced Gas-cooled Reactor
AHJ	Authority Having Jurisdiction
AICE	American Institute of Chemical Engineers
AISC	American Institute of Steel Construction
AISI	American Iron and Steel Institute
ALARA	As Low As Reasonable Achievable
AMB	Active Magnetic Bearing
ANSI	American National Standards Institute
API	American Petroleum Institute
ASHRAE	American Society of Heating Refrigeration and Air Conditioning Engineers
ASME	American Society of Mechanical Engineers
AWS	American Welding Society
BEA	Battelle Energy Alliance
BIL	Basic Impulse Insulation Level
BIM	Building Information Management
BS	British Standard
Btu/hr	British thermal unit per hour
CAD	Computer Aided Design
CAE	Computer Aided Engineering
CBCS	Core Barrel Conditioning System
CCS	Core Conditioning System
CFR	Code of Federal Regulations
CH	Cold Header
CMAA	Crane Manufacturers Association of America
COR	Client Observation Room
COTS	Commercial Off-The-Shelf (Commercial Grade Items)
CQL	Component Qualification Loop
CQL1	Component Qualification Loop 1
CQL2	Component Qualification Loop 2
CTF	Component Test Facility
CTL	Circulator Test Loop
CV	Valve Flow Coefficient
DAQ	Data Acquisition
db	Dry Bulb
DB	Distribution Board

Abbreviation or Acronym	Definition
DC	Direct Current
DCD	Design Criteria Document
DCS	Distributed Control System
DDN	Design Data Need
DOE	Department of Energy
dP	Differential Pressure
DPP	Demonstration Power Plant
EDMS	Engineering Data Management System
EHR	Essener Hochdruck Rohrleitung
EIA	Electronic Industry Alliance
EMB	Electro-magnetic Bearing
ENS	Emergency Notification System
EPACT	Energy Policy Act (of 2005)
EPC	Engineering Procurement and Construction
ER	Environmental Requirement
ES&H	Environmental, Safety and Health
ESD	Emergency Shutdown
F	Flow Rate
FDD	Facility Design Description
FHA	Fire Hazard Analysis
FIPS	Federal Information Processing Standards
FM	Factory Mutual
FMS	Facility Monitoring System
FS	Flow rate (switch)
GA	Gas analyzer (composition)
GHEP	Guidelines for Hazard Evaluation Procedures
gpm	Gallon per minute (US)
GR	General Requirements
H ₂	Hydrogen Production Test (Specifically referring to H ₂ SO ₄ Decomposition Reactor Test)
H ₂ SO ₄	Sulfuric Acid
HAZOP	Hazard and Operational Study
HDBK	Handbook
HGD	Hot Gas Duct
HGDs	Hot Gas Ducts
HH	Hot Header
HICS	Helium Inventory Control System
HIPCS	Helium Inventory and Pressure Control System
HIRA	Hazard and Risk Identification Analysis
HLR	High Level Requirement
HMI	Human Machine Interface

Abbreviation or Acronym	Definition
HPS	Helium Purification System
HT	Heat Transfer
HTF	Helium Test Facility
HTGR	High Temperature Gas -Cooled Reactor
HTS	Heat Transport System
HTSE	High Temperature Steam Electrolysis
HTTR	High Temperature Test Reactor
HTTU	High Temperature Test Unit
HV	High Voltage (>132 000V)
HVAC	Heating, Ventilation, & Air Conditioning
HX	Heat Exchanger
HyS	Hybrid Sulfur
I&C	Instrumentation and Control
I/O	Input/Output
IBC	International Building Code
ICC	International Code Council
ICD	Initial Conceptual Design
ICEA	Insulated Cable Engineers Association
IDAPA	Idaho Administrative Procedure Act
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IFC	International Fire Code
IFGC	International Fuel Gas Code
IHX	Integrated Heat Exchanger
IHXA	Intermediate Heat Exchanger A
IHXB	Intermediate Heat Exchanger B
IMC	International Mechanical Code
IMS	Information Management Systems
INL	Idaho National Laboratory
IPMC	International Property Maintenance Code
ISA	International Society of Automation
ISO	International Organization for Standardization
JB	Junction Box
kg/s	Kilogram per second
kV	Kilovolt (1000 Volts)
kl/h	Kilolitre per hour
kPa	Kilopascal (1000 Pascal)
kW	Kilowatt (1000 Watts)
LCD	Liquid Crystal Display
LCP	Local Control Panel
LRFDS	Load and Resistance Factor Design Specification

Abbreviation or Acronym	Definition
LV	Low Voltage (<1000 V)
MBMA	Metal Building Manufacturers Association
MCC	Motor Control Center
MCR	Mission Critical Requirement
MDB	Main Distribution Board
MES	Manufacturing Execution System
MPa	Megapascal = million Pascal
MTI	M-Tech Industrial (Pty) Ltd.
MV	Medium Voltage (>1000V< 132 000V)
MW	Megawatt (Million Watts)
N	Rotational Speed
NBIMS	National BIM Standards Project Committee
NEC	National Electrical Code
NEMA	National Electrical Manufacturers Association
NEPA	National Environmental Policy Act
NESC	National Electrical Safety Code
NFPA	National Fire Protection Association
NGNP	Next Generation Nuclear Plant
NHI	National Hydrogen Institute
NIST	National Institute of Standards and Technology
NQA-1	ASME NQA-1 2000, Quality Assurance for Nuclear Facilities
OPC	Operating Procedure Checklist
OSHA	Occupational Safety and Health Administration
P	Pressure
P&ID	Piping and Instrument Diagram
PBMR	Pebble Bed Nuclear Reactor (RSA)
PCDR	Preconceptual Design Report
PCFC	Preconceptual Facility Configurations
PCHX	Printed Circuit Heat Exchanger
PCS	Process Control System
PDA	Potential Deviation Analysis
PDMS	Project Data Management System
PDS	Plant Design System
PFD	Process Flow Diagram
PHA	Preliminary Hazard Analysis
PHTS	Primary Heat Transport System
PLC	Programmable Logic Controller
PLCs	Programmable Logic Controllers
PMN	Support Manager
PRV	Pressure Relief Valve
psig	Pound per square inch gauge

Abbreviation or Acronym	Definition
PSM	Support Modeler
QC	Quality Control
QCP	Quality Control Plan
RCS	Reactivity Control System
RIS	Relational Interface System
RPV	Reactor Pressure Vessel
RSA	Republic of South Africa
SBS	System Breakdown Structure
SCADA	Supervisory Control and Data Acquisition System
scfm	Standard cubic feet per minute
SDD	System Design Description
SDI	Steel Door Institute or Steel Deck Institute
SG	Steam Generator
SHEQ	Safety, Health, Environmental and Quality
SHTS	Secondary Heat Transport System
SI	Sulfur Iodine
SIL	Safety Integrity Level
SIS	Safety Instrument System
SJI	Steel Joist Institute
SNM	Special Nuclear Materials
SPEL	SmartPlant Electrical
SPF	SmartPlant Foundation
SPMat	SmartPlant Material
SPR	SmartPlant Review
SPS	Standby Power System
SR	Safety Requirement
SRM	System Requirement Manual
SSC	Systems Structures and Components
SSDT	Small Scale Development Test
SSS	Site Selection Study
SSSB	Specification for Structural Steel Buildings
STD	Standard
T	Temperature
T&FR	Technical and Functional Requirement
TBD	To Be Determined
TDL	Technology Development Loop
TDRM	Technology Development Road Map
TEDS	Transducer Electronic Data Sheet
TEMA	Tubular Exchanger Manufacturers Association
THTR	Thorium High Temperature Reactor
TIA	Telecommunications Industry Association

Abbreviation or Acronym	Definition
TRL	Technology Readiness Level
TSR	Technical Safety Requirement
UL	Underwriters Laboratories
UL	Underwriters' Laboratories
UPC	Uniform Plumbing Code
UPS	Uninterruptable Power Supply
UUT	Unit Under Test
V&V	Verification and Validation
VHTGR	Very High Temperature Gas-Cooled Reactor
VL	Valve
VSD	Variable Speed Drive
wb	Wet Bulb
WBS	Work Breakdown Structure
WEC	Westinghouse Electric Company
WE-SA	Westinghouse Electric - South Africa
ϵ	Strain

SUMMARY AND CONCLUSIONS

The initial concept to include a Component Qualification Loop (CQL1) within the Component Test Facility (CTF) arose from the idea of using the combined helium mass flows of possible carbon copy Technology Development Loop (TDL) building blocks. Utilizing such an approach permits for larger component testing capabilities than those tested within the TDLs alone. At present only two TDLs are incorporated into the thermal hydraulic calculations used for the anticipated operation of CQL1. CQL1 can be seen as a larger component testing area using the mass flow of combined TDLs.

Each TDL has a blanked-off flanged section at its heater outlet that is routed to the Hot Header. Beyond this flange is the interfacing section between the TDLs and CQL1. When tests, exclusive to TDL operation are being run, no heat, pressure or mass flow is supplied to CQL1. These blanked-off flanged sections will be opened during planned CTF shut-downs prior to scheduled CQL1 tests. Regarding the current concept, no TDL tests will be run whilst CQL1 is in operation, except if more than two TDLs are envisaged for the CTF, which opens up the possibility of running CQL1 component testing in parallel with TDL component testing.

At present, two component tests are anticipated for CQL1 operation. These are:

- Steam Generator (SG) Unit Under Test (UUT). There is no design on the prototype SG yet.
- Sulfuric Acid (H_2SO_4) Decomposition Reactor UUT. At the time of writing of this report, there was no design on this unit either. The H_2SO_4 Decomposition Reactor is one of the sub-systems of the Hydrogen Production System (HPS), which will utilize the exchange of high temperature helium.

Both these anticipated tests are to exchange heat with helium gas at 900 °C at pressures in the order of 8700 kPa for the SG test and 8934 kPa for the H_2SO_4 Decomposition Reactor test. CQL1's purpose is to provide helium at the abovementioned process conditions incorporating the use of the conditioning loops of two TDLs. In the absence of design of the Next Generation Nuclear Plant (NGNP), some assumptions had to be made to determine enveloping process values for CQL1.

The basis for CQL1 preconceptual design arose from enveloping all the different test specifications proposed for CTF testing. From these test specifications, the Intermediate Heat Exchanger (IHX) test stood out to be of primary importance, yet small enough for anticipated TDL testing. The TDL has accordingly been designed to accommodate testing of three IHX modules, totaling a heat duty of 3.6 MW. This specific IHX test has been used as corner stone for TDL and subsequent CQL1 preconceptual designs. Throughout the preconceptual design, a maximum of two TDLs was envisaged to conduct a CQL1 test.

Each TDL runs in separation from its neighbor and the control philosophy makes provision for secure data capturing and safeguarding thereof. When a CQL1 test is conducted,

there will be no need for test-data capturing on each of the CQL1-supplying TDLs, only process condition-data to operate the TDL will be necessary. Leeway exists to expand the CTF facility from the two proposed TDLs up to four TDLs. Possible CTF expansions will not interfere with CQL1 operation in that TDL/CQL1-connectivity is designed as such to connect any two existing TDLs within the CTF building.

7. COMPONENT QUALIFICATION LOOP (CQL1)

7.1 CQL1: Design Inputs And Requirements

The conceptual design of CQL1 stemmed from the idea that components with larger heat and mass flow duties envisioned for TDL testing, i.e. IHX, hydrogen production, steam generator testing etc, are also envisaged for CTF testing.

Consideration should be given to larger scale testing of IHX modules also. However, the current TDL sizing already addresses multi module IHX (3x 1.2 MW) testing and no specific requirement exists for larger IHX testing at present. Should larger scale testing of IHXs be anticipated, it could be incorporated within CQL1 by providing additional blanked-off flanged sections from the Hot Header (or blanked-off flanges on the HGDs extending from the Hot Headers) as well as additional CQL1 testing space (i.e. in addition to the Steam Generator and the H₂SO₄ Decomposition Reactor test stations).

The basis of the TDL design (multiple IHX-coupled cores) resulted in a building block approach to initially use at least two TDLs to drive CQL1. Due to the inbuilt expandability incorporated into this design, the possibility exists to expand the CTF facility from two TDLs to numerous, n , TDLs. The CQL1/TDL interface will in all cases be positioned centrally between the maximum possible located TDLs, not expected to be higher than four at this stage.

Each TDL runs separately from its neighbor and provision for data capturing and data safeguarding is handled as such. When a CQL1 test is run, no tests could be performed on the TDL supporting CQL1. Should additional TDLs be built, CQL1 interfacing will still be possible by using any two of the possible number of TDLs to provide CQL1 with adequate process conditions, whilst using the remainder of the TDLs for separate component testing. It must be stated however that tests not requiring energy from the TDLs, such as exposure of certain alloys to long-term process conditions, can be conducted at any time during TDL coupled CQL1 tests. These alloys can simply be placed in a designated exposed area of the TDL Test Loop, or some of the TDL's components can even be manufactured from these materials which will be exposed to the process conditions continuously.

The only test specifications referring to performance testing within the CTF are listed in the following table. Reference to these test specifications sprouted from the NGNP Technology Development Roadmapping Reports, as referenced in [7-1].

Table 7-1: Test specifications listed for anticipated CQL1 testing.

Section	Description	Test Number	Reference	TRL	CTF Testing
Steam Generator	Performance testing in CTF	WEC-TS-SG-005	NGNP-CTF MTECH - TDRM-009	TRL 6 - TRL 7	Yes
Hydrogen Production	PBMR Qualification Process Description	WEC-TS-HPS-001	-	-	Yes

It should be noted that the NGNP Technology Development Roadmapping Reports, referenced in [7-1] reveal no design information regarding the steam generator and the H₂SO₄ Decomposition reactor. None of these tests are defined in terms of component prototype sizes or their expected heat duties for commercial-scale testing as is envisaged for the CTF. Therefore, considering these two tests and basing all thermal hydraulic calculations in this report on the available process parameters, some preliminary design decisions were made based on good engineering judgment. These calculations, assumptions and decisions are all reflected in the attached appendices.

7.2 CQL1: Thermal Hydraulic Design

7.2.1 System-Level Process Design

The CTF CQL1 will allow for testing of components that require a higher thermal capacity than the maximum possible heat duty provided by a single TDL. For the purpose of this report, CQL1 uses the combined mass flows of two TDLs, merging at a Hot Header (HH), which acts as an interface between the TDLs and CQL1. A similar Cold Header (CH) allows for the connection of the cooler gases to the separate TDL streams' recuperators.

Allowance for flexibility is provided for the addition of a third and even a fourth TDL should the need arise to test components with higher heat duties or for testing CQL1 components jointly with TDL components. Keeping the latter in mind at least two TDLs will be necessary to supply sufficient heat, mass flow and pressure for CQL1 component testing.

From the Design Data Needs (DDNs) and Technology Maturation Plans (TMPs), two anticipated UUTs require helium-gas process-heat coupling at 900 °C and thermal loads in excess of approximately 6 MW. These UUTs are; the prototype steam generator and the H₂SO₄ decomposition reactor, which forms part of the Hybrid Sulfur (HyS) Hydrogen Production System (HPS). Should a prototype steam generator be designed that requires less than approximately 6 MW thermal duty, the possibility exists to test such a unit within the TDL instead of using CQL1. The same argument is valid for the thermal size (heat duty requirement) of the H₂SO₄ decomposition reactor unit.

The TDL design is driven by the coupled, three (3) x IHX A test requirement. The sizing of the TDL was designed accordingly, taking into account that three IHX modules be tested in parallel, thereby allowing for maximum thermal heat duty. Thermal hydraulic calculations based on the testing of the three IHX modules revealed an envelope sufficiently large for testing of all the other components arranged within the TDL, except for anticipated testing of the prototype steam generator and the H₂SO₄ decomposition reactor.

Hot gas duct sizing within the TDL has been designed to allow for an internal gas velocity of 20 m/s. This was based on helium gas with a temperature of 950 °C and a pressure of 9 MPa, giving a gas density of 3.5 kg/m³.

This preconceptual design report makes use of the assumption that both units under test i.e. the steam generator and the H₂SO₄ decomposition reactor will have anticipated heat duties larger than 6 MWth. Previous steam generator testing experience reveals thermal loads in the order of 10 MWth.

Concerning the H₂SO₄ decomposition reactor, one out of a possible nineteen tubes could be tested in CQL1, requiring approximately 9-10 MWth (based on preliminary decisions). The eventual heat duty of both reactor types is totally dependent on their respective prototype reactor designs.

The testing capability of CQL1 is constrained by the given process performance parameters. Concerning the steam generator, typical performance parameters are given in Table 9-1, p10 in the WEC NGNP Technology Development Road Mapping report, referenced in [7-2]. Most of these process values are repeated in Table 7-6 in this report. These parameters as well as estimated performance parameters for the Hybrid-Sulfur (HyS) and Sulfur-Iodine (SI) H₂SO₄ decomposition reactor are used to envelope CQL1 requirements. From this basis, the number of TDLs necessary to run a CQL1 test could be calculated.

Assuming steady state conditions and using basic thermodynamic equations, the following methodology was used to obtain enveloping process parameters for CQL1.

1. The heater thermal capacity in the primary circuit of a TDL (HT 2A_1.1) was calculated to supply enough heat for testing three IHX modules in parallel, each having a duty of 1.2 MWth. In terms of heat duty requirements, the IHX test is the largest of all the anticipated CTF tests to be conducted within a TDL.
2. The later leading to a primary TDL heater design delivering 6.158 MW thermal – refer to reference [7-9] Appendix E, MT-TLDR-CAL-F-T-0705. The electrical power of this heater is based on an electrical-to-thermal efficiency of 90 percent.
3. The large helium temperature transient anticipated for the SG test, i.e. from 900 °C to 273 °C, places some restriction on the mass flow of the helium as is evidenced from the following basic equations:

$$m = \frac{Q}{(h_m - h_{out})} \dots\dots\dots \text{Equation 1}$$

$$m = \frac{Q}{C_p (T_{in} - T_{out})}$$

Where m = mass flow, Q = heat duty, h = enthalpies, C_p = specific heat capacity at constant pressure and T = temperature. The second half of Equation 1 can be used since helium does not change phase between the two extreme process conditions.

4. The larger the temperature drop, the less the attainable mass flow.
5. The temperature drop anticipated for the SG test, i.e. from 900 °C to 273 °C allows for a mass flow of 1.786 kg/s per TDL, taking all the process conditions into consideration. Using two TDLs increases the mass flow to 3.572 kg/s per SG CQL1 test.
6. The temperature drop anticipated for the H₂SO₄ Decomposition Reactor test, i.e. from 900 °C to 659 °C allows for a mass flow of 3.336 kg/s per TDL, taking all the process conditions into consideration. Using two TDLs increases the mass flow to 6.671 kg/s per H₂SO₄ Decomposition Reactor CQL1 test.

Paragraph 7.2.1.1 of this report presents Process Flow Diagrams (PFDs) showing the essential process parameters of each main TDL component necessary to operate CQL1 for each of the two anticipated CQL1 tests. Each of the main TDL components is represented schematically in Figure 7-3, Figure 7-4, Figure 7-5 and Figure 7-6.

7.2.1.1 CQL1 Test Specific Process Values

The test specifications listed below were not used for TDL component design as they are enveloped well within the maximum design limits of each of the TDL components. They are however represented in this section to show the specific process parameters relating to each component within the TDLs for anticipated CQL1 tests. They are also shown to verify the fact that the two anticipated CQL1 tests' process requirements lie within the TDL component design limits.

CQL1 components consist of piping and vessel headers, which are:

- CQL1 Hot Gas Ducts
- CQL1 Hot and Cold Headers
- SG UUT and
- H₂SO₄ Decomposition Reactor UUT (blanked-off flanged sections)

Mass flow requirements for CQL1 are obtained from the primary TDLs (x2) conditioning loop components comprising the following:

- TDL Primary Loop Recuperator
- TDL Primary Loop Cooler
- TDL Primary Loop Circulator
- TDL Primary Loop Heater
- TDL Hot Gas Ducts, Cold Piping and Valves

A numbering sequence for both CQL1 tests was followed allowing for easy interpretation of their respective flow paths. Concerning CQL1, this same numbering sequence was followed in the thermal hydraulic calculations - refer to reference [7-5], Appendix A, MT-TLDR-CAL-F-T-0701 and reference [7-6], Appendix B, MT-TLDR-CAL-F-T-0702.

Considering the SG CQL1 test (Figure 7-1), the following numbering sequence was used:

- (1) Between CQL1 Hot Header (HH 3_1.1) and CQL1 SG test station (TS 3_1.1).
- (2) Between SG test station (TS 3_1.1) and CQL1 Cold Header (CH 3_1.1).
- (3) Between CQL1 Cold Header (CH 3_1.1) and TDL recuperator (RX 2A_1.1).
- (4) Between TDL recuperator (RX 2A_1.1) and TDL cooler (CL 2A_1.1).
- (5) Between TDL cooler (CL 2A_1.1) and TDL circulator (CR 2A_1.1).
- (6) Between TDL circulator (CR 2A_1.1) and TDL recuperator (RX 2A_1.1).
- (7) Between TDL recuperator (RX 2A_1.1) and TDL Heater (HT 2A_1.1).
- (8) Between TDL heater (HT 2A_1.1) and CQL1 Hot Header (HH 3_1.1).

Considering the H₂ CQL1 test (Figure 7-2), the following numbering sequence was used:

- (9) Between CQL1 Hot Header (HH 3_1.1) and CQL1 H₂ test station (TS 3_1.2).
- (10) Between CQL1 H₂ test station (TS 3_1.2) and CQL1 Cold Header (CH 3_1.1).
- (11) Between CQL1 Cold Header (CH 3_1.1) and TDL recuperator (RX 2A_1.1).
- (12) Between TDL recuperator (RX 2A_1.1) and TDL cooler (CL 2A_1.1).
- (13) Between TDL cooler (CL 2A_1.1) and TDL circulator (CR 2A_1.1).
- (14) Between TDL circulator (CR 2A_1.1) and TDL recuperator (RX 2A_1.1).
- (15) Between TDL recuperator (RX 2A_1.1) and TDL Heater (HT 2A_1.1).
- (16) Between TDL heater (HT 2A_1.1) and CQL1 Hot Header (HH 3_1.1).

The same numbers are also used in Figure 7-3, Figure 7-4, Figure 7-5 and Figure 7-6 accompanied by the necessary process values. Tabulated process values supplementing these figures are listed in Table 7-2, Table 7-3, Table 7-4 and Table 7-5.

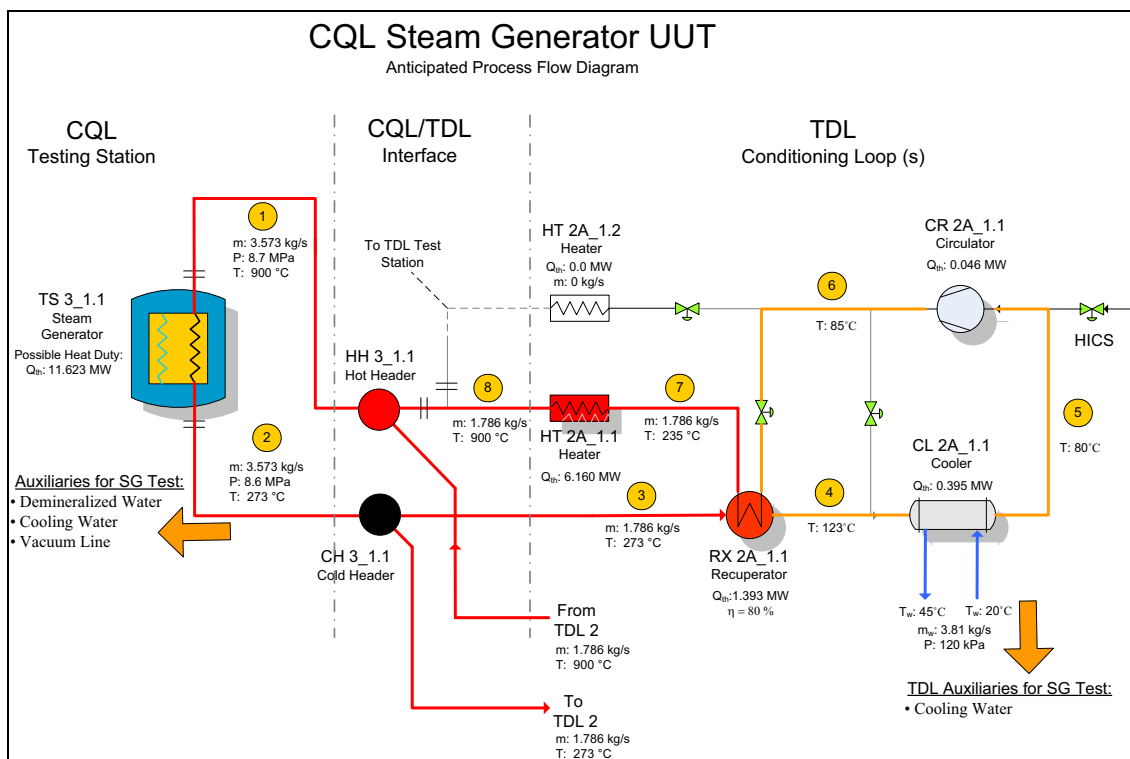
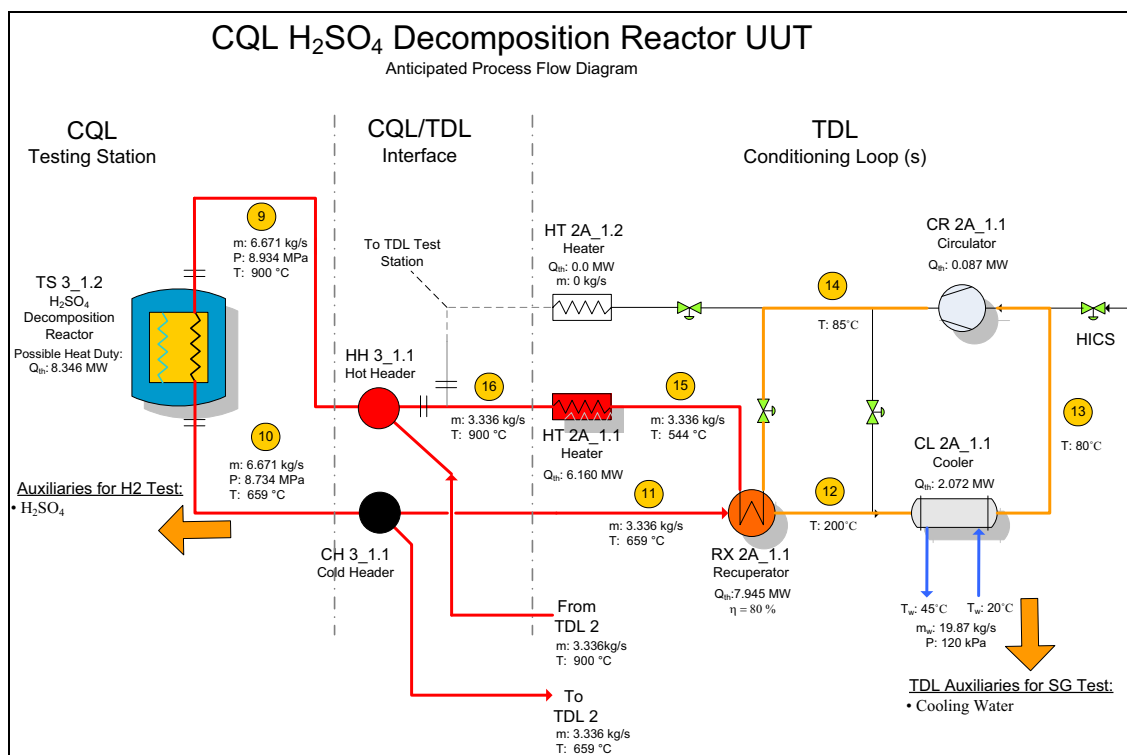


Figure 7-1: Simplified PFD for the Steam Generator CQL1 Test.

Figure 7-2: Simplified PFD for the H₂SO₄ Decomposition Reactor CQL1 Test.

7.2.1.1.1 Primary loop Recuperator(s)

This section refers to the following component(s): RX 2A_1.1 & RX 2B_1.1

Recuperator process conditions for one primary TDL loop are represented for both the Steam Generator and H₂SO₄ Decomposition Reactor CQL1 tests in Figure 7-3 below. Operation of two TDL primary loops is necessary to run the anticipated CQL1 tests.

Recuperator Efficiency: 80percent.

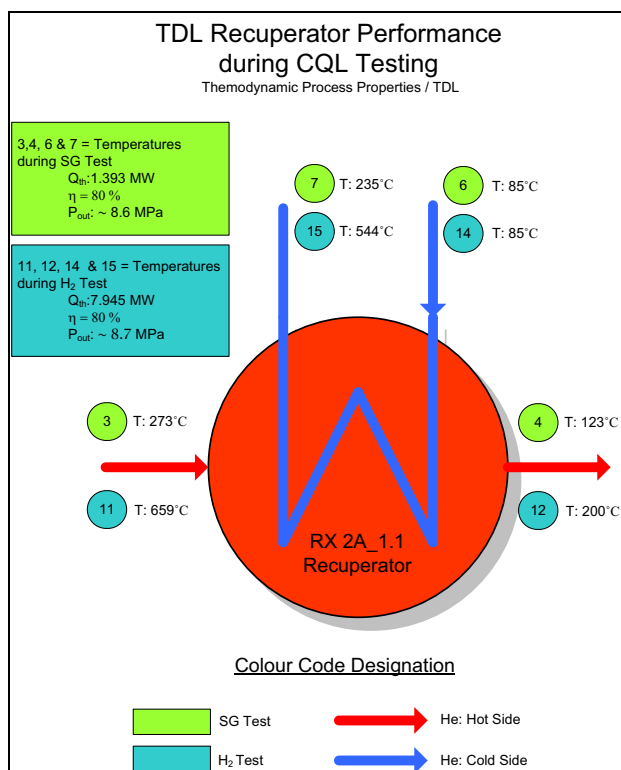


Figure 7-3: Schematic representation of process flow parameters entering and exiting the recuperator during anticipated CQL1 testing.

Table 7-2: Tabulated process values for a TDL recuperator during CQL1 testing.

Description	Unit	SG Test Value per TDL	H ₂ Test Value per TDL	Max / Design Value per TDL
P _{He} (Hot side)	kPa	8,600	8,734	9,600
T _{He in} (Hot side)	°C	273	659	950
T _{He out} (Hot side)	°C	123	200	454
m _{He} (Hot side)	kg/s	1.786	3.336	4.750
P _{He} (Cold side)	kPa	8,600	8,734	9,600
T _{He in} (Cold side)	°C	85	85	85
T _{He out} (Cold side)	°C	235	544	777
m _{He} (Cold side)	kg/s	1.786	3.336	4.750
Q _{th}	MW	1.393	7.945	13.208

7.2.1.1.2 Primary Loop Cooler(s)

This section refers to the following component(s): CL 2A_1.1 & CL 2B_1.1

The Primary Loop Cooler process conditions for one primary TDL loop are represented for both the Steam Generator and H₂SO₄ Decomposition Reactor CQL1 tests in Figure 7-4 below. Operation of two TDL primary loops is necessary to run the anticipated CQL1 tests.

Cooler Efficiency: 100 percent.

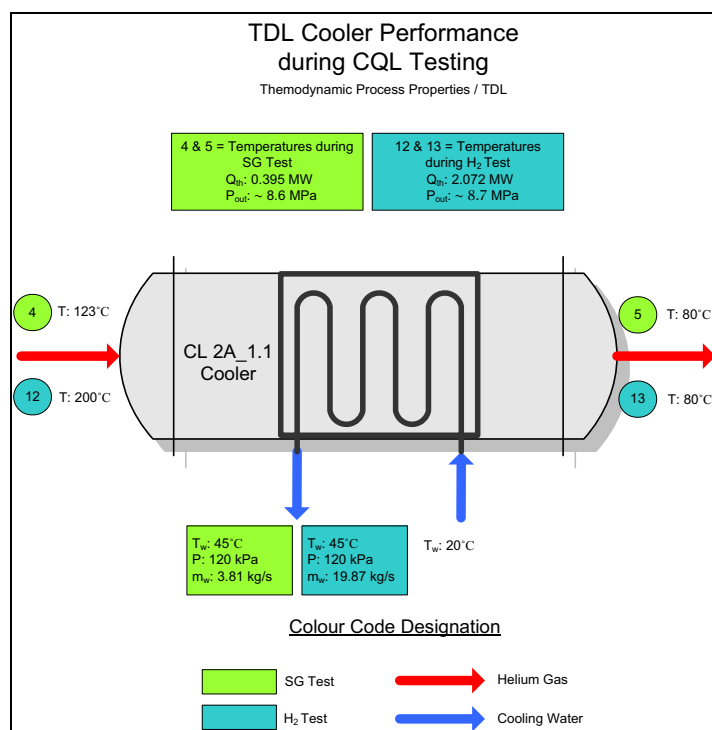


Figure 7-4: Schematic representation of process flow parameters entering and exiting the water-cooled cooler during anticipated CQL1 testing.

Table 7-3: Tabulated process values for a TDL cooler during CQL1 testing.

Description	Unit	SG Test Value per TDL	H ₂ Test Value per TDL	Max / Design Value per TDL
P_{He}	kPa	8,600	8,734	9,600
$T_{He \text{ in}}$	°C	123	200	454
$T_{He \text{ out}}$	°C	80	80	80
m_{He}	kg/s	1.786	3.336	4.750
P_w	kPa	120 - 300	120 - 300	120 - 500
$T_{w \text{ in}}$	°C	20	20	20
$T_{w \text{ out}}$	°C	45	45	<50
m_w	kg/s	3.81	19.87	61.1
Q_{th}	MW	0.395	2.072	6.343

7.2.1.1.3 Primary Loop Circulator(s)

This section refers to the following component(s): CR 2A_1.1 & CR 2B_1.1

Circulator process conditions for one primary TDL loop are represented for both the Steam Generator and H₂SO₄ Decomposition Reactor CQL1 tests in Figure 7-5 below. Operation of two TDL primary loops is necessary to run the anticipated CQL1 tests.

Circulator Efficiency: 60 percent of electrical input.

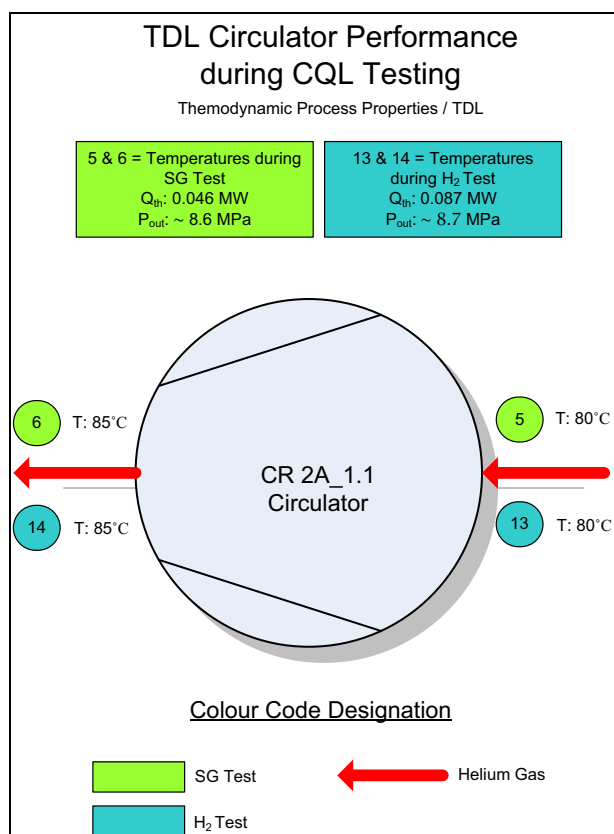


Figure 7-5: Schematic representation of process flow parameters entering and exiting the fully submerged circulator during anticipated CQL1 testing.

Table 7-4: Tabulated process values for a TDL circulator during CQL1 testing.

Description	Unit	SG Test Value per TDL	H ₂ Test Value per TDL	Max / Design Value per TDL
P _{He}	kPa	8,600	8,734	9,600
T _{He in}	°C	80	80	80
ΔP _{system}	kPa	-	-	299
m _{He}	kg/s	1.786	3.336	4.750
Q _{th}	MW	0.046	0.087	0.110
Q _e *	MW	0.077	0.145	0.183

*Q_e is the electrical input assuming 60 percent efficiency from electrical input to flow output.

7.2.1.1.4 Primary loop Heater(s)

This section refers to the following component(s): HT 2A_1.1 & HT 2B_1.1

Heater process conditions for one primary TDL loop are represented for both the Steam Generator and H₂SO₄ Decomposition Reactor CQL1 tests in Figure 7-6 below. Operation of two TDL primary loops is necessary to run the anticipated CQL1 tests.

Heater efficiency: 90 percent.

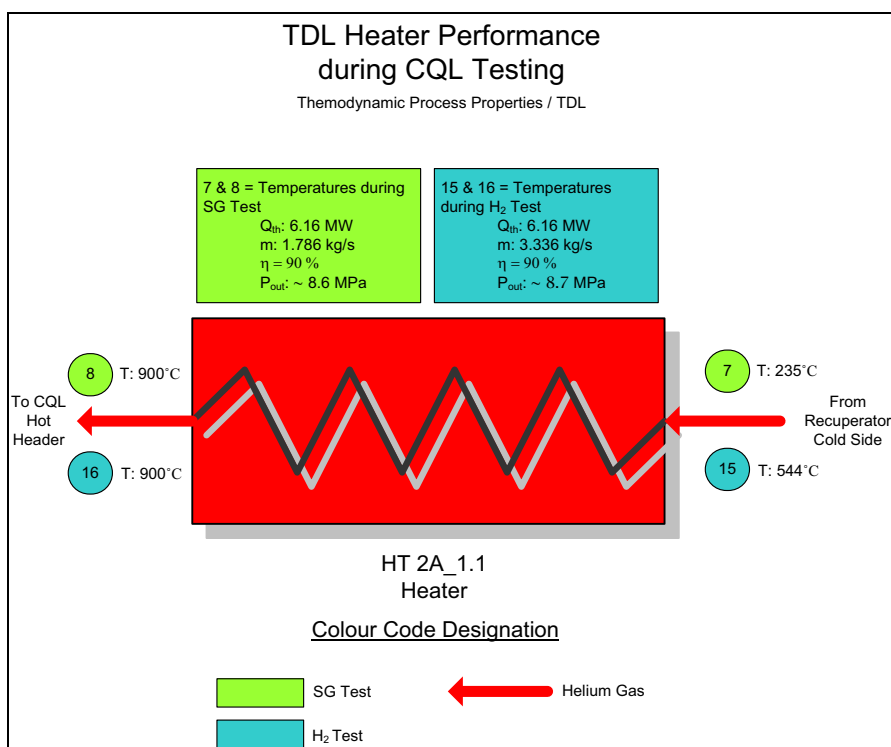


Figure 7-6: Schematic representation of process flow parameters entering and exiting the heater during anticipated CQL1 testing.

Table 7-5: Tabulated process values for a single primary loop TDL heater during CQL1 testing.

Description	Unit	SG Test Value per TDL	H ₂ Test Value per TDL	Max / Design Value per TDL
P_{He}	kPa	8600	8734	9600
$T_{He\ in}$	°C	235	544	777
$T_{He\ out}$	°C	900	900	950
m_{He}	kg/s	1.786	3.336	4.750
Q_{th}	MW	6.16	6.16	8.01
Q_e^*	MW	6.84	6.84	8.90

* Q_e is the electrical input assuming 90 percent Heat transfer efficiency.

7.2.1.1.5 CQL1 Test Station for Steam Generator

This section refers to the following component(s): TS 3_1.1

Process conditions of two combined primary TDL loops are represented for the Steam Generator test in Figure 7-7 below. Operation of at least two TDL primary loops is necessary to run the anticipated SG test.

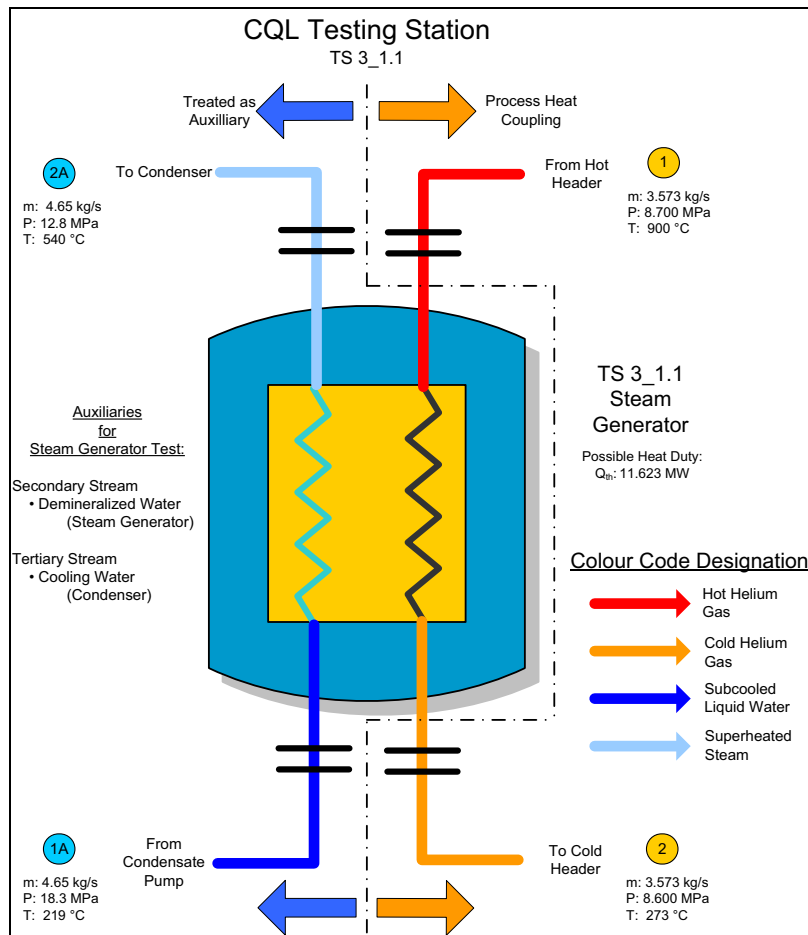


Figure 7-7: Schematic representation of the anticipated CQL1 process heat coupling to run a steam generator test.

Design and fabrication of a scale prototype SG for the CTF test facility and ensuing integrated systems testing will be necessary. Conceptually, the scale prototype steam generator will have the features of ensuring prototypical once-through tube circuits, prototypical water side conditions (including similar water chemistry) as well as prototypical helium side conditions. It is foreseen that the prototype steam generator testing in the CTF may proceed in two phases, namely SG-specific testing and integrated system testing.

Table 7-6: Typical Steam Generator Performance Parameters, referenced in [7-3].¹

Parameter	HPS in Operation	HPS not in Operation
Hot Side		
Fluid	Helium	Helium
Inlet Pressure	8.7 MPa	8.7 MPa
Inlet Temperature	840 °C	900 °C
Helium Flow (NGNP)	160 kg/s	160 kg/s
Outlet Temperature	273°C	273°C
Outlet Pressure	8.6 MPa	8.6 MPa
Design Temperature	TBD	TBD
Design Pressure	> 13.2 MPa	> 13.2 MPa
Cold Side		
Fluid	Water	Water
Superheated Outlet Pressure	12.8 MPa	12.8 MPa
Superheated Outlet Temperature	540 °C	540 °C
Main Steam Flow (NGNP)	206 kg/s	228 kg/s
Feed water Temperature	219 °C	219 °C
Feed water Press	18.3 MPa	18.3 MPa
Design Temperature	~ 300 °C	~ 300 °C
Design Pressure	>18.5 MPa	>18.5 MPa

Materials of construction for the tubes could be 2-1/4 Cr-1 Mo for the lower temperature sections of the once-through tube circuit and Alloy 800H for the higher temperature portions. Low alloy steel could be used for manufacturing the vessel.

The process values listed in the last column under the heading “HPS not in Operation” in Table 7-6, were used for the thermal hydraulic calculations anticipated for SG CQL1 testing. Prototypical mass flow values for helium will be in the order of 3 – 4 kg/s (shell side) and that of water will be slightly higher at approximately 4 – 5 kg/s (tube side).

7.2.1.1.6 Secondary Stream Process Values as per anticipated SG test

The secondary stream of the anticipated SG test is preconceptually designed to include a condenser (CD 3_2.1) followed by a condensate pump (PU 3_2.1), which precedes the steam generator test station (TS 3_1.1). From an energy balance point-of-view, the high-level preconceptual design allows for a de-mineralized water mass flow calculation, which is theoretically calculated as 4.65 kg/s – refer to reference [7-10], Appendix F, MT-TLDR-CAL-F-T-0706.

A process schematic of the secondary stream for the anticipated SG test is shown in Figure 7-8.

¹ This table is copied from the NNGP and Hydrogen Production Conceptual Design Study. NNGP Technology Development Road Mapping Report; Section 9: Power Conversion System Steam Generator, December 2008; NNGP-CTF MTECH –TDRM-009_Rev1.

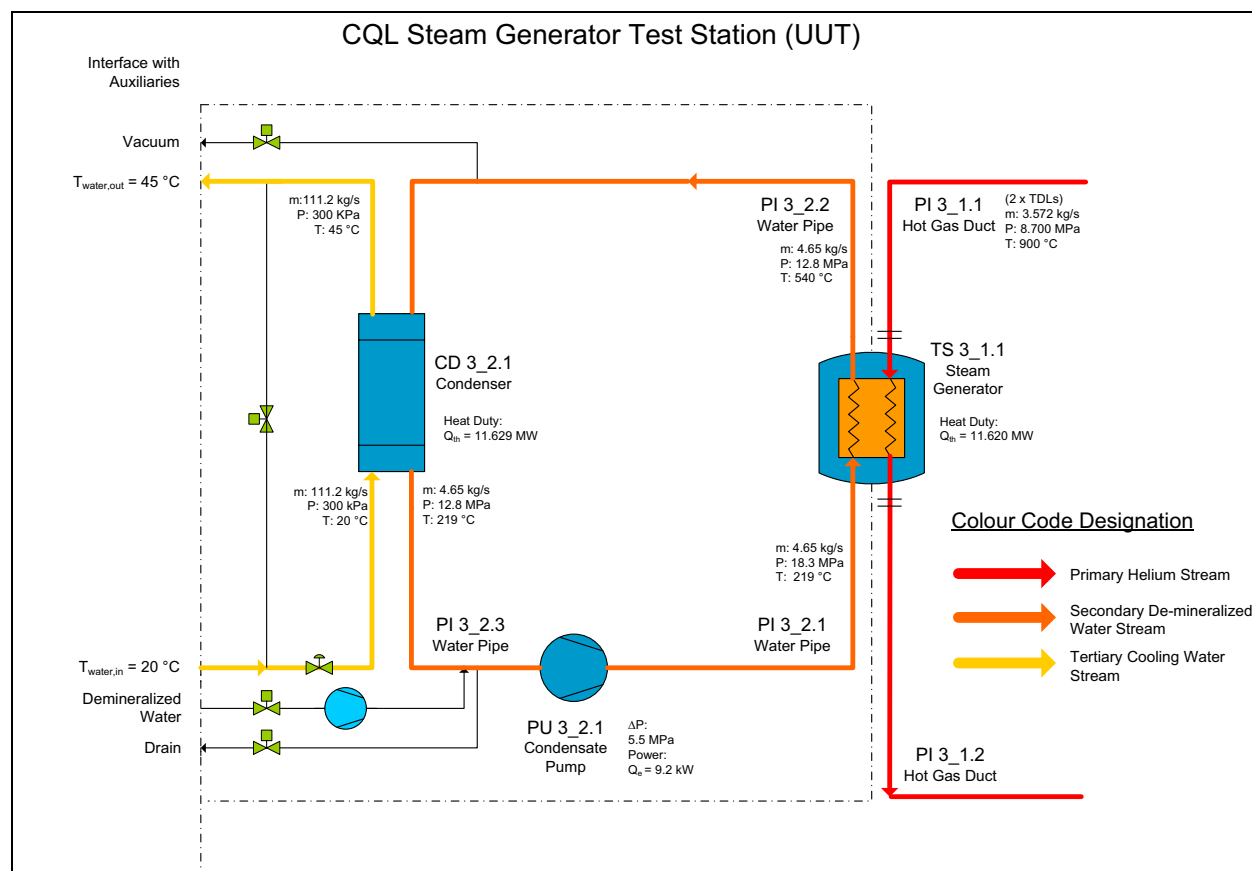


Figure 7-8: PFD diagram for the secondary loop of the anticipated SG test.

The above PFD is a high-level depiction revealing typical heat duties for the SG test station and the proposed condenser. The condensate pump adds little energy consumption to the secondary loop, i.e. only 9.2 kW.

7.2.1.1.7 Tertiary Stream Process Values as per anticipated SG test

The tertiary stream of the anticipated SG test is added to determine the auxiliary cooling water requirement. From Figure 7-8 above, the cooling water demand is 111.2 kg/s - refer to reference [7-10], Appendix F, MT-TLDR-CAL-F-T-0706.

7.2.1.1.8 CQL1 Test Station for H_2SO_4 Decomposition Reactor (TS 3_1.2)

Process conditions of two combined primary TDL loops are represented for the H_2SO_4 Decomposition Reactor shown schematically in Figure 7-9 below. Operation of at least two TDL primary loops is necessary to run the anticipated H_2 test.

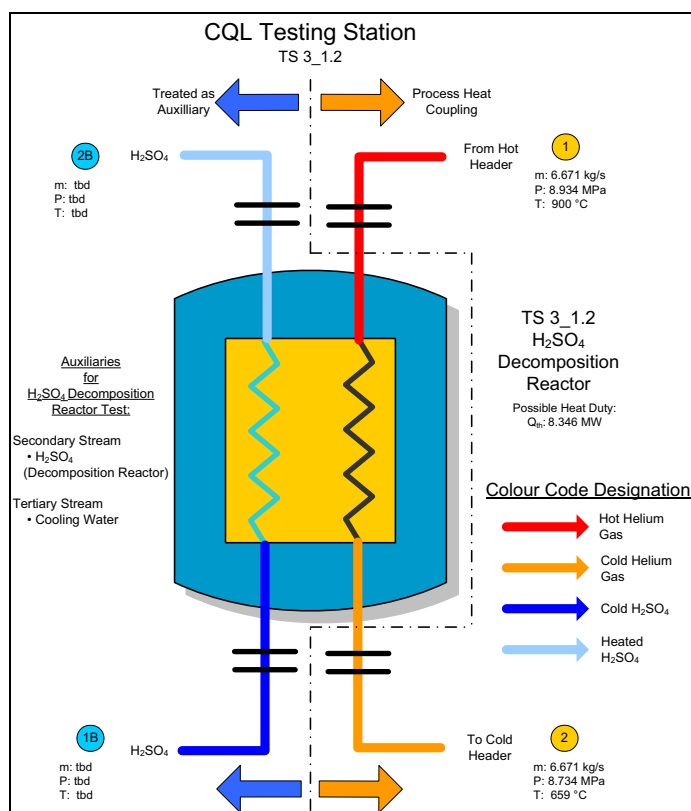


Figure 7-9: Schematic representation of the anticipated CQL1 process heat coupling to run an H_2SO_4 Decomposition Reactor test.

Based on preliminary decisions, component testing requirements for Hydrogen Production technologies could be divided into the following:

- High Temperature Steam Electrolysis (HTSE):
 - Process Coupling Heat Exchanger (PCHX) requiring helium at a temperature of 950 °C and 5 – 9 MPa pressure. The fluids exchanging heat are helium, steam and air.
- Sulfuric Acid Decomposition (shared between HyS and Sulfur-Iodine Technologies):
 - H_2SO_4 Decomposition Reactor requiring helium at 900 °C and 5 – 9 MPa pressure. This process information is preliminary and also has been used for the initial thermal hydraulic calculations in determining the possible helium mass flow and possible heat duty of the H_2SO_4 Decomposition Reactor.

The list above is for component testing of Hydrogen Production Technologies as far as process coupling with helium is concerned and does not include the following:

HTSE:

- HTSE Electrolyzer requiring steam, air and electricity.
- Feed water purification system.
- Heat recovery systems (Heat Exchangers).

Sulfuric Acid Decomposition – HyS Technology:

- Tests on Acid Concentration Vacuum Column.
- Tests on SiC ceramic tubing.

From a preconceptual point of view it is foreseen to draw a line as far as CTF process heat coupling is concerned for both the HTSE PCHX and the H₂SO₄ Decomposition Reactor. These two components will be treated as UUTs until more information is available concerning their prototype designs. It is envisaged that the HTSE PCHX could be tested in the TDL and the H₂SO₄ Decomposition Reactor in CQL1 due to the larger thermal requirement of the latter.

The steam and air leaving the HTSE PCHX enters an Electrolyzer requiring a high electrical input of 7.6 MWe at 1.8 MWth per testing of a single enclosed module. The combined heat duty of the HTSE PCHX is less than 1 MWth.

7.2.2 System Breakdown Structure

CQL1 consists of Hot Gas Duct (HGD) piping sections from the TDLs merged at a Hot Header, which is the interface between the TDLs and CQL1. The only mechanical components making up CQL1 are the hot and cold headers and the piping sections extending to and from these headers to the test station flanges. Two test stations are currently envisioned for CQL1. The units to be tested in CQL1, i.e. the steam generator and the H₂SO₄ Decomposition Reactor, are still to be designed resulting in a lack of detail regarding the secondary and tertiary loops of these test units. Provision has been made - on a conceptual design basis, to calculate estimate cooling water capacities for the SG test as these would be beneficial in providing more information regarding interface requirements to the auxiliary systems.

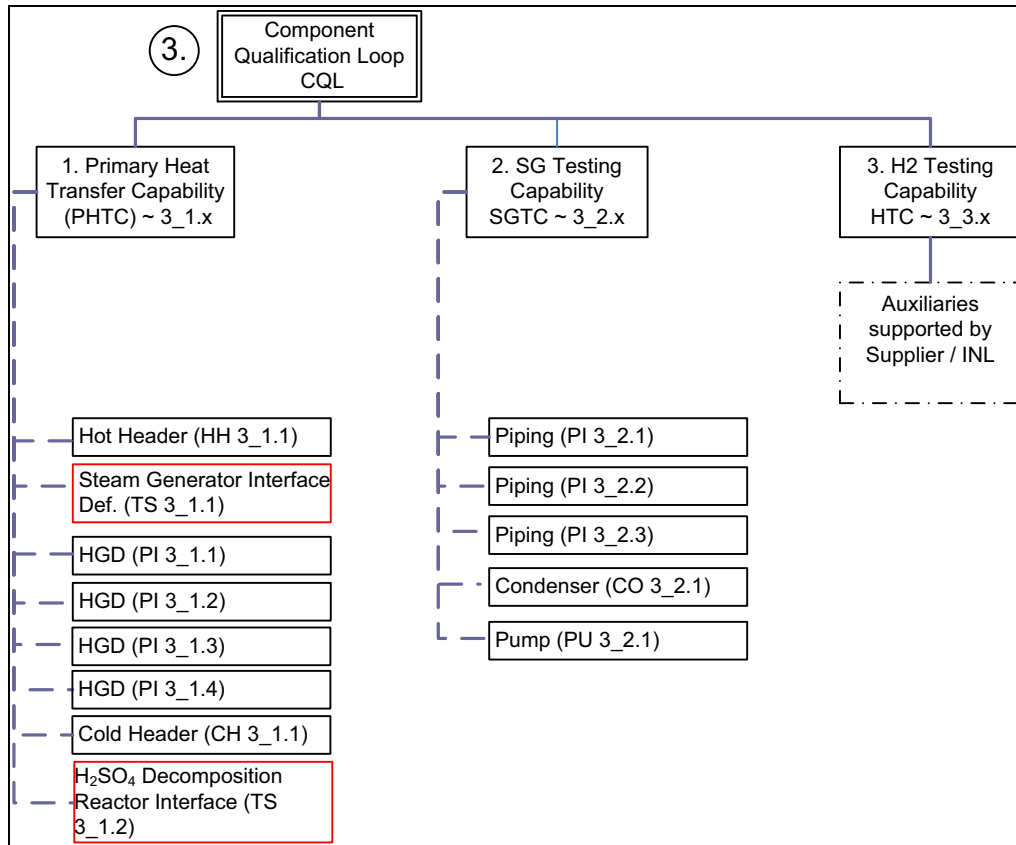


Figure 7-10: System Breakdown Structure (SBS) for CQL1.

7.2.3 Component Performance Specifications

The TDL secondary loops will be inactive during CQL1 component testing. The secondary loops of the TDLs are in effect replaced by either one of the two anticipated CQL1 testing loops.

The tabulated values under paragraph 7.2.1.1 in the primary loops of the TDLs reflect the nominal component performance values required for running the anticipated CQL1 tests calling for helium process heat coupling at 900 °C.

As mentioned before, two TDLs are required to run each of CQL1 tests taking into account that both the heat duties of the SG and the H₂SO₄ Decomposition reactor are in the order of 11.6 MWth for the former and 8.4 MWth for the latter.

The components in CQL1 are:

- Hot Header
- Cold Header
- Hot Gas Ducts
- Cold Piping

- SG UUT (blanked off and flanged for UUT connection)
- H₂SO₄ Decomposition Reactor UUT (blanked off and flanged for UUT connection)

7.2.3.1.1 Hot Gas Ducts (PI 3_1.1; PI 3_1.2; PI 3_1.3; PI 3_1.4)

Piping sections are grouped into “hot” and “cold” zones. Process values affecting the design of cold section pipes are listed under “Cold Piping” under paragraph 7.2.3.1.2 below.

All hot-section pipes in both the TDL and CQL1 test loops have been designed with internal flow liner diameters of 0.260 m. The internal diameter of the pressure boundary is 0.548 m leaving enough space for appropriate insulation – refer to reference [7-8], Appendix D, MT-TLDR-CAL-F-T-0704.

The pressure boundary is a standard NPS 24”, schedule 80 pipe, using SA-516 Gr.70 as proposed material. All hot gas duct dimensions regarding both TDLs as well as CQL1 connections have been standardized to simplify fabrication and maintenance of all the piping sections. Velocities within the pipe sections vary between 9 – 20 m/s for the SG CQL1 test. These are based on the process values as per the PFD depicted in Figure 7-1.

The H₂ CQL1 test has a much larger attainable helium mass flow than the SG test (due to a lower temperature differential passing through its Test Station) and therefore the velocities range in the order of 28 – 35 m/s. The higher velocity for this test is still acceptable when compared to those obtained in previous test loop facilities (~ 60 m/s)². Future work needs to be performed to verify the gas velocity threshold on the CTF HGDs.

The higher theoretical velocity calculated for the H₂ test compared to that obtained for the SG test lies in the fact that:

- Mass flow of H₂SO₄ Decomposition Reactor test is 3.336 kg/s per TDL compared to the lower mass flow of the SG test, which is 1.786 kg/s per TDL.

An inner pipe diameter of 0.26 m reflecting a nominal velocity of 20 m/s for the maximum mass flow of ~ 3.65 kg/s (refer to reference [7-8], Appendix D, MT-TLDR-CAL-F-T-0704 and reference [7-9], Appendix E, MT-TLDR-CAL-F-T-0705) in the TDL was chosen as reference diameter.

² IAEA Specialists’ Meeting on Heat Exchanging Components of Gas-Cooled Reactors; Düsseldorf, 16 – 19 April 1984. Status of the Development of Hot Gas Ducts for HTRs; H Stehle, E Klas; INTERATOM GMBH, FRG.

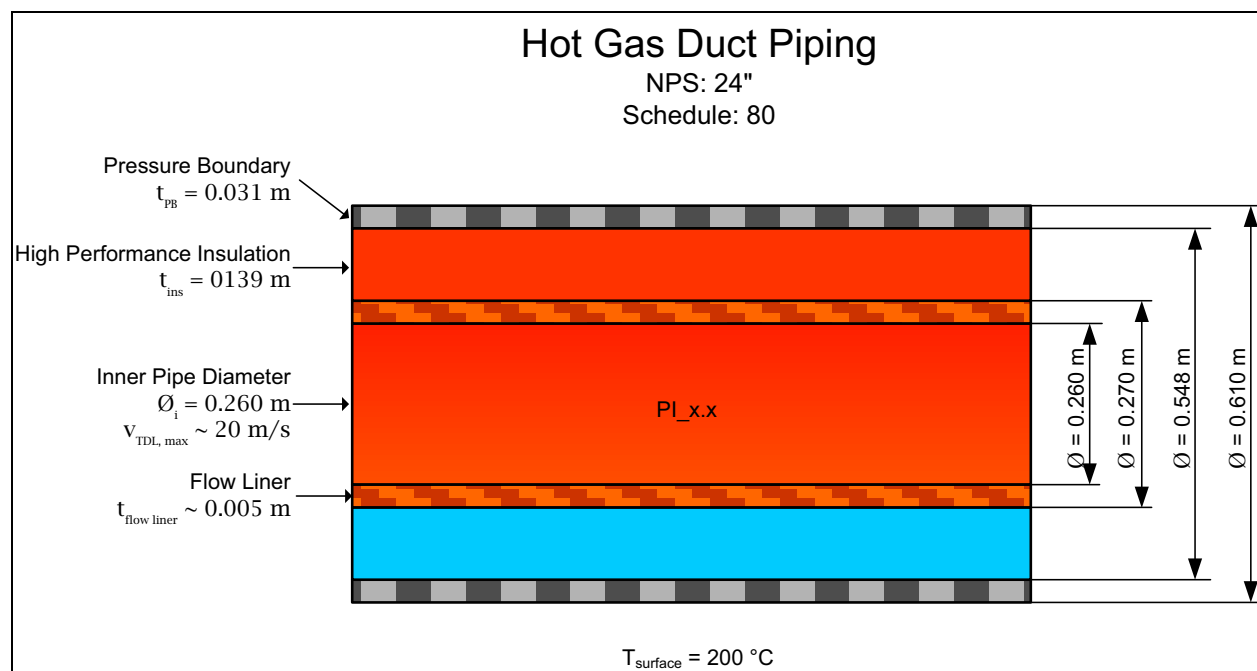


Figure 7-11: Schematic representation of a section of the hot gas duct showing dimensions of the flow liner, internal insulation and pressure boundary.

Table 7-7: Tabulated process values affecting the design of the HGDs (TDL & CQL1).

Description	Unit	SG Test Value per TDL	H ₂ Test Value per TDL	Max / Design Value per TDL
P _{He}	kPa	8700	8934	9600
T _{He in}	°C	900	900	1000
d _{internal liner}	m	0.26	0.26	0.26
m _{He}	kg/s	1.786	3.336	4.750 (3.650) ³
d _{pressure internal} ⁴	m	0.548	0.548	0.548
T _{surface}	°C	200	200	200

³ The design value of 3.65 kg/s was used for HGD dimensioning. The value of 4.75 kg/s was incorporated to allow for 30 percent over-capacity.

⁴ From document MT-TLDR-CAL-F-T-0704 in Appendix D, Section 7, the internal diameter of the pressure boundary follows the external layer of the insulation, which was calculated at 0.510 m. The standard pipe closest to this internal dimension is a NPS: 24", Schedule 80 pipe, with an internal diameter of 0.548 m. This leaves an additional width of 0.019 m for insulation material.

7.2.3.1.2 Cold Piping

This section refers to the following component(s): PI 2A_1.1; PI 2A_2.1

No cold piping is anticipated for the CQL1 test loop. Although both UUTs in CQL1 act as heat exchanging devices with expected temperatures leaving the SG and H₂ Test Stations at 273 °C and 659 °C respectively, a conservative approach was followed to allow for sufficient insulation between the flow liners and the internal pressure boundaries should any of the UUTs fail during testing. Thus, the pipes following the UUTs are designed in accordance with the inlet temperatures at the UUTs i.e. as “hot section” pipes. This implies similar dimensions for both the hot and cold section pipes in CQL1 i.e. PI 3_1.1; PI 3_1.2; PI 3_1.3 and PI 3_1.4 – refer to the PFD drawing in Appendix G referenced as [7-11]: MT-TLDR-CQL-02-0001.

Cold pipes on the TDL conditioning loops (flow from recuperator outlet via the cooler, circulator and back to the recuperator inlet) are designed according to TDL test loop specifications. These design dimensions on the TDL conditioning loops also suffice for CQL1 testing. The dimensions of the cold piping are shown in Figure 7-12 (for TDLs only).

Insulation is proposed for the outside of the cold pipes for the sections between the recuperator hot side outlets and the cooler inlets, where temperatures can be higher than 400 °C during certain TDL test conditions.

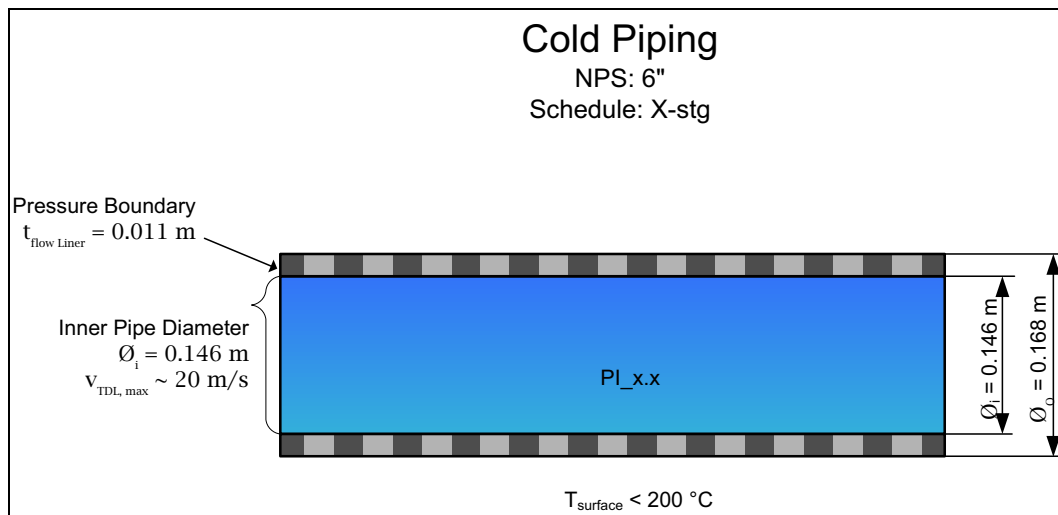


Figure 7-12: Schematic representation of a section of the cold piping within the TDL showing dimensions of the flow liner and pressure boundary. No cold piping is used in CQL1.

The process values given in Table 7-8 below verifies that CQL1 test conditions are enveloped by the TDL design values.

Table 7-8: Tabulated process values affecting the design of the cold piping (TDL only).

Description	Unit	SG Test Value per TDL	H ₂ Test Value per TDL	Max / Design Value per TDL
P _{He}	kPa	8600	8734	9600
T _{He in}	°C	123	200	454
d _{i, flow liner}	m	0.14	0.14	0.14
m _{He}	kg/s	1.786	3.336	4.750
d _{i, pressure boundary}	m	0.146	0.146	0.146
T _{surface, recuperator→cooler}	°C	123	200	454 ⁵
T _{surface, cooler→recuperator}	°C	<100	<100	<100

7.2.3.1.3 Control Valves

No valves are used within the helium loop side of the CQL1 circuit - where the temperatures are as high as 900 °C. The valves in the primary TDL circuits (with operating temperatures at approximately 85 °C) are used to control the helium flow delivered to CQL1. The operating conditions for CQL1 tests are enveloped by the control valve dimensions that are specifically designed for TDL use as shown in Table 7-9 below.

Table 7-9: Process values as per CQL1 tests compared with maximum TDL Control Valve requirements

Description	Unit	SG Test Value per TDL	H ₂ Test Value per TDL	Max / Design Value per TDL
P _{He}	kPa	8700	8934	9600
T _{He in}	°C	85	85	100
d _{internal pipe}	m	0.14	0.14	0.14
m _{He}	kg/s	1.786	3.336	4.750

⁵ Certain tests on the TDL leaves the surface temperature of the “cold piping” section at above 200 °C. Thus outside insulation of the section between the primary TDL recuperator and the primary TDL cooler is required to ensure a surface temperature of 200 °C and below.

7.2.3.1.4 HICS Valves & HICS Primary Heat Transport Capacity

There is no Helium Inventory Control System (HICS) connected to the CQL1 circuit. All the helium requirements for CQL1 testing cross the TDL threshold via its HICS interface. The same mass flow rates during startup conditions will be used for both TDL and CQL1 tests, thus no additional strain is placed on HICS for CQL1 tests. The helium purification system will form part of the auxiliary plant.

Table 7-10: Process values as per CQL1 tests compared with maximum TDL HICS requirements.

Description	Unit	SG Test Value per TDL	H ₂ Test Value per TDL	Max / Design Value per TDL
P _{He}	kPa	8700	8934	9600
T _{He in}	°C	85	85	85
d _{internal pipe}	m	0.05	0.05	0.05
m _{He}	kg/s	0.524	0.524	0.524
P _{range He}	kPa	10 - 8700	10 - 8934	10 - 9600
T _{He in}	°C	20	20	20
T _{He out}	°C	80	80	80
d _{internal pipe}	m	0.05	0.05	0.05
m _{He}	kg/s	0.524	0.524	0.524

Table 7-10 confirms that the same helium filling mass flow rate will be used for both TDL and CQL1 tests.

7.3 CQL1: Component Design

7.3.1 Hot Gas Duct

This section refers to the following component(s): PI 3_1.1, PI 3_1.2, PI 3_1.3 and PI 3_1.4

The component data sheet for the HGDs of CQL1 is the same as for the TDL's HGDs and its system-specific data sheet is found in reference [7-14], Appendix J, data sheet number: MT-TLDR-CQL-CMPT-05-0003 as well as reference [7-15], Appendix K, MT-TLDR-CAL-M-0701.

Hot gas ducts are required to circulate the helium in the test loops at internal pressures up to 9.6 MPa (secondary circuit of the TDL), thus the HGDs are treated as pressure components. Concurrently, the HGDs need to be designed to lower the surface temperature, and subsequently the pipe dimensions to values being economically justifiable. Piping in CQL1 can be divided into

the following sections – refer to the PFD drawing in reference [7-11], Appendix G, document number MT-TLDR-CQL-02-0001:

- PI 3_1.1 (Hot section pipe from HH 3_1.1 to TS 3_1.1)
- PI 3_1.2 (Cold section pipe from TS 3_1.1 to CH 3_1.1)
- PI 3_1.3 (Hot section pipe from HH 3_1.1 to TS 3_1.2)
- PI 3_1.4 (Cold section pipe from TS 3_1.2 to CH 3_1.1)

Table 7-11: Velocities of helium gas within the HGDs at given process conditions (CQL1 tests).

Piping Section	Temperature °C	Density (kg/m ³)	Velocity (m/s)
CQL1 Piping to SG Test Station (PI 3_1.1)	900	3.54	19.0
CQL1 Piping from SG Test Station (PI 3_1.2)	273	7.43	9.1
CQL1 Piping to H ₂ Test Station (PI 3_1.3)	900	3.64	34.6
CQL1 Piping from H ₂ Test Station (PI 3_1.4)	659	4.46	28.2
TDL Hot Piping Sections	950	3.40	20.5

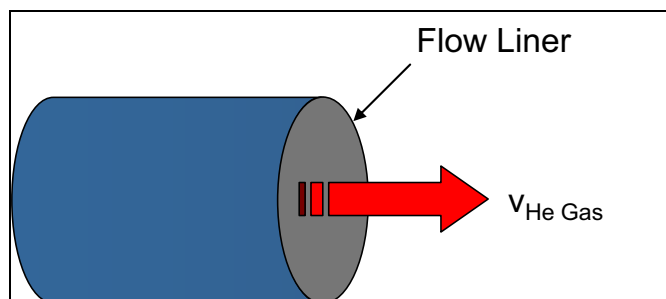


Figure 7-13: Schematic of the flow liner acting as barrier (and not as pressure boundary) for the internal helium flow.

The velocities presented in the table above were calculated for an inner flow liner diameter, $d_{\text{flow liner}}$ of 0.26 m - refer to reference [7-8], Appendix D, document number MT-TLDR-CAL-F-T-0704. This calculation was based on the following assumptions:

- Maximum mass flow rate of helium in TDL = 3.65 kg/s (refer to reference [7-9], Appendix E, MT-TLDR-CAL-F-T-0705).
- Density of helium at 950 °C and 9.0 MPa = 3.514 kg/m³.
- Helium flow rate (Q) = mass flow rate (m) / density (ρ) = 1.039 m³/s.
- Design velocity, v = 20 m/s.

From the above assumptions, the internal flow liner diameter is:

$$\begin{aligned}
 Area &= \frac{Q}{v} \\
 \therefore d &= \sqrt{\frac{Q \times 4}{\pi v}} \dots\dots\dots \text{Equation 2} \\
 \therefore d &= 0.257 \text{ m}
 \end{aligned}$$

The internal diameter was rounded to 0.26 m, resulting in a velocity of 19.6 m/s for the above assumed conditions.

From the SG CQL1 testing requirements the following inputs are available:

- Maximum mass flow rate of helium in SG CQL1 = 3.573 kg/s (refer to reference [7-5], Appendix A, MT-TLDR-CAL-F-T-0701).
- Density of helium at 900 °C and 8.7 MPa = 3.541 kg/m³.
- Flow Rate (Q) = mass flow rate (m) / density (ρ) = 1.009 m³/s.
- Internal Diameter = 0.260 m.

From the above inputs, the helium velocity for the SG test in pipe section PI 3_1.1 is:

$$\begin{aligned}
 v &= \frac{Q}{A} \\
 \therefore v &= \frac{Q \times 4}{\pi d^2} \dots\dots\dots \text{Equation 3} \\
 \therefore v &= 19.0 \frac{m}{s}
 \end{aligned}$$

This velocity is very close to the TDL design velocity of 20 m/s, using similar internal diameters (0.26m). The gas-side exit-velocity of the of the SG test station (TS 3_1.1) is 9.05 m/s for this same internal diameter.

A decision was made to use similar dimensions for both pipe sections entering and leaving the SG test station (TS 3_1.1), purely based on maintenance and standardization grounds. Future techno-economic tradeoff studies need to be done to determine a cost for all the proposed piping in the CTF, followed by an all-inclusive engineering optimization, thereby taking into account matters of standardization, thermal fluid considerations, material choice, location, cooling mode (active/passive), HVAC and costs.

Considering this preconceptual design report, piping at the outlets of the two provided Test Stations will be treated as passively-cooled hot pipes for worst case scenarios in case of CQL1 test failure. In such cases, helium at 900 °C will not have exchanged heat with the test unit, thus exiting the Test Station with the same temperature it has entered into. Although this leads to higher costs due to larger pressure boundary HGD piping, justification thereto could be granted purely from a safety and HVAC point of view. Provision is therefore made to insulate both the hot and cold sections by using similar design criteria for both “hot” and “cold” piping sections i.e. $T_{\text{helium, design}} = 1000 \text{ °C}$ and $T_{\text{surface}} = 200 \text{ °C}$.

Table 7-12: Process values used for the HGD piping design.

Description	Unit	SG Test Value per TDL	H ₂ Test Value per TDL	Max / Design Value per TDL
P_{He}	kPa	8700	8934	9600
$T_{\text{He in}}$	°C	900	900	1000
$d_{\text{internal liner}}$	m	0.26	0.26	0.26
m_{He}	kg/s	1.786	3.336	4.750 (3.650) ⁶
$d_{\text{insulation, external}}$	m	0.510	0.510	0.510
$d_{\text{pressure internal}}$	m	0.548	0.548	0.548
$d_{\text{pressure internal}}$	m	0.610	0.610	0.610
$t_{\text{pressure boundary}}$	m	0.031	0.031	0.031
T_{surface}	°C	200	200	200

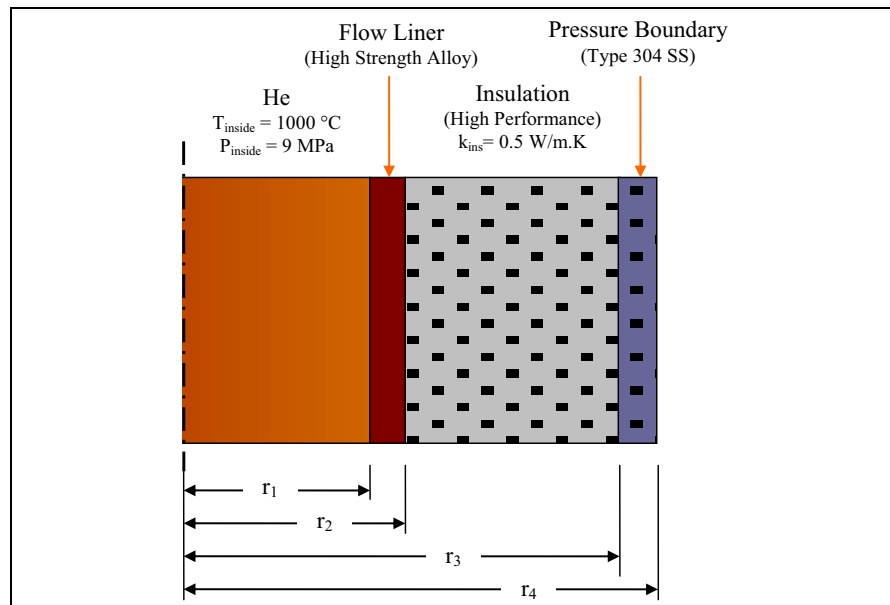


Figure 7-14: Schematic representation of a HGD section revealing the different sections, i.e. inside pipe, flow liner, insulation and pressure boundary.

⁶ The design value of 3.65 kg/s was used for HGD dimensioning. The value of 4.75 kg/s was incorporated to allow for 30 percent over-capacity.

From Figure 7-14 and thermal hydraulic calculations (reference [7-8], Appendix D, MT-TLDR-CAL-F-T-0704), the following dimensions are listed:

- r_1 = inside of flow liner = 0.13 m
- r_2 = inside of insulation = 0.135 m
- r_3 = inside of pressure boundary = 0.274 m
- r_4 = inside of flow liner = 0.305 m

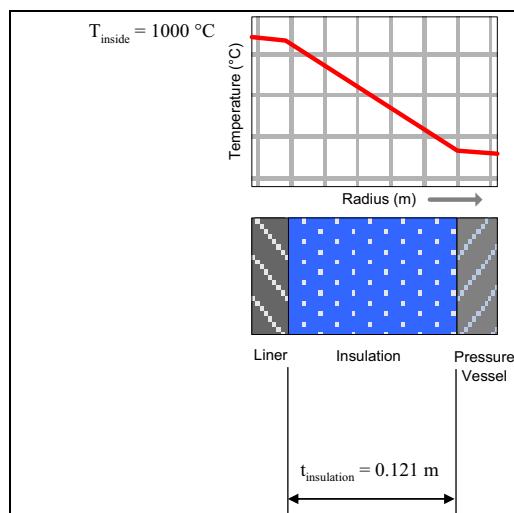


Figure 7-15: Schematic of the flow liner, insulation material and the pressure boundary, depicting the importance of using appropriate insulation material.

Insulation up to a diameter of 0.510 m will be sufficient to retain the surface temperature at 200 °C. For the given process conditions, a standard pipe size with an internal diameter closest to this size is a NPS 24", schedule 80 pipe, which has an internal diameter of 0.548 m. This leaves an additional width of 0.019 m for insulation material.

The additional width of 19 mm insulation material will reduce the surface temperature by another 20 °C – refer to use of equations in paragraph 7.3.1.2 below.

It is proposed that the internal flow liner sections of the HGDs are made-up from conical sections funneling into cylindrical flow geometries. Such an arrangement is schematically depicted in Figure 7-16 below. Making use of the conical flow liner arrangement allows for expansion, which is in the order of 11.6 mm/m when operating temperatures of 950 °C are expected.

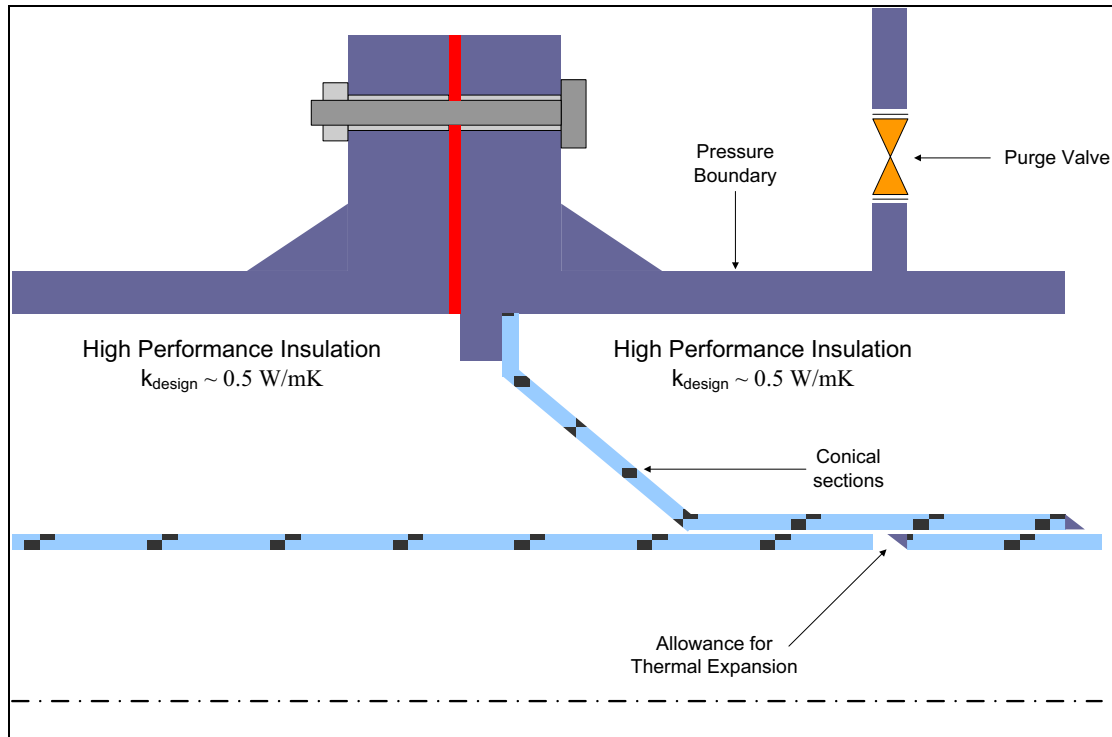


Figure 7-16: Schematic representation of a top section slice through the HGDs.

7.3.1.1 Materials of Construction for HGDs

7.3.1.1.1 Flow liner

It is proposed that the flow liner be constructed from high strength alloys to serve as a containment barrier for the internal insulation. The inside surface of the flow liner needs to be smooth to reduce friction.

Typical materials of construction for the flow liner are:

- High Strength Nickel Alloy (only ~ 1.5 mm thick).
- Machined graphite (up to 5 mm thick). This option is only listed as alternative to the first choice i.e. high-strength Nickel Alloy flow liners.
- Another option is carbon composites

The High strength Nickel alloy flow liner will be preferred due to a proven history in high temperature environments. Machined graphite will be much heavier, thereby requiring additional support within the HGDs. The advantage of graphite is that it has a very low thermal expansion coefficient compared to that of steels such as Nickel alloys. Machinability of graphite liners could pose some serious challenges though, which is not in line with the COTS philosophy anticipated for components in the CTF.

7.3.1.1.2 Insulation

High performance insulation is necessary to increase the thermal resistance across the hot gas duct. The outside surface temperature is assumed to be 200 °C.
Typical materials of construction for the insulation are:

- Aerogel
- Micro-porous Silica

7.3.1.1.3 Pressure Boundary

The pressure boundary will be made from a standard NPS 24", schedule 80 pipe with typical materials being:

- SA-240 (304 stainless steel)
- SA-516 (carbon steel)

7.3.1.2 HVAC Requirements

HVAC requirements for the CQL, mainly consisting of piping, have been calculated using the following equations:

$$A_{per,meter} = \pi \cdot d_{outside} \cdot L \dots\dots\dots \text{Equation 4}$$

$$h_{rad,outside} = 5.67 \times 10^{-8} \cdot (T_1 + T_2) \left[\frac{T_1^2 + T_2^2}{\frac{1 + \varepsilon_{outside}}{\varepsilon_{outside}} + 1} \right] \dots\dots\dots \text{Equation 5}$$

The following two equations are solved simultaneously for the variables $Q_{per,meter}$ and $d_{outside}$:

$$Q_{per,meter} = A_{per,meter} \cdot (h_{conv,outside} + h_{rad,outside}) \cdot (T_{surface} - T_{\infty}) \dots\dots\dots \text{Equation 6}$$

$$Q_{per,meter} = 2 \cdot \pi \cdot k \cdot \frac{L}{\ln \left[\frac{d_{outside}}{d_{HGD,outside,liner}} \right]} \cdot (T_{inside} - T_{surface}) \dots\dots\dots \text{Equation 7}$$

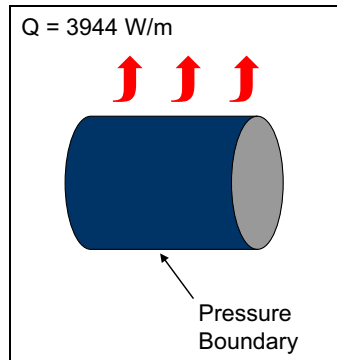


Figure 7-17: Schematic of the HGDs in CQL1 showing the average heat loss per meter.

The inputs for the HVAC calculations are based on the following:

- $T_{\text{inside}} = 1000 \text{ } [^{\circ}\text{C}]$
- $T_{\text{surface}} = 200 \text{ } [^{\circ}\text{C}]$
- $T_{\infty} = 30 \text{ } [^{\circ}\text{C}]$
- $k_{\text{insulation}} = 0.5 \text{ } [\text{W/m.K}]$
- $h_{\text{outside,conv}} = 10 \text{ } [\text{W/m}^2.\text{K}]$
- $\epsilon_{\text{outside}} = 0.9 \text{ } [-]$
- $d_{\text{HGD,outside liner}} = 0.27 \text{ } [\text{m}]$

An estimated CQL1 length of $\sim 60 \text{ m}$ (2 x TDLs + 1 Test Station) is assumed, thus.

- $Q_{\text{per,meter}} = 3944 \text{ W/m}$

Subsequently,

- $Q_{\text{CQL1, HVAC}} = \sim 237 \text{ kW}$

The above mentioned heat loss calculation was done for a worst case scenario, i.e. 1000°C running through the complete section of CQL1. It is a preliminary calculation to get a feel of the heat loss whilst a CQL1 test is in operation.

7.3.2 Hot Header

This section refers to the following component(s): HH 3_1.1

The component data sheet for the HH of CQL1 is shown in reference [7-12], Appendix H, data sheet number: MT-TLDR-CQL-CMPT-05-0001.

The Hot Header's function is to ensure merging of two TDL mass flows into the bottom section of the HH pressure vessel, located near the Test Stations of the TDLs. Departure from the HH is from the top half of the vessel to either one of two test stations i.e. TS 3_1.1 or TS 3_1.2.

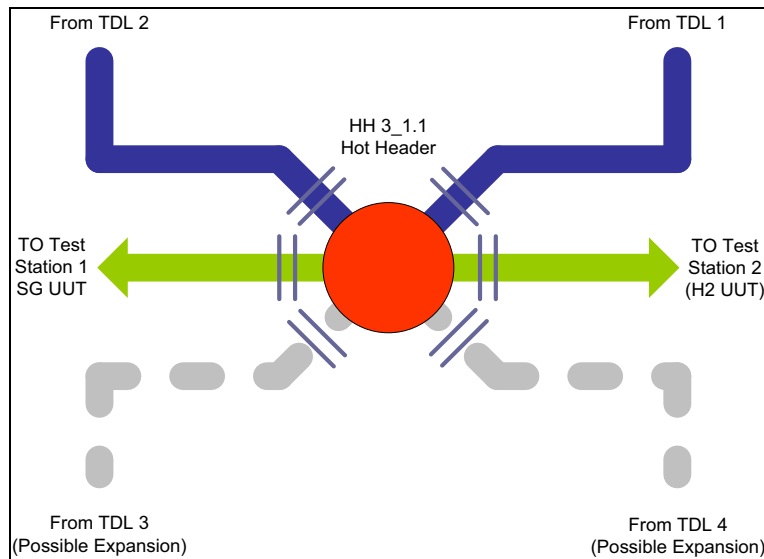


Figure 7-18: Schematic representation of the HH showing two TDL connections and two departing HGDs. Only one departing HGD will be used during component testing.

7.3.3 Cold Header

This section refers to the following component(s): CH 3_1.1

The component data sheet for the CH of CQL1 is shown in reference [7-13], Appendix I, data sheet number: MT-TLDR-CQL-CMPT-05-0002.

The purpose of the Cold Header is to provide a departure vessel so that the combined mass flows used in CQL1 Test Station could be separated into equal amounts back to their originating TDL streams.

Due to fluid friction, the TDL path with the lowest system resistance will experience the largest flow. In order to obtain near-equal system resistances, replicas as far as system design of TDLs are proposed. Nonetheless, mass flow streams will be controlled by means of adjusting the bypass valves situated in the TDLs in order to establish near equivalent motor power on each of the circulators.

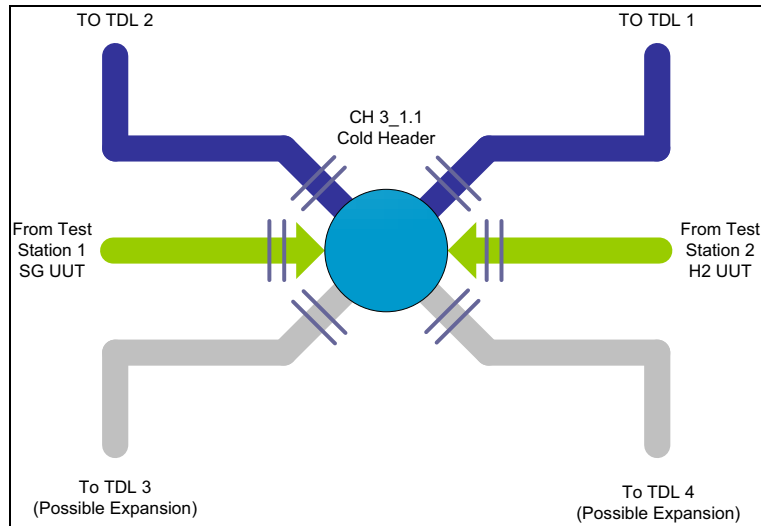


Figure 7-19: Schematic representation of the CH showing two incoming connections and departure to the TDLs. Only one incoming HGD will be used during component testing.

7.4 CQL1: 3D Mechanical Layout

The Hydrogen Building is proposed to be located next to the CTF, shielded by explosion-proof walling. It is proposed that auxiliaries to the plant be located outside the CTF building, as is schematically shown in Figure 7-20 below.

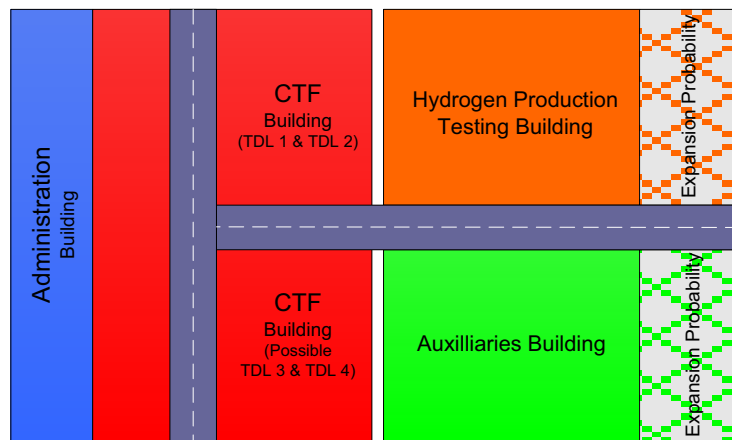


Figure 7-20: Schematic representation of possible Hydrogen & Auxiliary Building locations.

For the purpose of representing the mechanical layout of CQL1 and proposed expansion of the CTF (by incorporating more TDLs), schematic CTF layout representations are given below:

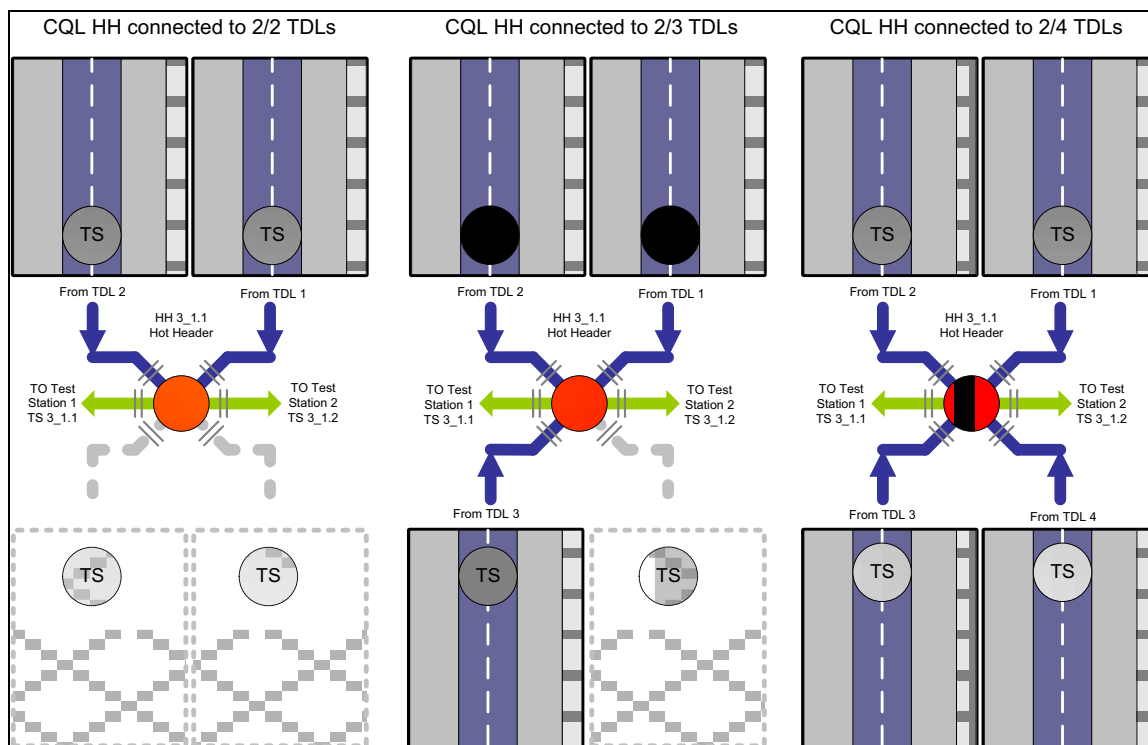


Figure 7-21: Schematic representation of the Hot Header stationed between the proposed TDLs.

The Cold Header is similar in design to the Hot Header with a reverse functionality i.e. taking CQL1 helium stream and dividing it into two equal parts for departure to the TDLs.

The same arrangement is proposed by allowing the CH to be placed as close as possible to the two TDL testing stations. Should further TDL expansion be brought to fruition, they will be positioned as such (mirrored) to minimize piping to and from CQL1 hot and cold headers.

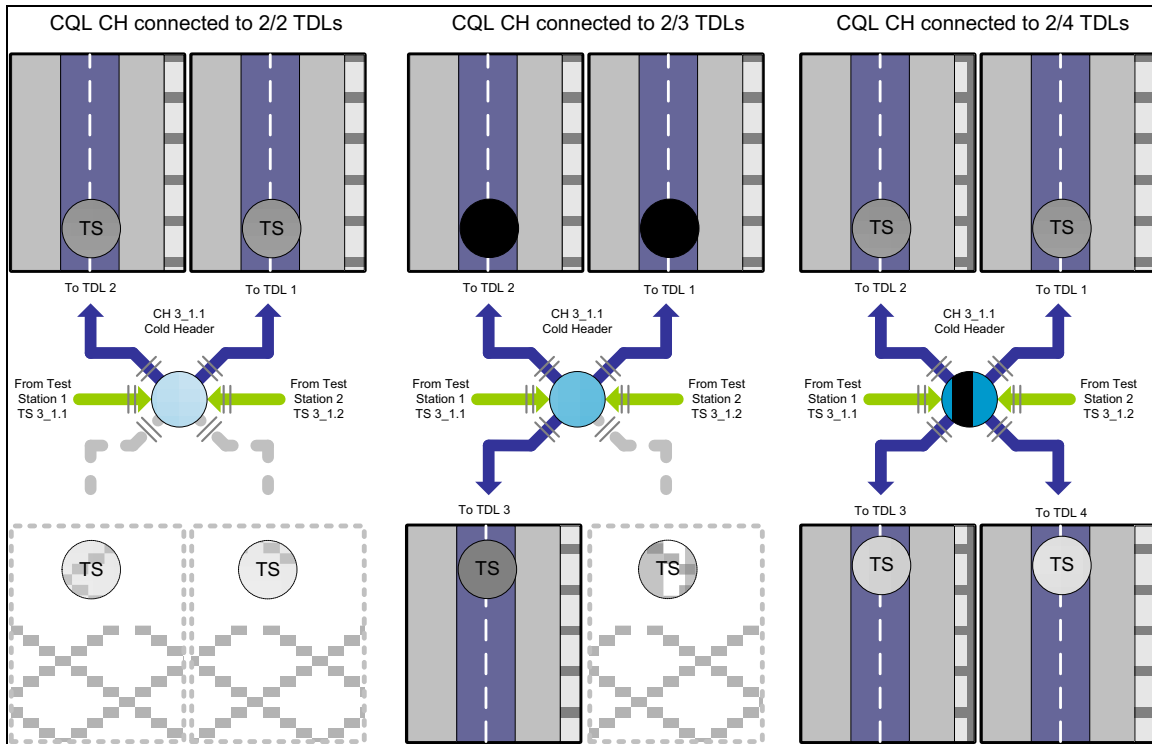


Figure 7-22: Schematic representation of the Cold Header stationed between the proposed TDLs.

CQL1 is conceptually shown in 3D view in the figures below (Figure 7-23, Figure 7-24, Figure 7-25, Figure 7-26 and Figure 7-27).

This is a very basic rendering of the piping running from the TDL flanges to the Hot Headers to the Test Station flanges and back again from the Test Station flanges to the Cold Headers once more tying up with the TDL flange connections. Optimization of the HGD piping dimensions i.e. piping pressure boundary diameters as well as piping lengths will have to be performed in future work, as HGD piping is known to be a very costly item in any envisaged high-temperature / high pressure engineering plant such as required by the CTF.

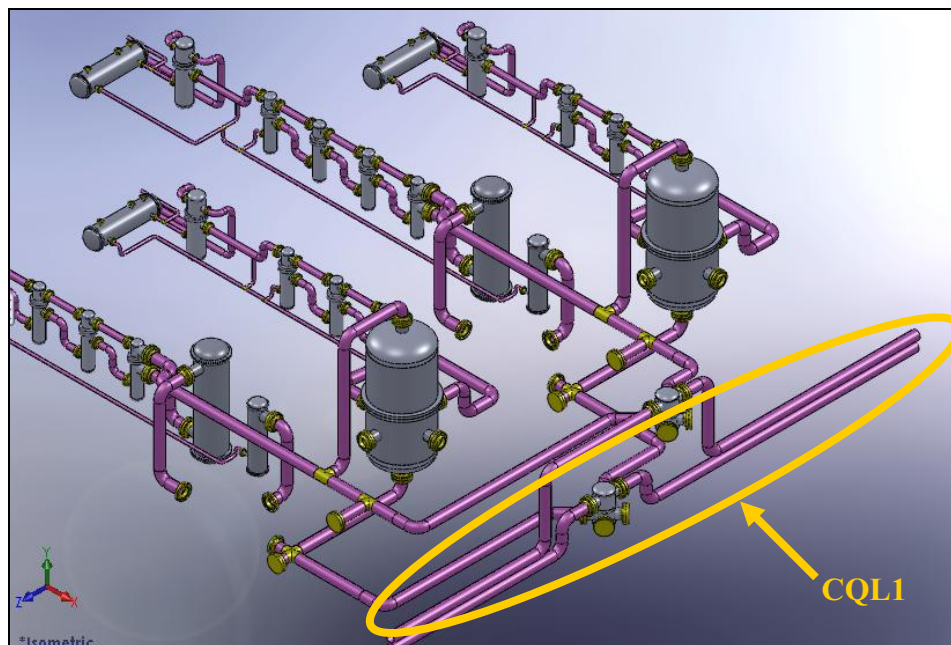


Figure 7-23: General view showing two TDL loops in the background and CQL1 (piping and headers) in the foreground.

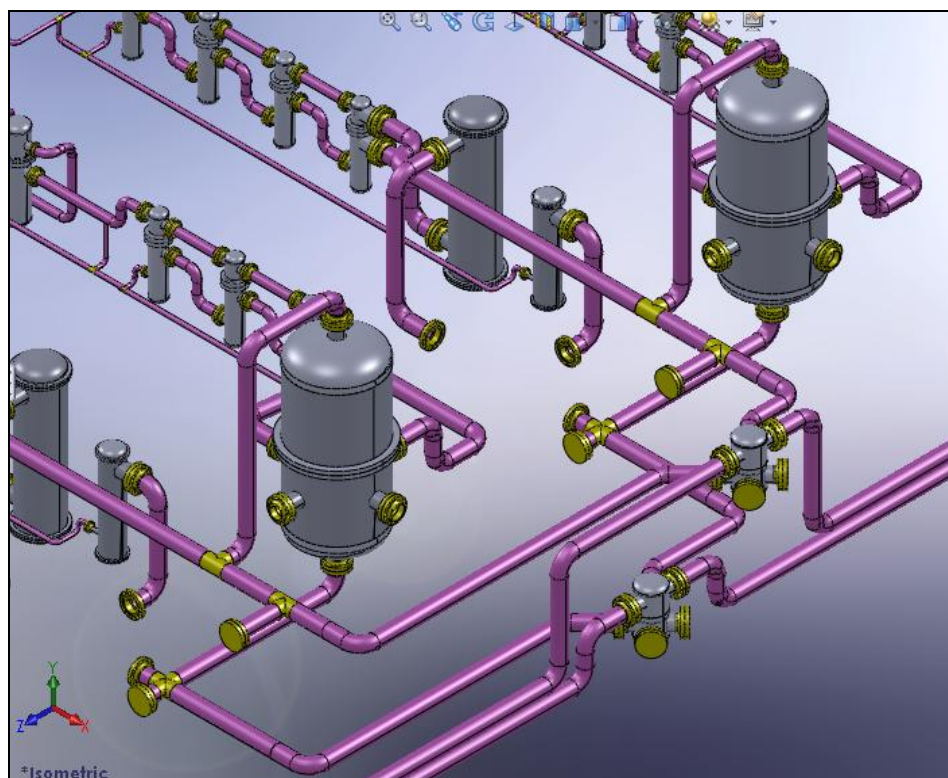


Figure 7-24: Closer view of CQL1 section.

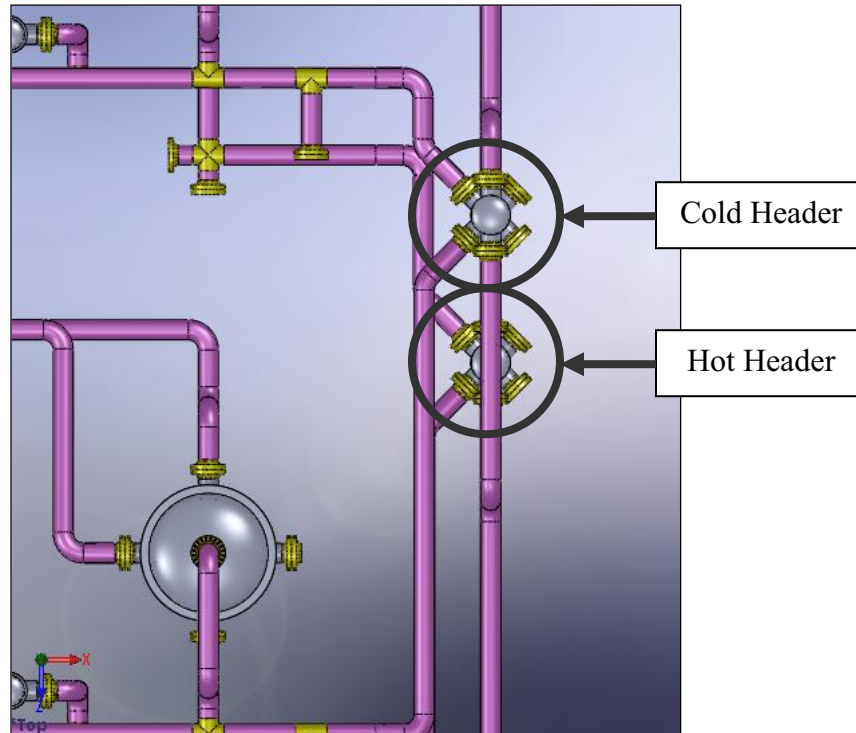


Figure 7-25: Top view of the Hot and Cold Headers of CQL1.

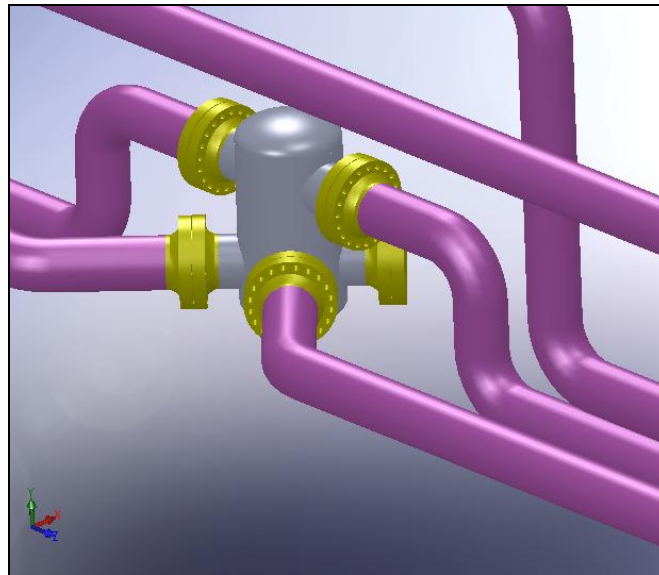


Figure 7-26: Closer view of the Hot Header, showing the two incoming TDL streams at the bottom and two departure streams at the top.

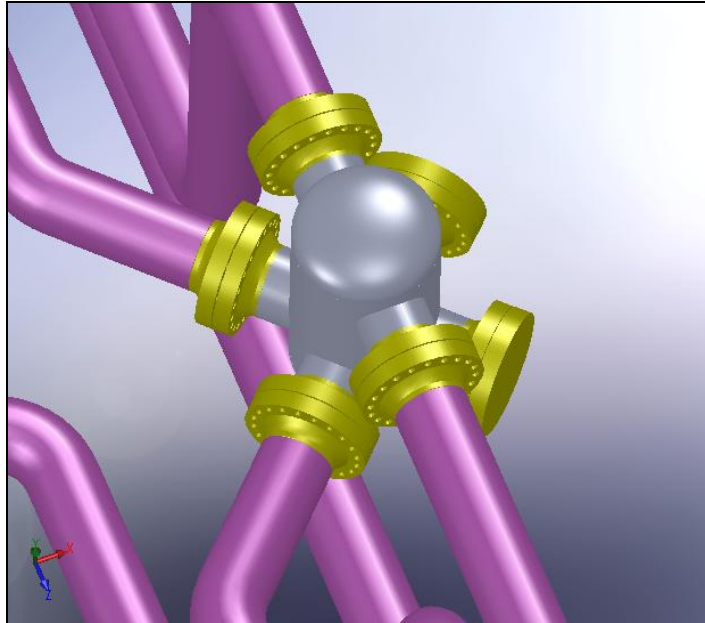


Figure 7-27: View of the Cold Header revealing the two blanked-off flanges (for CTF expansion).

7.5 CQL1: Instrumentation & Control Design

This section addresses the following:

- Typical modes and transitions
- Control loops
- Initial instrumentation specification

7.5.1 Typical Modes and Transitions

The modes and transitions of CQL1 loops can be subdivided into the stream sequences', process sequences' and system sequences' modes and transitions respectively as discussed in the control and instrumentation philosophy. The sequences of the different tests will typically look the same especially on stream sequence level. Figure 7-28, Figure 7-29 and Figure 7-30 respectively portray a stream, process and system sequence for a typical steam generation test.

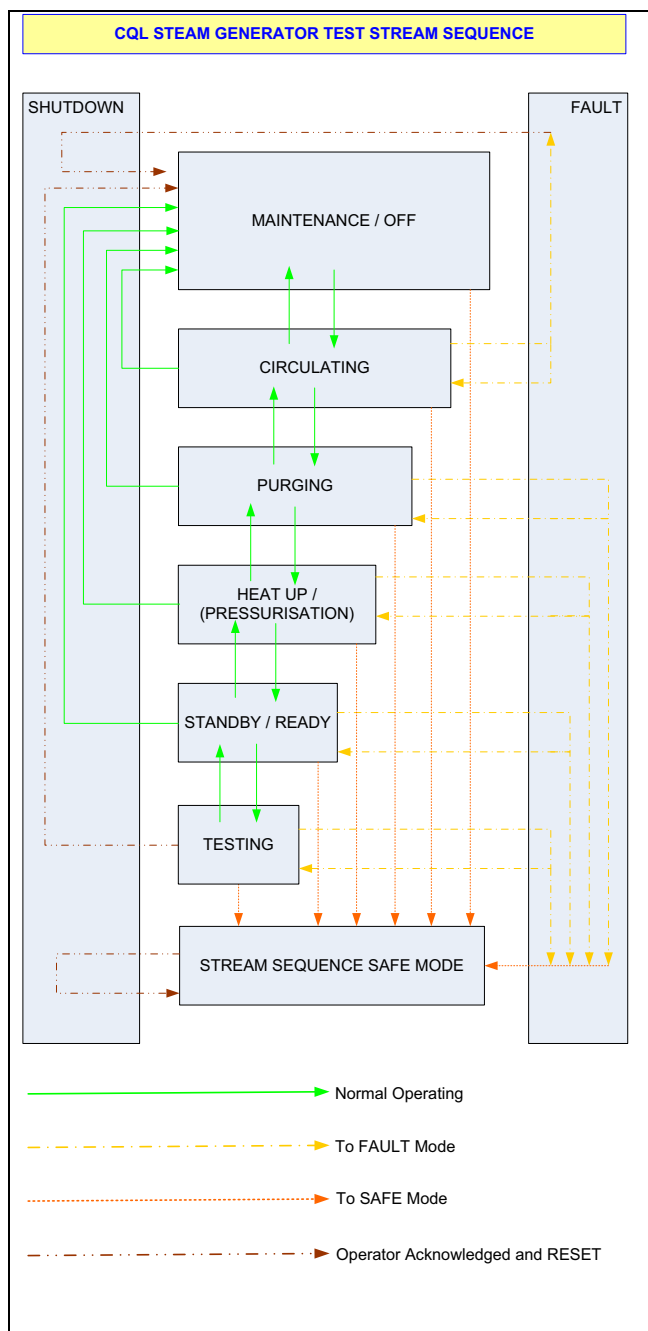


Figure 7-28: Typical CQL1 stream sequence.

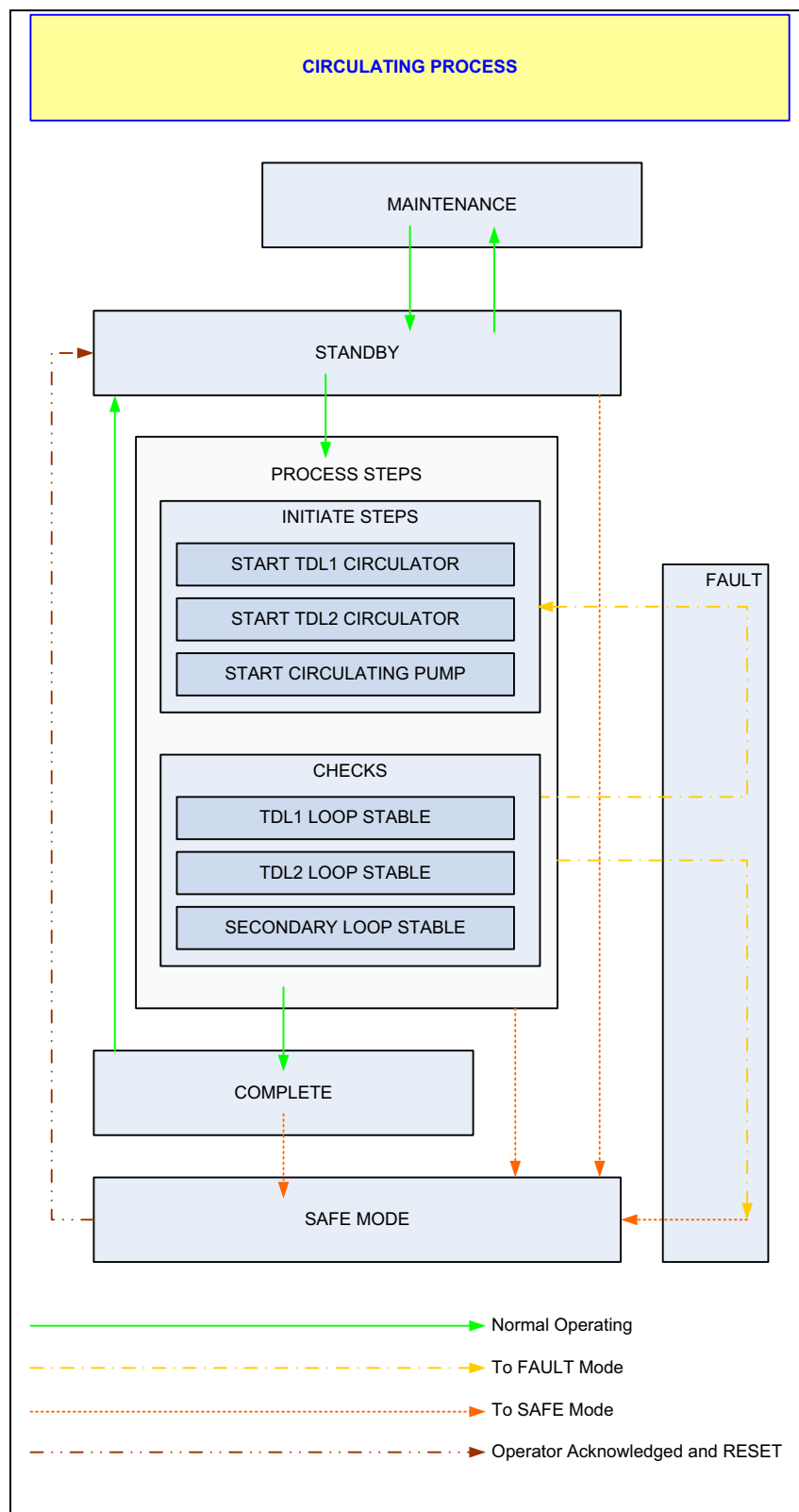


Figure 7-29: Typical CQL1 process sequence.

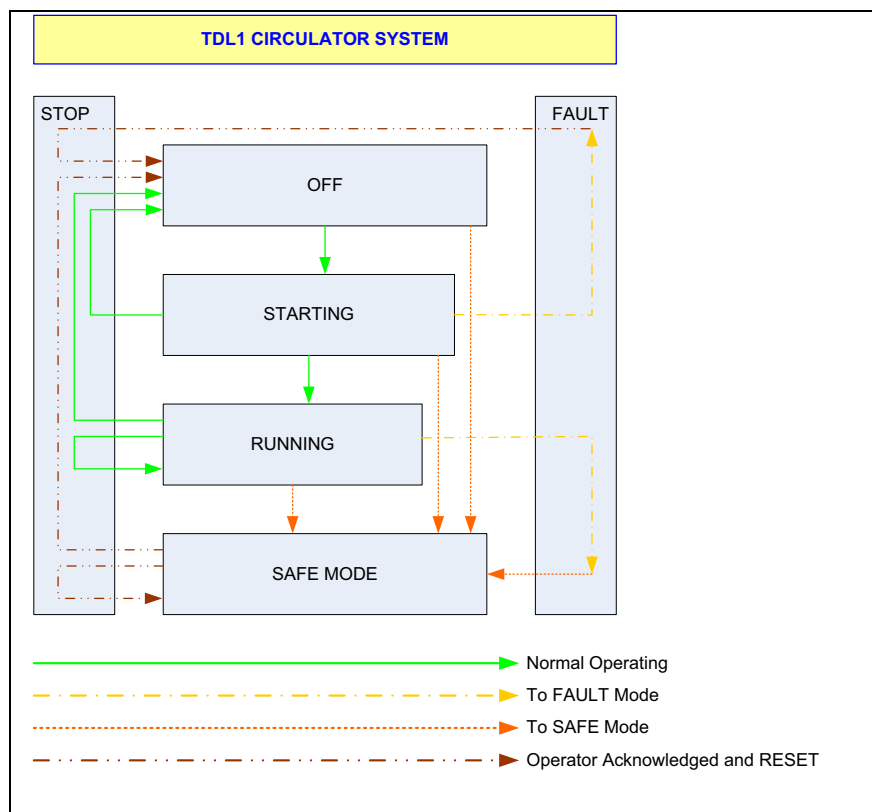


Figure 7-30: Typical CQL1 system sequence.

7.5.2 Control loops

With reference to the P&ID's for CQL1 the following types of controllers are discussed:

- Temperature control,
- Mass flow rate control,
- Pressure control.

7.5.2.1 Temperature control

The following temperatures will be controlled by adjusting the power supply to the TDL heaters (HT 2A_1.1 and HT 2B_1.1):

- Temperature (T1) at the inlet of the steam generator test station (TS 3_1.1) primary side.
- Temperature (T3) at the inlet of the H₂SO₄ decomposition reactor (TS 3_1.2) primary side.

The temperature (T7) at the outlet of the primary side of the condenser (CD 3_2.1) is anticipated to be controlled by adjusting the percentage opening of the valve located at the inlet of the condenser's secondary side (Figure 7-31).

The temperature (T10) at the outlet to the auxiliary cooling water is anticipated to be controlled below 45 °C by adjusting the percentage opening of the bypass valve located at the condenser's secondary side (Figure 7-31).

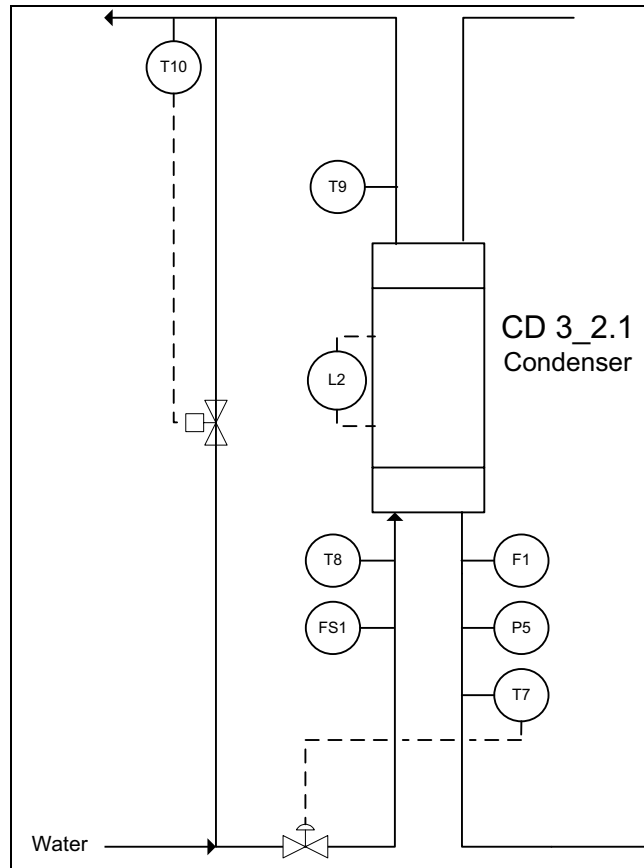


Figure 7-31: Part of the secondary water loop depicting high-level control in the anticipated CQL1 SG test.

7.5.2.2 Mass flow rate control

The mass flow rate control of CQL1 will be realized by utilizing the circulators of the TDL loops (CR 2A_1.1 and CR 2B_1.1). The mass flow control of the TDLs is discussed within the TDL loop control section, paragraph 6.5, “TDL: Instrumentation and Control Design”. It is recommended that the physical layout of the TDL loops be as similar as possible to ensure that their flow resistances are as identical as possible. This will ensure that the loads on the different TDL circulators will have the minimum deviation from one another thus maximizing circulator lifetime.

7.5.2.3 Pressure control

The pressure control will be realized from the TDL side as discussed within the TDL loop control section of this report. It is assumed that there will be helium available from the auxiliary side at the precise prescribed pressure.

7.5.3 Initial Instrumentation Specification

Table 7-13 shows the minimum instrument requirements with an indication of whether the instrument will be used for protection, control or validation and verification and whether it is required for a specific test specification. The maximum nominal conditions are given at which each instrument will be operating. Preliminary operating ranges for each instrument were obtained from the maximum nominal conditions.

Table 7-13: High-Level Instrument requirements for CQL1.

Component	Instrument	Protection	Control	V&V	Test spec	Temperatures (°C)		Mass flows (kg/s)		Pressures (MPa)		Diff Press (kPa)		Other	
						Max nom	Range	Max nom	Range	Max nom	Range	Max nom	Range	Max nom	Range
TS 3_1.1	T1	x			WEC-TS-SG-005	900	0-1100	3.75	0-5	8.7	0-10				
	T2	x				273	0-400	3.75	0-5	8.7	0-10				
	T5	x				540	0-700	4.6	0-6	12.8	0-14				
	T6	x				219	0-300	4.6	0-6	18.3	0-20				
	P1	x				900	0-1100	3.75	0-5	8.7	0-10				
	P3	x				540	0-700	4.6	0-6	12.8	0-14				
	P4	x				219	0-300	4.6	0-6	18.3	0-20				
	dP1	x				900	0-1100	3.75	0-5	8.7	0-10	TBD	TBD		
	L1	x				900	0-1100			18.3	0-20			TBD	0-100%
	A1	x				900	0-1100	4.6	0-6	18.3	0-20			TBD	TBD
TS 3_1.2	T3					900	0-1100	6.4	0-8	5	0-6				
	T4					659	0-800	6.4	0-8	5	0-6				
	P2					900	0-1100	6.4	0-8	5	0-6				
	dP2					900	0-1100	6.4	0-8	5	0-6				
	T11		x			TBD	TBD	TBD	TBD	TBD	TBD				
	T12		x			TBD	TBD	TBD	TBD	TBD	TBD				
	P6		x			TBD	TBD	TBD	TBD	TBD	TBD				
	P7		x			TBD	TBD	TBD	TBD	TBD	TBD				
	F2		x			TBD	TBD	TBD	TBD	TBD	TBD				
	FS2		x			TBD	TBD	TBD	TBD	TBD	TBD				
CD 3_2.1	T7		x			219	0-300	4.6	0-6	12.8	0-14				
	P5		x			219	0-300	4.6	0-6	12.8	0-14				
	F1		x			219	0-300	4.6	0-6	12.8	0-14				
	T8		x			219	0-300	139	0-150	0.5	0-0.7				
	T9		x			40	0-100	139	0-150	0.5	0-0.7				
	T10		x			40	0-100	139	0-150	0.5	0-0.7				
	L2		x			219	0-300	139	0-150	0.5	0-0.7			TBD	0-100%
	FS1		x			219	0-300	139	0-150	0.5	0-0.7				

7.6 CQL1: Electrical Design

7.6.1.1 Power requirements

The preliminary electrical loads required by CQL1 components were calculated from the steady state analysis of the test requirements. The TDL components were oversized by ~30 percent as mentioned in the Systems Level Process Design. The anticipated electrical requirements within CQL1 are given below:

Table 7-14: Anticipated electrical requirements for CQL1 SG test.

Description	Unit	Value
Condensate pump (PU 3_2.1)	MW	0.009
Total	MW	0.009

In addition to the above mentioned requirements are the power requirements for the measurement instrumentation.

7.6.1.2 One line diagrams

An electrical one-line diagram was drawn up for the CTF as a whole and is given in the global appendix, reference [7-4]. The document number for this one line electrical diagram is: NNGP-CTF-E-WIR-001-2 NNGP CTF.

7.7 CQL1: Future Work

Future work to be done:

- Design and safety issues related to H_2SO_4 decomposition reactor component testing required. The NNGP HPS is made up of seven sub-systems and thus significant design and safety related issues will have to be addressed during the early design stages to ensure legitimate testing of these prototypical components. Revisiting of the HPS design, as it evolves is of paramount importance for the prototypical designs of the H_2SO_4 Decomposition reactor and its associated main components.
- Design and safety issues related to Steam Generator reactor component testing required.
- CFD, FEA and Transient calculations to be done on CQL1 components.
- Optimization of complete system layout especially optimization of HGDs.
- Larger scale circulators could also be tested on the TDL as part of CQL1 testing. Such an option is to be addressed as part of future studies.

7.8 Appendices

7.8.1 Interface Specification / Requirements

In terms of interface requirements for anticipated CQL1 component testing, the following is necessary:

Cooling Water

The maximum continuous cooling water requirements during the two anticipated CQL1 tests are as follows:

- SG test: 3.81 kg/s per TDL at 20°C supply and 45°C return temperature.
- H₂ test: 19.87 kg/s per TDL at 20°C supply and 45°C return temperature.

In terms of the SG test, the following secondary stream water requirement is necessary (de-mineralized water for heat exchange Steam Generator):

- De-mineralized water for steam generator (treated as auxiliary) is 4.65 kg/s. To be heated to 219 °C and to be pressurized to a pressure of 18.3 MPa.

In terms of the SG test, the following tertiary stream cooling water requirements are necessary (cooling water for heat exchange with the condenser, which is treated as an auxiliary):

- 139.0 kg/s at 20°C supply and 45°C return temperature.
- 111.2 kg/s at 20°C supply and 45°C return temperature.

In terms of H₂SO₄ requirements for the H₂SO₄ Decomposition reactor, no specifications / process values have been given.

Electrical Power Requirement

CQL1 requires 9 kW for the Condensate Pump (PU 3_2.1).

HVAC

The estimated heat loss to the environment is 237 kW (at 30°C ambient temperature) per CQL1 test.

Hoisting/Crane requirement

In terms of the HGD (piping), the weight is:

- 442.2 kg per meter. This is only the weight of the pressure boundary pipe and does not include the weight of the insulation and flow liners.

In terms of the Hot and Cold Headers (similar in current preconceptual design), the weight is:

- 1620.5 kg per vessel half. This is only the weight of the vessel (pressure boundary) and does not include the insulation material.
- 742.3 kg per elliptical head. This is only the weight of the vessel (pressure boundary) and does not include the insulation material.
- 442.2 kg per meter for the nozzles extending from the Hot/Cold Header. This is only the weight of the pressure boundary pipe and does not include the weight of the insulation and flow liners.

In terms of hoisting or crane requirements, the top half of the Hot/Cold Header vessel is 2805 kg. This includes two 0.5 m nozzles.

Physical space requirement

CQL1 will have the following approximate space requirements:

- CQL 1 HGDs and Hot and Cold Headers will require approximately 5m x 40m x 6m (w x l x h – see Figure 7-23).

In terms of physical space requirements of the two anticipated UUTs, the following can be postulated:

- SG Test Station Reactor Vessel with following dimensions:
 - $\varnothing = 3$ to 5m (dependent on prototypical design).
 - Height = 10 – 12m.
- SG test space requirements:
 - Dependent on prototypical reactor design.
 - Possible footprint size = 20m x 36m x 15m (w x l x h).
 - Anticipated location is next to the two TDLs within the CTF building.
- Condenser in secondary stream of SG test will have vessel dimensions similar to that of the SG Test Station Vessel dimensions due to its similarity in heat duty size. Design could be of U-tube exchanger type.
- H₂SO₄ Decomposition Reactor Vessel with following dimensions:
 - $\varnothing = 3$ to 5m (dependent on proto-typical design).

- Height = 10 – 12m.
- H₂SO₄ Decomposition Reactor test space requirements:
 - Dependent on prototypical reactor design and its associated main components i.e. Sulfuric Acid Concentrator, SO_x Cooler, SO₂ Absorbers and Electrolyzers. The Decomposition Reactor together with all its associated main components are treated as auxiliaries in this pre-conceptual design report.
 - Possible footprint size = 20m x 36m x 15m (w x l x h).
 - Best anticipated location is next to the CTF building due to safety concerns with the production of H₂.

7.9 References

- [7-1] “NGNP Technology Development Road Mapping Report,” NNGP-CTF MTECH-TDRM.
- [7-2] “NGNP Technology Development Road Mapping Report,” NNGP-CTF MTECH-TDRM-009_Rev1.
- [7-3] “NGNP and Hydrogen Production Conceptual Design Study. NNGP Technology Development Road Mapping Report; Section 9: Power Conversion System Steam Generator,” December 2008; NNGP-CTF MTECH –TDRM-009_Rev1.
- [7-4] “NNGP-CTF-E-WIR-001-2 NNGP,” CTF Electrical One-Line Diagram.

7.10 Appendices: Supporting Documentation

- [7-5] Appendix A: Steam Generator Calculation Sheet
- [7-6] Appendix B: H₂SO₄ Decomposition Reactor Calculation Sheet
- [7-7] Appendix C: Cooling Water Requirements Calculation Sheet
- [7-8] Appendix D: Hot Gas Ducts Calculation Sheet
- [7-9] Appendix E: Building Block Calculation Sheet
- [7-10] Appendix F: SG Tertiary Cooling Water Requirements Calculation Sheet
- [7-11] Appendix G: PFD and P&ID Drawings
- [7-12] Appendix H: Hot Header Component Specification Sheet
- [7-13] Appendix I: Cold Header Component Specification Sheet
- [7-14] Appendix J: CQL1 Hot Gas Duct(s) Component Specification Sheet
- [7-15] Appendix K: Mechanical Design – CQL1 Design Components Calculation Sheet

Appendix A



M - T e c h
i n d u s t r i a l

***Attachment to Section 7: Component Qualification
Loop (CQL1)
Appendix A Thermal Hydraulic Calculations for the
Steam Generator Test***

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B J Nel

November 2008

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Change Forecast

The document format and contents have been approved.

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1. Objective:

To calculate the helium mass flow and subsequent component heat duties on a single primary loop TDL during the anticipated Steam Generator (SG) test taking into consideration that the primary loop TDL Heater (HT 2A_1.1) has a thermal power of 6.16 MW.

2. Methodology:

2.1. APPROACH

- The Helium mass-flow for the SG CQL1 test is calculated. A thermal heater duty of 6.160 MW is used to calculate the helium mass flow.
- Subsequent component heat duties are determined using the above calculated helium mass flow.
- A numbering sequence for the SG CQL1 test is applied as follows – refer to figures 7.1 – 7.6. This same numbering sequence has been used in the thermal hydraulic calculations to eliminate unnecessary confusion.
 - ▶ (1) Between CQL1 Hot Header (HH 3_1.1) and CQL1 SG test station (TS 3_1.1).
 - ▶ (2) Between SG test station (TS 3_1.1) and CQL1 Cold Header (CH 3_1.1).
 - ▶ (3) Between CQL1 Cold Header (CH 3_1.1) and TDL recuperator (RX 2A_1.1).
 - ▶ (4) Between TDL recuperator (RX 2A_1.1) and TDL cooler (CL 2A_1.1).
 - ▶ (5) Between TDL cooler (CL 2A_1.1) and TDL circulator (CR 2A_1.1).
 - ▶ (6) Between TDL circulator (CR 2A_1.1) and TDL recuperator (RX 2A_1.1).
 - ▶ (7) Between TDL recuperator (RX 2A_1.1) and TDL Heater (HT 2A_1.1).
 - ▶ (8) Between TDL heater (HT 2A_1.1) and CQL1 Hot Header (HH 3_1.1).
- Steady state process conditions are assumed.
- Make use of appropriate assumptions for thermal hydraulic calculations.

2.2. COMPUTER PROGRAMS

The computer program used is Engineering Equation Solver® (EES).

3. Inputs and Assumptions:

3.1. ASSUMPTIONS:

- No heat loss is assumed across both the TDL and CQL1 circuits.
- Kinetic and potential energies are negligible, thus $ke \cong pe \cong 0$.
- Recuperator efficiency (η_{RX}) = 80 %.
- Heater efficiency i.e. electrical to thermal output (η_{HT}) = 90 %.

3.2. INPUTS:

- Helium inlet temperature at CQL1 SG test station (TS 3_1.1) = 900 °C.
- Helium outlet temperature at CQL1 SG test station (TS 3_1.1) = 273 °C.
- Helium inlet pressure at CQL1 SG test station (TS 3_1.1) = 8.7 MPa.
- Helium outlet pressure at CQL1 SG test station (TS 3_1.1) = 8.6 MPa.

- TDL Heater (HT 2A_1.1) thermal power = 6.160 MW.

4. Equations Used and Calculations:

See attached EES calculation sheet.

5. Results:

See attached EES calculation sheet.

6. Conclusions:

The following conclusions can be made regarding the helium mass flow and subsequent component heat duties on a single primary loop TDL during the anticipated Steam Generator (SG) test. It is important to note that two TDLs need to be operational for the CQL1 SG test to be performed to obtain a heat duty on the SG of ~ 11.6 MW. Process values given for each of the components are given per single TDL.

- $m_{SG} = 1.786 \text{ kg/s}$
- $Q_{RX\ 2A\_1.1} = 1.393 \text{ MW thermal (Recuperator Heat Duty)}$
- $Q_{CL\ 2A\_1.1} = 0.395 \text{ MW thermal (Cooler Heat Duty)}$
- $Q_{CR\ 2A\_1.1} = 0.046 \text{ MW thermal (Circulator Power)}$
- $Q_{HT\ 2A\_1.1} = 6.160 \text{ MW thermal (Heater Thermal Power)}$
- $Q_{TS\ 3\_1.1} = 11.620 \text{ MW thermal (Steam Generator Test Unit Heat Duty)}$

All of the above heat duties as well as the helium mass flow rate are well within the maximum design limits of the TDLs.

A simple heat balance for the SG test reveals the following:

Table 6-1: Simple Heat Balance of the anticipated CQL1 SG Test

Component	Heat IN (MW _{th})	Heat OUT (MW _{th})
Heater (HT 2A_1.1) x 2	12.320	-
Cooler (CL 2A_1.1) x 2	-	0.790
Circulator (CR 2A_1.1) x 2	0.092	-
SG Test Unit (TS 3_1.1) x 1	-	11.623
Total	12.412	12.413

The recuperator (RX 2A_1.1) exchanges an equal amount of heat of 1.393 MW between shell and tube.

Attachment A

Attachment of Formatted EES Sheet (CQL1_TDL_Steam Generator.EES) to Section 7, Appendix
A: Component Qualification Loop (CQL1)

*CQL1_{TDL} Cooler Thermal Fluid Calculations for Steam Generator Test**This is an attachment to MT-TLDR-CAL-F-T-0701**Assumptions Units Reference / Description*

=====

Inputs/Assumptions (as per NGNP-RM-RPT-09) Units Reference / Description

=====

$$T_{He1} = 900 \text{ [C]} \text{ Helium SG maximum test temperature}$$

$$T_{He2} = 273 \text{ [C]} \text{ Recuperator hot side inlet temperature during SG test}$$

$$T_{He3} = T_{He2} \text{ Same temperature as } T_{He2}; \text{ half the mass flow}$$

$$T_{He4} = T_{He3} - [T_{He3} - T_{He6}] \cdot RX_{Eff} \text{ Recuperator hot side outlet temperature during SG test}$$

$$T_{He5} = 80 \text{ [C]} \text{ Cooler outlet temperature during SG test}$$

$$T_{He6} = 85 \text{ [C]} \text{ Recuperator cold side inlet temperature during SG test}$$

$$T_{He7} = T_{He6} + [T_{He3} - T_{He6}] \cdot RX_{Eff} \text{ Recuperator cold side outlet temperature during SG test}$$

$$T_{He8} = T_{He1} \text{ Same temperature as } T_{He1}; \text{ half the mass flow}$$

$$P_{He1} = 8700 \text{ [kPa]} \text{ Helium SG test Recuperator cold side outlet pressure}$$

$$P_{He2} = 8600 \text{ [kPa]} \text{ Helium SG test Recuperator hot side inlet pressure}$$

$$RX_{Eff} = 0.8 \text{ Recuperator Efficiency}$$

$$Q_{HT} = 6160 \text{ [kW]} \text{ Heater Power - not including 30\% overcapacity}$$

$$P_{He3} = P_{He2} \quad P_{He4} = P_{He2} \quad P_{He5} = P_{He2} \text{ Pressure differentials over TDL components are considered to be negligible}$$

$$P_{He6} = P_{He2} \quad P_{He7} = P_{He2} \quad P_{He8} = P_{He1} \text{ Pressure differentials over TDL components are considered to be negligible}$$

Fluid Properties Units Reference / Description

=====

$$h_{He1} = h \text{ ['Helium', } T = T_{He1}, P = P_{He1} \text{]}$$

$$h_{He2} = h \text{ ['Helium', } T = T_{He2}, P = P_{He2} \text{]}$$

$$h_{He3} = h \text{ ['Helium', } T = T_{He3}, P = P_{He3} \text{]}$$

$$h_{He4} = h \text{ ['Helium', } T = T_{He4}, P = P_{He4} \text{]}$$

$$h_{He5} = h \text{ ['Helium', } T = T_{He5}, P = P_{He5} \text{]}$$

$$h_{He6} = h \left[\text{'Helium'} , T = T_{He6} , P = P_{He6} \right]$$

$$h_{He7} = h \left[\text{'Helium'} , T = T_{He7} , P = P_{He7} \right]$$

$$h_{He8} = h \left[\text{'Helium'} , T = T_{He8} , P = P_{He8} \right]$$

Equations and calculations

$$m_{HeSG} = \frac{Q_{HT}}{h_{He8} - h_{He7}} \text{ kg/s } \text{Maximum achievable helium mass flow per TDL during SG test - based on 6.16 MW Heater}$$

$$m_{HeSG,CQL} = m_{HeSG} \cdot 2$$

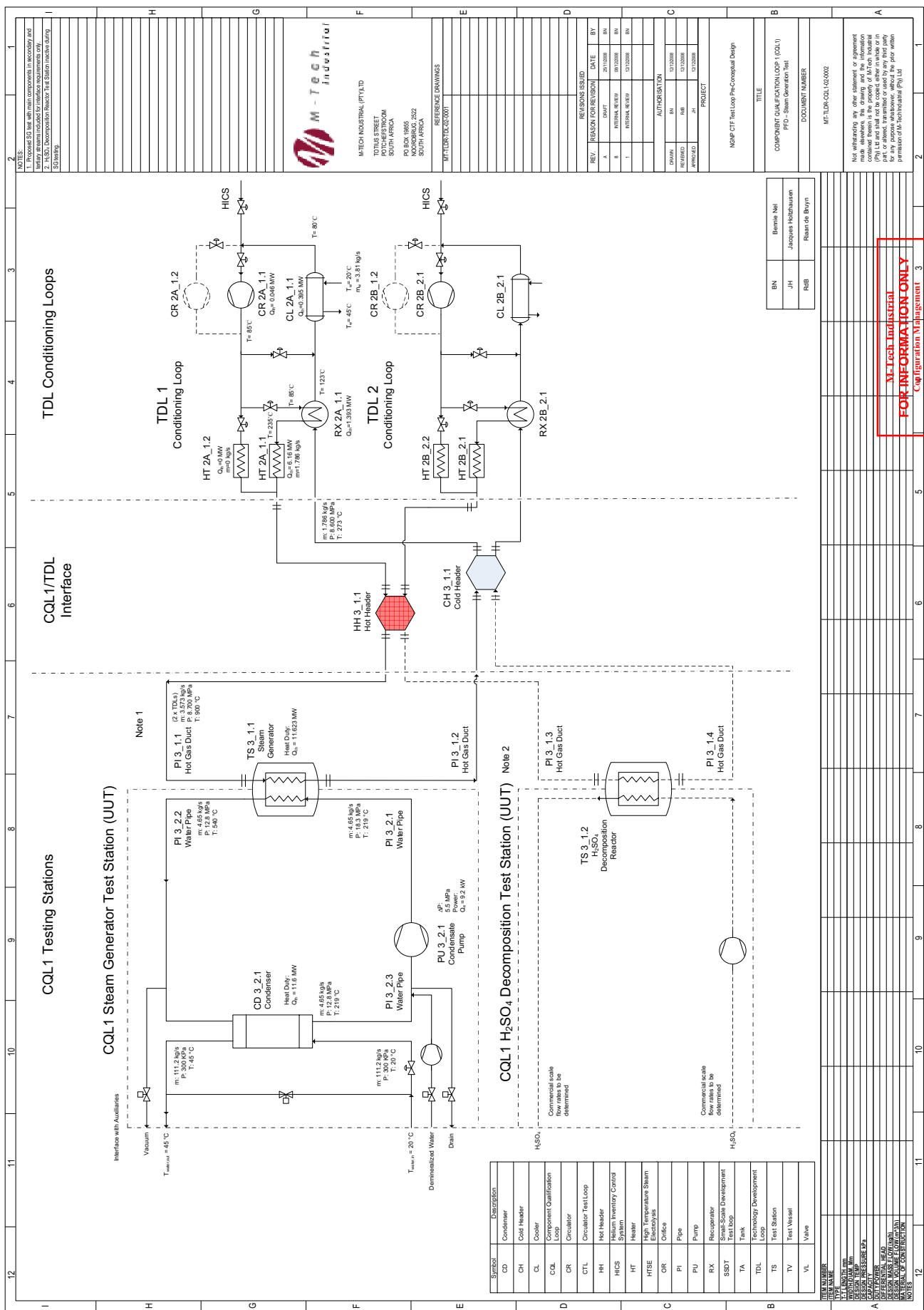
$$Q_{RX,SG} = m_{HeSG} \cdot [h_{He3} - h_{He4}] \text{ kW } \text{Recuperator heat duty during SG test}$$

$$Q_{CL,SG} = m_{HeSG} \cdot [h_{He4} - h_{He5}] \text{ kW } \text{Cooler heat duty during SG test}$$

$$Q_{CR,SG} = m_{HeSG} \cdot [h_{He6} - h_{He5}] \text{ kW } \text{Circulator heat added during SG test}$$

$$Q_{RX2,SG} = m_{HeSG} \cdot [h_{He7} - h_{He6}] \text{ kW } \text{Recuperator heat duty during SG test - double check}$$

$$Q_{SG,Test,Unit} = m_{HeSG,CQL} \cdot [h_{He1} - h_{He2}] \text{ kW } \text{Possible heat duty for prototype Steam Generator test unit. NB: 2 x TDLs are used for this test}$$



Appendix B



M - T e c h
i n d u s t r i a l

***Attachment to Section 7: Component Qualification
Loop (CQL1)
Appendix B Thermal Hydraulic Calculations for the
H₂SO₄ Decomposition Reactor Test***

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Attachment to Section 7: Component Qualification
 Loop (CQL1) Appendix B Thermal Hydraulic
 Calculations for the H₂SO₄ Decomposition Reactor
 Test

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Change Forecast

The document format and contents have been approved.

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1. Objective:

To calculate the helium mass flow and subsequent component heat duties on a single primary loop TDL during the anticipated H₂SO₄ Decomposition Reactor (H2) test taking into consideration that the primary loop TDL Heater (HT 2A_1.1) has a thermal power of 6.16 MW.

2. Methodology:

2.1. APPROACH

- The Helium mass-flow for the H2 CQL1 test is to be calculated. A thermal heater duty of 6.160 MW is used to calculate the helium mass flow.
- Subsequent component heat duties are determined using the above calculated helium mass flow.
- A numbering sequence for the H2 CQL1 test is applied as follows – refer to figures 7.1 – 7.5. This same numbering sequence has been used in the thermal hydraulic calculations to eliminate unnecessary confusion.
 - (9) Between CQL1 Hot Header (HH 3_1.1) and CQL1 H2 test station (TS 3_1.2).
 - (10) Between H2 test station (TS 3_1.2) and CQL1 Cold Header (CH 3_1.1).
 - (11) Between CQL1 Cold Header (CH 3_1.1) and TDL recuperator (RX 2A_1.1).
 - (12) Between TDL recuperator (RX 2A_1.1) and TDL cooler (CL 2A_1.1).
 - (13) Between TDL cooler (CL 2A_1.1) and TDL circulator (CR 2A_1.1).
 - (14) Between TDL circulator (CR 2A_1.1) and TDL recuperator (RX 2A_1.1).
 - (15) Between TDL recuperator (RX 2A_1.1) and TDL Heater (HT 2A_1.1).
 - (16) Between TDL heater (HT 2A_1.1) and CQL1 Hot Header (HH 3_1.1).
- Steady state process conditions are assumed.
- Make use of appropriate assumptions for thermal hydraulic calculations.

2.2. COMPUTER PROGRAMS

The computer program used is Engineering Equation Solver® (EES).

3. Inputs and Assumptions:

3.1. ASSUMPTIONS:

- No heat loss is assumed across both the TDL and CQL1 circuits.
- Kinetic & Potential energies are negligible, thus $ke \cong pe \cong 0$.
- Recuperator efficiency (η_{RX}) = 80 %.
- Heater efficiency i.e. electrical to thermal output (η_{HT}) = 90 %.

3.2. INPUTS:

- Helium inlet temperature at CQL1 H2 test station (TS 3_1.2) = 900 °C.
- Helium outlet temperature at CQL1 H2 test station (TS 3_1.2) = 659 °C.
- Helium inlet pressure at CQL1 H2 test station (TS 3_1.2) = 8.934 MPa.
- Helium outlet pressure at CQL1 H2 test station (TS 3_1.2) = 8.734 MPa.
- TDL Heater (HT 2A_1.1) thermal power = 6.160 MW.

4. Equations Used and Calculations:

See attached EES calculation sheet.

5. Results:

See attached EES calculation sheet.

6. Conclusions:

The following conclusions can be made regarding the helium mass flow and subsequent component heat duties on a single primary loop TDL during the anticipated H₂SO₄ Decomposition Reactor (H2) test. It is important to note that two TDLs need to be operational for the CQL1 H2 test to be performed to obtain a heat duty on the H₂SO₄ Decomposition Reactor of ~ 8.3 MW. Process values given for each of the components are given per single TDL.

- $m_{H_2} = 3.336 \text{ kg/s}$
- $Q_{RX\ 2A\_1.1} = 7.945 \text{ MW thermal (Recuperator Heat Duty)}$
- $Q_{CL\ 2A\_1.1} = 2.072 \text{ MW thermal (Cooler Heat Duty)}$
- $Q_{CR\ 2A\_1.1} = 0.087 \text{ MW thermal (Circulator Power)}$
- $Q_{HT\ 2A\_1.1} = 6.160 \text{ MW thermal (Heater Thermal Power)}$
- $Q_{TS\ 3\_1.2} = 8.346 \text{ MW thermal (H}_2\text{SO}_4\text{ Decomposition Reactor Test Unit Heat Duty)}$

All of the above heat duties as well as the helium mass flow rate are well within the maximum design limits of the TDLs.

A simple heat balance for the H2 test reveals the following:

Table 6-1: Simple Heat Balance of the CQL1 H2 Test

Component	Heat IN (MW _{th})	Heat OUT (MW _{th})
Heater (HT 2A_1.1) x 2	12.320	-
Cooler (CL 2A_1.1) x 2	-	4.144
Circulator (CR 2A_1.1) x 2	0.173	-
H2 Test Unit (TS 3_1.1) x 1	-	8.346
Total	12.493	12.490

The recuperator (RX 2A_1.1) exchanges an equal amount of heat of 7.945 MW between shell and tube.

Attachment A

Attachment of Formatted EES Sheet (CQL1_TDL_H2 Production.EES) to Section 7, Appendix A:
Component Qualification Loop (CQL1)

*CQL1_{TDL} Cooler Thermal Fluid Calculations for H2 Production Test**This is an attachment to MT-TLDR-CAL-F-T-0702**Assumptions Units Reference / Description*

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Inputs/Assumptions (as per H2 Production Test) Units Reference / Description

=====

$$T_{\text{He9}} = 900 \text{ [C] } \text{Helium H2 maximum test temperature}$$

$$T_{\text{He10}} = 659 \text{ [C] } \text{Recuperator hot side inlet temperature during H2 test}$$

$$T_{\text{He11}} = T_{\text{He10}} \text{ Same temperature as } T_{\text{He10}}, \text{ half the mass flow}$$

$$T_{\text{He12}} = T_{\text{He11}} - [T_{\text{He11}} - T_{\text{He14}}] \cdot \text{RX}_{\text{Eff}} \text{ Recuperator hot side outlet temperature during H2 test}$$

$$T_{\text{He13}} = 80 \text{ [C] } \text{Cooler outlet temperature during H2 test}$$

$$T_{\text{He14}} = 85 \text{ [C] } \text{Recuperator cold side inlet temperature during H2 test}$$

$$T_{\text{He15}} = T_{\text{He14}} + [T_{\text{He11}} - T_{\text{He14}}] \cdot \text{RX}_{\text{Eff}} \text{ Recuperator cold side outlet temperature during H2 test}$$

$$T_{\text{He16}} = T_{\text{He9}} \text{ Same temperature as } T_{\text{He9}}, \text{ half the mass flow}$$

$$P_{\text{He9}} = 8934 \text{ [kPa] } \text{Helium H2 test inlet pressure}$$

$$P_{\text{He10}} = 8734 \text{ [kPa] } \text{Helium H2 test outlet pressure}$$

$$\text{RX}_{\text{Eff}} = 0.8 \text{ Recuperator Efficiency}$$

$$Q_{\text{HT}} = 6160 \text{ [kW] } \text{Heater Power - not including 30\% overcapacity}$$

$$P_{\text{He11}} = P_{\text{He10}} \quad P_{\text{He12}} = P_{\text{He10}} \quad P_{\text{He13}} = P_{\text{He10}} \text{ Pressure differentials over TDL components are considered to be negligible}$$

$$P_{\text{He14}} = P_{\text{He10}} \quad P_{\text{He15}} = P_{\text{He10}} \quad P_{\text{He16}} = P_{\text{He9}} \text{ Pressure differentials over TDL components are considered to be negligible}$$

Fluid Properties Units Reference / Description

=====

$$h_{\text{He9}} = h \text{ ['Helium' , } T = T_{\text{He9}} \text{ , } P = P_{\text{He9}} \text{]}$$

$$h_{\text{He10}} = h \text{ ['Helium' , } T = T_{\text{He10}} \text{ , } P = P_{\text{He10}} \text{]}$$

$$h_{\text{He11}} = h \text{ ['Helium' , } T = T_{\text{He11}} \text{ , } P = P_{\text{He11}} \text{]}$$

$$h_{\text{He12}} = h \text{ ['Helium' , } T = T_{\text{He12}} \text{ , } P = P_{\text{He12}} \text{]}$$

$$h_{\text{He13}} = h \text{ ['Helium' , } T = T_{\text{He13}} \text{ , } P = P_{\text{He13}} \text{]}$$

$$h_{He14} = h \left[\text{'Helium'}, T = T_{He14}, P = P_{He14} \right]$$

$$h_{He15} = h \left[\text{'Helium'}, T = T_{He15}, P = P_{He15} \right]$$

$$h_{He16} = h \left[\text{'Helium'}, T = T_{He16}, P = P_{He16} \right]$$

Equations and calculations

$$m_{HeH2} = \frac{Q_{HT}}{h_{He16} - h_{He15}} \text{ kg/s } \text{Maximum achievable helium mass flow per TDL during SG test - based on 6.16 MW Heater}$$

$$m_{HeH2,CQL} = m_{HeH2} \cdot 2$$

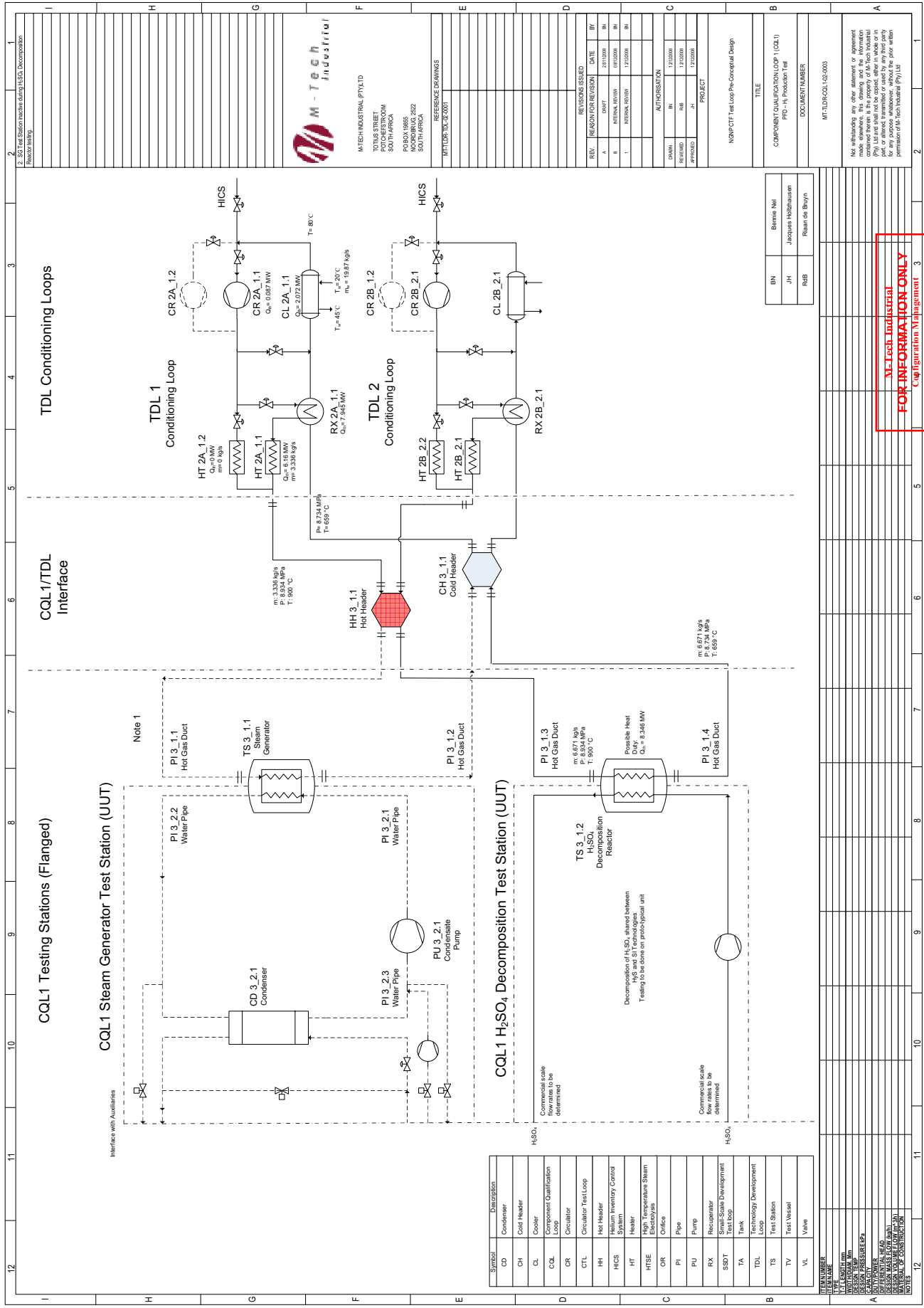
$$Q_{RX,H2} = m_{HeH2} \cdot [h_{He11} - h_{He12}] \text{ kW } \text{Recuperator heat duty during SG test}$$

$$Q_{CL,H2} = m_{HeH2} \cdot [h_{He12} - h_{He13}] \text{ kW } \text{Cooler heat duty during SG test}$$

$$Q_{CR,H2} = m_{HeH2} \cdot [h_{He14} - h_{He13}] \text{ kW } \text{Circulator heat added during SG test}$$

$$Q_{RX2,H2} = m_{HeH2} \cdot [h_{He15} - h_{He14}] \text{ kW } \text{Recuperator heat duty during SG test - double check}$$

$$Q_{H2,Test,Unit} = m_{HeH2,CQL} \cdot [h_{He9} - h_{He10}] \text{ kW } \text{Possible heat duty for prototype Steam Generator test unit. NB: 2 x TDLs are used for this test}$$



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Appendix C



M - T e c h
i n d u s t r i a l

***Attachment to Section 7: Component Qualification
Loop (CQL1)
Appendix C Thermal Hydraulic Calculations for
CQL1 Cooling Water Requirements***

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Change Forecast

The document format and contents have been approved.

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1. Objective:

To calculate the cooling water requirement on coolers CL 2A_1.1 and CL 2B_1.1 during anticipated CQL1 component test runs. Two TDL primary loops are necessary to run CQL1. Values on the cooling water requirements are given for 1 TDL only.

2. Methodology:

2.1. APPROACH

- Helium mass-flows for each of the two anticipated CQL1 tests (SG & H2) are used as calculated. A thermal heater duty of 6.160 MW was used to calculate the respective cooling water mass flows. Cooling water to exchange heat with the high temperature helium stream.
- Use steady state Thermodynamic calculations.
- Make use of appropriate assumptions for thermal hydraulic calculations.

2.2. COMPUTER PROGRAMS

The computer program used is Engineering Equation Solver© (EES).

3. Inputs and Assumptions:

3.1. ASSUMPTIONS:

- No heat loss is assumed across primary TDL Cooler.
- Kinetic & Potential energies are negligible, thus $ke \cong pe \cong 0$.
- Cooling water inlet and outlet temperatures are assumed to be 20 °C and 45 °C respectively.
- Cooling water pressure assumed to be 120 kPa.
- Cooler efficiency (η_{CL}) = 100 %.

3.2. INPUTS:

- Mass-flow of 1 x TDL is assumed to be 1.786 kg/s for the Steam Generator (SG) CQL1 test. This mass flow is based on the following:
 - ▶ Helium inlet temperature at heater (HT 2A_1.1) = 235 °C.
 - ▶ Helium outlet temperature at heater (HT 2A_1.1) = 900 °C.
 - ▶ Helium pressure at heater (HT 2A_1.1) inlet = 8.60 Mpa.
 - ▶ Heater (HT 2A_1.1) thermal power = 6.158 MW.
 - ▶ No heat loss assumed across system.
- Mass-flow of 1 x TDL is assumed to be 3.336 kg/s for Hydrogen H₂SO₄ Decomposition Reactor (H2) CQL1 test. This mass flow is based on the following:

- ▶ Helium inlet temperature at heater (HT 2A_1.1) = 544 °C.
- ▶ Helium outlet temperature at heater (HT 2A_1.1) = 900 °C.
- ▶ Helium pressure at heater (HT 2A_1.1) inlet = 8.734 Mpa.
- ▶ Heater (HT 2A_1.1) thermal power = 6.158 MW.

4. Equations Used and Calculations:

See attached EES calculation sheet.

5. Results:

See attached EES calculation sheet.

6. Conclusions:

The cooling water requirements for the two anticipated CQL1 tests are as follows:

- 3.81 kg/s for the SG test.
- 19.86 kg/s for the H₂SO₄ Decomposition Reactor test.
- The above values are enveloped by the TDL Cooler component (CL 2A_1.1 & CL 2B_1.1) design, which is 61.1 kg/s.

Attachment A

Attachment of Formatted EES Sheet (CQL1_TDL_Cooling Water.EES) to Section 7, Appendix A:
Component Qualification Loop (CQL1)

*CQL1_{TDL} Cooler Thermal Fluid Calculations**This is an attachment to MT-TLDR-CAL-F-T-0703**Assumptions Units Reference / Description*

=====

*No heat loss is assumed across primary TDL Cooler.**Kinetic & Potential energies are negligible, thus $ke = pe = 0$.**Cooling water inlet and outlet temperatures are assumed to be 20 °C and 45 °C respectively.**Cooling water pressure assumed to be 120 kPa.**Cooler efficiency (CL) = 100 %.**Inputs (as per CQL_{TDL} SG Thermal Fluid Calculations)Units Reference / Description*

=====

 $T_{He,SGin} = 123$ [C] *Helium temperature at cooler inlet during SG test* $T_{He,SGout} = 80$ [C] *Assumed helium temperature (design temperature) at cooler outlet during SG test* $P_{He,SGin} = 8600$ [kPa] *Helium pressure at cooler inlet during SG test* $P_{He,SGout} = 8600$ [kPa] *Helium pressure at cooler outlet during SG test* $T_{CW1} = 20$ [C] *Cooling water inlet temperature - both SG and H2 tests* $T_{CW2} = 45$ [C] *Cooling water outlet temperature - both SG and H2 tests* $P_{CW1} = 120$ [kPa] *Cooling water inlet pressure - both SG and H2 tests* $P_{CW2} = 120$ [kPa] *Cooling water outlet pressure - both SG and H2 tests**Inputs (as per H2 Production Test)Units Reference / Description*

=====

 $T_{He,H2in} = 200$ [C] *Cooler Inlet Temperature during H2 test* $T_{He,H2out} = 80$ [C] *Assumed cooler outlet temperature (design temperature) during H2test* $P_{He,H2in} = 8934$ [kPa] *Cooler Inlet Pressure during H2 test* $P_{He,H2out} = 8734$ [kPa] *Cooler Outlet Pressure during H2 test**Inputs / Assumptions - Additional Units Reference / Description*

=====

 $CL_{Eff} = 1$ *Cooler Efficiency*

$$m_{\text{HeSG}} = \frac{6160}{h_{\text{He,SG8}} - h_{\text{He,SG7}}} \quad \text{kg/s} \quad \text{Helium mass flow as calculated for SG test}$$

$$m_{\text{HeH2}} = \frac{6160}{h_{\text{He,H2,16}} - h_{\text{He,H2,15}}} \quad \text{kg/s} \quad \text{Helium mass flow as calculated for H2 test}$$

$$h_{\text{He,SGin}} = h \left[\text{'Helium'}, T = T_{\text{He,SGin}}, P = P_{\text{He,SGin}} \right]$$

$$h_{\text{He,SGout}} = h \left[\text{'Helium'}, T = T_{\text{He,SGout}}, P = P_{\text{He,SGout}} \right]$$

$$h_{\text{He,H2in}} = h \left[\text{'Helium'}, T = T_{\text{He,H2in}}, P = P_{\text{He,H2in}} \right]$$

$$h_{\text{He,H2out}} = h \left[\text{'Helium'}, T = T_{\text{He,H2out}}, P = P_{\text{He,H2out}} \right]$$

$$h_{\text{CW1}} = h \left[\text{'Water'}, T = T_{\text{CW1}}, P = P_{\text{CW1}} \right]$$

$$h_{\text{CW2}} = h \left[\text{'Water'}, T = T_{\text{CW2}}, P = P_{\text{CW2}} \right]$$

$$T_7 = 235.4 \quad [\text{C}]$$

$$P_7 = 8600 \quad [\text{kPa}]$$

$$T_8 = 900 \quad [\text{C}]$$

$$P_8 = 8700 \quad [\text{kPa}]$$

$$T_{15} = 544.2 \quad [\text{C}]$$

$$P_{15} = 8734 \quad [\text{kPa}]$$

$$T_{16} = 900 \quad [\text{C}]$$

$$P_{16} = 8934 \quad [\text{kPa}]$$

$$h_{\text{He,SG7}} = h \left[\text{'Helium'}, T = T_7, P = P_7 \right]$$

$$h_{\text{He,SG8}} = h \left[\text{'Helium'}, T = T_8, P = P_8 \right]$$

$$h_{\text{He,H2,15}} = h \left[\text{'Helium'}, T = T_{15}, P = P_{15} \right]$$

$$h_{\text{He,H2,16}} = h \left[\text{'Helium'}, T = T_{16}, P = P_{16} \right]$$

Equations and calculations

$$Q_{\text{CL,SG}} = m_{\text{HeSG}} \cdot [h_{\text{He,SGin}} - h_{\text{He,SGout}}]$$

$$Q_{\text{CL,H2}} = m_{\text{HeH2}} \cdot [h_{\text{He,H2in}} - h_{\text{He,H2out}}]$$

$$m_{\text{CW,SG}} = \frac{Q_{\text{CL,SG}}}{h_{\text{CW2}} - h_{\text{CW1}}}$$

$$m_{\text{CW,H2}} = \frac{Q_{\text{CL,H2}}}{h_{\text{CW2}} - h_{\text{CW1}}}$$

Appendix D



M - T e c h
i n d u s t r i a l

***Attachment to Section 7: Component Qualification
Loop (CQL1)
Appendix D Thermal Hydraulic Calculations on
CQL1 HGDs***

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Attachment to Section 7: Component Qualification Loop (CQL1)

Appendix D Thermal Hydraulic Calculations on CQL1 HGDs

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Change Forecast

The document format and contents have been approved.

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1. Objective

To calculate the insulation thickness of the Hot Gas Ducts (HGDs) to be used in CQL1.

2. Methodology

2.1. APPROACH

- Maximum helium mass flow per TDL is used to obtain an inner flow diameter, based on a design velocity of ~ 20 m/s.
- A flow liner thickness of 5 mm is used to determine the inner diameter of the insulation packing.
- Calculations performed to determine the outer diameter of the insulation, subsequently determining the inner pressure boundary to select the appropriate standard pipe size.
- Steady state process conditions are assumed.
- Make use of appropriate assumptions for thermal hydraulic calculations.

2.2. COMPUTER PROGRAMS

The computer program used is Engineering Equation Solver© (EES).

3. Inputs and Assumptions

3.1. ASSUMPTIONS:

- A passively cooled hot gas duct design is used.
- $T_{\text{environment}} = 30\text{ }^{\circ}\text{C}$
- $T_{\text{outer\_surface}} = 200\text{ }^{\circ}\text{C}$
- Radiative heat transfer view factor from pipe surface to environment = 1.
- Radiative environment area is assumed to be infinitely large. This simplifies the radiation heat transfer calculation.

3.2. INPUTS

- Thermal conductivity, $k = 0.5\text{ W/mK}$. This value is based on an assessment of current insulation materials and is a conservative assumption. It is in agreement with results from the HENDEL tests: "Construction and Performance Tests of Helium Engineering Demonstration Loop, (HENDEL) for VHTR, Hishida et al., JAERI, 1984"
- Outside convection heat transfer coefficient, $h_o = 10\text{ W/m}^2\text{.K}$ (Insulation data sheet).

- Liner thickness, $t_{\text{liner}} = 5$ mm, which is a conservative value for the flow liner. High-alloy steel liners could be constructed with a thickness in the order of ~ 1.5 mm.
- Outside surface emissivity, $\epsilon = 0.9$. This is a typical value for a painted surface.
- Pipe section unit length, L taken as 1 m.
- Inside temperature (design temperature), $T_{\text{inside}} = 1000$ °C.
- Thermal expansion coefficient, $\alpha = 12 \times 10^{-6}$ 1/K. Thermal expansion coefficient for high-alloy steels: "Engineering Materials 2; An Introduction to Microstructures, Processing and Design; Michael F Ashby & David R H Jones"

4. Equations used and calculations

See attached EES calculation sheet.

5. Results

See attached EES calculation sheet.

6. Conclusions

The following conclusions can be made regarding the insulation thickness, based on an internal flow liner diameter of 0.26 m, thereby standardizing on the flow liner as well as the pressure boundary dimensions, which is a NPS 24", schedule 80 standard pipe for the latter.

Table 6-1: Velocities of helium gas within the HGDs at process conditions given for the two anticipated CQL1 tests.

Flow Liner Diameter based on max TDL process requirements. $T_{\text{flow liner}} = 0.260$ m	Temperature °C	Density (kg/m ³)	Velocity (m/s)
TDL Hot Piping Sections	950	3.40	19.6
CQL1 Piping to SG Test Station	900	3.54	19.0
CQL1 Piping from SG Test Station	273	7.43	9.1
CQL1 Piping to H2 Test Station	900	3.64	34.6
CQL1 Piping from H2 Test Station	659	4.46	28.2

The velocities to and from the H2 testing station are somewhat on the high side using an internal flow liner diameter of 0.26 m.

Regarding this anticipated test, the flow liner for that particular section, i.e. HGD connected from the Hot Header (HH 3_1.1) to the H2 Test station (TS 3_1.2) as well as the piping running back to the Cold Header (CH 3_1.1) could be enlarged to a value of 0.29 m without affecting the design surface temperature of 200 °C (based on the listed assumptions).

In such a case, the internal helium velocities to and from the H2 testing station are reduced to the following:

Table 6-2: Velocities of helium gas within the HGDs of the H2 CQL1 tests at given process conditions and slightly enlarged Flow Liner Diameter

Enlarged Flow Liner Diameter $T_{\text{flow liner}} = 0.29 \text{ m}$	Temperature °C	Density (kg/m ³)	Velocity (m/s)
CQL1 Piping to H2 Test Station	900	3.64	27.8
CQL1 Piping from H2 Test Station	659	4.46	22.6

It should also be noted that the thermal expansion of the assumed high-alloy steel is 11.6 mm/m for a design temperature of 1000 °C.

A slightly enlarged flow liner diameter has been used for the conditions given in Table 6-2 above.

The pressure boundary (NPS 24", schedule 80 standard pipe) diameter however, has remained the same.

Attachment A

Attachment of Formatted EES Sheet (CQL1_TDL_Hot Gas Ducts.EES to Section 7, Appendix A:
Component Qualification Loop (CQL1)

*CQL1 Hot Gas Duct Calculation**This is an attachment to MT-TLDR-CAL-F-T-0704**Assumptions*

=====

A passively cooled hot gas duct design is used

$$T_{\text{environment}} = 30 \text{ [C]}$$

$$T_{\text{outer,surface}} = 200 \text{ [C]} \text{ Depends on the steel type}$$

*Radiative heat transfer view factor from pipe surface to environment = 1**Radiative Area_{environment} is infinitely large**This simplifies the radiation heat transfer calculation**Inputs Units Reference*

=====

$$k = 0.5 \text{ [W/mK]} \text{ Based on an assessment of current insulation materials, this is a conservative assumption}$$

*It is in agreement with results from the HENDEL tests:**Construction and Performance Tests of Helium Engineering Demonstration Loop (HENDEL) for VHTR, Hishida et al., JAERI, 1984*

$$h_{\text{outside,convection}} = 10 \text{ [W/m}^2\text{K]} \text{ Insulation data sheet}$$

$$\text{Thickness}_{\text{liner}} = 0.005 \text{ [m]} \text{ Conservative value for flow liner; High-alloy steel liners could be in range of 1.5 mm}$$

$$d_{\text{HGD,outside,liner}} = 0.27 \text{ [m]} \text{ Outside diameter of flow liner}$$

$$d_{\text{HGD,inside,liner}} = d_{\text{HGD,outside,liner}} - 2 \cdot \text{Thickness}_{\text{liner}} \text{ Inside diameter of flow liner}$$

$$d_{\text{HGD,inside,liner,enl}} = 0.29 \text{ [m]} \text{ Enlarged inside diameter to allow for decrease in the gas velocity for H2 HGD piping - Pressure boundary stays the same, i.e. NPS 24 inch, schedule 80}$$

$$\text{emissivity}_{\text{outside}} = 0.9 \text{ [-]} \text{ Typical for a painted surface}$$

$$L = 1 \text{ [m]} \text{ Pipe section unit length}$$

$$T_{\text{inside}} = 1000 \text{ [C]}$$

$$\alpha_{\text{ss}} = 12 \cdot 10^{-6} \cdot 1 \text{ [1/K]} \text{ Thermal expansion coefficient for high-alloy steels, Engineering Materials 2; An Introduction to Microstructures, Processing and Design; Michael F Ashby & David R H Jones}$$

Equations

=====

$$A_{\text{per,meter}} = \pi \cdot d_{\text{outside}} \cdot L \text{ Outside area of a cylinder}$$

$$T1 = T_{\text{environment}} + 273$$

$$T2 = T_{\text{outer,surface}} + 273$$

$$h_{\text{outside,radiation}} = 5.670\text{E-}08 \text{ [W/m}^2\text{-K}^4] \cdot [T1 + T2] \cdot \left[\frac{T1^2 + T2^2}{\frac{1 + \text{emissivity}_{\text{outside}}}{\text{emissivity}_{\text{outside}}} + 1} \right]$$

Heat and Mass Transfer, Incropera and De Witt, Fifth Edition, 2002

The following two simultaneous equations solve for the variables $Q_{\text{per,meter}}$ and d_{outside}

$$Q_{\text{per,meter}} = [h_{\text{outside,convection}} + h_{\text{outside,radiation}}] \cdot A_{\text{per,meter}} \cdot [T_{\text{outer,surface}} - T_{\text{environment}}]$$

Heat and Mass Transfer, Incropera and De Witt, Fifth Edition, 2002

$$Q_{\text{per,meter}} = k \cdot 2 \cdot \pi \cdot \frac{L}{\ln \left[\frac{d_{\text{outside}}}{d_{\text{HGD,outside,liner}}} \right]} \cdot [T_{\text{inside}} - T_{\text{outer,surface}}]$$

Heat and Mass Transfer, Incropera and De Witt, Fifth Edition, 2002

Thermal strain & expansion calculations

$$\text{Thermal}_{\text{Strain,ss}} = \alpha_{\text{ss}} \cdot [T_{\text{inside}} - T_{\text{environment}}]$$

Velocity Calculations

$$\text{Area}_{\text{inside,TDL,design}} = \pi \cdot \frac{d_{\text{HGD,inside,liner}}^2}{4}$$

$$\text{Area}_{\text{inside,enlarged}} = \pi \cdot \frac{d_{\text{HGD,inside,liner,enl}}^2}{4}$$

Maximum and minimum Process Conditions during SG test

$$T_{\text{He1}} = 900 \text{ [C] Helium SG maximum Test Temperature}$$

$$T_{\text{He2}} = 273 \text{ [C] Helium SG Test Station Outlet Temperature}$$

$$P_{\text{He1}} = 8700 \text{ [kPa] Helium SG Test Station Inlet pressure}$$

$$P_{\text{He2}} = 8600 \text{ [kPa] Helium SG Test Station Outlet Pressure}$$

$$\rho_{\text{He1}} = \rho \text{ ['Helium', } T = T_{\text{He1}}, P = P_{\text{He1}}]$$

$$\rho_{\text{He2}} = \rho \text{ ['Helium', } T = T_{\text{He2}}, P = P_{\text{He2}}]$$

Maximum and minimum Process Conditions during H2 test

$$T_{\text{He7}} = 900 \text{ [C] Helium H2 maximum Test Temperature}$$

$$T_{\text{He8}} = 659 \text{ [C] Helium H2 Test Station Outlet Temperature}$$

$$P_{\text{He7}} = 8934 \text{ [kPa] Helium H2 Test Station Inlet Pressure}$$

$$P_{He8} = 8734 \text{ [kPa] Helium H2 Test Station Outlet Pressure}$$

$$\rho_{He7} = \rho \left[\text{'Helium'} , T = T_{He7} , P = P_{He7} \right]$$

$$\rho_{He8} = \rho \left[\text{'Helium'} , T = T_{He8} , P = P_{He8} \right]$$

$$T_{He,max} = 950 \text{ [C]}$$

$$P_{He,max} = 9000 \text{ [kPa]}$$

$$\rho_{TDL,max} = \rho \left[\text{'Helium'} , T = T_{He,max} , P = P_{He,max} \right]$$

$$m_{CQL,SG} = 1.786 \cdot 2 \text{ kg/s From MT-TLDR-CALC-F-T-0701}$$

$$m_{CQL,H2} = 3.336 \cdot 2 \text{ kg/s From MT-TLDR-CALC-F-T-0702}$$

$$m_{TDL,max} = 3.65 \text{ kg/s From MT-TLDR-CALC-F-T-0601}$$

$$velocity_{He1} = \frac{m_{CQL,SG}}{\rho_{He1} \cdot Area_{inside,TDL,design}} \text{ Velocity of He at inlet of SG test station with 0.26 m internal flow liner}$$

$$velocity_{He2} = \frac{m_{CQL,SG}}{\rho_{He2} \cdot Area_{inside,TDL,design}} \text{ Velocity of He at outlet of SG test station with 0.26 m internal flow liner}$$

$$velocity_{He7} = \frac{m_{CQL,H2}}{\rho_{He7} \cdot Area_{inside,TDL,design}} \text{ Velocity of He at inlet of H2 test station with 0.26 m internal flow liner}$$

$$velocity_{He8} = \frac{m_{CQL,H2}}{\rho_{He8} \cdot Area_{inside,TDL,design}} \text{ Velocity of He at outlet of H2 test station with 0.26 m internal flow liner}$$

$$velocity_{He7,enl} = \frac{m_{CQL,H2}}{\rho_{He7} \cdot Area_{inside,enlarged}} \text{ Velocity of He at inlet of H2 test station with 0.29 m internal flow liner}$$

$$velocity_{He8,enl} = \frac{m_{CQL,H2}}{\rho_{He8} \cdot Area_{inside,enlarged}} \text{ Velocity of He at outlet of H2 test station with 0.29 m internal flow liner}$$

$$velocity_{TDL,max} = \frac{m_{TDL,max}}{\rho_{TDL,max} \cdot Area_{inside,TDL,design}} \text{ Velocity of He at inlet of SG test station with 0.26 m internal flow liner}$$

Appendix E



M - T e c h
i n d u s t r i a l

***Attachment to Section 7: Component Qualification
Loop (CQL1)
Appendix E Thermal Hydraulic Calculations to
Determine Maximum TDL Thermal Heater Power***

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1. Objective

To calculate the maximum attainable heating capacity per TDL and subsequently per CQL1 using the 3 x IHX A test specification as basis for TDL component testing.

2. Methodology

2.1. APPROACH

Assuming steady state conditions and using basic thermodynamic equations, the following logical steps of events were used to obtain enveloping process parameters for CQL1.

- From the 3 x IHX A test specification, using a recuperator efficiency of 80 %, a heat duty of 3600 kW on the 3 x IHX A test station, the maximum attainable mass-flow per TDL is based on the following:

$$m = \frac{Q_{3xIHX\ A\ Test}}{(h_{out} - h_{in})}$$

$$\therefore m = \frac{3600\ kW}{(4828 - 3141)\ kJ / kg} \dots\dots\dots \text{Equation 1}$$

$$\therefore m = 3.651\ kg / s$$

where m = mass flow, Q = heat duty, h = enthalpies and T = temperature.

- The above requirement leads to a TDL primary loop heater design delivering 6.158 MW thermal.

2.2. COMPUTER PROGRAMS

The computer program used is Engineering Equation Solver© (EES).

3. Inputs and Assumptions

3.1. ASSUMPTIONS:

- No heat loss is assumed across the TDL circuit.
- Kinetic & Potential energies are negligible, thus $ke \cong pe \cong 0$.
- Recuperator efficiency = 80%.

3.2. INPUTS

- The heat duty per IHX module is 1 200 kW, thus for three (3) modules it is 3 600 kW.
- The IHX A test requires heat exchange from 950 °C to 760 °C.
- The inlet temperature to the heater is calculated using a circulator outlet temperature of 85 °C and a recuperator hot side inlet temperature of 760 °C. With a recuperator efficiency of 80 %, this leads to a recuperator cold side outlet temperature of 625 °C.
- The heater needs to rise its inlet temperature of 625 °C to 950 °C.

4. Equations used and calculations

See attached EES calculation sheet.

5. Results

See attached EES calculation sheet.

6. Conclusions

The following conclusions can be made:

- With a test station heat duty of 3.6 MW a helium mass flow of 3.651 kg/s is attainable.
- With above mass flow taken into consideration, a heater with a thermal output of 6.158 MW is required.
- This same thermal heater power is to be used when CQL1 test specific calculations are to be performed to acquire the maximum possible heat duties of the anticipated Steam Generator and H₂SO₄ Decomposition Reactor tests.

Attachment A

Attachment of Formatted EES Sheet (CQL1_TDL_Building Block.EES to Section 7, Appendix A:
Component Qualification Loop (CQL1)

*CQL_{TDL} Building Block Thermal Fluid Calculations**This is an attachment to MT-TLDR-CAL-F-T-0705**Assumptions Units Reference / Description*

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*No heat loss is assumed across primary TDL Cooler.**Kinetic & Potential energies are negligible, thus $ke = pe = 0$.**Inputs Units Reference / Description*

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 $T_{IHX,TS,in} = 950 \text{ [C]}$ *Hot side helium temperature at TDL TS inlet during 3 x IHX A test* $T_{IHX,TS,out} = 760 \text{ [C]}$ *Hot side helium temperature at TDL TS outlet during 3 x IHX A test* $P_{IHX,TS,in} = 9000 \text{ [kPa]}$ *Helium pressure at TDL TS inlet during 3 x IHX A test* $P_{IHX,TS,out} = 9000 \text{ [kPa]}$ *Helium pressure at TDL TS outlet during 3 x IHX test* $h_{IHX,TS,in} = h \text{ ['Helium', } T=T_{IHX,TS,in}, P=P_{IHX,TS,in} \text{]}$ *Enthalpy of helium at TDL TS inlet during 3 x IHX A test* $h_{IHX,TS,out} = h \text{ ['Helium', } T=T_{IHX,TS,out}, P=P_{IHX,TS,out} \text{]}$ *Enthalpy of helium at TDL TS outlet during 3 x IHX A test* $Q_{IHX,TS} = 1200 \cdot 3 \text{ [kW]}$ *Thermal duty specified for 3 x IHX test* $m = \frac{Q_{IHX,TS}}{h_{IHX,TS,in} - h_{IHX,TS,out}}$ *Maximum attainable helium mass flow for 3 x IHX A test**Heater inlet temperature*

=====

 $\eta_{RX} = 0.8$ $T_{RX,hotside,in} = T_{IHX,TS,out}$ $T_{RX,hotside,out} = T_{RX,hotside,in} - \eta_{RX} \cdot [T_{RX,hotside,in} - T_{RX,coldside,in}]$ $T_{RX,coldside,in} = 85 \text{ [C]}$ *Helium temperature at circulator outlet* $T_{RX,coldside,out} = T_{RX,coldside,in} + \eta_{RX} \cdot [T_{RX,hotside,in} - T_{RX,coldside,in}]$ $P_{HT,in} = 9000 \text{ [kPa]}$ $h_{HT,in} = h \text{ ['Helium', } T=T_{RX,coldside,out}, P=P_{HT,in} \text{]}$ $h_{HT,out} = h \text{ ['Helium', } T=T_{IHX,TS,in}, P=P_{IHX,TS,out} \text{]}$ $Q_{HT} = m \cdot [h_{HT,out} - h_{HT,in}]$

Appendix F



M - T e c h
i n d u s t r i a l

***Attachment to Section 7: Component Qualification
Loop (CQL1)
Appendix F Thermal Hydraulic Calculations to
Determine Cooling Water Requirements for the SG
Tertiary Stream***

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1. Objective

To calculate the theoretical cooling water demand as per anticipated Steam Generator test.

2. Methodology

2.1. APPROACH

Assuming steady state conditions and using basic thermodynamic equations, the following logical steps of events were used to obtain the cooling water requirements as per CQL1 SG test.

- Using the maximum attainable helium mass flow of 3.572 kg/s for the SG test, the mass flow of the water/steam in the secondary loop can be determined.
- From the above mass flow a maximum heat duty size for the secondary stream condenser can be calculated.
- The tertiary cooling water demand is then calculated by using the Condenser heat duty size and the assumed cooling water inlet temperatures and pressures.

From the 3 x IHX A test specification, using a recuperator efficiency of 80 %, a heat duty of 3600 kW on the 3 x IHX A test station, the maximum attainable mass-flow per TDL is based on the following:

$$m = \frac{Q_{\text{Condenser}}}{(h_{\text{out}} - h_{\text{in}})} \dots \dots \dots \text{Equation 1}$$

Where, m = cooling water mass flow, Q = Condenser heat duty, h = cooling water enthalpies.

2.2. COMPUTER PROGRAMS

The computer program used is Engineering Equation Solver© (EES).

3. Inputs and Assumptions

3.1. ASSUMPTIONS:

- No heat loss is assumed across the TDL circuit.
- Kinetic & Potential energies are negligible, thus $ke \cong pe \cong 0$.
- Cooling water inlet and outlet temperatures are assumed to be 20 °C and 45 °C respectively.
- Cooling water pressure assumed to be 300 kPa.
- Condenser efficiency (η_{CD}) = 100 %.

3.2. INPUTS

- Mass-flow of 1 x TDL is assumed to be 1.786 kg/s for the Steam Generator (SG) CQL1 test. This mass flow is based on the following:
 - ▶ Helium inlet temperature at heater (HT 2A_1.1) = 235 °C.
 - ▶ Helium outlet temperature at heater (HT 2A_1.1) = 900 °C.
 - ▶ Helium pressure at heater (HT 2A_1.1) inlet = 8.60 MPa.
 - ▶ Heater (HT 2A_1.1) thermal power = 6.158 MW.

4. Equations used and calculations

See attached EES calculation sheet.

5. Results

See attached EES calculation sheet.

6. Conclusions

The following conclusions can be made:

- With a maximum helium mass flow of 3.572 kg/s, the following theoretical values were obtained:
 - ▶ Maximum Steam Generator (TS 3_1.1) Heat Duty = 11.620 MW.
 - ▶ Condenser (CD 3_2.1) Heat Duty = 11.629 MW.
 - ▶ Water/steam mass flow in secondary stream of SG test = 4.65 kg/s.
 - ▶ Cooling water mass flow in tertiary stream of SG test = 111.20 kg/s.
 - ▶ Pumping power of condensate pump (PU 3_2.1) = 9.2 kW.

Attachment A

Attachment of Formatted EES Sheet (CQL1_TDL_Building Block.EES to Section 7, Appendix A:
Component Qualification Loop (CQL1)

*CQL_{SG} Cooling Water Thermal Fluid Calculations**This is an attachment to MT-TLDR-CAL-F-T-0706**Assumptions Units Reference / Description*

=====

*No heat loss is assumed across CQL circuit**Kinetic & Potential energies are negligible, thus $ke = pe = 0$.**Inputs Units Reference / Description*

=====

$$T_{SGHe1} = 900 \text{ [C] Helium Inlet Temperature}$$

$$T_{SGHe2} = 273 \text{ [C] Test Helium Outlet Temperature}$$

$$P_{SGHe1} = 8700 \text{ [kPa] Helium Inlet Pressure}$$

$$P_{SGHe2} = 8600 \text{ [kPa] Helium Outlet Pressure}$$

$$T_{SGW1} = 219 \text{ [C] Steam Generator Inlet Water Temperature}$$

$$T_{SGW2} = 540 \text{ [C] Steam Generator Outlet Water Temperature}$$

$$P_{SGW1} = 18300 \text{ [kPa] Steam Generator Inlet Water Pressure}$$

$$P_{SGW2} = 12800 \text{ [kPa] Steam Generator Outlet Water Pressure}$$

$$T_{CDW,in} = 20 \text{ [C] Cooling water inlet temperature at Condenser inlet}$$

$$T_{CDW,out} = 45 \text{ [C] Cooling water outlet temperature at Condenser outlet}$$

$$P_{CDW,in} = 300 \text{ [kPa] Cooling water inlet pressure at Condenser inlet}$$

$$P_{CDW,out} = 300 \text{ [kPa] Cooling water outlet pressure at Condenser outlet}$$

$$h_{SGHe1} = h \left[\text{'Helium'}, T = T_{SGHe1}, P = P_{SGHe1} \right]$$

$$h_{SGHe2} = h \left[\text{'Helium'}, T = T_{SGHe2}, P = P_{SGHe2} \right]$$

$$h_{SGW1} = h \left[\text{'Water'}, T = T_{SGW1}, P = P_{SGW1} \right]$$

$$h_{SGW2} = h \left[\text{'Water'}, T = T_{SGW2}, P = P_{SGW2} \right]$$

Helium Mass Flow - Primary Circuit

=====

$$T_{Cir} = 85 \text{ [C] Assumed circulator outlet temperature}$$

$$\eta_{RX} = 0.8$$

$$\delta T_{RX,SG} = T_{SGHe2} - T_{Cir} \text{ Delta temperature drop across Recuperator - SG Test}$$

$$T_{HT,SG,in} = T_{Cir} + \eta_{RX} \cdot \delta T_{RX,SG}$$

$$T_{HT,SG,out} = T_{SGHe1}$$

$$h_{HT,SG,in} = h \left[\text{'Helium'}, T = T_{HT,SG,in}, P = P_{SGHe2} \right]$$

$$h_{HT,SG,out} = h \left[\text{'Helium'}, T = T_{HT,SG,out}, P = P_{SGHe1} \right]$$

$$m_{SGHe,per,TDL} = \frac{6158}{h_{HT,SG,out} - h_{HT,SG,in}} \quad \text{Heater power of 6158 kW as per CQL1}_{TDL, Building} \text{ Block.EES}$$

$$m_{SGHe,total} = m_{SGHe,per,TDL} \cdot 2$$

$$Q_{SG} = m_{SGHe,total} \cdot [h_{SGHe1} - h_{SGHe2}]$$

Determining the mass flow of the Water/Steam in secondary SG circuit

=====

$$m_{SGW} = \frac{Q_{SG}}{h_{SGW2} - h_{SGW1}}$$

Determining the heat duty of the Condenser in the secondary SG circuit

=====

$$h_{CD,in} = h \left[\text{'Water'}, T = T_{SGW2}, P = P_{SGW2} \right]$$

$$h_{CD,out} = h \left[\text{'Water'}, T = T_{SGW1}, P = P_{SGW2} - 200 \right] \quad \text{Assuming a 200 kPa pressure drop}$$

$$Q_{CD} = m_{SGW} \cdot [h_{CD,in} - h_{CD,out}]$$

Pumping Power

=====

$$v_{PU,in} = v \left[\text{'Water'}, T = T_{SGW1}, P = P_{SGW2} \right]$$

$$v_{PU,out} = v \left[\text{'Water'}, T = T_{SGW2}, P = P_{SGW2} \right]$$

$$P_{PU} = \int_{v_{PU,in}}^{v_{PU,out}} [v] dv \cdot [P_{SGW1} - P_{SGW2}] \cdot m_{SGW}$$

Cooling Water Requirements on Condenser - Tertiary Loop

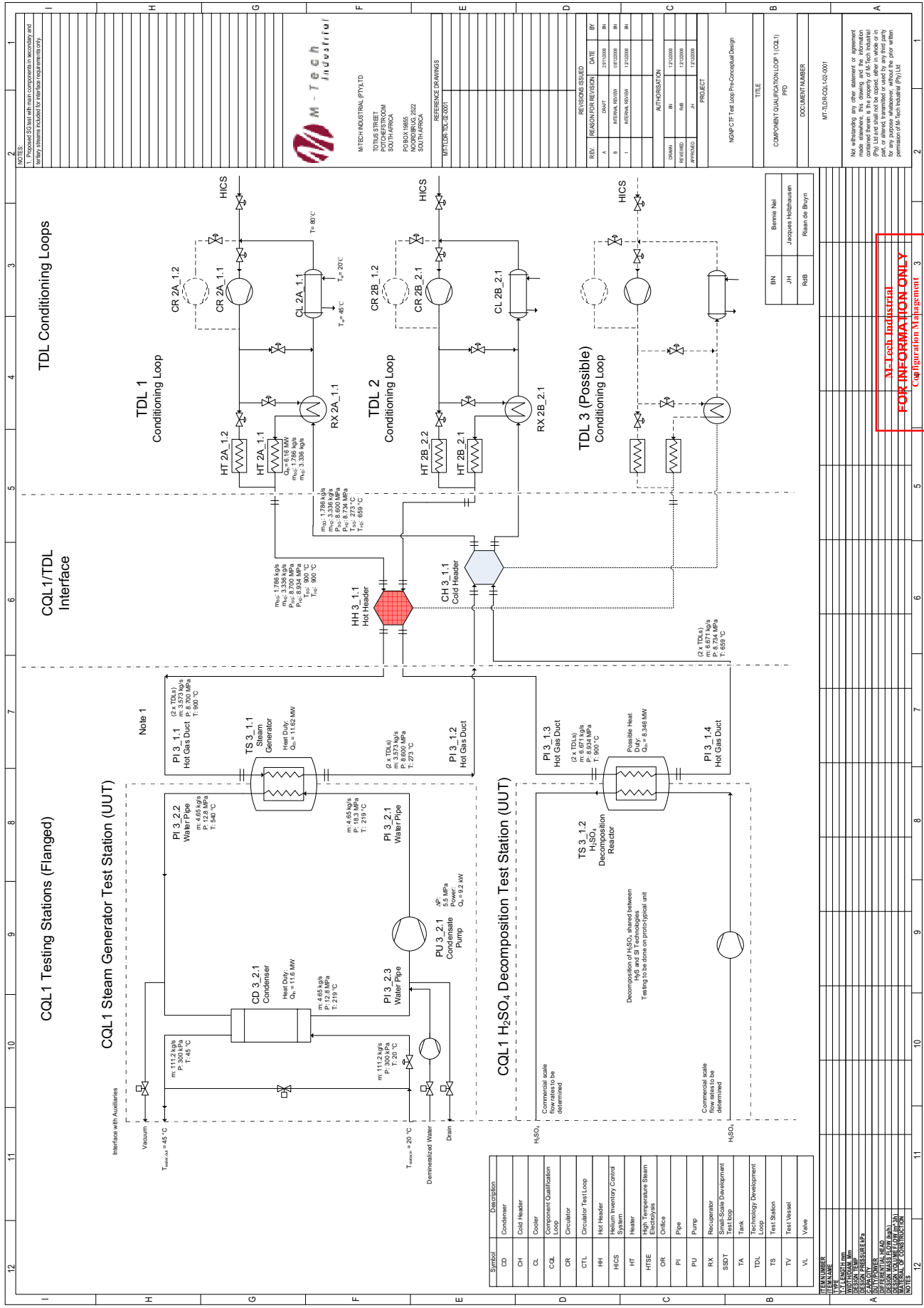
=====

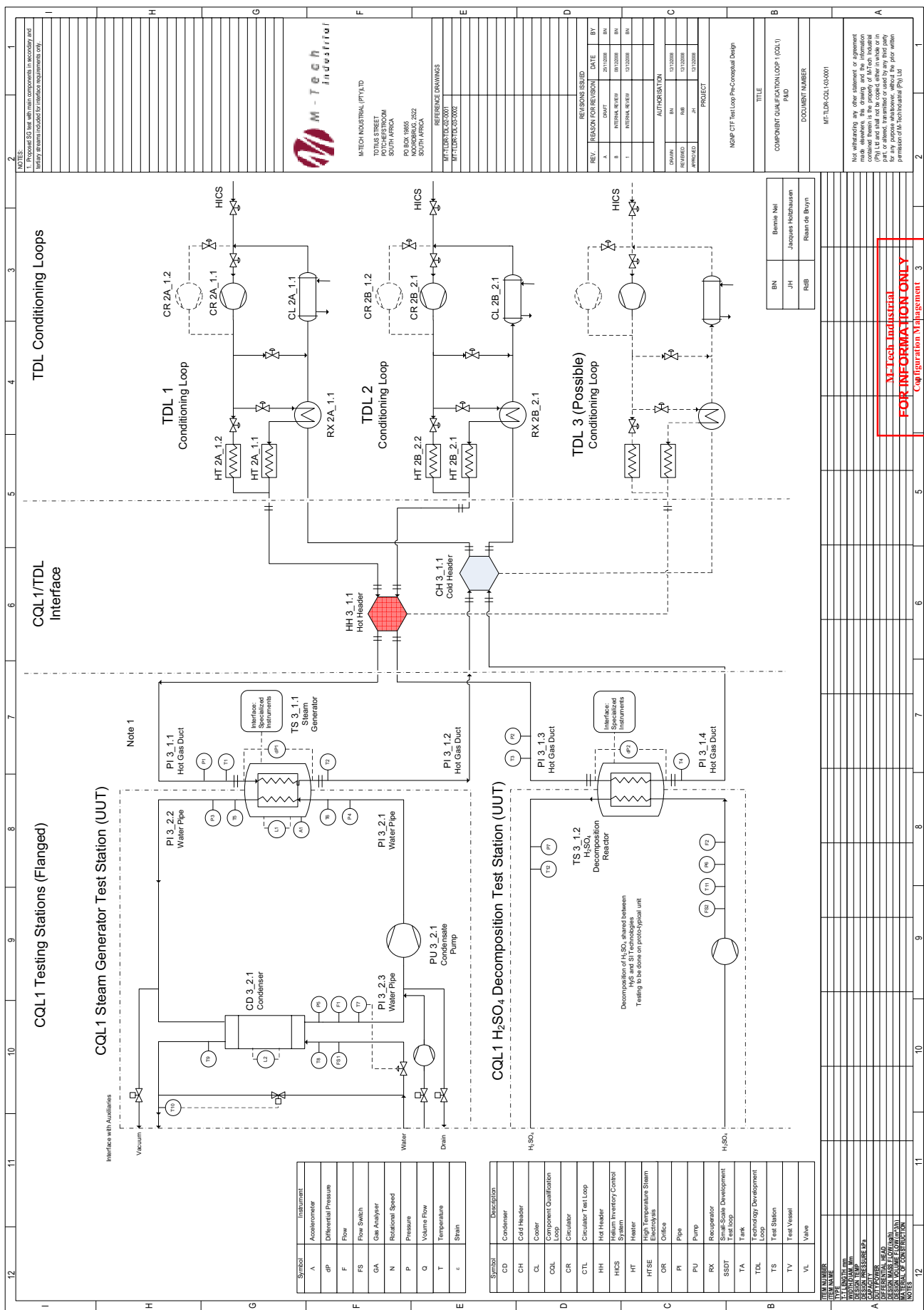
$$h_{CDW,in} = h \left[\text{'Water'}, T = T_{CDW,in}, P = P_{CDW,in} \right]$$

$$h_{CDW,out} = h \left[\text{'Water'}, T = T_{CDW,out}, P = P_{CDW,out} \right]$$

$$m_{CD} = \frac{Q_{CD}}{h_{CDW,out} - h_{CDW,in}}$$

Appendix G





Appendix H

Appendix H

Component Specification Sheet

Company:	M-Tech Industrial (Pty) Ltd		
Location:	Potchefstroom, South Africa		
Document Number:	MT-TLDR-CQL1-CMPT-05-0001		
Component:	CQL1 Hot Header (HH 3_1.1)		
Date:	10 December 2008	Rev. No.:	2

Authorisation			
Action	Name	Signature	Date
Preparer	Bennie Nel		December 11, 2008
Reviewer	David Viljoen		December 11, 2008
Approver	Riaan de Bruyn		December 17, 2008

Record of Changes	
Revision	Description of Changes
A	Initial Draft
1	Document Approved
2	Configuration tables added

HH 3_1.1		
Component Specification Sheet		
	<u>Value & Unit</u>	<u>Remarks</u>
P _{he} :	9 600 kPa	Nominal Pressure
T _{he in} :	950 °C	Inlet temperature
d _{internal vessel} :	1.077 m	
L _{vessel} :	2.690 m	Length of Shell body + 2 elliptical heads
Fluid:	Helium	
T _{design} :	1 000 °C	
P _{design} :	9 600 kPa	
<u>Shell:</u>		
Length:	991 mm	For each section (top and bottom)
Outside diameter:	1 194 mm	
Wall thickness:	58.4 mm	
Corrosion allowance:	0 mm	
<u>Nozzles:</u>		
No. of protrusions:	6	
Length:	-	
Outside diameter:	601 mm	
Wall thickness:	31 mm	
<u>Elliptical Head:</u>		
Head ratio:	2 : 1	
Height:	268 mm	Height before and after forming
Wall thickness before:	50.8 mm	
Wall thickness after:	50.8 mm	
Skirt:	127 mm	
<u>Material:</u>		
Component material:	SA-516 Gr.70	
Allowable stress:	115.14 MPa	

Appendix I

Appendix I

Component Specification Sheet

Company:	M-Tech Industrial (Pty) Ltd		
Location:	Potchefstroom, South Africa		
Document Number:	MT-TLDR-CQL1-CMPT-05-0002		
Component:	CQL1 Cold Header (CH 3_1.1)		
Date:	10 December 2008	Rev. No.:	2

Authorisation			
Action	Name	Signature	Date
Preparer	Bennie Nel		December 11, 2008
Reviewer	David Viljoen		December 11, 2008
Approver	Riaan de Bruyn		December 17, 2008

Record of Changes	
Revision	Description of Changes
A	Initial Draft
1	Document Approved
2	Configuration tables added

CH 3_1.1		
Component Specification Sheet		
	<u>Value & Unit</u>	<u>Remarks</u>
P _{he} :	9 600 kPa	Nominal Pressure
T _{he in} :	950 °C	Inlet temperature
d _{internal vessel} :	1.077 m	
L _{vessel}	2.690 m	Length of Shell body + 2 elliptical heads
Fluid:	Helium	
T _{design} :	1 000 °C	
P _{design} :	9 600 kPa	
<u>Shell:</u>		
Length:	991 mm	For each section (top and bottom)
Outside diameter:	1 194 mm	
Wall thickness:	58.4 mm	
Corrosion allowance:	0 mm	
<u>Nozzles:</u>		
No. of protrusions:	6	
Length:	-	
Outside diameter:	601 mm	
Wall thickness:	31 mm	
<u>Elliptical Head:</u>		
Head ratio:	2 : 1	
Height:	268 mm	Height before and after forming
Wall thickness before:	50.8 mm	
Wall thickness after:	50.8 mm	
Skirt:	127 mm	
<u>Material:</u>		
Component material:	SA-516 Gr.70	
Allowable stress:	115.14 MPa	

Appendix J

Appendix J

Component Specification Sheet

Company:	M-Tech Industrial (Pty) Ltd		
Location:	Potchefstroom, South Africa		
Document Number:	MT-TLDR-CQL1-CMPT-05-0003		
Component:	CQL1 Hot Gas Ducts (PI 3_1.1; PI 3_1.2; PI 3_1.3 and PI 3_1.4;)		
Date:	10 December 2008	Rev. No.:	2

Authorisation			
Action	Name	Signature	Date
Preparer	Bennie Nel		December 11, 2008
Reviewer	David Viljoen		December 11, 2008
Approver	Riaan de Bruyn		December 17, 2008

Record of Changes	
Revision	Description of Changes
A	Initial Draft
1	Document Approved
2	Configuration tables added

PI 3_1.1; PI 3_1.2; PI 3_1.3 and PI 3_1.4 (All four pipes based on similar specifications) Component Specification Sheet		
	<u>Value & Unit</u>	<u>Remarks</u>
P _{he} :	9 600 kPa	Nominal Pressure
T _{he in} :	900 °C	Inlet temperature for both anticipated CQL1 tests.
d _{internal liner} :	0.26 m	Based on design velocity of ~ 20 m/s.
m _{he} :	3.65 kg/s	Mass flow obtained from IHX TDL test.
T _{surface} :	200 °C	
Fluid:	Helium	
T _{design} :	1 000 °C	
P _{design} :	9 600 kPa	
<u>Shell:</u>		
Length:	N / A	
Outside diameter:	609.6 mm	
Wall thickness:	31 mm	
Corrosion allowance:	0 mm	
<u>Nozzles:</u>	0	
<u>Elliptical Head:</u>	N / A	
<u>Material:</u>		
Component material:	SA-516 Gr.70	
Allowable stress:	115.14 MPa	

Appendix K



M - T e c h
i n d u s t r i a l

***Attachment to Section 7: Component Qualification
Loop (CQL1)
Appendix K Mechanical Design Calculations for
CQL1:
Hot Header, Cold Header and Hot Gas Ducts***

Document number: MT-TLDR-CAL-M-0701

Revision: 1

Status: Approved

B J Nel

December 2008

M-Tech Industrial
FOR INFORMATION ONLY
Configuration Management

CHANGE HISTORY

Configuration Control	
Client Name:	Westinghouse Electric Company
Project Number:	NGNP-CTF MTECH-TLDR
Project Name:	NGNP CTF Test Loop Preconceptual Design
Calculation Title:	Thermal Hydraulic Calculations for Steam Generator Test
Calculation Identification Number:	MT-TLDR-CAL-F-T-0701
Quality Level:	3

Template No: MT-TLDR-CAL-REP rev 1

Authorisation			
Action	Name	Signature	Date
Preparer	B J Nel	_____	December 03, 2008
Reviewer	D J Viljoen	_____	December 03, 2008
Approver	R de Bruyn	_____	November 28, 2008

Original Signed Copy at CMC

Distribution					
Discipline	Name	Discipline	Name	Discipline	Name

Confirmation Required Status			
Calculation Page	Input/Assumption that Requires Confirmation	Preparer and Date Input/Assumption Confirmed	Reviewer and Date Input/Assumption Approved

MT-TLDR-CAL-M-0701
Rev 1

Attachment to Section 7: Component Qualification
 Loop (CQL1) Appendix K Mechanical Design
 Calculations for CQL1:
 Hot Header, Cold Header and Hot Gas Ducts
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 Configuration Management

Record of Changes	
Revision	Description of Changes
A	Initial Draft
1	Document Approved

References to this Document
NGNP-CTF MTECH-TLDR-0007

Change Forecast

The document format and contents have been approved.

Calculation Table of Contents

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2.2. COMPUTER PROGRAMS	5
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1. Objective:

To perform initial pressure boundary calculations with the intention of addressing design requirements as well as providing input to the facility interface plant requirements. The output of these calculations are also to be used as bases for costing exercises.

All pressure boundary calculations were performed according to ASME Code VIII Div 1 standards.

2. Methodology:

2.1. APPROACH

- To use ASME Code VIII Div 1 standards.

2.2. COMPUTER PROGRAMS

The computer program used is a MS Excel spreadsheet incorporating ASME Code VIII Div 1 2001, No Addenda.

3. Inputs and Assumptions:

3.1. ASSUMPTIONS:

- All pressure boundary calculations are done using a MS Excel spreadsheet incorporating ASME Code VIII Div 1 2001, No Addenda.
- No corrosion allowance was included.
- All pressure boundary outside temperatures are taken as 200°C.

3.2. INPUTS:

- Proposed material is SA-516 Gr.70.
- Allowable stress was taken as 20 KSI¹ at 204°C (400°F) from ASME material property database.
- Internal pressures taken as 9.6 MPa.
- All other related input can be found in the attached calculation spreadsheet and are included in sections: **Dimensions** and **Material and Conditions**.

4. Equations Used and Calculations:

All equations used are included in the calculation spreadsheet.

¹ Units according to ASME code.

5. Results:

See attached MS Excel calculation spreadsheets.

6. Conclusions:

Considering all the assumptions and inputs given in paragraph 3 above, the following table gives a summary of the mechanical design of the Hot Header, the Cold Header and the Hot Gas Ducts in CQL1.

Table 6-1: Summarized component dimensions originating from the mechanical design on CQL1 components i.e. HH, CH and HGDs.

	Unit	Hot Header HH 3_1.1	Cold Header CH 3_1.1	Hot Gas Ducts PI 3_1.x; x = 1,2,3,4
Shell:				
Outside Diameter	mm	1194	1194	610
Nominal Wall Thickness	mm	58.4	58.4	31.0
Length	mm	991	991	-
Nozzles:				
Outside Diameter	mm	610	610	-
Nominal Wall Thickness	mm	31.0	31.0	-
Elliptical Head:				
Outside Diameter	mm	1194	1194	-
Height	mm	268	268	-
Thickness	mm	50.8	50.8	-
Straight Skirt Length	mm	127	127	-
Material:	-	SA-516 Gr.70	SA-516 Gr.70	SA-516 Gr.70

Attachment A

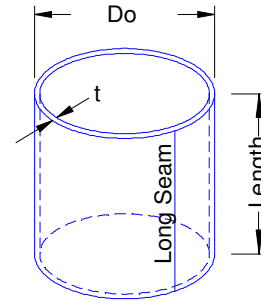
Attachment of mechanical design Excel Spreadsheets to Section 7, Appendix I: Component Qualification Loop (CQL)

Pipe and Shell HH 3_1.1

ASME Code VIII Div I 2001 edition no addenda

ASME L-2.2.1 <- BM **1** <- BM Item #**Verification Calc #3** <- Vessel, description**1** <- BM Qty**Dimensions:**

47.000 <- Do - Outside Diameter
2.300 <- t - Nominal Wall Thickness
39.000 <- Length
0.000 <- Corr, Corrosion Allowance

**Material and Conditions:**

SA-516 <- Material
20 000 <- S, Allowable Stress Level (psi)
0.85 <- E1 - Longitudinal Efficiency (circ. stress)
0.65 <- Ec - Circ. Connecting Efficiency (longitudinal stress)
0.0% <- UTP, Undertolerance allowance (%) **31.87** <- Volume (cubic ft)
0.000 <- UTI, Undertolerance allowance (inch) **3 572.5** <- Material Weight (lbs cs)
1392.4 <- P, Interior Pressure
0.0 <- Pa, Exterior Pressure
1 <- B, From exterior pressure curve **0.019467** <- A (use to lookup B)

Variables:

UT = t*UTP+UTI = 2.3*0+0 undertolerance UT = **0.000**
 Ri = Do/2-t+corr = 47/2-2.3+0 inside radius Ri = **21.200**
 nt = t-Corr-UT = 2.3-0-0 nominal thick nt = **2.300**
 LDo = L/Do = 39/47 LDo = **0.830**
 DoT = Do/nt = 47/2.3 DoT = **20.435**

Interior Pressure UG-27 (c) (1,2)

ta = P*Ri/(S*E1-0.6*P) = 1392.4*21.2/(20000*0.85-0.6*1392.4) ta = **1.826**
 tb = P*Ri/(2*S*Ec+0.4*P) = 1392.4*21.2/(2*20000*0.65+0.4*1392.4) tb = **1.112**
 tmin = Max(ta,tb) <= nt **Okay** tmin = **1.826**
 PMaxA = (S*E1*nt)/(Ri+0.6*nt) = (20000*0.85*2.3)/(21.2+0.6*2.3) PMaxA = **1731.6**
 PMaxB = (2*S*Ec*nt)/(Ri-0.4*nt) = (2*20000*0.65*2.3)/(21.2-0.4*2.3) PMaxB = **2948.7**
 PMax = Min(PMaxA, PMaxB) **Okay** PMax = **1731.6**
 tr1 = P*Ri/(S*1-0.6*P) = 1392.4*21.2/(20000*1-0.6*1392.4) tr1 = **1.540**

Exterior Pressure UG-28 (c)

A = Interpolated from IID Part D Table G A = **0.019467**
 PaMax = 4*B/(3*DoT) = 4*1/(3*20.435) **Okay** PaMax = **0.1**
 tre = (3*Do*Pa)/(4*B) = (3*47*0)/(4*1) tre = **0.000**

Shell stress relief -UCS-79(d), UNF-79(d), UHA-44(d)

Rf = (do-t)/2 = (47-2.3)/2 **22.35**
 % elong = (50*t/Rf)*(1-0) = (50*2.3/22.35)*(1-0) % elongation = **5.1**

0.1% <- Max Elongation**Yes** <- Cold formed **5.1%** <- Elongation**no** <- Vessel carries lethal substances (Yes/no)**no** <- Impact testing is required (Yes/no)**no** <- Greater than 10% reduction in thickness**no** <- Formed between 250 and 900 Degrees F**YES** <- Shell is greater than 5/8" thick before forming

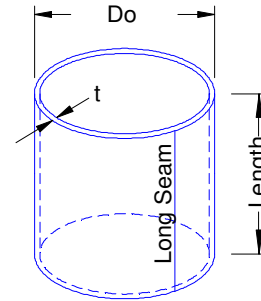
Required	Yes ?
no	no
no	no
no	no
no	no
no	no
no	no
Stress Relieve ?	no

Pipe and Shell HH 3_1.1

ASME Code VIII Div I 2001 edition no addenda

ASME L-2.2.1 <- BM **1** <- BM Item #**Verification Calc #3** <- Vessel, description**1** <- BM Qty**Dimensions:**

24.000 <- Do - Outside Diameter
1.220 <- t - Nominal Wall Thickness
39.370 <- Length
0.000 <- Corr, Corrosion Allowance

**Material and Conditions:**

SA-516 <- Material
20 000 <- S, Allowable Stress Level (psi)
0.85 <- E1 - Longitudinal Efficiency (circ. stress)
0.65 <- Ec - Circ. Connecting Efficiency (longitudinal stress)
0.0% <- UTP, Undertolerance allowance (%) **8.32** <- Volume (cubic ft)
0.000 <- UTI, Undertolerance allowance (inch) **974.9** <- Material Weight (lbs cs)
1392.4 <- P, Interior Pressure
0.0 <- Pa, Exterior Pressure
1 <- B, From exterior pressure curve **0.009696** <- A (use to lookup B)

Variables:

UT = $t \cdot \text{UTP} + \text{UTI}$ = $1.22 \cdot 0 + 0$ undertolerance UT = **0.000**
 $R_i = \text{Do} / 2 - t + \text{corr}$ = $24 / 2 - 1.22 + 0$ inside radius R_i = **10.780**
 $n_t = t - \text{Corr} - \text{UT}$ = $1.22 - 0 - 0$ nominal thick n_t = **1.220**
 $L_{Do} = L / \text{Do}$ = $39.37 / 24$ L_{Do} = **1.640**
 $\text{DoT} = \text{Do} / n_t$ = $24 / 1.22$ DoT = **19.672**

Interior Pressure UG-27 (c) (1,2)

$t_a = P \cdot R_i / (S \cdot E1 - 0.6 \cdot P)$ = $1392.4 \cdot 10.78 / (20000 \cdot 0.85 - 0.6 \cdot 1392.4)$ t_a = **0.929**
 $t_b = P \cdot R_i / (2 \cdot S \cdot E_c + 0.4 \cdot P)$ = $1392.4 \cdot 10.78 / (2 \cdot 20000 \cdot 0.65 + 0.4 \cdot 1392.4)$ t_b = **0.565**
 $t_{\min} = \text{Max}(t_a, t_b) \leq n_t$ **Okay** $t_{\min}$ = **0.929**
 $P_{\text{MaxA}} = (S \cdot E1 \cdot n_t) / (R_i + 0.6 \cdot n_t)$ = $(20000 \cdot 0.85 \cdot 1.22) / (10.78 + 0.6 \cdot 1.22)$ P_{MaxA} = **1801.6**
 $P_{\text{MaxB}} = (2 \cdot S \cdot E_c \cdot n_t) / (R_i - 0.4 \cdot n_t)$ = $(2 \cdot 20000 \cdot 0.65 \cdot 1.22) / (10.78 - 0.4 \cdot 1.22)$ P_{MaxB} = **3082.0**
 $P_{\text{Max}} = \text{Min}(P_{\text{MaxA}}, P_{\text{MaxB}})$ **Okay** P_{Max} = **1801.6**
 $t_{r1} = P \cdot R_i / (S \cdot 1 - 0.6 \cdot P)$ = $1392.4 \cdot 10.78 / (20000 \cdot 1 - 0.6 \cdot 1392.4)$ t_{r1} = **0.783**

Exterior Pressure UG-28 (c)

A = Interpolated from IID Part D Table G A = **0.009696**
 $P_{\text{Max}} = 4 \cdot B / (3 \cdot \text{DoT})$ = $4 \cdot 1 / (3 \cdot 19.672)$ **Okay** P_{Max} = **0.1**
 $t_{re} = (3 \cdot \text{Do} \cdot P_a) / (4 \cdot B)$ = $(3 \cdot 24 \cdot 0) / (4 \cdot 1)$ t_{re} = **0.000**

Shell stress relief -UCS-79(d), UNF-79(d), UHA-44(d)

$R_f = (\text{do} - t) / 2$ = $(24 - 1.22) / 2$
 $\% \text{ elong} = (50 \cdot t / R_f) \cdot (1 - 0)$ = $(50 \cdot 1.22 / 11.39) \cdot (1 - 0)$ $\% \text{ elongation}$ = **5.4**

0.1% <- Max Elongation**Yes** <- Cold formed **5.4%** <- Elongation**no** <- Vessel carries lethal substances (Yes/no)**no** <- Impact testing is required (Yes/no)**no** <- Greater than 10% reduction in thickness**no** <- Formed between 250 and 900 Degrees F**YES** <- Shell is greater than 5/8" thick before forming

Required	Yes ?
no	no
no	no
no	no
no	no
no	no
no	no
Stress Relieve ?	no

Elliptical Head HH 3_1.1

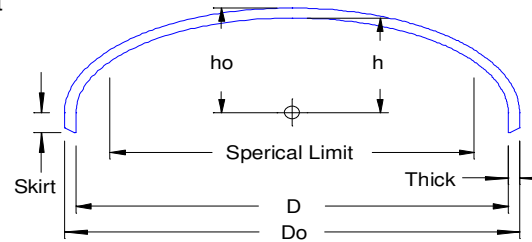
ASME Code VIII Div I 2001 no Addenda

<- BM <- BM Item # <- BM Qty

Heads <- Component

Dimensions:

47.000 <- Do, outside diameter
10.550 <- h
2.000 <- tb, thickness before forming
2.000 <- tf, thickness after forming
0.000 <- Corr, corrosion allowance
5.000 <- Skirt, straight skirt length

**Material and Conditions:**

SA-516 <- material
20 000 <- S, allowable stress level (psi)
1.00 <- E, efficiency
1392.4 <- P, interior pressure
0.0 <- Pa, exterior pressure
1 <- B, from exterior pressure curve

Calculated Properties:

60.6 <- Approximate blank diameter
1636.6 <- Approximate weight for steel, (lbs)
10.11 <- Volume (cuft, includes skirt)
34.40 <- Spherical Limit (0.8 * D)
0.00631 <- A value to lookup B

Variables:

D = Do-2*t = 47-2*2 = **43.00**
 ho = h+t = 10.55+2 = **12.55**
 D/2h = D/(2*h) = 43/(2*10.55) = **2.038**
 Do/2ho = Do/(2*ho) = 47/(2*12.55) = **1.873**
 K = Interpolated value from table 1-4.1 interior = **1.027**
 Kone = Interpolated value from table UG-37 spherical = **0.917**
 Kzero = Interpolated value from table UG-33.1 exterior = **0.843**
 t = tf-corr = 2-0 = **2.000**
 Ro = Ko*Do = 0.843*47 = **39.604**

Interior Pressure App 1-4(c)(d), UG-37 1(a)

TMinl = (P*D*K)/(2*S*E-0.2*P) <= t TMinl (min thickness) = **1.547**
 = (1392.4*43*1.027)/(2*20000*1-0.2*1392.4) <= 2 **Okay**
 PMax = (2*S*E*t)/(K*D+0.2*t) >= P PMax = **1796**
 = (2*20000*1*2)/(1.027*43+0.2*2) >= 1392 **Okay**
 TSpl = (P*D*Kone)/(2*S*E-0.2*P) TSpl (required sphere zone thick) = **1.382**
 = (1392.4*43*0.917)/(2*20000*1-0.2*1392.4)

Exterior Pressure UG-33(d), UG-28(d)

A = 0.125/(Ro/t) = 0.125/(39.604/2) **Okay**
 PaMax = B/(Ro/t) >= Pa = 1/(39.604/2) >= 0 PaMax = **0.1**
 TMinE = (Ro*Pa)/B = (39.604*0)/1 TMinE = **0.000**

Head stress relief UCS-79(d), UNF-79(d), UHA-44(d)

% elong = ((75*t)/h)*(1-0) = ((75*2)/10.55)*(1-0) % elong = **14.2**

5.0% <- Max Elongation
Yes <- Cold Formed **14.2%** <- Elongation
no <- Vessel carries lethal substances(Yes/no)
no <- Impact testing is required (Yes/no)
no <- Formed between 250 and 900 Degrees F
no <- Greater than 10% reduction in thickness
Yes <- Head is greater than 5/8" thick before forming

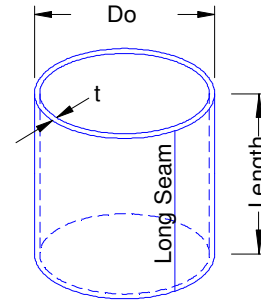
Required	Yes ?
no	no
no	no
no	no
no	no
Yes ?	YES
Stress Relieve ?	YES

Pipe and Shell CH 3_1.1

ASME Code VIII Div I 2001 edition no addenda

ASME L-2.2.1 <- BM **1** <- BM Item #**Verification Calc #3** <- Vessel, description**1** <- BM Qty**Dimensions:**

47.000 <- Do - Outside Diameter
2.300 <- t - Nominal Wall Thickness
39.000 <- Length
0.000 <- Corr, Corrosion Allowance

**Material and Conditions:**

SA-516 <- Material
20 000 <- S, Allowable Stress Level (psi)
0.85 <- E1 - Longitudinal Efficiency (circ. stress)
0.65 <- Ec - Circ. Connecting Efficiency (longitudinal stress)
0.0% <- UTP, Undertolerance allowance (%) **31.87** <- Volume (cubic ft)
0.000 <- UTI, Undertolerance allowance (inch) **3 572.5** <- Material Weight (lbs cs)
1392.4 <- P, Interior Pressure
0.0 <- Pa, Exterior Pressure
1 <- B, From exterior pressure curve **0.019467** <- A (use to lookup B)

Variables:

UT = t*UTP+UTI = 2.3*0+0 undertolerance UT = **0.000**
 Ri = Do/2-t+corr = 47/2-2.3+0 inside radius Ri = **21.200**
 nt = t-Corr-UT = 2.3-0-0 nominal thick nt = **2.300**
 LDo = L/Do = 39/47 LDo = **0.830**
 DoT = Do/nt = 47/2.3 DoT = **20.435**

Interior Pressure UG-27 (c) (1,2)

ta = P*Ri/(S*E1-0.6*P) = 1392.4*21.2/(20000*0.85-0.6*1392.4) ta = **1.826**
 tb = P*Ri/(2*S*Ec+0.4*P) = 1392.4*21.2/(2*20000*0.65+0.4*1392.4) tb = **1.112**
 tmin = Max(ta,tb) <= nt **Okay** tmin = **1.826**
 PMaxA = (S*E1*nt)/(Ri+0.6*nt) = (20000*0.85*2.3)/(21.2+0.6*2.3) PMaxA = **1731.6**
 PMaxB = (2*S*Ec*nt)/(Ri-0.4*nt) = (2*20000*0.65*2.3)/(21.2-0.4*2.3) PMaxB = **2948.7**
 PMax = Min(PMaxA, PMaxB) **Okay** PMax = **1731.6**
 tr1 = P*Ri/(S*1-0.6*P) = 1392.4*21.2/(20000*1-0.6*1392.4) tr1 = **1.540**

Exterior Pressure UG-28 (c)

A = Interpolated from IID Part D Table G A = **0.019467**
 PaMax = 4*B/(3*DoT) = 4*1/(3*20.435) **Okay** PaMax = **0.1**
 tre = (3*Do*Pa)/(4*B) = (3*47*0)/(4*1) tre = **0.000**

Shell stress relief -UCS-79(d), UNF-79(d), UHA-44(d)

Rf = (do-t)/2 = (47-2.3)/2 **22.35**
 % elong = (50*t/Rf)*(1-0) = (50*2.3/22.35)*(1-0) % elongation = **5.1**

0.1% <- Max Elongation**Yes** <- Cold formed **5.1%** <- Elongation**no** <- Vessel carries lethal substances (Yes/no)**no** <- Impact testing is required (Yes/no)**no** <- Greater than 10% reduction in thickness**no** <- Formed between 250 and 900 Degrees F**YES** <- Shell is greater than 5/8" thick before forming

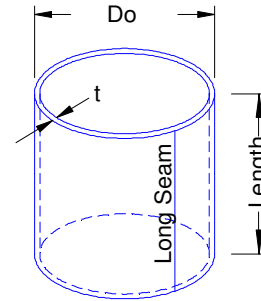
Required	Yes ?
no	no
no	no
no	no
no	no
no	no
no	no
Stress Relieve ?	no

Pipe and Shell CH 3_1.1

ASME Code VIII Div I 2001 edition no addenda

ASME L-2.2.1 <- BM **1** <- BM Item #**Verification Calc #3** <- Vessel, description**1** <- BM Qty**Dimensions:**

24.000 <- Do - Outside Diameter
1.220 <- t - Nominal Wall Thickness
39.370 <- Length
0.000 <- Corr, Corrosion Allowance

**Material and Conditions:**

SA-516 <- Material
20 000 <- S, Allowable Stress Level (psi)
0.85 <- E1 - Longitudinal Efficiency (circ. stress)
0.65 <- Ec - Circ. Connecting Efficiency (longitudinal stress)
0.0% <- UTP, Undertolerance allowance (%) **8.32** <- Volume (cubic ft)
0.000 <- UTI, Undertolerance allowance (inch) **974.9** <- Material Weight (lbs cs)
1392.4 <- P, Interior Pressure
0.0 <- Pa, Exterior Pressure
1 <- B, From exterior pressure curve **0.009696** <- A (use to lookup B)

Variables:

UT = $t \cdot \text{UTP} + \text{UTI}$ = $1.22 \cdot 0 + 0$ undertolerance UT = **0.000**
Ri = $\text{Do} / 2 - t + \text{corr}$ = $24 / 2 - 1.22 + 0$ inside radius Ri = **10.780**
nt = $t - \text{Corr} - \text{UT}$ = $1.22 - 0 - 0$ nominal thick nt = **1.220**
LDo = L / Do = $39.37 / 24$ LDo = **1.640**
DoT = Do / nt = $24 / 1.22$ DoT = **19.672**

Interior Pressure UG-27 (c) (1,2)

ta = $P \cdot \text{Ri} / (S \cdot E1 - 0.6 \cdot P)$ = $1392.4 \cdot 10.78 / (20000 \cdot 0.85 - 0.6 \cdot 1392.4)$ ta = **0.929**
tb = $P \cdot \text{Ri} / (2 \cdot S \cdot \text{Ec} + 0.4 \cdot P)$ = $1392.4 \cdot 10.78 / (2 \cdot 20000 \cdot 0.65 + 0.4 \cdot 1392.4)$ tb = **0.565**
tmin = $\text{Max}(ta, tb) \leq nt$ **Okay** tmin = **0.929**
PMaxA = $(S \cdot E1 \cdot nt) / (\text{Ri} + 0.6 \cdot nt)$ = $(20000 \cdot 0.85 \cdot 1.22) / (10.78 + 0.6 \cdot 1.22)$ PMaxA = **1801.6**
PMaxB = $(2 \cdot S \cdot \text{Ec} \cdot nt) / (\text{Ri} - 0.4 \cdot nt)$ = $(2 \cdot 20000 \cdot 0.65 \cdot 1.22) / (10.78 - 0.4 \cdot 1.22)$ PMaxB = **3082.0**
PMax = $\text{Min}(\text{PMaxA}, \text{PMaxB})$ **Okay** PMax = **1801.6**
tr1 = $P \cdot \text{Ri} / (S \cdot 1 - 0.6 \cdot P)$ = $1392.4 \cdot 10.78 / (20000 \cdot 1 - 0.6 \cdot 1392.4)$ tr1 = **0.783**

Exterior Pressure UG-28 (c)

A = Interpolated from IID Part D Table G A = **0.009696**
PaMax = $4 \cdot B / (3 \cdot \text{DoT})$ = $4 \cdot 1 / (3 \cdot 19.672)$ **Okay** PaMax = **0.1**
tre = $(3 \cdot \text{Do} \cdot \text{Pa}) / (4 \cdot B)$ = $(3 \cdot 24 \cdot 0) / (4 \cdot 1)$ tre = **0.000**

Shell stress relief -UCS-79(d), UNF-79(d), UHA-44(d)

Rf = $(\text{do} - t) / 2$ = $(24 - 1.22) / 2$
% elong = $(50 \cdot t / \text{Rf}) \cdot (1 - 0)$ = $(50 \cdot 1.22 / 11.39) \cdot (1 - 0)$ % elongation = **11.39**
0.1% <- Max Elongation **5.4**

Yes <- Cold formed **5.4%** <- Elongation
no <- Vessel carries lethal substances (Yes/no)
no <- Impact testing is required (Yes/no)
no <- Greater than 10% reduction in thickness
no <- Formed between 250 and 900 Degrees F
YES <- Shell is greater than 5/8" thick before forming

Required	Yes ?
no	no
no	no
no	no
no	no
no	no
no	no
Stress Relieve ?	no

Elliptical Head CH 3_1.1

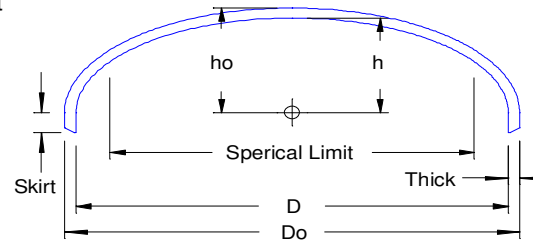
ASME Code VIII Div I 2001 no Addenda

<- BM <- BM Item # <- BM Qty

Heads <- Component

Dimensions:

47.000 <- Do, outside diameter
10.550 <- h
2.000 <- tb, thickness before forming
2.000 <- tf, thickness after forming
0.000 <- Corr, corrosion allowance
5.000 <- Skirt, straight skirt length

**Material and Conditions:**

SA-516 <- material
20 000 <- S, allowable stress level (psi)
1.00 <- E, efficiency
1392.4 <- P, interior pressure
0.0 <- Pa, exterior pressure
1 <- B, from exterior pressure curve

Calculated Properties:

60.6 <- Approximate blank diameter
1636.6 <- Approximate weight for steel, (lbs)
10.11 <- Volume (cuft, includes skirt)
34.40 <- Spherical Limit (0.8 * D)
0.00631 <- A value to lookup B

Variables:

D = Do-2*t = 47-2*2 = **43.00**
 ho = h+t = 10.55+2 = **12.55**
 D/2h = D/(2*h) = 43/(2*10.55) = **2.038**
 Do/2ho = Do/(2*ho) = 47/(2*12.55) = **1.873**
 K = Interpolated value from table 1-4.1 interior = **1.027**
 Kone = Interpolated value from table UG-37 spherical = **0.917**
 Kzero = Interpolated value from table UG-33.1 exterior = **0.843**
 t = tf-corr = 2-0 = **2.000**
 Ro = Ko*Do = 0.843*47 = **39.604**

Interior Pressure App 1-4(c)(d), UG-37 1(a)

TMinl = (P*D*K)/(2*S*E-0.2*P) <= t TMinl (min thickness) = **1.547**
 = (1392.4*43*1.027)/(2*20000*1-0.2*1392.4) <= 2 **Okay**
 PMax = (2*S*E*t)/(K*D+0.2*t) >= P PMax = **1796**
 = (2*20000*1*2)/(1.027*43+0.2*2) >= 1392 **Okay**
 TSpl = (P*D*Kone)/(2*S*E-0.2*P) TSpl (required sphere zone thick) = **1.382**
 = (1392.4*43*0.917)/(2*20000*1-0.2*1392.4)

Exterior Pressure UG-33(d), UG-28(d)

A = 0.125/(Ro/t) = 0.125/(39.604/2) **Okay**
 A = **0.006313**
 PaMax = B/(Ro/t) >= Pa = 1/(39.604/2) >= 0 PaMax = **0.1**
 TMinE = (Ro*Pa)/B = (39.604*0)/1 TMinE = **0.000**

Head stress relief UCS-79(d), UNF-79(d), UHA-44(d)

% elong = ((75*t)/h)*(1-0) = ((75*2)/10.55)*(1-0) % elong = **14.2**

5.0% <- Max Elongation
Yes <- Cold Formed **14.2%** <- Elongation
no <- Vessel carries lethal substances(Yes/no)
no <- Impact testing is required (Yes/no)
no <- Formed between 250 and 900 Degrees F
no <- Greater than 10% reduction in thickness
Yes <- Head is greater than 5/8" thick before forming

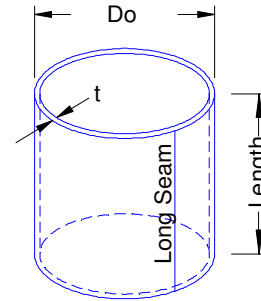
Required	Yes ?
no	no
no	no
no	no
no	no
Yes ?	YES
Stress Relieve ?	YES

Pipe and Shell CQL_1

ASME Code VIII Div I 2001 edition no addenda

ASME L-2.2.1 <- BM **1** <- BM Item #**Verification Calc #3** <- Vessel, description**1** <- BM Qty**Dimensions:**

24.000 <- Do - Outside Diameter
1.220 <- t - Nominal Wall Thickness
39.370 <- Length
0.000 <- Corr, Corrosion Allowance

**Material and Conditions:**

SA-516 <- Material
20 000 <- S, Allowable Stress Level (psi)
0.85 <- E1 - Longitudinal Efficiency (circ. stress)
0.65 <- Ec - Circ. Connecting Efficiency (longitudinal stress)
0.0% <- UTP, Undertolerance allowance (%) **8.32** <- Volume (cubic ft)
0.000 <- UTI, Undertolerance allowance (inch) **974.9** <- Material Weight (lbs cs)
1392.4 <- P, Interior Pressure
0.0 <- Pa, Exterior Pressure
1 <- B, From exterior pressure curve **0.009696** <- A (use to lookup B)

Variables:

UT = $t \cdot \text{UTP} + \text{UTI}$ = $1.22 \cdot 0 + 0$ undertolerance UT = **0.000**
 Ri = $\text{Do} / 2 - t + \text{corr}$ = $24 / 2 - 1.22 + 0$ inside radius Ri = **10.780**
 nt = $t - \text{Corr} - \text{UT}$ = $1.22 - 0 - 0$ nominal thick nt = **1.220**
 LDo = L / Do = $39.37 / 24$ LDo = **1.640**
 DoT = Do / nt = $24 / 1.22$ DoT = **19.672**

Interior Pressure UG-27 (c) (1,2)

ta = $P \cdot \text{Ri} / (S \cdot E1 - 0.6 \cdot P)$ = $1392.4 \cdot 10.78 / (20000 \cdot 0.85 - 0.6 \cdot 1392.4)$ ta = **0.929**
 tb = $P \cdot \text{Ri} / (2 \cdot S \cdot \text{Ec} + 0.4 \cdot P)$ = $1392.4 \cdot 10.78 / (2 \cdot 20000 \cdot 0.65 + 0.4 \cdot 1392.4)$ tb = **0.565**
 tmin = $\text{Max}(ta, tb) \leq nt$ **Okay** tmin = **0.929**
 PMaxA = $(S \cdot E1 \cdot nt) / (\text{Ri} + 0.6 \cdot nt)$ = $(20000 \cdot 0.85 \cdot 1.22) / (10.78 + 0.6 \cdot 1.22)$ PMaxA = **1801.6**
 PMaxB = $(2 \cdot S \cdot \text{Ec} \cdot nt) / (\text{Ri} - 0.4 \cdot nt)$ = $(2 \cdot 20000 \cdot 0.65 \cdot 1.22) / (10.78 - 0.4 \cdot 1.22)$ PMaxB = **3082.0**
 PMax = $\text{Min}(\text{PMaxA}, \text{PMaxB})$ **Okay** PMax = **1801.6**
 tr1 = $P \cdot \text{Ri} / (S \cdot 1 - 0.6 \cdot P)$ = $1392.4 \cdot 10.78 / (20000 \cdot 1 - 0.6 \cdot 1392.4)$ tr1 = **0.783**

Exterior Pressure UG-28 (c)

A = Interpolated from IID Part D Table G A = **0.009696**
 PaMax = $4 \cdot B / (3 \cdot \text{DoT})$ = $4 \cdot 1 / (3 \cdot 19.672)$ **Okay** PaMax = **0.1**
 tre = $(3 \cdot \text{Do} \cdot \text{Pa}) / (4 \cdot B)$ = $(3 \cdot 24 \cdot 0) / (4 \cdot 1)$ tre = **0.000**

Shell stress relief -UCS-79(d), UNF-79(d), UHA-44(d)

Rf = $(\text{do} - t) / 2$ = $(24 - 1.22) / 2$
 % elong = $(50 \cdot t / \text{Rf}) \cdot (1 - 0)$ = $(50 \cdot 1.22 / 11.39) \cdot (1 - 0)$ % elongation = **11.39**
0.1% <- Max Elongation **5.4**

Yes <- Cold formed **5.4%** <- Elongation
no <- Vessel carries lethal substances (Yes/no)
no <- Impact testing is required (Yes/no)
no <- Greater than 10% reduction in thickness
no <- Formed between 250 and 900 Degrees F
YES <- Shell is greater than 5/8" thick before forming

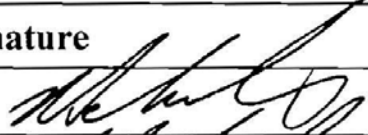
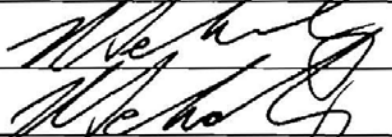
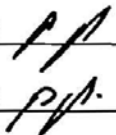
Required	Yes ?
no	no
no	no
no	no
no	no
no	no
no	no
Stress Relieve ?	no

NGNP and Hydrogen Production Conceptual Design Study

NGNP CTF Test Loop Pre-Conceptual Design Report

Section 8: Component Qualification Loop 2 (CQL2)

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BACKGROUND INTELLECTUAL PROPERTY CONTENT

Section	Title	Description
N/A		

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B	I. Scholtz	First Release to BEA	November 24, 2008
C	I. Scholtz	Updated release to BEA	November 29, 2008
D	I. Scholtz	Updated and includes BEA comments and resolutions from design review held on 02 Dec. 2008. Updated for consistency with regards to references and nomenclature.	December 5, 2008
0	I. Scholtz	Document for final release to BEA	December 15, 2008

DOCUMENT TRACEABILITY

Created to Support the Following Document(s)	Document Number	Revision
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ACRONYMS

Abbreviation or acronym	Definition
A	Accelerometer
A-E-C	Architecture – Engineering -Construction
AGR	Advanced Gas-cooled Reactor
AHJ	Authority Having Jurisdiction
AICE	American Institute of Chemical Engineers
AISC	American Institute of Steel Construction
AISI	American Iron and Steel Institute
ALARA	As Low As Reasonable Achievable
AMB	Active Magnetic Bearing
ANSI	American National Standards Institute
API	American Petroleum Institute
ASHRAE	American Society of Heating Refrigeration and Air Conditioning Engineers
ASME	American Society of Mechanical Engineers
AWS	American Welding Society
BEA	Battelle Energy Alliance
BIL	Basic Impulse Insulation Level
BIM	Building Information Management
BS	British Standard
Btu/hr	British thermal unit per hour
CAD	Computer Aided Design
CAE	Computer Aided Engineering
CBCS	Core Barrel Conditioning System
CCS	Core Conditioning System
CFR	Code of Federal Regulations
CH	Cold Header
CMAA	Crane Manufacturers Association of America
COR	Client Observation Room
COTS	Commercial Off-The-Shelf (Commercial Grade Items)
CQL	Component Qualification Loop
CQL1	Component Qualification Loop 1
CQL2	Component Qualification Loop 2
CTF	Component Test Facility
CTL	Circulator Test Loop
CV	Valve Flow Coefficient
DAQ	Data Acquisition
db	Dry Bulb
DB	Distribution Board
DC	Direct Current
DCD	Design Criteria Document
DCS	Distributed Control System
DDN	Design Data Need
DOE	Department of Energy
dP	Differential Pressure
DPP	Demonstration Power Plant
EDMS	Engineering Data Management System
EHR	Essener Hochdruck Rohrleitung

Abbreviation or acronym	Definition
EIA	Electronic Industry Alliance
EMB	Electro-magnetic Bearing
ENS	Emergency Notification System
EPACT	Energy Policy Act (of 2005)
EPC	Engineering Procurement and Construction
ER	Environmental Requirement
ES&H	Environmental, Safety and Health
ESD	Emergency Shutdown
F	Flow Rate
FDD	Facility Design Description
FHA	Fire Hazard Analysis
FIPS	Federal Information Processing Standards
FM	Factory Mutual
FMS	Facility Monitoring System
FS	Flow rate (switch)
GA	Gas analyzer (composition)
GHEP	Guidelines for Hazard Evaluation Procedures
gpm	Gallon per minute (US)
GR	General Requirements
H2	Hydrogen Production Test (Specifically referring to H2SO4 Decomposition Reactor Test)
H2SO4	Sulfuric Acid
HAZOP	Hazard and Operational Study
HDBK	Handbook
HGD	Hot Gas Duct
HGDs	Hot Gas Ducts
HH	Hot Header
HICS	Helium Inventory Control System
HIPCS	Helium Inventory and Pressure Control System
HIRA	Hazard and Risk Identification Analysis
HLR	High Level Requirement
HMI	Human Machine Interface
HPS	Helium Purification System
HT	Heat Transfer
HTF	Helium Test Facility
HTGR	High Temperature Gas -Cooled Reactor
HTS	Heat Transport System
HTSE	High Temperature Steam Electrolysis
HTTR	High Temperature Test Reactor
HTTU	High Temperature Test Unit
HV	High Voltage (>132,000V)
HVAC	Heating, Ventilation, & Air Conditioning
HX	Heat Exchanger
HyS	Hybrid Sulfur
I&C	Instrumentation and Control
I/O	Input/Output
IBC	International Building Code
ICC	International Code Council
ICD	Initial Conceptual Design

Abbreviation or acronym	Definition
ICEA	Insulated Cable Engineers Association
IDAPA	Idaho Administrative Procedure Act
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IFC	International Fire Code
IFGC	International Fuel Gas Code
IHX	Intermediate Heat Exchanger
IHX A	Intermediate Heat Exchanger A
IHX B	Intermediate Heat Exchanger B
IMC	International Mechanical Code
IMS	Information Management Systems
INL	Idaho National Laboratory
IPMC	International Property Maintenance Code
ISA	International Society of Automation
ISO	International Organization for Standardization
JB	Junction Box
kg/s	Kilogram per second
kV	Kilovolt (1000 Volts)
kl/h	Kilolitre per hour
kPa	Kilopascal (1000 Pascal)
kW	Kilowatt (1000 Watts)
LCD	Liquid Crystal Display
LCP	Local Control Panel
LRFDS	Load and Resistance Factor Design Specification
LV	Low Voltage (<1000 V)
MBMA	Metal Building Manufacturers Association
MCC	Motor Control Center
MCR	Mission Critical Requirement
MDB	Main Distribution Board
MES	Manufacturing Execution System
MPa	Megapascal = million Pascal
MTI	M-Tech Industrial (Pty) Ltd.
MV	Medium Voltage (>1000V< 132 000V)
MW	Megawatt (Million Watts)
N	Speed
NBIMS	National BIM Standards Project Committee
NEC	National Electrical Code
NEMA	National Electrical Manufacturers Association
NEPA	National Environmental Policy Act
NESC	National Electrical Safety Code
NFPA	National Fire Protection Association
NGNP	Next Generation Nuclear Plant
NHI	Nuclear Hydrogen Initiative
NIST	National Institute of Standards and Technology
NQA-1	ASME NQA-1 2000, Quality Assurance for Nuclear Facilities
OPC	Operating Procedure Checklist
OSHA	Occupational Safety and Health Administration
P	Pressure
P&ID	Piping and Instrument Diagram

Abbreviation or acronym	Definition
PBMR	Pebble Bed Modular Reactor
PCDR	Preconceptual Design Report
PCFC	Preconceptual Facility Configurations
PCHX	Printed Circuit Heat Exchanger
PCS	Process Control System
PDA	Potential Deviation Analysis
PDMS	Project Data Management System
PDS	Plant Design System
PFD	Process Flow Diagram
PHA	Preliminary Hazard Analysis
PHTS	Primary Heat Transport System
PLC	Programmable Logic Controller
PLCs	Programmable Logic Controllers
PMN	Support Manager
PRV	Pressure Relief Valve
psig	Pound per square inch gauge
PSM	Support Modeler
QC	Quality Control
QCP	Quality Control Plan
RCS	Reactivity Control System
RIS	Relational Interface System
RPV	Reactor Pressure Vessel
RSA	Republic of South Africa
SBS	System Breakdown Structure
SCADA	Supervisory Control and Data Acquisition System
scfm	Standard cubic feet per minute
SDD	System Design Description
SDI	Steel Door Institute or Steel Deck Institute
SG	Steam Generator
SHEQ	Safety, Health, Environmental and Quality
SHTS	Secondary Heat Transport System
SI	Sulfur Iodine
SIL	Safety Integrity Level
SIS	Safety Instrument System
SJI	Steel Joist Institute
SNM	Special Nuclear Materials
SPEL	SmartPlant Electrical
SPF	SmartPlant Foundation
SPMat	SmartPlant Material
SPR	SmartPlant Review
SPS	Standby Power System
SR	Safety Requirement
SRM	System Requirement Manual
SSC	Systems Structures and Components
SSDT	Small Scale Development Test
SSS	Site Selection Study
SSSB	Specification for Structural Steel Buildings
STD	Standard
T	Temperature

Abbreviation or acronym	Definition
T&FR	Technical and Functional Requirement
TBC	To Be Confirmed
TBD	To Be Determined
TDL	Technology Development Loop
TDRM	Technology Development Road Map
TEDS	Transducer Electronic Data Sheet
TEMA	Tubular Exchanger Manufacturers Association
THTR	Thorium High Temperature Reactor
TIA	Telecommunications Industry Association
TRL	Technology Readiness Level
TSR	Technical Safety Requirement
UL	Underwriters Laboratories
UPC	Uniform Plumbing Code
UPS	Uninterruptable Power Supply
UUT	Unit Under Test
V&V	Verification and Validation
VHTGR	Very High Temperature Gas-Cooled Reactor
VL	Valve
VSD	Variable Speed Drive
wb	Wet Bulb
WBS	Work Breakdown Structure
WEC	Westinghouse Electric Company
WE-SA	Westinghouse Electric - South Africa
ϵ	Strain

SUMMARY AND CONCLUSIONS

The proposed Component Qualification Loop 2 (CQL2) is referred to as Concept 2 in the Next Generation Nuclear Plant (NGNP) CTF Feasibility and Recommendation Study (Reference [8-4]). This concept proposes a two-loop flow system that simulates the NGNP demonstration plant primary and secondary loops. Both the loops use Helium as flow medium. The CQL2 system operating pressure is design to be similar to that of the NGNP at 9 MPa. A high-temperature section, reaching temperatures of up to 950°C is also included in the design.

The mass flow of CQL2 should be 25 kg/s, representing approximately 14 percent of anticipated NGNP maximum flow. The blower section of the loop operates at 250°C to accommodate the use of existing technology blowers.

The design of the CQL2 is conservative, flexible and suitable for qualification of large NGNP components. It makes provision for a number of different configurations, to allow for testing of a wide spectrum of high temperature reactor system components in five different test bays. These include but are not limited to:

1. The primary loop test bay for testing
 - a. Intermediate Heat Exchanger (IHx)
 - b. Hot pipes
 - c. Valves
 - d. Core flow model
2. The secondary loop test bay for testing
 - a. Instrumentation
 - b. Seals
3. The steam generator loop for testing
 - a. High temperature steam generators
 - b. Mixing chambers
 - c. Process heat experiments
4. The ultra-high temperature test bay for testing
 - a. Control rods and control rod drives
 - b. Reserve shutdown systems
5. The gas turbine set test bay for testing
 - a. Brayton cycle components
 - b. Co-generation components for direct loop

Experience with the Helium Test Facility (HTF) in South Africa showed that testing with flow simulation of less than 10 percent does not necessarily provide accurate extrapolation compared to full size flow.

The CQL2, at 14 percent of proposed NGNP maximum flow, forms an integral building block towards the final realization of NGNP component development and qualification, without which it may not be possible to progress existing components under development to reach a technology readiness level of 8 as is required (Reference [8-1]).

8. NGNP CTF TEST LOOP PCDR COMPONENT QUALIFICATION LOOP2

8.1 Design Philosophy

The existing needs for testing of high temperature nuclear reactor process heat components were defined in previous studies through an evaluation, selecting and grouping process as defined in the CTF Feasibility and Recommendation (Reference [8-4]). Also the down selection argumentation of technologies defined the technology readiness levels Technology Readiness Level (TRL) of the individual main components (Reference [8-5]). In some cases credit is given to design and development work done and predicted for the PBMR program, especially those engineering related to reactor-unit subsystems and components e.g. control drive lines, graphite core structures etc.

The CQL2 Test Loop, which can be configured in seven different configurations, has a flow capability simulating about 14 percent of the proposed NGNP flow rate. The seven different configurations provide the necessary flexibility for testing the different main components under the maximum attainable process conditions and provide for flexibility in the readiness levels of components under test. Examples include: the use of the Main Loop without the Secondary Loop or using the developed highly efficient compact intermediate heat exchangers as recuperators in the Main Loop to perform the tests more economically.

The design of CQL2 provides for a wider range of tests as identified or requested. This extended use and flexibility is demonstrated in the different configurations of the loop. The CQL2 maximum helium flow rate of 25 kg/s was selected with the objective to test representative engineering size products under reactor simulated flow conditions.

- Insulation function
- Full flow hot pipe to test fluid induced vibrations
- Connecting piece effectiveness
- Mixing chamber to test mixing effectiveness with dimensional equality
- Gas circulators on magnetic bearings
- Graphite dust effect tests
- Integrated extreme high temperature gas-to-gas integrated modular heat exchanger
- Temperature and stress distribution experiments etc.

All of the above mentioned examples need a test loop providing a relatively large mass flow at near simulated temperature and pressure conditions. The largest realistic and affordable test loop to test this integrated product is recommended. Such integrated/assembled product performance and behavior cannot be predicted and qualified by analytic methods.

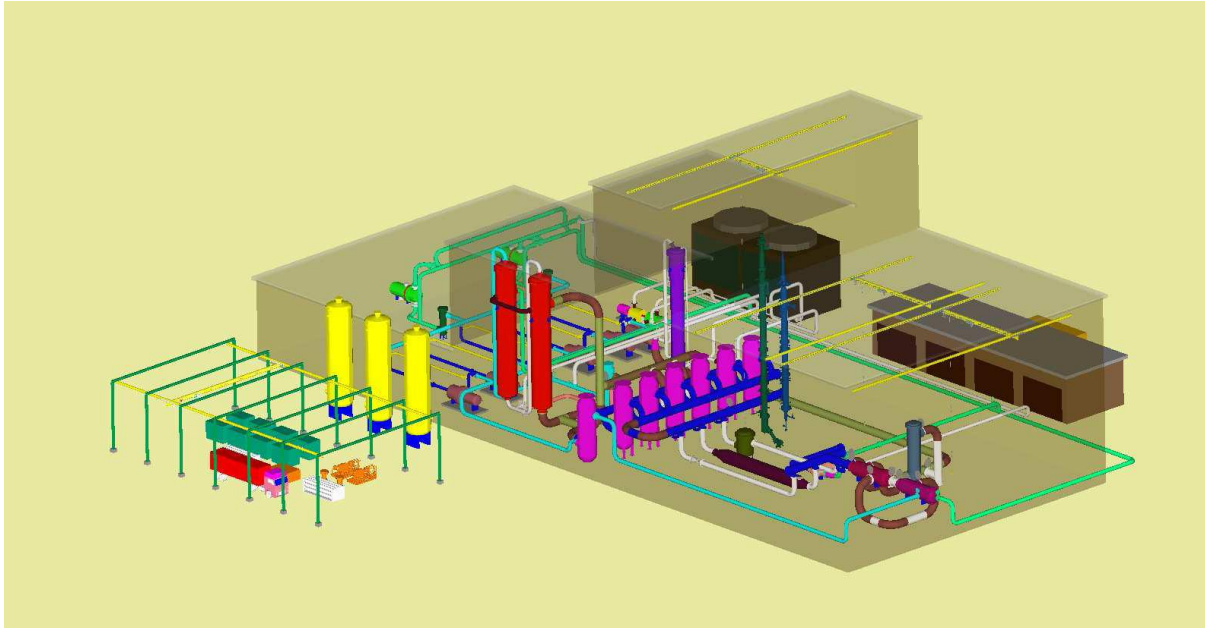


Figure 8-1: CQL2 Artist's Impression

8.2 High Level Assumptions

8.2.1 Strategies

8.2.1.1 Design and Engineering

The design strategy for the CQL2 is to maximize use of available technology on all mission critical components. The TRLs of certain key components that are required for CQL2 in accordance with the roadmap document (Reference [8-5]).

The required TRL for CQL2 main components is set as a requirement to be six or higher. Where level six or higher technology level is not attainable, a roadmap for the development of such equipment to reach the higher levels is proposed. Interpretation is depicted below for clarity and reference purposes.

8.2.1.2 Technology Readiness

Roadmap course:

- Function and operational status
- Design selection status (candidates, decision discriminators, reference designs, alternative investigation, down selection)
- Technology Readiness Level (TRL) status
- Technology development roadmap
- Technology maturation plan
- Technology development
- Input to Component Test Facility (CTF)
- Appendices

Technology readiness levels

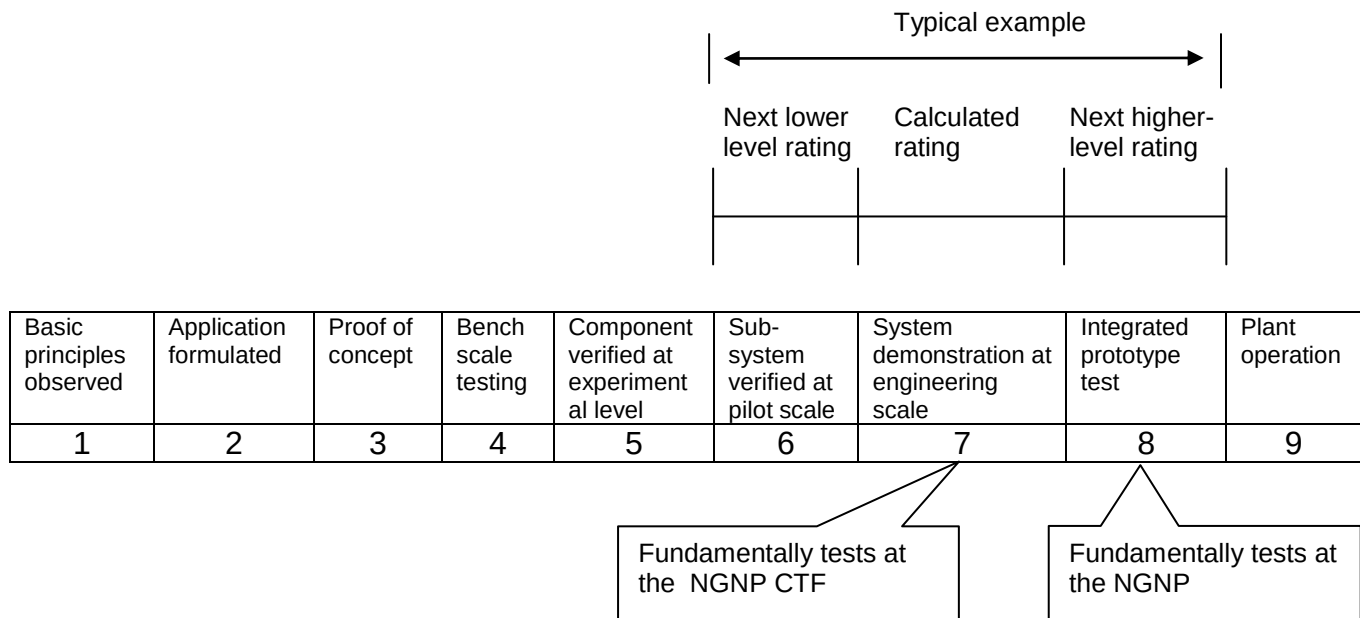


Table 8-1: Development products

Product under test	TRL		Comments	Large CTF requirements i.e. Engineering scale tests TRL 7 (6 to7)
	Components	System		
1) Gas circulator	8	6		Required
2) IHE (high temp.)		2 metal 1 ceramic		Required
3) IHE (low temp.)		3		Required
4) High temp. piping		4		Required
5) Steam generator		6		Required
6) High temp. valves				Required
7) High temp. Instrumentation				Required
8) H ₂ production components				Required
9) Mixing chamber		6		Required
16) Blower (Submerged). EMB bearings		5	Howden, HTF blower RSA. CBCS blower DPP	UUT

8.2.1.3 Component Test Facility Criteria

With Reference to the NGNP CTF – Feasibility & Recommendations document of February 2008 (Reference [8-4]), Concept 2 of this document was used as basis for this preconceptual design. The assumptions and recommendations are used as design input for the work described in this section.

Some components are limited by existing technology readiness levels, placing constraint on their usage as primary devices within CQL2. In such cases such components are referred to as Units Under Test (UUTs).

An iterative design process will be followed, keeping within the boundaries or constraints as determined in previous studies.

8.2.2 CQL2 System Assumptions

- The Test Loop is configured in:
 - The blower section, blowers, coolers and load control / anti surge control valves
 - The energy section heaters and recuperators
 - The test hall to provide for high (tall) test set-ups as well as medium height set-ups
 - Helium Inventory and Pressure Control System (HIPCS)

- Differently configurable loops is an advantage
- Main considerations are:
 - Conservative design
 - Flexibility
 - Energy logic
- A flow rate of 25 kg/s
- Conditioning of pressure boundary, to remain within design limits of pressure and temperature, is possible.

8.2.3 CQL2 Component Assumptions

- Technology Readiness Level of 8 is preferred for all main loop components
- Not all piping is designed as high temperature pipes, optimum classes are used
- Life of main components are not to be guaranteed for 40 years full life
- Monitoring and instrumentation will be more extensive compared to normal industrial installations
- High industrial standards will be applied for design and construction, full data books and logbooks to be held for all components.

8.2.4 Operational Assumptions

- Although the control system will be capable of fully automated operation, the plant will always be attended by trained, qualified and certified process controllers
- Entire plant, including any modifications or additions, will be under formal configuration control and management
- All tests will be thermal-hydraulically simulated and test procedures prepared, reviewed and accepted prior to test execution
- Testing and commissioning procedure will be prepared, reviewed, implemented and followed

8.3 Thermal Hydraulics

8.3.1 Intermediate Heat Exchanger

The IHX will typically be tested with “primary” circuit helium entering at 950°C. The most obvious method to achieve this is with a heater in the primary circuit and a recuperator transferring heat from the hot secondary loop flow exiting the IHX back to the primary loop to improve efficiency: 950°C flow entering the primary side of the IHX could heat the secondary side flow to 900°C. This can in turn be used to preheat the primary loop flow to 800°C using a recuperator. A mass flow of 32kg/s can theoretically be heated from 800°C to 950°C with a 25MW heater. See Configuration 1 [Paragraph 8.7.1].

A more compact way to test an IHX is to do away with the recuperator and to direct the secondary side flow preheated through the IHX through the heater and then back through the primary side of the IHX. The heater inlet temperature could then be as high as 875°C to 900°C. A mass flow of 64kg/s can theoretically be heated from 875°C to 950°C using a 25MW heater. See Configuration 2 [Paragraph 8.7.2]. Blower power and pipe sizing considerations limited the mass flow for this configuration to around 53kg/s, one third of the NGNP 160kg/s flow. The 25kg/s specified for IHX testing is therefore easily achievable.

8.3.2 Steam Generator

For a test loop with a steam generator and Printed Circuit Heat Exchanger (PCHX), the maximum PCHX inlet temperature is assumed to be 900°C and the steam generator outlet temperature 250°C. The 660°C PCHX outlet flow will mix with 900°C bypass flow to give a steam generator inlet temperature of 840°C. A heater will be necessary to heat the helium from around 240°C back to 900°C. A 25MW heater could only heat 7.3kg/s helium from 240°C to 900°C, 4.6 percent of full NGNP flow. Preheating the helium to 400°C, using a heat exchanger to recuperate heat from the steam could increase the helium flow to 9.6kg/s, 6 percent of full NGNP flow. See Configuration 3 [Paragraph 8.7.3]. Only 25 percent of flow through steam generator is first diverted through the PCHX. This 1.5 percent to 2.5 percent of full reactor flow is probably on the low side to test the PCHX and other configurations are proposed to test the PCHX. Configuration 7 tests the Steam Generator together with an IHX set, with around 9kg/s flow [Paragraph 8.7.7].

8.3.3 Printed Circuit Heat Exchanger

Testing a PCHX with an inlet of 900°C and an outlet of 660°C could be accomplished in combination with Configuration 2. See Configuration 4 [Paragraph 8.7.4]. A 25MW heater can heat 16kg/s from 660°C to 950°C. 10 percent of full NGNP flow. This configuration could be further optimized with IHX flow bypassing the PCHX for possibly more ideal higher flow through the IHX and lower flow through the PCHX. 14kg/s PCHX flow is possible in combination with full 25kg/s IHX testing flow using 25MW of heating.

8.3.4 Direct Cycle Components: Turbine and Compressor

Assuming 900°C turbine inlet, 512°C turbine outlet, a 100°C temperature difference between the two streams through the recuperator result in a heater inlet and outlet temperature of 412°C and 900°C respectively. 25MW could heat a flow of 9.5kg/s, 6 percent of full NGNP flow. See Configuration 5.

8.3.5 Full-Scale Circulator

The full-scale circulator is tested in Configuration 8. This is a separate test loop, similar but bigger than the surge loop around one of the other blowers. It is connected to a cooler to control gas temperatures and system resistance is controlled with a large control valve.

Table 8-2: Configurations and test summary

L-CTF Configuration	Components under test	Mass flow
C1: Principle two loop configuration	IHXA, IHXB Test Group A, B	IHX: 25kg/s
C2: High efficiency component test	IHXA, IHXB Test Group A	IHX: 53kg/s theoretical (25kg/s specified)
C3: Main-loop-process heat component test (Steam Generator)	Steam generator PCHX Group A	SG: 9kg/s PCHX: 2.25kg/s
C4: Intermediate heat exchanger with H2 generation test	IHXA, IHXB PCHX Test Group A	IHX: 25kg/s PCHX: 14kg/s
C5: Brayton Cycle test	Turbine Compressor	9.5kg/s
C6: Basic Component Test	Test Group A	25kg/s
C7: Steam generator coupled to secondary loop	IHXA, IHXB Steam generator PCHX Test Group A, B	8.7kg/s (PCHX 2.175kg/s)
C8: Full-scale circulator test	Full-scale circulator	160kg/s

8.3.6 Mass and energy balance

8.3.6.1 Assumptions

Heat input

The main plant constraint is the 50MW (Reference [8-1]) electrical supply for most configurations. It is assumed that half of this; 25MW is available for heating through Heater H1.

Circulators or blowers and component sizing

The circulator pressure differential, component sizing and pipe sizing came from previous experience and through iteration. In general, one to four of similar type PBMR CBCS blower curves in parallel are a close fit for the requirements of the different configurations. The blowers for the CTF could typically have external motors and dry gas seals, but due to similar flows, the CBCS blowers are a good starting point for impeller configuration. Optimizing the impeller curve for lower mass flow and higher pressure differential while staying with 450kW motors make around 130kPa to 160kPa pressure differential possible depending on flow. Although it is possible to use larger 1000kW motors that could double this pressure differential, it was decided to aim for around 100kPa pressure differential in sizing piping. With Configuration 2 [Paragraph 8.7.2] with four blowers running in parallel, the mass flow per blower is lower in relation to blower pressure differential and the working point is moved to a point on the curve where higher pressure differential is available. The aim for maximum flow in Configuration 2 is around 140kPa (160kPa minus margin).

Theoretically, flow will be heated by around 4°C, depending on circulating work done, as it passes through the circulators, but previous experience shows that this gas temperature rise does not materialize as the heat is typically removed by the circulator cooling system and other heat sinks.

Assumption list

Design pressure	9000kPa
Overall plant maximum electrical load	50MW
PBMR reactor 100 percent flow	160kg/s
Blowers B1, B2 maximum outlet temperature	250°C
Blowers B1, B2	$T_{in} = T_{out}$
Heater H1 maximum outlet temperature	950°C
Heater H1 maximum electrical load	25MW
ΔT between R1 primary and secondary streams	100°C
IHX primary side test inlet temperature	950°C
IHX secondary streams required inlet temperature	287°C
ΔT between IHX primary and secondary streams	50°C
Steam generator SG test helium inlet temperature	840°C

Steam generator SG helium outlet temperature	250°C
Steam generator SG steam outlet temperature	540°C
PCHX outlet temperature	660°C
Pre Heater H3 outlet temperature	400°C

H3 outlet temperature is based on its inlet temperature, PBMR steam generator values and conservatism on heat exchanger efficiency.

Turbine inlet temperature	900°C
Turbine outlet temperature	512°C
Turbine inlet pressure	9000kPa
Turbine outlet pressure	2900kPa
Compressor inlet temperature	30°C
Compressor outlet temperature	110°C

8.3.6.2 Configurations

8.3.6.2.1 C1: Principle-two loop-configuration

An IHX set is tested using a primary and secondary loop with the aid of a recuperator.

Assumptions

Test requirements assumptions:

Heater H1 outlet temperature	950°C

IHX secondary streams required inlet temperature	287°C

Component characteristic assumptions:

Heater H1 maximum electrical load	25MW

IHX ΔT between primary and secondary streams	50°C

R1 ΔT between primary and secondary streams	100°C

B1, B2 maximum Tout	250°C

B1, B2 maximum pressure differential	100kPa

Process description, mass and energy balance

This preliminary mass and energy balance excludes temperature drops in piping and other inefficiencies:

Hot side:

950°C flow exiting Heater H1 enters the primary side of the IHX and heats the secondary side flow to 900°C. This flow in turn preheats the primary loop flow to 800°C through the recuperator set. The 800°C flow is heated to 950°C through Heater H1. Theoretically 25MW heat input can heat a mass flow of 32kg/s from 800°C to 950°C. Due to inefficiencies and heat loss from equipment and piping and from discussions of what flows are required for such an experiment, mass flows of 25kg/s for both primary and secondary loops was decided on for this test configuration (19.5MW heating inside Heater H1).

Cold side:

25kg/s 250°C flow through circulators B1a and B1b (primary loop) cools the secondary loop flow through R1 down to 350°C (100°C ΔT between sides through R1). Cooler C2 then cools secondary loop flow to 250°C (13MW cooling). The flow then passes through circulators B2a and B2b and is heated to 287°C by Heater H2 (4.8MW heating) before entering the IHX. This 287°C flow entering the IHX cools the primary loop flow through the IHX to 337 °C. Cooler C1 then cools the flow to 250°C (11.3MW cooling).

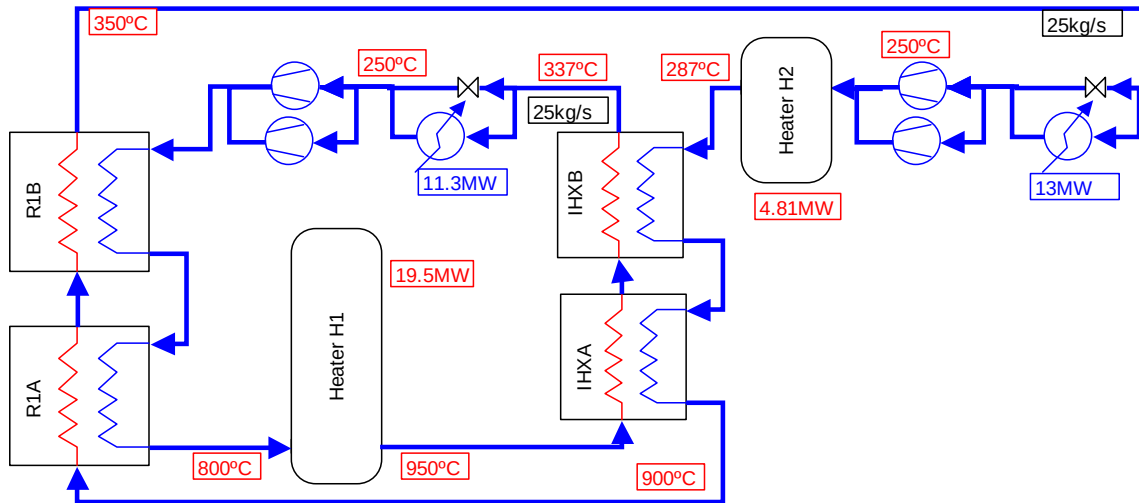
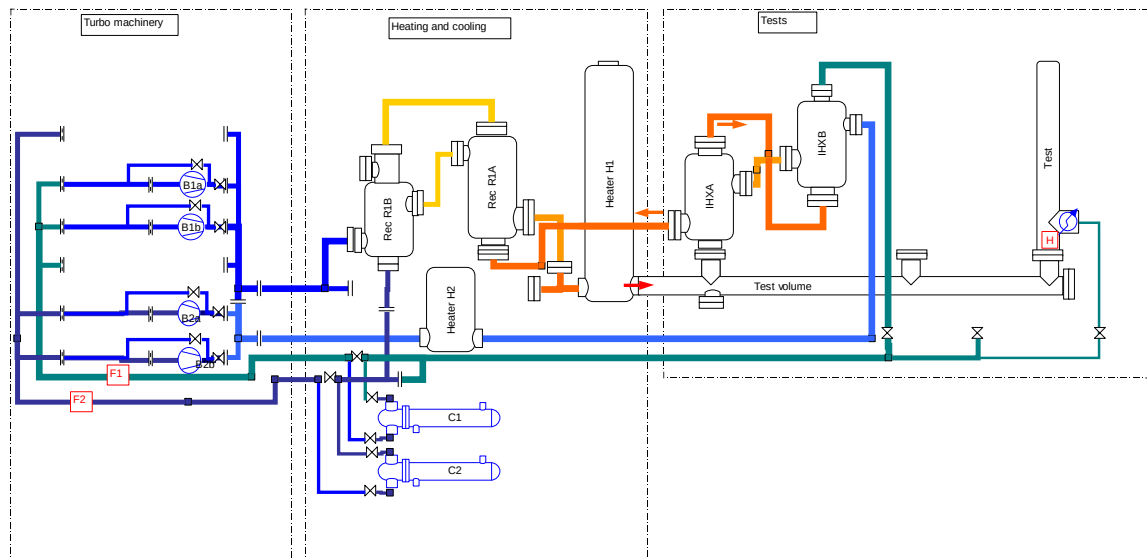
**Figure 8-2: C1: Simplified PFD****Figure 8-3: C1: Block flow diagram**

Table 8-3: C1: Component data

	P nominal	m	Ti	To	Q
	[kPa]	[kg/s]	[°C]	[°C]	[MW]
Cooler C1	9000	7.58	337	50	-11.3
Cooler C2	9000	8.33	350	50	-13.0
Blower B1a	9000	12.5	250	250	
Blower B1b	9000	12.5	250	250	
Blower B2a	9000	12.5	250	250	
Blower B2b	9000	12.5	250	250	
R1a primary side	9000	25	900	487.5	-53.6
R1a secondary side	9000	25	387.5	800	53.6
R1b primary side	9000	25	487.5	350	-17.9
R1b secondary side	9000	25	250	387.5	17.9
Heater H1	9000	25	800	950	19.5
Heater H2	9000	25	250	287	4.8
IHX A primary side	9000	25	950	643.5	-39.8
IHX A secondary side	9000	25	593.5	900	39.8
IHX B primary side	9000	25	643.5	337	-39.8
IHX B secondary side	9000	25	287	593.5	39.8
Filter F1	9000	25	250	250	
Filter F2	9000	25	250	250	

Preliminary pipe sizing

Aiming for 100kPa maximum system pressure drop using guessed pipe lengths and loss factors result in 24" main hot piping (piping hotter than 550°C: inner pipe 24", outer pipe around 48"), 24" main single piping, 18" pipes to and from each blower and 12" to and from each cooler. With more accurate pipe lengths and numbers of bends available, less margin for uncertainty will be required and smaller diameter pipes might be proposed.

Electrical consumption

Heaters H1 and H2 together with the blowers consume around 25MW. Margin should be added to this for heat losses from components and possibly higher system resistance increasing blower power.

Table 8-4: C1: Primary loop preliminary pipe sizing and pressure drops

	NS ["]	Di [m]	L [m]	K	ΔP [kPa]
Blower B1a					-80
Pipe	18	0.41	5	2	1.15
Pipe	24	0.55	10	2	1.45
B1 supply manifold	24	0.55	20	2	1.61
Pipe	24	0.55	20	2	1.61
R1B secondary side					10
R1B to R1A	24	0.61	10	1.5	0.93
R1A secondary side					10
Pipe	24	0.61	10	1.5	1.51
Heater H1					5
H1 supply manifold	24	0.61	10	1.5	1.73
IHXA primary side					10
IHXA to IHXB	24	0.61	10	1.5	1.30
IHXB primary side					10
Pipe	24	0.55	10	2	1.74
B1 return manifold	24	0.55	10	2	1.74
Pipe	24	0.55	10	2	1.74
Flow split to C1	12	0.29	10	2	1.95
Cooler C1					5
Pipe	12	0.29	10	2	1.04
Rejoin main stream	24	0.55	10	2	1.49
Split to B1a	18	0.41	20	2	1.38
Flow meter x 2	16	0.36	0.1	2	3.50
Pipe	18	0.41	3	2	1.13

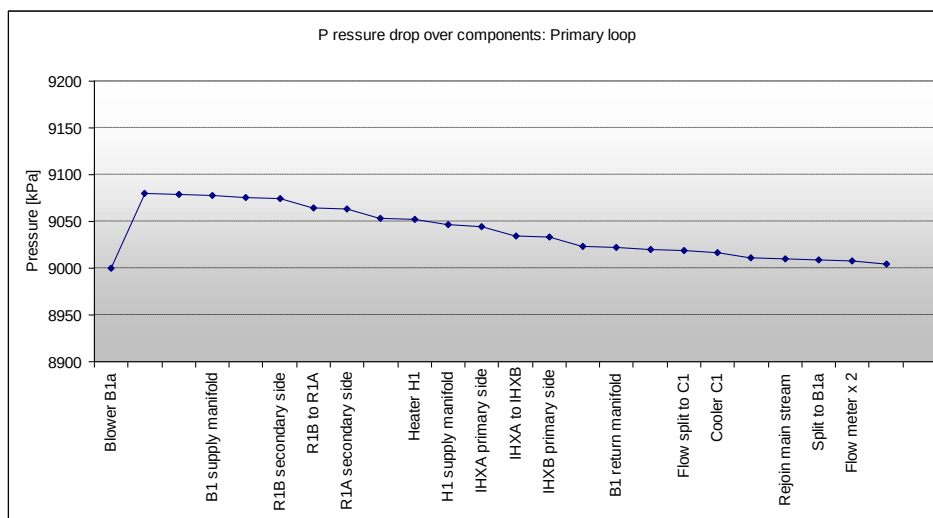
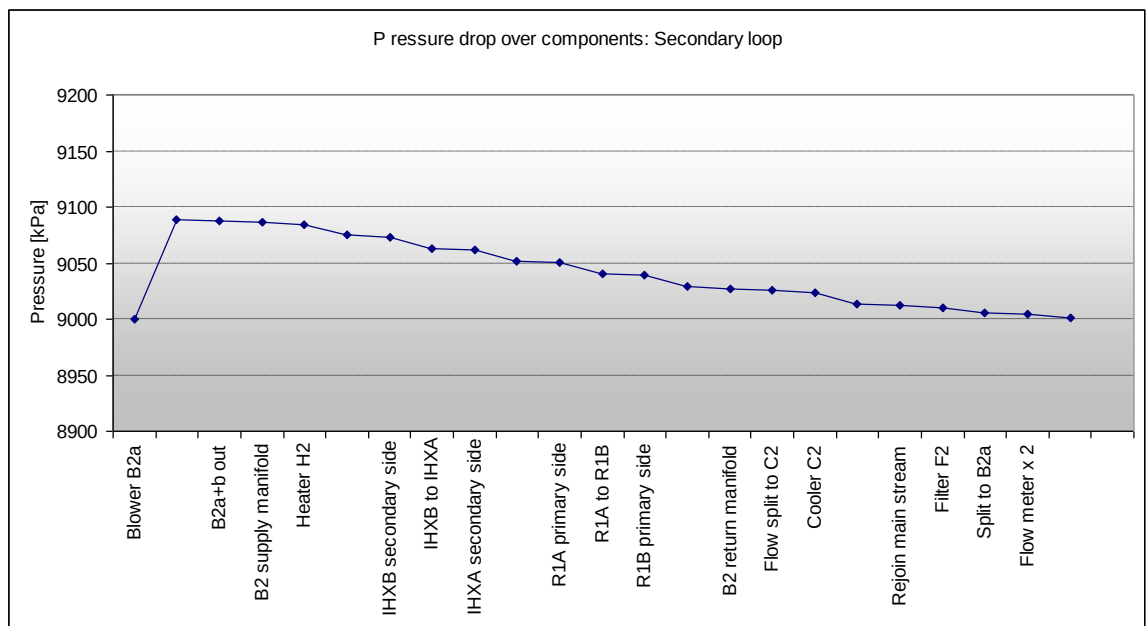
**Figure 8-4: C1: Pressure drop through primary loop**

Table 8-5: C1: Secondary loop preliminary pipe sizing and pressure drops

	NS ["]	Di [m]	L [m]	K	ΔP [kPa]
Blower B2a					-89
Pipe	18	0.41	5	2	1.15
B2a+b out	24	0.55	10	2	1.48
B2 supply manifold	24	0.55	20	2	1.61
Heater H2					10
Pipe	24	0.55	20	2	1.61
IHXB secondary side					10
IHXB to IHXA	24	0.61	10	1.5	1.22
IHXA secondary side					10
Pipe	24	0.61	10	1.5	1.65
R1A primary side					10
R1A to R1B	24	0.61	10	1.5	1.07
R1B primary side					10
Pipe	24	0.55	10	2	1.77
B2 return manifold	24	0.55	10	2	1.77
Flow split to C2	12	0.30	10	2	2.41
Cooler C2					10
Pipe	12	0.30	10	2	1.25
Rejoin main stream	24	0.55	10	2	1.49
Filter F2					5
Split to B2a	18	0.41	8	2	1.21
Flow meter x 2	16	0.36	0.1	2	3.51
Pipe	18	0.41	3	2	1.13

**Figure 8-5: C1: Pressure drop through secondary loop**

8.3.6.2.2 C2: High efficiency component test

This configuration is to test IHX in a simpler test loop.

Assumptions

Test requirements assumptions:

Heater H1 outlet temperature	950°C

IHX secondary streams required inlet temperature	287°C

Component characteristic assumptions:

Heater H1 maximum electrical load	25MW

IHX ΔT between primary and secondary streams	50°C

B1, B2 maximum Tout	250°C

B1, B2 maximum pressure differential	140kPa

With this configuration, the recuperator is done away with by directing the secondary side flow preheated through the IHX through the heater as well and back through the primary side of the IHX. The heater inlet temperature could then be as high as 875°C to 900°C. A mass flow of 64kg/s can be heated from 875°C to 950°C using a 25MW heater. Blower power and pipe sizing limited the mass flow for this configuration to around 53kg/s, one third of the NGNP 160kg/s flow. All four circulators, B1a, B1b, B2a and B2b could be run in parallel to give the required flow. This configuration can therefore achieve much higher mass flows than with Configuration C1. The plant specified maximum 25kg/s flow of Configuration C1 was however used for the energy balance below. Only two blowers are required to provide the 25kg/s flow. With the right pipe routing, two sets of IHXs can even be tested in parallel.

Process description, mass and energy balance

This preliminary mass and energy balance excludes temperature drops in piping and other inefficiencies:

Hot side:

25kg/s 950°C flow exiting Heater H1 enters the primary side of the IHX set and heats the “secondary side” flow to 900°C. This flow in turn heated back to 950°C through Heater H1 (6.5MW heating) before passing through the primary side of the IHX set.

Cold side:

25kg/s 250°C flow through circulators is heated to 287°C through Heater H2. It then cools the primary loop flow through the IHX set down to 337°C (100°C ΔT between sides through IHX). Cooler C1 then cools this flow to 250°C (11.3MW cooling) before it enters the circulators.

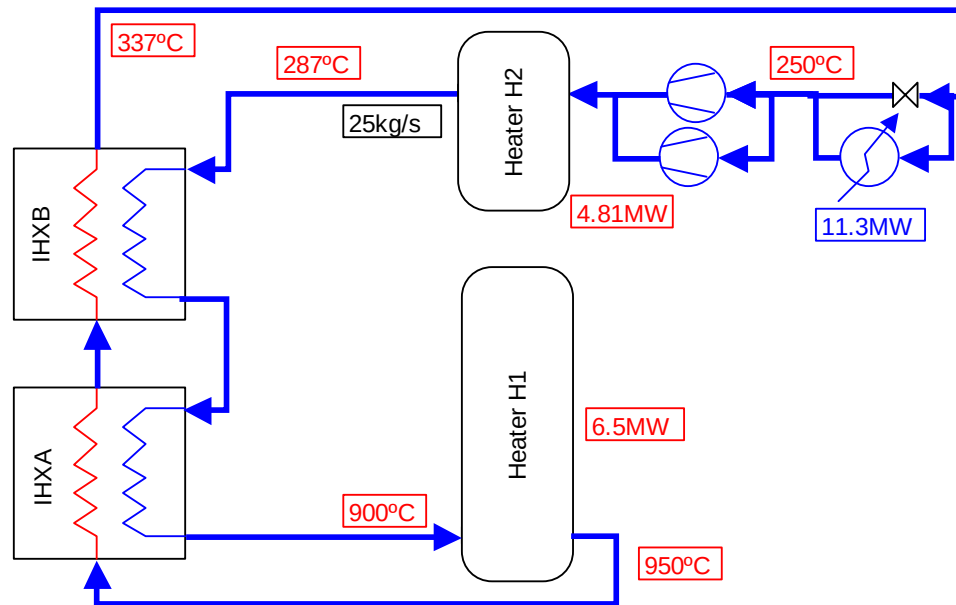


Figure 8-6: C2: Simplified PFD

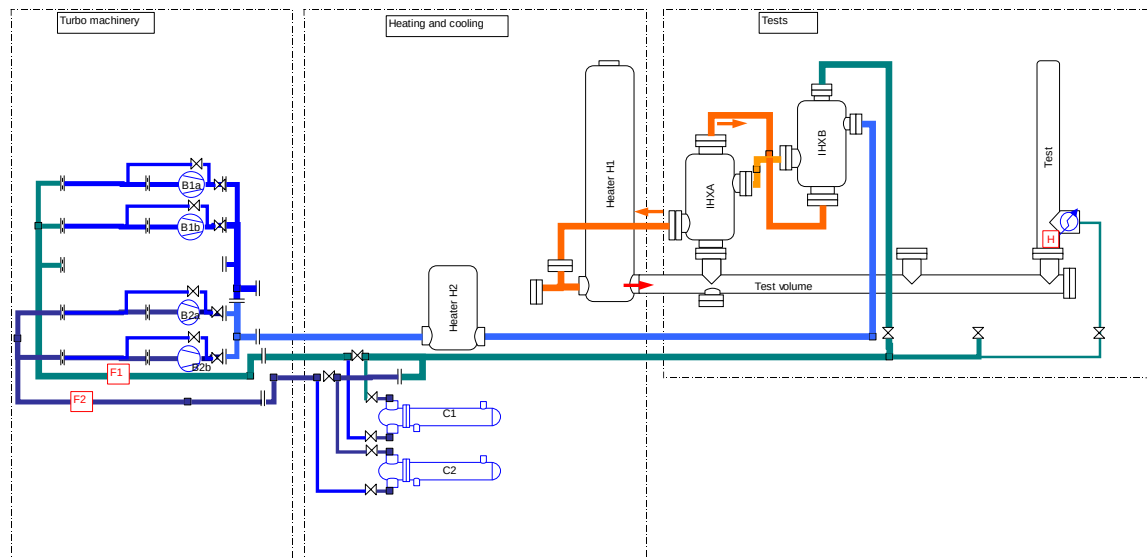


Figure 8-7: C2: Block flow diagram

Table 8-6: C2: Component for specified 25kg/s flow

2 x blowers	P nominal	m	T _i	T _o	Q
	[kPa]	[kg/s]	[°C]	[°C]	[MW]
Cooler C2	9000	7.58	337	50	-11.3
Blower B2a	9000	12.5	250	250	
Blower B2b	9000	12.5	250	250	
Heater H1	9000	25	900	950	6.5
Heater H2	9000	25	250	287	4.8
IHXa primary side	9000	25	950	643.5	-39.8
IHXa secondary side	9000	25	593.5	900	39.8
IHXb primary side	9000	25	643.5	337	-39.8
IHXb secondary side	9000	25	287	593.5	39.8
Filter F2	9000	25	250	250	

Table 8-7: C2: Component data for maximum theoretical flow

4 x blowers	P nominal	m	T _i	T _o	Q
	[kPa]	[kg/s]	[°C]	[°C]	[MW]
Cooler C1	9000	9.708	337	50	-14.5
Cooler C2	9000	8.03	337	50	-12.0
Blower B1a	9000	13.25	250	250	
Blower B1b	9000	13.25	250	250	
Blower B2a	9000	13.25	250	250	
Blower B2b	9000	13.25	250	250	
Heater H1	9000	53	900	950	13.8
Heater H2	9000	53	250	287	10.2
IHXa primary side	9000	53	950	643.5	-84.5
IHXa secondary side	9000	53	593.5	900	84.5
IHXb primary side	9000	53	643.5	337	-84.5
IHXb secondary side	9000	53	287	593.5	84.5
Filter F1	9000	53	250	250	
Filter F2	9000	53	250	250	

It must be pointed out that the heat input of Heater H2 is higher than the chosen 5MW, but Heater H1 has spare capacity. Setting up for maximum flow in this configuration will therefore include transferring capacity from Heater H1 to Heater H2.

Preliminary pipe sizing

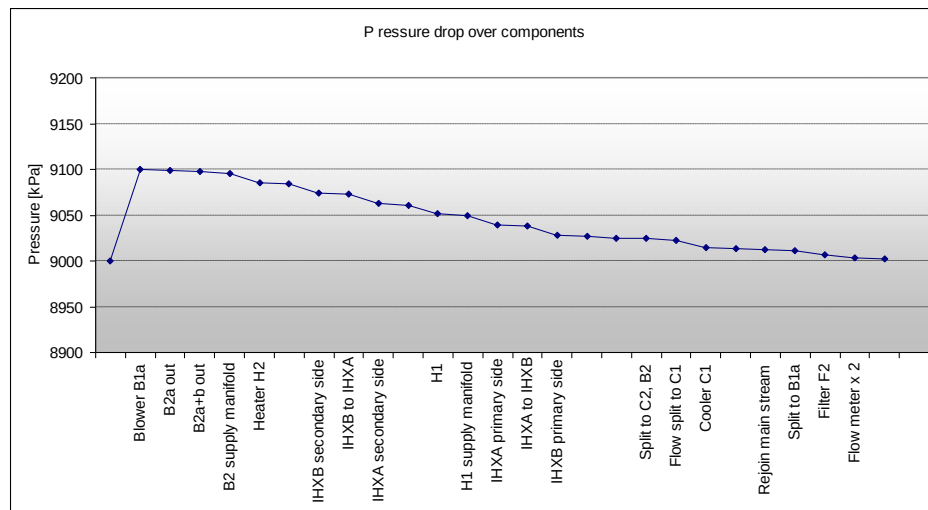
Aiming for 140kPa maximum system pressure drop using guessed pipe lengths and loss factors result in 24" main hot piping (piping hotter than 550°C: inner pipe 24", outer pipe around 48"), 24" main single piping, 18" pipes to and from each blower and 12" to and from each cooler.

Electrical consumption

Heaters H1 and H2 together with the blowers consume around 12MW. Margin should be added to this for heat losses from components and possibly higher system resistance increasing blower power.

Table 8-8: C2: Preliminary pipe sizing and pressure drops

		NS ["]	Di [m]	L [m]	K	ΔP [kPa]
Blower B1a						-100
B2a out		18	0.41	5	2	1.15
B2a+b out		24	0.55	10	2	1.48
B2 supply manifold		24	0.55	20	2	1.61
Heater H2						10
Pipe		24	0.55	20	2	1.73
IHXB secondary side						10
IHXB to IHXA		24	0.61	10	1.5	1.22
IHXA secondary side						10
Pipe		24	0.61	10	1.5	1.65
H1						10
H1 supply manifold		24	0.61	10	1.5	1.73
IHXA primary side						10
IHXA to IHXB		24	0.61	10	1.5	1.29
IHXB primary side						10
Pipe		24	0.55	10	2	1.73
Pipe		24	0.55	10	2	1.73
Split to C2, B2		24	0.55	0.55	2	0.43
Flow split to C1		12	0.30	10	2	1.95
Cooler C1						8
Pipe		12	0.30	10	2	1.04
Rejoin main stream		24	0.55	10	2	0.37
Split to B1a		18	0.41	20	2	1.38
Filter F2						5
Flow meter x 2		16	0.36	0.1	2	3.50
Pipe		18	0.41	3	2	1.13

**Figure 8-8: C2: Pressure drop along flow path**

8.3.6.2.3 C3: Main-loop-process heat component test (steam generator)

This configuration tests a Steam Generator and PCHX.

Assumptions

Test requirements assumptions:

Heater H1 outlet temperature	900°C

Component characteristic assumptions:

Heater H1 maximum electrical load	25MW

PCHX Tout	60°C

Mixer Tout	840°C

Steam generator Tout	250°C

Steam Tout	540°C

B1, B2 maximum Tout	250°C

Steam generator steam Tout	540°C

Pre Heater H3 Tout	400°C

Pre Heater H3 outlet temperature is based on its inlet temperature, NGNP PCDR steam generator values and conservatism on heat exchanger efficiency.

Process description, mass and energy balance

This preliminary mass and energy balance excludes temperature drops in piping and other inefficiencies:

9kg/s 900°C flow exiting Heater H1 flows to the steam generator and PCHX. To achieve a mixer outlet temperature of 840°C implies 25 percent of the flow passes through the PCHX. The flow leaves the steam generator at 250°C and flows through a circulator, typically B1a. Pre Heater H3, using energy from steam generated by the steam generator heats this flow to 400°C. The flow is then heated back to 900°C through Heater H1 (24MW heating). Only one blower is required to provide the flow.

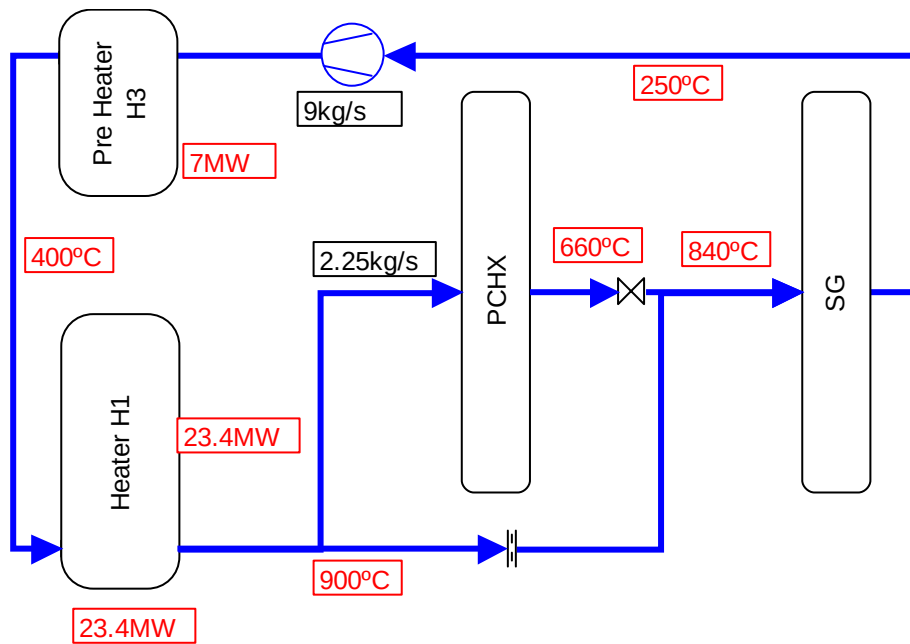


Figure 8-9: C3: Simplified PFD

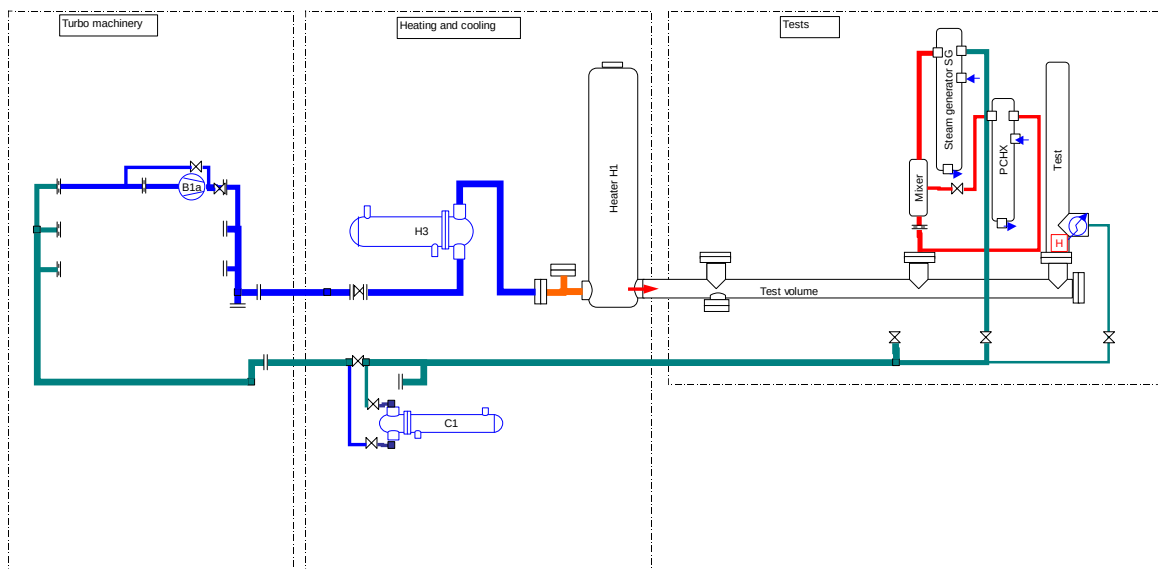


Figure 8-10: C3: Block flow diagram

Table 8-9: C3: Component data for maximum flow without Pre-heater H3

	P nominal	m	Ti	To	Q
	[kPa]	[kg/s]	[°C]	[°C]	[MW]
Blower B1a	9000	7	250	250	
Heater H1	9000	7	250	900	23.7
Pre heater H3	9000	7	250	250	0.0
Steam generator SG	9000	7	840	250	-21.5
PCHX	9000	1.75	900	660	-2.2
Filter F1	9000	7	250	250	

Table 8-10: C3: Component data for maximum flow with Pre heater H3

	P nominal	m	Ti	To	Q
	[kPa]	[kg/s]	[°C]	[°C]	[MW]
Blower B1a	9000	9	250	250	
Heater H1	9000	9	400	900	23.4
Pre heater H3	9000	9	250	400	7.0
Steam generator	9000	9	840	250	-27.6
PCHX	9000	2.25	900	660	-2.8
Filter F1	9000	9	250	250	

Preliminary pipe sizing

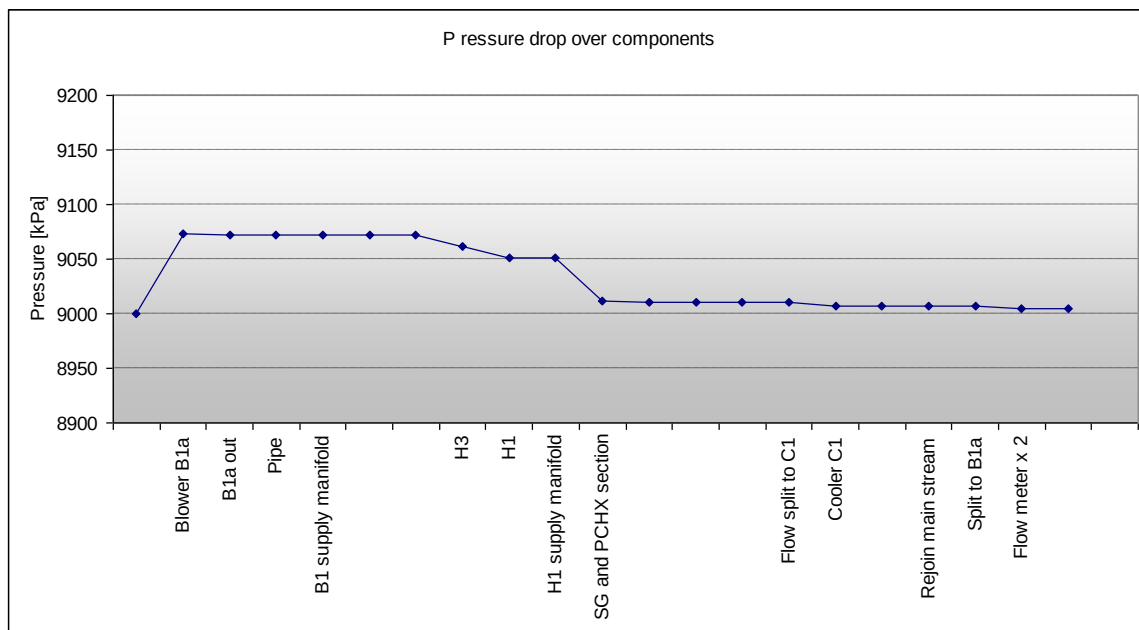
Most of the pipes were already sized for Configuration C1 and C2 for higher flows.

Electrical consumption

Heaters H1 and H2 together with the blowers consume around 25MW. Margin should be added to this for heat losses from components and possibly higher system resistance increasing blower power.

Table 8-11: C3: Preliminary pipe sizing and pressure drops

	NS ["]	Di [m]	L [m]	K	ΔP [kPa]
Blower B1a					-73
B1a out	18	0.41	5	2	0.60
Pipe	24	0.55	10	2	0.19
B1 supply manifold	24	0.55	20	2	0.21
Pipe	24	0.55	20	2	0.21
Pipe	24	0.61	10	1.5	0.10
H3					10
H1					10
H1 supply manifold	24	0.61	10	1.5	0.21
SG and PCHX section					40
Pipe	18	0.41	10	2	0.64
Pipe	24	0.55	10	2	0.19
Pipe	24	0.55	10	2	0.19
Flow split to C1	12	0.30	10	2	0
Cooler C1					3
Pipe	12	0.30	10	2	0
Rejoin main stream	24	0.55	10	2	0.19
Split to B1a	18	0.41	20	2	0.72
Flow meter x 2	16	0.36	0.1	2	1.82
Pipe	18	0.41	3	2	0.59

**Figure 8-11: C3: Pressure drop along flow path**

8.3.6.2.4 C4: Intermediate Heat Exchanger with H_2 generation test

The PCHX is tested here along with an IHX. Much higher mass flow is possible this way than with Configuration 3 [Paragraph 8.7.3]. This is basically a modification of Configuration 2 [Paragraph 8.7.2].

Assumptions

Test requirements assumptions:

Heater H1 outlet temperature 950°C

IHX secondary streams required inlet temperature 287°C

Component characteristic assumptions:

Heater H1 maximum electrical load 25MW

IHX ΔT between primary and secondary streams 50°C

B1, B2 maximum Tout 250°C

B1, B2 maximum pressure differential 140kPa

PCHX Tout 660°C

Process description, mass and energy balance

Testing a PCHX with an inlet of 900°C and an outlet of 660°C could be accomplished in combination with Configuration 2. A 25MW heater can heat 16kg/s from 660°C to 950°C. 10 percent of full PBMR flow. This configuration could be further optimized with IHX flow bypassing the PCHX for possibly more ideal higher flow through the IHX and lower flow through the PCHX. 25kg/s maximum specified flow through the IHX and 25MW heating through Heater H1 could be achieved with 14kg/s flowing through the PCHX. Two blowers are required to provide the flow.

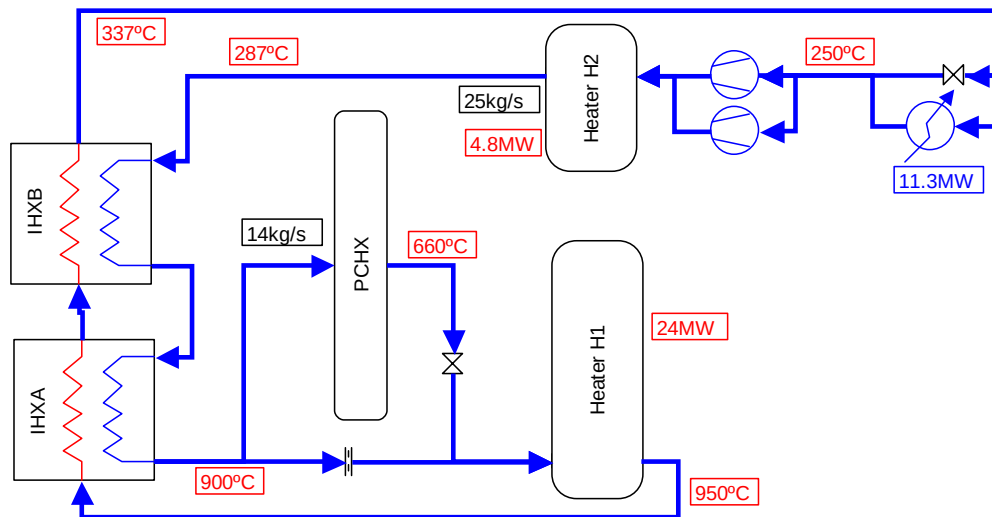


Figure 8-12: C4: Simplified PFD

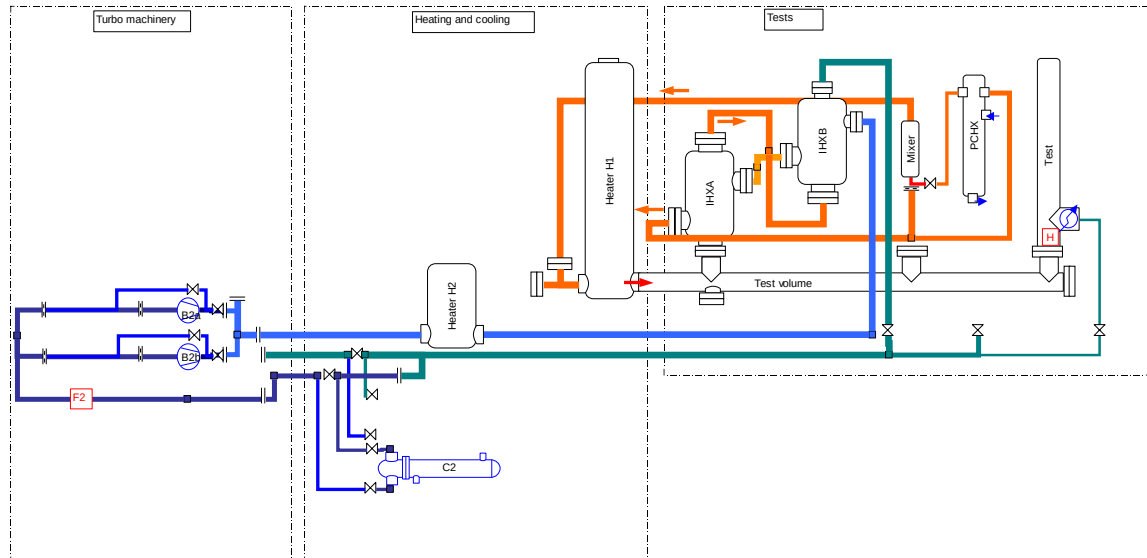


Figure 8-13: C4: Block flow diagram

Table 8-12: C4: Component data

	P nominal	m	Ti	To	Q
	[kPa]	[kg/s]	[°C]	[°C]	[MW]
Cooler C2	9000	7.58	337	50	-11.3
Blower B2a	9000	12.5	250	250	
Blower B2b	9000	12.5	250	250	
Heater H1	9000	25	765.6	950	24.0
Heater H2	9000	25	250	287	4.8
IHX A primary side	9000	25	950	643.5	-39.8
IHX A secondary side	9000	25	593.5	900	39.8
IHX B primary side	9000	25	643.5	337	-39.8
IHX B secondary side	9000	25	287	593.5	39.8
PCHX	9000	14	900	660	-17.5
Filter F2	9000	25	250	250	

Preliminary pipe sizing

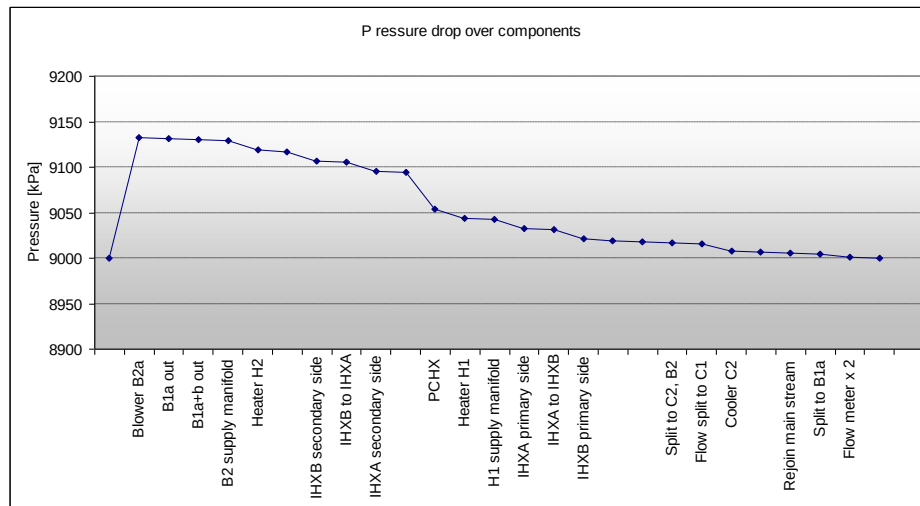
Preliminary pipe sizing for piping is the same as for Configurations 1 and 2: 24" for main piping, 18" pipes to and from each blower, 12" to and from each cooler.

Electrical consumption

Heaters H1 and H2 together with the blowers consume around 25MW. Margin should be added to this for heat losses from components and possibly higher system resistance increasing blower power.

Table 8-13: C4: Preliminary pipe sizing and pressure drops

	NS ["]	Di [m]	L [m]	K	ΔP [kPa]
Blower B2a					-133
B1a out	18	0.41	5	2	1.16
B1a+b out	24	0.55	10	2	1.47
B2 supply manifold	24	0.55	20	2	1.60
Heater H2					10
Pipe	24	0.55	20	2	1.72
IHX B secondary side					10
IHX B to IHX A	24	0.61	10	1.5	1.22
IHX A secondary side					10
Pipe	24	0.61	10	1.5	1.65
PCHX					40
Heater H1					10
H1 supply manifold	24	0.61	10	1.5	1.73
IHX A primary side					10
IHX A to IHX B	24	0.61	10	1.5	1.30
IHX B primary side					10
Pipe	24	0.55	10	2	1.74
Pipe	24	0.55	10	2	1.74
Split to C2, B2	24	0.55	10	2	0.43
Flow split to C1	12	0.30	10	2	1.95
Cooler C2					8
Pipe	12	0.30	10	2	1.04
Rejoin main stream	24	0.55	10	2	0.37
Split to B1a	18	0.41	20	2	1.38
Flow meter x 2	16	0.36	0.1	2	3.51
Pipe	18	0.41	3	2	1.13

**Figure 8-14: C4: Pressure drop along flow path**

8.3.6.2.5 C5: Brayton cycle test

This configuration is for the testing of scale direct cycle components such as turbine and compressor sets.

Assumptions

Turbine T_{in}	900°C
Turbine T_{out}	512°C
Turbine P_{in}	9000kPa
Turbine P_{out}	2900kPa
Compressor T_{in}	30°C
Compressor T_{out}	110°C

Process description, mass and energy balance

Assuming 900°C turbine inlet, 512°C turbine outlet, a 100°C temperature difference between the two streams through the recuperator result in a heater inlet and outlet temperature of 412°C and 900°C respectively. 24MW could heat a flow of 9.5kg/s, 6 percent of full NGNP flow.

The compressor inlet temperature is expected to be as low as possible, 30°C and its outlet 110°C. The primary side outlet temperature of the recuperator is therefore 210°C and the cooler outlet temperature 30°C.

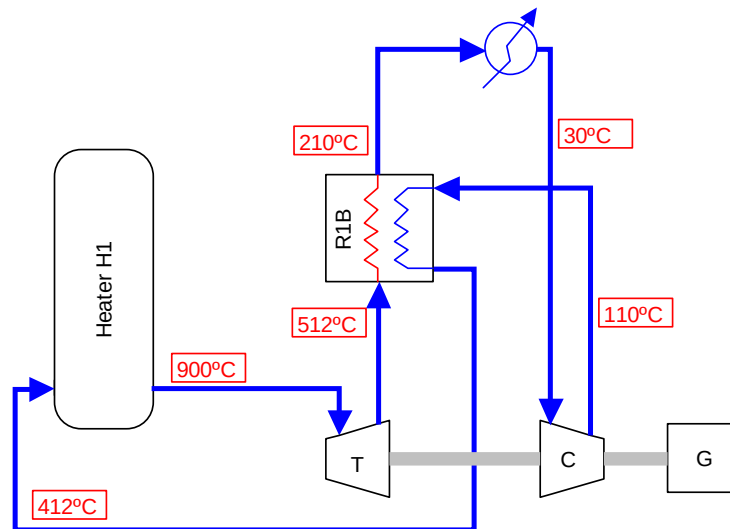
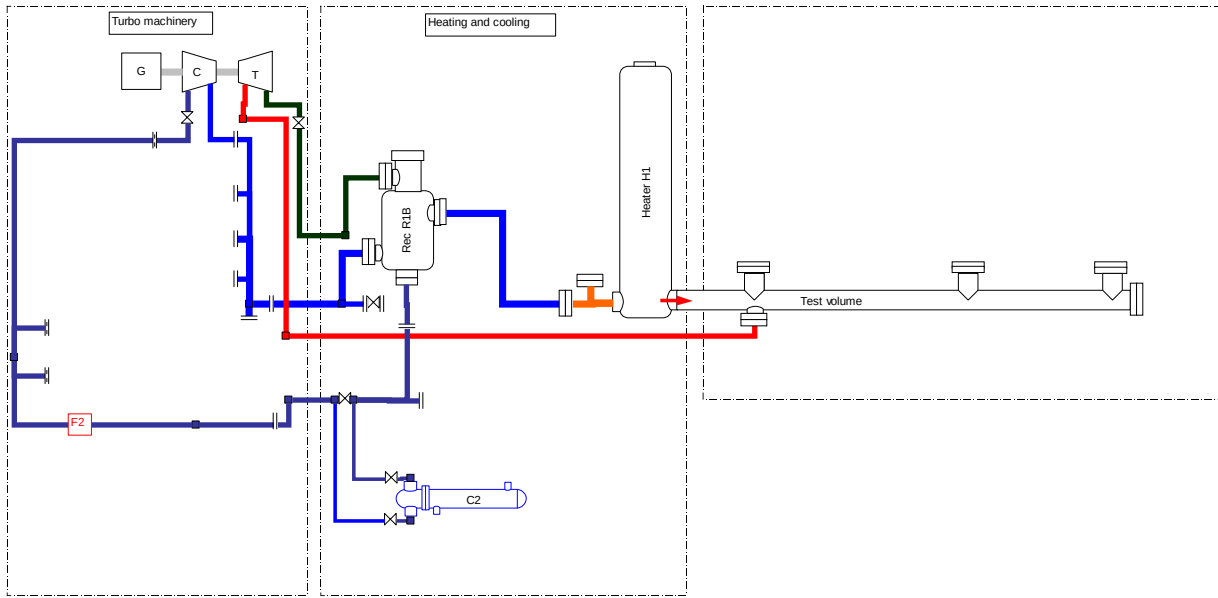


Figure 8-15: C5: Simplified PFD

**Figure 8-16: C5: Block flow diagram****Table 8-14: C5: Component data**

	Pin nominal	Pout nominal	m	Ti	To	Q
	[kPa]	[kPa]	[kg/s]	[°C]	[°C]	[MW]
Cooler C2	2900	2900	9.5	210	30	-3.7
R1b primary side	2900	2900	9.5	512	210	-6.3
R1b secondary side	9000	9000	9.5	110	412	6.3
Heater H1	9000	9000	9.5	412	900	10.2
Turbine T	9000	2900	9.5	900	512	
Compressor C	2900	9000	9.5	30	110	
Filter F2	2900	2900	9.5	30	30	

Preliminary pipe sizing

Preliminary sizing for most pipes are for Configurations 1 and 2. Sizing is for around 100kPa pressure differential, but with low mass flow. All flow passes through the cooler and its 12” piping, so other piping such as between R1B and the cooler and to and from the compressor and to the turbine can be 12” as well. The piping from the turbine should be around 16”. The pipe from Heater H1 to the turbine is hotter than 550°C and will be a hot duct with the outer pipe roughly double the diameter of the inner pipe.

Electrical consumption

Heaters H1 and H2 together with the blowers consume around 25MW. Margin should be added to this for heat losses from components.

8.3.6.2.6 C6: Basic component test

Configuration C6 uses components already sized for C1, so the same pipe sizing is used.

8.3.6.2.7 C7: Steam Generator coupled to secondary loop

Configuration C7 still has to be analyzed. It is similar to Configuration C3. The steam generator makes recuperation of energy difficult, resulting in low maximum mass flows of around 8.7kg/s. Configurations C1 and C2 will therefore typically determine most of the component sizing. Only one blower is required for the primary loop and one for the secondary loop. One of the extra blowers could therefore be used for the loop that recuperates heat from the steam and circulates it through the recuperator to heat up the primary loop flow.

8.3.6.2.8 C8: Full-scale Circulator test loop

This is a separate loop to test full-scale reactor circulators.

Assumptions

NGNP reactor 100 percent flow	160kg/s
Circulator maximum pressure differential	500kPa
Pipe length maximum	60m
Pipe maximum pressure differential	150kPa
Temperature	300°C

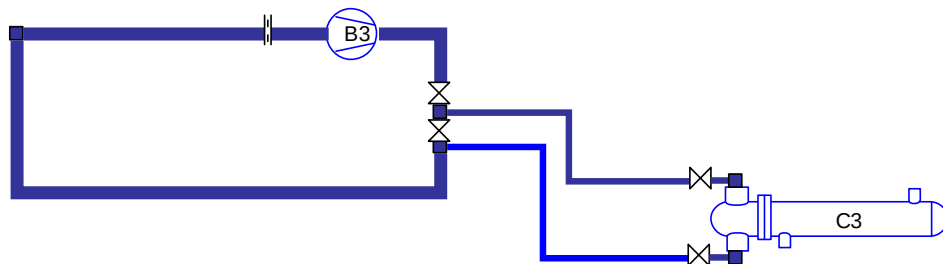


Figure 8-17: C8: Block flow diagram

Process description, mass and energy balance

This test loop is similar, but bigger than the surge loop around the other blowers. A control valve will adjust the system resistance to for instance provide 300kPa pressure drop with a mass flow of 160kg/s. A flow meter is required to measure the flow. 24" pipe will give acceptable pressure drop. Maximum circulator power of 11MW is expected. Cooler C3 has to remove the heat generated by the circulator and is therefore similar in size to Coolers C1 and C2.

8.4 CQL2 Mechanical Design

8.4.1 NGNP CQL2 Main Component Assumptions

8.4.1.1 Total Helium Inventory

Total Loop Inventory = 6 000 kg at 9 MPa.
HIPCS Vessels dimensions are similar to that of the PBMR Demonstration Power Plant (DPP), but half the number of vessels is required.

8.4.1.2 Initial Liquid Fill of Helium

Fill with Initial Fill truck at 4500 kg liquid helium

Helium Purification System (HPS)

8.4.1.3 Compressors

Diaphragm Type of compressor – as per nuclear application – gas reactors (HTTR piston type not so good for containment reasons)

Low and high pressure units – to accommodate the initial fill and high pressure requirements
Compressor Process requirements similar to PBMR DPP.

8.4.1.4 Blowers

Similar to the CBCS blowers with a side outlet nozzle.
(Submerged electric motor drive. External motors could be fitted and bigger 1000kW motors could give double the pressure differential)

8.4.1.5 Heaters

Heater capacity sizes at 25 MW plus 5MW margin. Same concept as in HTF with a heat flux rate of $6\text{W}/\text{cm}^2$.

The heater section has a diameter of 1300 mm and height of 5000 mm (per heater unit of 5 MW)

PCHX main design parameters

Helium inlet temperature	900°C
Helium outlet temperature	660°C
Helium mass flow rate	19 kg/s

8.4.1.6 Recuperator

The HTTR design with a heat load of 10 MW per unit
(scaled in model)

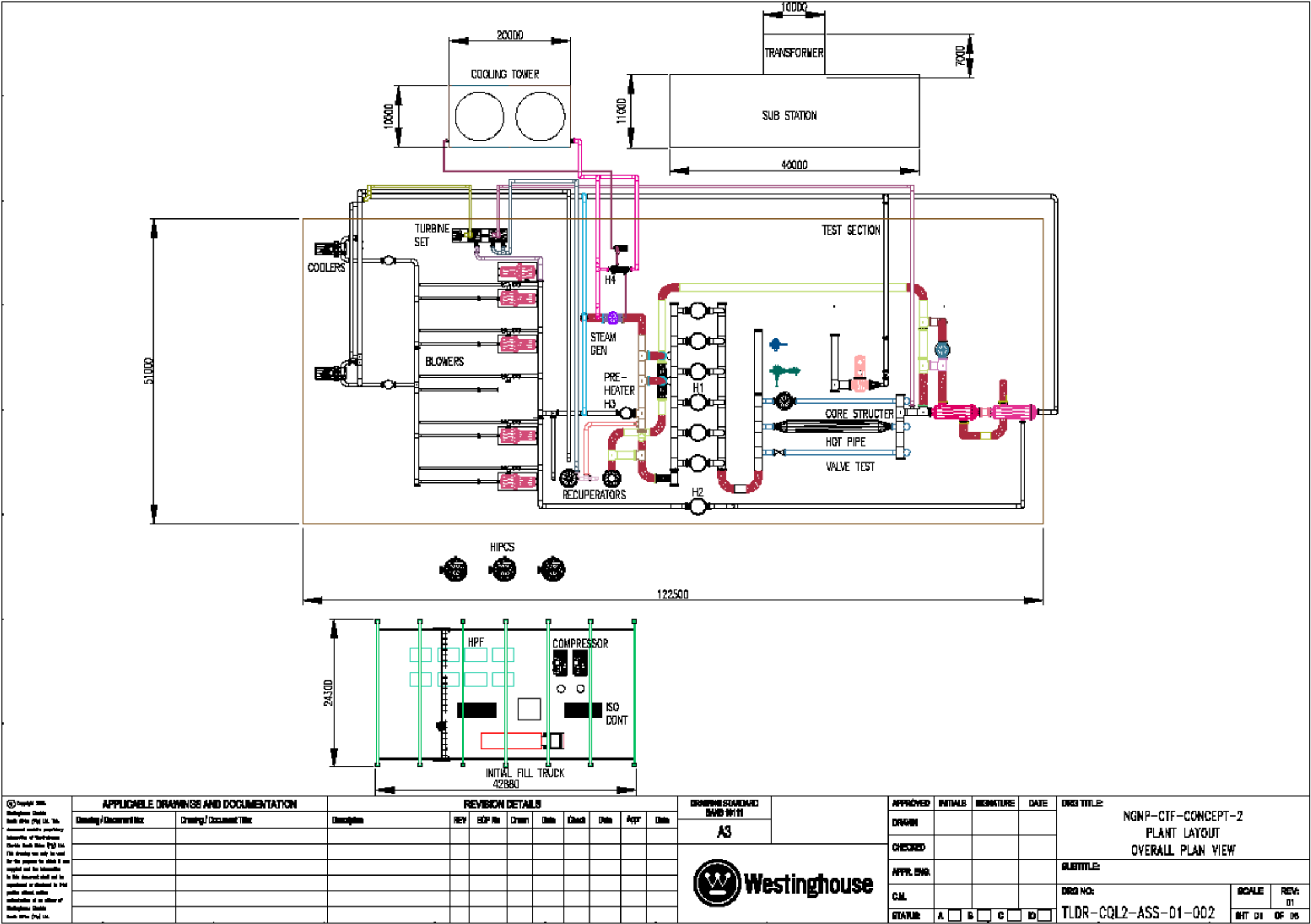
8.4.1.7 Steam Generator

The THTR design with a heat load of 125 MW (thermal) per unit - 50 MW (electrical)
- scaled in model.

8.4.1.8 Cooler C1 and C2

The process design parameters of Cooler C1 and C2 are the same.
The following process design parameters were assumed:

Helium inlet temperature	350°C
Helium outlet temperature	below 50°C
Helium mass flow rate	9.9 kg/s
Water inlet temperature	25°C
Water outlet temperature	50°C
Water mass flow rate	150 kg/s



8.4.2 Description of Main Blower

The blowers are mounted horizontally with center inlet and side discharge. The inlet pipe provides a sufficient straight length to promote smooth flow into the Inlet Cone, which minimizes losses into the Impeller. The Impeller is directly mounted on the Shaft, which is supported by oil or gas bearings. A blower with electromagnetic bearings is currently under testing and if it is proved to be industrially reliable, it can be installed. A variable speed submerged electric motor could be fitted.

The blower vessel consists of two main compartments; the system side and the motor side. A Barrier Plate and Insulator Plate separate these compartments for the purpose of minimizing heat ingress into the motor compartment. The Motor Mounting Flange is attached to the Barrier Plate assembly. The Motor / Barrier Plate Assembly is bolted to the vessel yoke section. This connection allows fitting and removal of the entire blower internal assembly from the Pressure Vessel.

Electrical conductors, instrumentation cabling and cooling water services enter the Pressure Vessel through special pressure penetrations.

The estimated weights and dimensions are:
Total Length 6300, total height 3200 and total width 2765 (mm) with a weight of 30,000 kg.

8.4.3 Recuperator

The Recuperator is a vertical, helical coiled counter flow type heat exchanger. The primary helium enters the Recuperator through the inner pipe of the primary concentric hot gas duct attached to the bottom of the Recuperator. It flows upwards outside the tubes transferring the heat to the secondary helium cooling system and flows back through the annular space between the inner and outer shells. The secondary helium flows downwards inside the heat transfer tubes and flows upwards in the central hot gas pipe through. The estimated height of the Recuperator is 20 000 mm with a diameter of 3 000 mm.

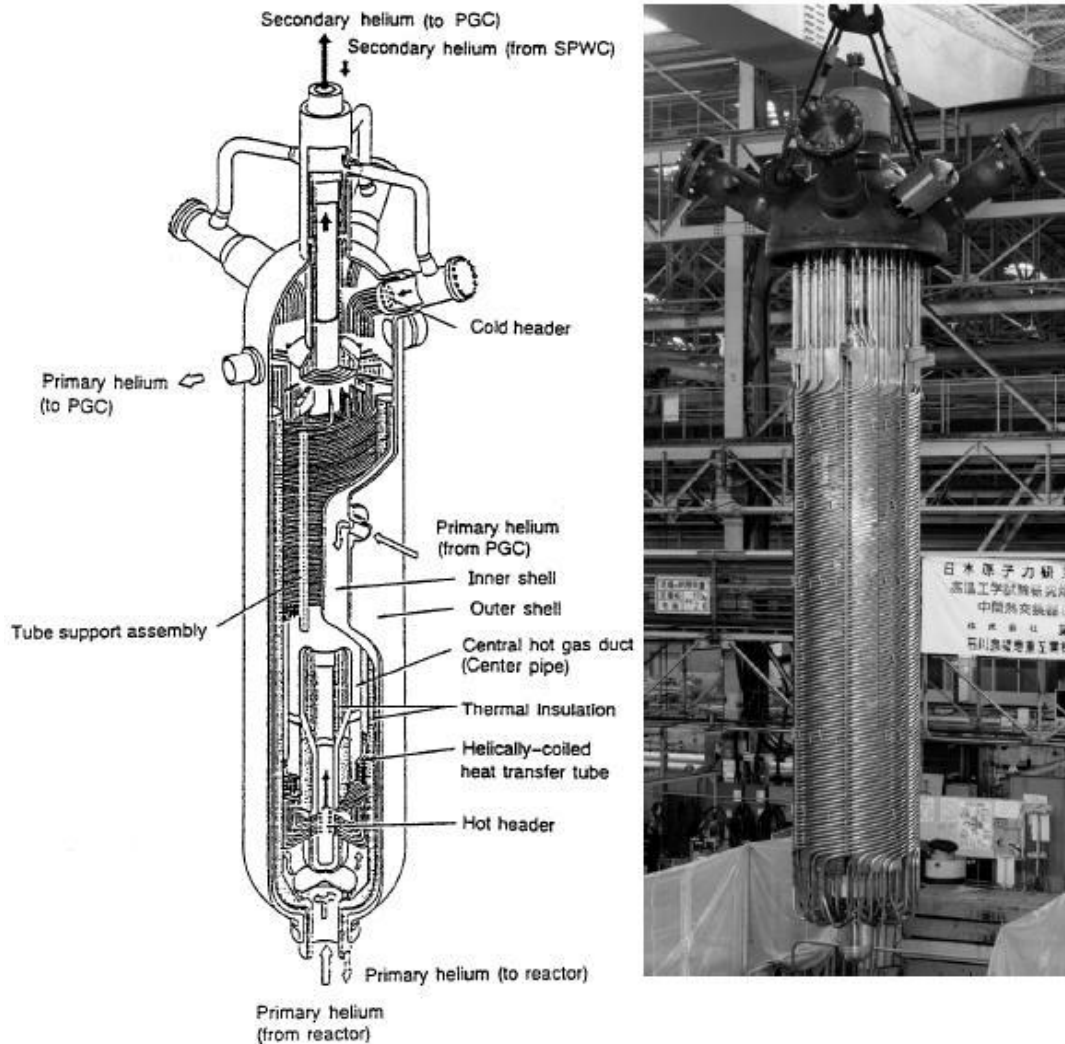


Figure 8-19: Depiction of the He-He intermediate heat exchanger in the HTTR.

8.4.4 Helium Inventory and Pressure Control System (HIPCS)

8.4.4.1 Initial Filling

Liquid helium will be delivered in Liquid Helium Container. Each container can store 4500 kg of liquid helium.

The components included for the initial plant filling are additional pipes and isolation valves which require a connection point. The evaporating equipment and the off-loading compressor (or liquid pump) are standard equipment and can be supplied by the specialist gas supplier.

The length of the Liquid Helium Container is 12,2 m with a width of 2,44 and weights 29 000 kg (excluding tri-axle trailer) 32 000 kg (including tri-axle trailer). The helium supplier will be responsible for the initial filling procedure.

8.4.4.2 Helium Supply

Helium Gas could be delivered in ISO-Containers to provide for the helium leakage of the plant. Each container can store 500 kg of gas helium. The mass of a fully loaded ISO-Container is approximately 20 000 kg.

The helium will be supplied at a pressure of 17 MPa (170 Bar). Provision is made for two ISO-Containers for the plant to accommodate the leakage requirement of the plant. The one ISO-Container will be connected to the plant, while the other one will be empty or in the standby mode.

A 30 000 kg overhead crane is installed to allow for the unloading and loading ISO-Containers.

8.4.4.3 Compressors

Two Diaphragm Compressors will be used in series with each other. The Diaphragm type of compressor was selected because they are suitable for the NGNP application. There will be a low- and high-pressure compressor. The pressure range of the low pressure compressor is from 60 kPa 800 kPa while the high pressure compressor pressure range is from 600 kPa to 9,0 MPa.

The compressors will be used in the following applications:

- To fill the system with helium during the initial fill operation.
- To transfer helium from the test section to the helium Storage Vessel and vice versa.
- To transfer helium from one Storage Vessel to another Storage Vessel.
- To empty the helium ISO-Containers (supply to the storage vessels).

The compressors are fitted on a frame of 3500 x 2200 mm and are approximately 2500 mm high. The total mass of a compressor is estimated at 6000kg.

8.4.4.4 Helium Storage Vessels

There will be three Helium Storage Vessels which will be able to store the total helium inventory of the plant.

Each vessel can store 2 180 kg of helium at 9 MPa at 25°C

A Helium Storage Vessel is approximately 17 000 mm high with a diameter of 3 964 mm and weights 181 000 kg.

8.4.4.5 Coolers C1 and C2

The coolers are shell and tube type heat exchangers, which are mounted horizontally. The helium flows through in inside of the tubes while the water flows on the outside of the tubes (shell side)

Operation parameters:

Helium inlet temperature	350°C
Helium outlet temperature	50°C
Water inlet temperature	25°C
Water outlet temperature	50°C
Helium mass flow rate	9.9 kg/s
Water mass flow rate	150 kg/s
The cooler weight is approximately	15 000 kg.

8.4.4.6 Filters

There will be three types of filters in the system.

The first type will be installed in the supply line of helium gas, from the road delivery tanks, to filter out impurities before the helium is admitted into the CTF system.

The second type will be at the compressor inlets to prevent impurities entering and damaging the compressors.

The third type will be in the test loops at blowers' inlet piping to prevent particulate matter entering and damaging the blowers.

The filter element material will be type 316 Porous Sintered Stainless Steel, Grade H, with a filter rating of 20 μm @ 98 percent efficiency.

8.4.4.7 Heaters

The maximum capacity of the Heater system H1 will be 30 MW (25 MW minimum specified). There will be six heater units in parallel with each other. The heaters will be installed vertically with the inlet at the bottom and an outlet at the top of the vessel. The maximum outlet temperature is 950°C. A "hot pipe" design approach will be incorporated at the outside of the pressure vessels and at the outlet nozzles.

The pressure vessel of one heater unit is 10 000 mm high and has a diameter of 2600mm and weights approximately 185 000 kg.

Heater H2 is similar to one of 5 MW heater units used in Heater H1.

8.4.4.8 Helium Purification System

Although the Helium Purification System (HPS) is not part of the scope of work for this document, some proposals are made here.

The HPS is a polishing system that purifies dust-filtered helium (0.5 - 3 micron) received from a compressor at a constant pressure of 7 000 kPa (g) and 120 kg/hr flow rate.

Bleeding off a continuous stream of helium from the high-pressure side of the loop will flow through the HPS to the low-pressure side of the loop and the following techniques are used: Catalytic Oxidation, Adsorption and Regeneration, Temperature Manipulation.

The HPS Consists of Catalytic Oxidizers, a Water Separation Section, Molecular Sieves a Cryogenic Section and regeneration section.

The following impurities are removed:

- Hydrogen
- Water
- Carbon oxides
- Nitrogen
- Oxygen

Methane will also be treated should ASME VIII Div. 1 be selected as the design code.

8.4.4.9 Hot Pipes

The Hot Pipes use a coaxial flow. The hot gas is transported in the inner pipe section and a special design cold stream does the conditioning of the pressure boundary. Special care is taken in the internal insulation system to prevent helium convection streams from transmitting heat flow. A pressure equalizing system is incorporated to prevent implosion of the inner lined section during sudden depressurization of the system.

A typical German / Japanese hot pipe design will be followed.

8.4.4.10 Valves

High temperature valves will be tested in the testing area.

To set the plant up for the different testing configurations blanks, spectacle blinds, elbows etc. will be used.

8.5 CQL2 Instrumentation & Control Design

8.5.1 Instrumentation & Control Philosophies

8.5.1.1 Overview of the SCADA and DCS system

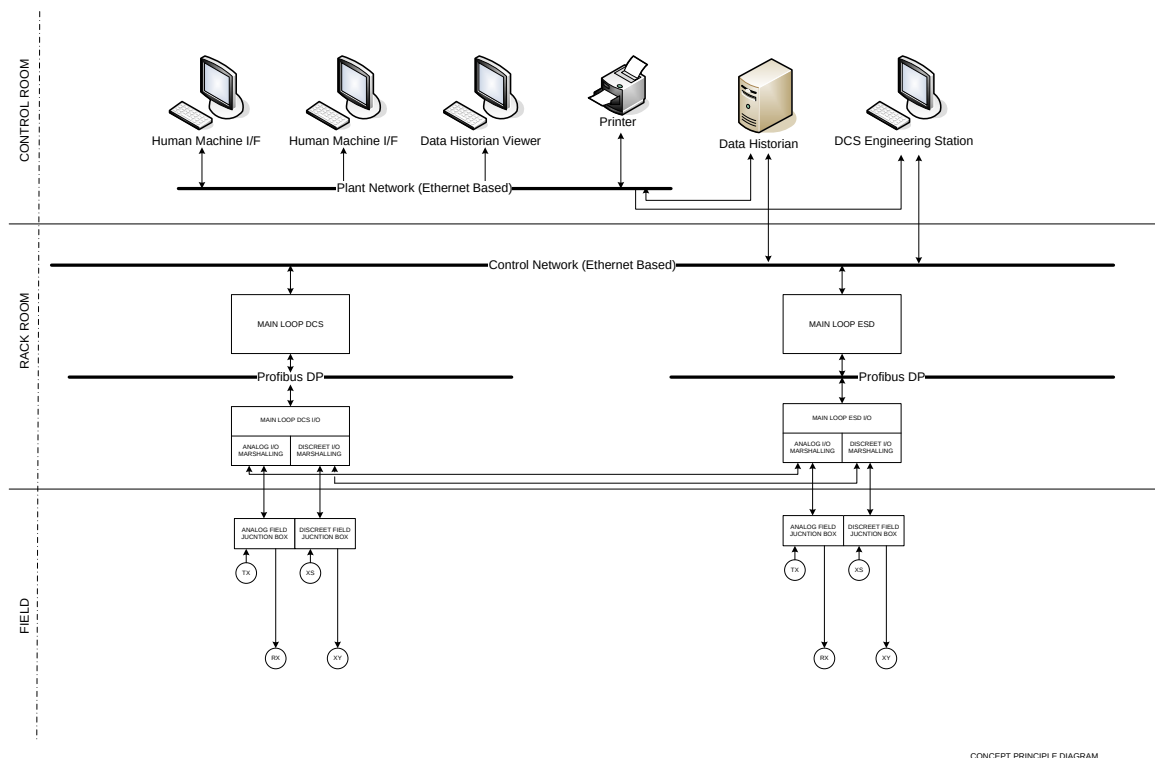


Figure 8-20: Schematic SCADA overview

The above schematic shows a proposed SCADA control system. A main control room will locate all human machine interface equipment to a complete overview of the plant as well as direct control and monitoring of process parameters. It is possible to provide in-plant satellite control consoles or remote monitors in separate enclosures, depending on user preference and associated distances of key elements from the main control room.

The rack room houses all the cabinets that interface between the HMI network interface and the DCS systems. Digital and analog signals are joined and these inputs and outputs are used as control handles. The rack room equipment interfaces via a Profibus network to PLC's that directly convert field equipment signals into usable inputs and outputs. All input/output data are captured by the data logger and saved in the historian. A special high-speed data logger with sufficient channels will be provided for data acquisition during critical performance testing of components.

Finally, the rack room interfaces to the plant through dedicated junction boxes located on all plant building levels, close to equipment but in safe demarcated areas.

8.5.1.2 Helium Inventory and Pressure Control System

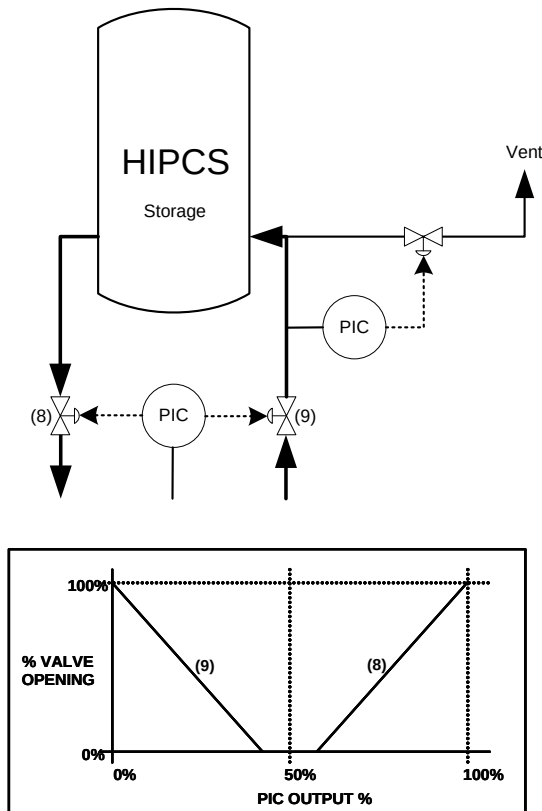


Figure 8-21: HIPCS Control

The Helium Inventory and Pressure Control system (HIPCS) is used to control the loop pressures in any given cycle. It has a set of vessels charged at a high pressure, higher-than-loop-target-pressure, and a set of vessels at lower-than-loop-target-pressure. For a given inventory of process fluid, Helium in this instance, in an enclosed portion of a loop, pressure varies in accordance with temperature. The HIPCS will receive helium from the loop as the temperature in the loop rises and it will inject helium into the loop when temperature in the loop is decreased.

With reference to the sketch above, a pressure-indicating controller (PIC) is used to monitor and control the pressure in the system. If the system pressure is too high, valve 9, will be opened by the PIC to relief the pressure in the system. A small amount of time will be allowed for the system to reach stability, before a pressure increase may be requested (valve 8).

Should the system at any time have more pressure to relief than the storage vessel can accommodate, pressure will be vented as waste through a second PIC/valve combination.

8.5.1.3 Other Controls

Note that all the other test loop equipment control philosophies are covered within the section on Process Design.

8.5.2 CQL2: Electrical Design

8.5.1.4 Basic System Operating Description

The basic overall single line diagram for CQL2 electrical supply and distribution is shown in drawing TLDR-CQL2-SS-04-0001(Reference [8-14]) sheet 1 and 2.

Power is distributed at 138 kV, 161 kV and 230 kV via Antelope Substation, Idaho. Two main supply voltages were investigated that will supply power from this substation to the CTF. The electrical process loads of the CTF concept 2 are characterized by high power consumers (i.e. > 1000 kW) and general low power consumers which support the operation of the plant, and loads related to the infrastructure of the plant, which will include lighting and auxiliary loads.

Two distribution trains will be used to supply the electrical consumers of the plant in order to establish flexibility and redundancy within the electrical supply and distribution system. It will be possible to perform maintenance activities to power distribution equipment without affecting the power supply to the whole plant.

Power is distributed from two main medium voltage distribution boards to low voltage distribution boards via power transformers. These low voltage distribution boards feed the low voltage 3-phase and single-phase loads of the plant.

The power transformers will furthermore provide line isolation from the medium voltage distribution boards, provide a return path through a grounded neutral connection for zero-sequence currents to flow and limit the size of possible fault currents on the secondary (load) side of the transformer.

Process loads which are supplied from low voltage electrical motors are supplied from one of two separate Motor Control Centers (MCC's) in order to limit failure modes and impact on the process and to provide advanced control infrastructure to process related loads supplied from these MCC's.

The two MCC's are coupled via a bus coupler, which will enable the loads of both MCC's to be fed from one power supply train.

Preliminary allowance was made for some of the low voltage process loads that could be expected in the NGNP CTF Concept 2 design, but does not include the entire final load, as is shown in drawing TLDR-CQL2-SS-04-0001 (Reference [8-14]).

The main blowers, B1A, B1B, B2A, B2B, B3 and B4 will be supplied from Variable Speed Drives (VSD's) and supplied directly from the main distribution boards. A suitable voltage (6,6 kV) is chosen that provides the capability to feed both the higher power blowers, blower B3, the lower power blowers, as well as the process heaters, heater H1 and H2. This will reduce the amount of power distribution equipment required, i.e. power transformers and distribution boards. The blowers as well as the heaters will each be operated from a control panel that will utilize power electronic devices to change the frequency, voltage, duty or current to each load. Heater 1 is divided into 5 separate units and will each be supplied from a separate control panel.

The variable speed drives of the blowers will utilize a constant voltage/frequency technique to control the start-up, acceleration, deceleration and steady state operation of each motor. A multi-pulsed inverter is required for each Variable Speed Drives (VSD) to limit line current distortion and to ensure Electromagnetic Compatibility (EMC) of the drive to the plant and power system environment.

Each VSD will consist of an integrated input power transformer that will provide a multi-phase output to drive the power converter of the VSD.

The heater supply will consist of a power electronic converter, similar to a VSD, which will control the power input into the heater bank in accordance with a set-point determined by the Distributed Control System (DCS). The output voltage and current relationship of the control panel will be influenced by the power penetrations into the heater bank. Multiple power penetrations will be required to power the heater elements inside the heater.

A turbo machinery generator is required and will be a synchronous machine. It is required for this machine to operate in a generating mode as well as in a motoring mode. The synchronous machine will require a series of control panels which will control as well as regulate and protect the machine. The control panels will consist of a control system that will enable line synchronization with the main supply. The output voltage developed by the machine in generating mode will be synchronized with the main supply and electrical power fed into the supply system. Allowance is made for power factor correction equipment on each power supply train by means of capacitor banks. It will be required to control and regulate the amount of reactive power delivered or absorbed by the synchronous machine in motoring and generating mode in order to ensure stability of the power system as well as to ensure that the system overall power factor remains at the designed value. A harmonic analysis will be required in basic engineering to determine resonance within the power system, influenced by the power electronic devices, capacitor banks and generator. Power will be fed to any one of the two main power distribution boards of the plant via a separate generator transformer.

The capacitor banks are each provided with a protection system and automatic switching system that will control and limit the switching of the capacitors to the voltage cross-over point.

A communication protocol and communication bus is used between electrical switchboards and the Distributed Control System (DCS). Electrical loads supplied from the Motor Control Centers (MCC's) are controlled via this communication bus by the DCS.

Electrical properties of loads and feeders as well as operational data and data related to protective actions are provided to the DCS via this communication bus.

Protection functions of processes and equipment involving electrical switch- and control gear are wired separately through an electrical- and Instrumentation & Control (I&C) interface panel which will properly separate different voltage and power levels of the electrical and I&C systems and provide the required interface between the two systems. Safety related trips from the DCS are therefore hard-wired to switch gear and will not be dependable on the operation of the communication bus.

The communication bus and hard-wired safety related signals are also used between the DCS and electrical switch- and control gear situated in the field. Such equipment will include the VSD's of the gas blowers and heater control panels.

Loads will be supplied directly from one of the two main medium voltage distribution boards or from one of the low voltage Motor Control Centers (MCC's) or one of the low voltage Utility distribution boards.

Redundant loads will be connected to separate distribution boards connected to separate power supply trains.

Electrical loads, except lighting and general consumers, will be equipped with a device located in the field in proximity of the load that will be able to cause the electrical power to the load to be interrupted and the load to stop in the case of an emergency. Electrical loads will also be equipped with the means to start the load from the field if the power supply to the electrical load is controlled by the DCS. The control will be done through the applicable starter in the applicable MCC by enabling or disabling current flow to the load, through a Local Control Panel (LCP) or directly at load terminal.

Electrical power to the DCS and I&C equipment is provided by one of two Uninterruptible Power Supply (UPS) systems which will regulate the quality of electrical power supplied and will provide protection against short time power loss enabling a safe shutdown of the plant.

The two UPS's is supplied by two different distribution boards, each from a different power supply train. It will be possible to connect the distribution boards on the output side of the UPS's (load side) in order to supply these loads from any one of the UPS's, should one of the UPS's not be available for service as a result of a failure or a maintenance activity.

Power to Electrical control and protection functions is fed from the UPS- systems. This will provide protection for control and protection devices against supply conditions that may temporally fall outside the design scope.

The design will reduce the need for operator interaction in the field by eliminating control requirements over electrical power from equipment situated in the field, but still provide the means to control this equipment manually with the necessary emphasis on reliability and safety.

Allowance was made for three 100 percent duty fire fighting pumps. The fire protection philosophy for the plant still needs to be established.

Allowance is made for two 100 percent instrument air supplies. Electrical power will be provided to each of the instrument air systems from a different power supply train. Power will be supplied from one of the Utility distribution boards.

Emergency power is supplied by a Diesel generator which is sized to supply power to the plant's DCS, emergency lighting, emergency HVAC (Heating, Ventilation and Air Conditioning) and essential utility power outlets.

Interface Requirements

The required interfaces of the electrical system are:

- I&C interface
 - The electrical-I&C interface is a physical and functional interface enabling power control to electrical loads, including safety related interlocks and to provide information to the control system regarding the power consumption and status of electrical loads. This interface is characterized by a communication bus with a dedicated communication protocol (i.e. Modbus, Profibus, and ControlNet) as well as a hardwired interface for safety related signals.
 - Control power is supplied to the DCS via the plants UPS's. This interface is characterized by a power quality, power type, availability and consumption requirement as well as a physical interface which will end the electrical distribution from the UPS at the DCS power supply and I&C remote input/output (I/O) cabinets in the field.
- Electrical network interface
 - The plant has a physical and functional interface with the local supply authority, characterized by voltage level, reactive and apparent power demand, energy as well as availability and duty.
- Earth interface
 - A physical interface with the CIVIL design and construction of the building is required. This interface is characterized by the design of the plant's global earth mat, interface with structural members and steel re-enforcement. This is critical for proper protection against lighting, proper EMC of equipment and systems and safety in the event of an electrical fault.
- Building and civil design interface
 - This interface is characterized by the space occupied by electrical equipment as well as the loading on foundation and floors. Mounting detail of distribution boards, panels and equipment is included.
 - A physical interface with the CIVIL design and construction of the building is characterized by the design of the plant's global earth mat, interface with structural members and steel re-enforcement. This is critical for proper protection against lighting, proper EMC of equipment and systems and safety in the event of an electrical fault.
- Heating, Ventilation and Air Conditioning (HVAC) system interface
 - This interface is characterized by functional and physical properties such as the amount and type of electrical power required for the operation of the HVAC system.

- Heat load of electrical equipment is included as a load to the HVAC system.
- Electrical Consumer List

The preliminary list of main power consumers is shown in drawing number TLDR-CQL2-SS-04-0002 (Reference [8-14]).

The test Blower B3 and Generator GS1 forms part of a test set-up and will not form part of the initial plant design.

Electromagnetic Compatibility

Emission and immunity requirements for electrical systems and components will be based on the applicable IEC 61000 series specifications and the design and selection of these systems and components will be based on the power supply quality which will be determined in the basic engineering and design phase.

8.6 CQL2 Civil and Structural Design

Civil and Structural Design is not addressed as part of this report, but will receive attention during Basic Design Phase. (Refer to Future Work).

8.7 CQL2 Process Design – Process Flow Diagrams

8.7.1 Configuration 1: C1-Principle Two Loop Configuration

Overall Functionality of configuration

This configuration consists of 2 separate loops called the main and secondary loops, which provide simulated condition of the NGNP primary and secondary loops. See PFD TLDR-CQL2-SS-02-0001(Reference[8-12]) for a schematic presentation of the plant configuration.

This configuration provides helium at high temperature and high pressure in order to simulate conditions to enable testing of various components.

Table 8-15 for main components of this loop.

Table 8-15: Main components of configuration C1

Component	Description
B1a	Blower
B1b	Blower
B2a	Blower
B2b	Blower
R1A	Recuperator
R1B	Recuperator
IHX A	Intermediate Heat exchanger A
IHX B	Intermediate Heat exchanger B
C1	Cooler
C2	Cooler
F1	Filter
F2	Filter
H1	Heater
H2	Heater

Cooler C1 and C2 and Blower B1 and B2

8.7.1.1.1 *Functional activities*

Provides helium at high temperature at the required pressure and flow rate;
Traps solid particles in helium returning from sub-systems by means of Filters F1 and F2;
Cools common Blower inlet stream in order to achieve helium outlet temperature of 250°C;
Load control of Blowers;
Anti-surge control of Blowers;

Inputs and Outputs

All the Helium returning from units under test (UUT's) and sub-systems within this configuration, as well as the incoming feed from the Helium Purification System (HPS) or Helium Inventory and Pressure System (HIPCS) is routed back to the Blowers in both the main and secondary loop. The helium supply line from the HPS or HIPCS provides a helium flow into this facility.

8.7.1.1.2 *Process flow and control description*

Cooler C1 and Cooler C2

The temperature of the helium to the inlet of the Blowers (B1 and B2) is controlled by means of water Coolers C1 and C2.

The maximum temperature set point for Blower B1 and B2's inlet is 250°C. A temperature transmitter measures the helium inlet temperature to Blower B1 and B2.

The function of the cooler is to feed the blower with helium within a safe operable temperature margin to prevent damage to the blower. Note that the cooler is sized to absorb a sizable heat load under certain operating conditions, thus it is over-sized for other operating conditions and turn-down ratio becomes insufficient, hence the by-pass system.

Two valves are utilized to obtain the correct gas temperature in the blower suction stream. Valves are placed downstream of the cooler. (Hot valves will be more expensive)

Please refer to Figure 8-22 for control detail.

The main goal is to control the outlet temperature by changing the ratio of flow diverted through the cooler.

At first the hot valve, (6-in cooler bypass) is completely shut. The main stream is forced through the cooler. This is to guarantee that the helium feed to the blowers is below the allowable temperature. The temperature at the output of the cooler is measured and compared to the desired input temperature to the blower. If the controller senses that the temperature is too cold, the cold valve (5) starts to close and the hot valve opens accordingly.

The pressure differential over Cooler C1 and C2 is also monitored to indicate when the cooler is blocked by solid particles (like graphite) present in the helium and is therefore losing its efficiency.

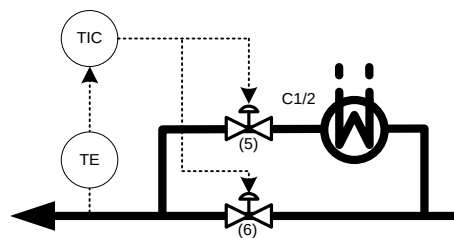


Figure 8-22: Cooler control

Filter F1 and F2

The cooled helium is routed to Filters F1 and F2 for removal of solid particles in the gas stream.

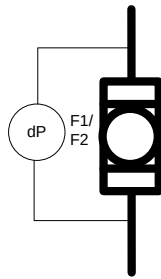


Figure 8-23: Filter control

The pressure difference over the filters are recorded and replacement is suggested when the pressure differential reaches a certain value at maximum flow conditions. Refer to Figure 8-23.

Blower B1 and B2

The main function of the Blower B1 and B2 is to provide the main and secondary loop with helium at the required flow rates and pressures for the experiments in the test set-ups. For the load control of the blowers, the required flow rates and pressures are achieved by measuring the system differential pressure and adjusting the speed of the blower.

In other words, the load required for a specific configuration will be achieved by adjusting the blower speed until the desired pressure difference over the blower(s) (control parameter) is reached.

At start up, the differential pressure over the blower will be low. The blower starts and runs at idle speed (typically 3000 r/min for submerged units). As more differential pressure is required, the VSD will speed up the blower until it runs at maximum speed i.e. 100 percent output.

As the system pressure approaches the maximum input pressure, resistance to flow will start to increase. At this point the PIC output will decrease and therefore the VSD (variable speed drive) output will be lowered.

If the system flow decreases to a point where the blower goes into surge (jumps between flow work point at a constant pressure), the required anti-surge control of the blowers is achieved by measuring the pressure ratio over the blowers, the inlet flow rate and the inlet and outlet temperatures. These parameters are utilized to calculate the required bypass flow rate to achieve the working limits and the anti-surge control valve is manipulated accordingly.

This control is typically fast reaction control. The safe operating point will normally be within 10 percent of the vendor specified anti-surge control line.

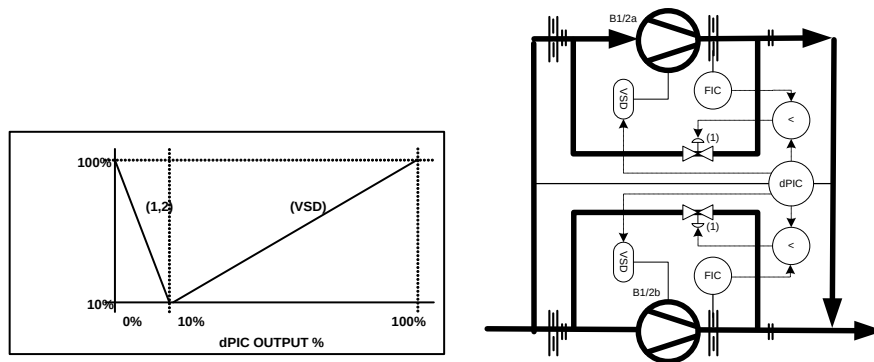


Figure 8-24: Blower Control

Refer to Figure 8-24 for control detail.

A recycle control valve will also form part of the blower control to accommodate for variable loads at the test bench side. A slow reaction control fashion will be applied to keep process inputs on the experimental side as constant as possible.

Recuperator R1 and Heater H1 and H2 Segment

8.7.1.1.3 Functional activities

To recover the energy input of the heater units after the different UUT's.

Further electrical heating of the helium supply in the main loop in order to achieve the temperatures required for the different UUT's.

Further electrical heating of the helium supply in the secondary loop in order to achieve the temperatures required for the different UUT's.

8.7.1.1.4 Inputs and outputs

The inputs to the Recuperator are:

- the supply helium from main loop (Blower B1), and
- the return helium from the secondary loop,
- Inputs to Heater H1 are:
- the supply helium from main loop (Blower B1).
- Inputs to Heater H2 are:
- the supply helium from secondary loop (Blower B2).

8.7.1.1.5 Process flow and control description

Recuperator R1A and R1B

The helium supply stream routed from Blower B1 enters the Recuperator where heat exchange takes place with the helium return in the secondary loop. The extent of the heat exchange between these lines is dependent on the respective flow-rates and the difference between the inlet temperatures. The passive heat exchange properties can therefore only be influenced indirectly by the velocity and mass flow through it.

The pressure differential measurement will be used to monitor the possibility of a blockage in the Recuperator flow path.

The temperature differentials over the Recuperator of the cross flow helium streams are also measured to determine the effectiveness of the Recuperator (between the main and secondary loop).

Heater H1

The helium supply line exits the Recuperator R1B and is routed to Heater H1 (where the helium is further heated by the electrical elements of the heater). The outlet temperature (measured by thermocouple) of Heater H1 controls the heater. In the case that the helium temperature is lower than the set point, the thyristor control will increase the energy (kW) input to the heater elements to raise the helium outlet temperature, and vice versa (gas burners as a heat source is also a possibility). The set-point temperature will typically be different for specific configurations. Refer to Figure 8-25 for heater control.

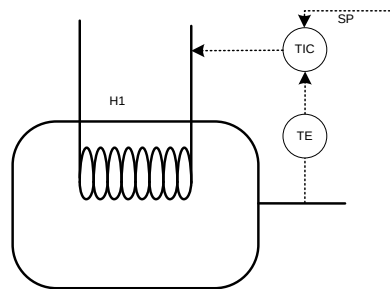
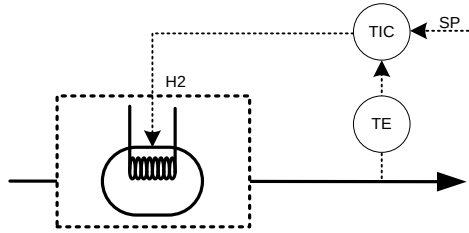


Figure 8-25: Heater control

Heater H2

The helium supply from Blower B2 is routed to Heater H2 (where the helium is further heated by the electrical elements of the heater). The outlet temperature (measured by a thermocouple) of Heater H2 controls the heater. In the case that the helium temperature is lower than the set point, the thyristor control will increase the energy (kW) input to the heater elements to raise the helium outlet temperature, and vice versa (gas burners as a heat source is also a possibility). The set-point temperature will typically be different for specific configurations. Refer to Figure 8-26 for heater control.

**Figure 8-26: Heater control 2****Table 8-16: Units under test**

Unit	Description
IHXA	Intermediate Heat exchanger
IHXB	Intermediate Heat exchanger
Test Group A	TBD
Test Group B	TBD
Ultra High Temperature Test unit	TBD

8.7.1.1.6 Functional activities

By customer

8.7.1.1.7 Inputs and outputs

The inputs to Test Group A are:

- the supply helium from main loop (Heater H1).

The inputs to the intermediate heat exchangers are:

- the supply helium from main loop (Heater H1), and
- the return helium from the secondary loop (Heater H2),

The inputs to Test Group B are:

- the supply helium from intermediate heat exchanger IHXA.

8.7.1.1.8 Process flow and control description

Helium at a specified temperature, pressure and flow rate will be supplied to these units from the main and secondary loop. These are units under test and the scope of control will be a customer input.

8.7.2 Configuration 2: C2-High Efficiency Component Test

Overall Functionality of configuration

This configuration consists of the secondary loop diverted to the main loop by circulating through the primary and secondary sides of the intermediate heat exchangers (IHX A and IHX B). A special spool piece will be required to reroute helium from the secondary loop to the inlet of Heater H1. See PFD TLDR-CQL2-SS-02-0008 (Reference [8-12]) for a schematic presentation of the plant configuration.

This configuration provides helium at high temperature and high pressure in order to simulate conditions to enable testing of various components. See

Table 8-15 for main components of this loop.

Table 8-17: Main components of configuration C2

Component	Description
B1a	Blower
B1b	Blower
IHXA	Intermediate Heat exchanger
IHXB	Intermediate Heat exchanger
C1	Cooler
F1	Filter
H1	Heater
H2	Heater

Cooler C2 and Blower B2

8.7.2.1.1 Functional activities

Provides helium at high temperature at the required pressure and flow rate;
Traps solid particles in helium returning from sub-systems by means of Filter F1 and;
Cools common Blower inlet stream in order to achieve helium outlet temperature of 250°C;
Load control of Blowers;
Anti-surge control of Blowers.

8.7.2.1.2 Inputs and outputs

All the Helium returning from units under test (UUT's) and sub-systems within this configuration, as well as the incoming feed from the Helium Purification System (HPS) or Helium Inventory and Pressure System (HIPCS) is routed back to the Blowers the main loop. The helium supply line from the HPS or HIPCS provides a helium flow into this facility.

8.7.2.1.3 Process flow and control description

Cooler C2

The temperature of the helium to the inlet of the Blower (B2) is controlled by means of water Coolers C2.

The maximum temperature set point for Blower B2 inlet is 250°C. A temperature transmitter measures the helium inlet temperature to Blower B2. Refer to paragraph 8.7.1.1.2 for cooler control.

Filter F2

The cooled helium is routed to Filter F2 for removal of solid particles in the gas stream.

The pressure difference over the filter are recorded and replacement is suggested when the pressure differential reaches a certain value at maximum flow conditions.

Blower B2

The main function of the Blower B2 is to provide the main and secondary loops with helium at the required flow rates and pressures for the experiments in the test set-ups. Refer to paragraph 8.7.1.1.2 for blower control.

Heater H1 and H2 Segment:

8.7.2.1.4 Functional activities

Further electrical heating of the helium supply in the main loop in order to achieve the temperatures required for the different UUT's.

Further electrical heating of the helium supply in the secondary loop in order to achieve the temperatures required for the different UUT's.

8.7.2.1.5 Inputs and outputs

Inputs to Heater H1 are:

the supply helium from intermediate heat exchangers IHXA and IHXB.

Inputs to Heater H2 are:

the supply helium from secondary loop (Blower B2).

8.7.2.1.6 Process flow and control description

Heater H1

The helium supply line exits the intermediate Heat exchangers and is routed to Heater H1 (where the helium is further heated by the electrical elements of the heater). The outlet temperature (measured by thermocouple) of Heater H1 controls the heater. In the case that the helium temperature is lower than the set point, the thyristor control will increase the energy (kW) input to the heater elements to raise the helium outlet temperature, and vice versa (gas burners as a heat source is also a possibility). The set-point temperature will typically be different for specific configurations.

Heater H2

The helium supply from Blower B2 is routed to Heater H2 (where the helium is further heated by the electrical elements of the heater). The outlet temperature (measured by thermocouple) of Heater H2 controls the heater. In the case that the helium temperature is lower than the set point, the thyristor control will increase the energy (kW) input to the heater elements to raise the helium outlet temperature, and vice versa (gas burners as a heat source is also a possibility). The set-point temperature will typically be different for specific configurations.

Table 8-18: Units under test

Unit	Description
IHXA	Intermediate Heat exchanger
IHXB	Intermediate Heat exchanger
Test Group A	TBD

8.7.2.1.7 Functional activities

By customer

8.7.2.1.8 Inputs and outputs

The inputs to Test Group A are:
the supply helium from main loop (Heater H1).

The inputs to the intermediate heat exchangers are:
the supply helium from main loop (Heater H1), and
the return helium from the secondary loop (Heater H2).

8.7.2.1.9 Process flow and control description

Helium at a specified temperature, pressure and flow rate will be supplied to these units from the secondary loop. These are units under test and the scope of control will be a customer input.

8.7.3 Configuration 3: C3 - Main-loop Process Heat Component Test

Overall Functionality of configuration

This configuration consists of the main loop utilized as a helium source for steam and hydrogen generation. The main loop circulates helium through Heater H1 and the routes the heated stream to the hydrogen and steam generation units. See PFD TLDR-CQL2-SS-02-0003 (Reference [8-12]) for a schematic presentation of the plant configuration.

This configuration provides helium at high temperature and high pressure in order to simulate conditions to enable testing of various components. See Table 8-19 for main components of this loop.

Table 8-19: Main components of configuration C3

Component	Description
B1a	Blower
B1b	Blower
C1	Cooler
F1	Filter
H1	Heater
H3	Pre Heater
H5	Steam Generator Test
PCHX	Hydrogen Test
H4	Steam Generator pre-heater
P1	Cooling water pump
HT1	Hot well
CN1	Condenser
M1	Mixer

Cooler C1 and Blower B1

8.7.3.1.1 Functional activities

Provides helium at high temperature at the required pressure and flow rate;
Traps solid particles in helium returning from sub-systems by means of Filter F1 and;
Cools common Blower inlet stream in order to achieve helium outlet temperature of 250°C;
Load control of Blowers;
Anti-surge control of Blowers;

8.7.3.1.2 Inputs and outputs

All the Helium returning from units under test (UUT's) and sub-systems within this configuration, as well as the incoming feed from the Helium Purification System (HPS) or Helium Inventory and Pressure System (HIPCS) is routed back to the Blowers in the main loop. The helium supply line from the HPS or HIPCS provides a helium flow into this facility.

8.7.3.1.3 Process flow and control description

Cooler C1

The temperature of the helium to the inlet of the Blower (B1) is controlled by means of water Coolers C1.

The maximum temperature set point for Blower B1 inlet is 250°C. A temperature transmitter measures the helium inlet temperature to Blower B1.

Refer to paragraph 8.7.1.1.2 for cooler control.

Filter F1

The cooled helium is routed to Filter F1 for removal of solid particles in the gas stream. The pressure difference over the filter are recorded and replacement is suggested when the pressure differential reaches a certain value at maximum flow conditions.

Blower B1

The main function of the Blower B1 is to provide the main and secondary loops with helium at the required flow rates and pressures for the experiments in the test set-ups. Refer to paragraph 8.7.1.1.2 for blower control.

Pre heater H3 and Heater H1

8.7.3.1.4 Functional activities

Further electrical heating of the helium supply in the main loop in order to achieve the temperatures required for the different UUT's.

8.7.3.1.5 Inputs and outputs

Inputs to Heater H1 are:
the supply helium from pre heater H3.

Inputs to Heater H3 are:
the supply helium from main loop (Blower B1).

8.7.3.1.6 Process flow and control description

Heater H1

The helium supply line exits the Pre-heater H3 and is routed to Heater H1 (where the helium is further heated by the electrical elements of the heater). The outlet temperature (measured by thermocouple) of Heater H1 controls the heater. In the case that the helium temperature is lower than the set point, the thyristor control will increase the energy (kW) input to the heater elements to raise the helium outlet temperature, and vice versa (gas burners as a heat source is also a possibility). The set-point temperature will typically be different for specific configurations.

Heater H3

The helium supply from Blower B1 is heated with hot steam from the steam generator loop in Heater H3. The extent of the heat exchange between these lines is dependent on the respective flow-rates and the difference between the inlet temperatures. The passive heat exchange properties can therefore only be influenced indirectly by the velocity and mass flow through it.

The pressure differential measurement will be used to monitor the possibility of a blockage in the heater flow path.

The temperature differentials over the cross flow streams are also measured to determine the effectiveness of the heater.

Table 8-20: Units under test

Unit	Description
PCHX	Hydrogen Generator
H5	Steam Generator
Test Group A	TBD

8.7.3.1.7 Functional activities

Generation of steam

Generation of hydrogen

Waste heat minimization with pre-heater in main loop

8.7.3.1.8 Inputs and outputs

The inputs to Test Group A are:

The supply helium from main loop (Heater H1).

The inputs to the Steam Generator are:

The supply helium from main loop (Heater H1). A portion of the flow is directed to the hydrogen generation plant.

The inputs to the Steam Generator are:

The supply helium from main loop (Heater H1) mixed with outlet flow from the hydrogen generation plant in mixer M1.

8.7.3.1.9 Process flow and control description

Helium at a specified temperature, pressure and flow rate will be supplied to these units from the main loop. The steam will be utilized to pre heat the helium in the main loop. The hot helium for the Hydrogen generation plant will be re routed to the steam generation plant via Mixer M1.

These are units under test and the scope of control will be a customer input.

8.7.4 Configuration 4: C4-Testing Intermediate Heat Exchanger With Hydrogen Generation

Overall Functionality of configuration

This configuration consists of the secondary loop diverted to the main loop by circulating through the primary and secondary sides of the intermediate heat exchangers (IHXA and IHXB). A special spool piece will be required to reroute helium from the secondary loop to the inlet of Heater H1. See PFD TLDR-CQL2-SS-02-0004 (Reference [8-12]) for a schematic presentation of the plant configuration.

This configuration provides helium at high temperature and high pressure in order to simulate conditions to enable testing of various components. See Table 8-21 for main components of this loop.

Table 8-21: Main components of configuration C4

Component	Description
B1a	Blower
B1b	Blower
IHXA	Intermediate Heat exchanger
IHXB	Intermediate Heat exchanger
C1	Cooler
F1	Filter
H1	Heater
H2	Heater
PCHX	Hydrogen generator

Cooler C2 and Blower B2

8.7.4.1.1 Functional activities

- Provides helium at high temperature at the required pressure and flow rate;
- Traps solid particles in helium returning from sub-systems by means of Filter F1 and;
- Cools common Blower inlet stream in order to achieve helium outlet temperature of 250°C;
- Load control of Blowers;
- Anti-surge control of Blowers.

8.7.4.1.2 Inputs and outputs

All the Helium returning from units under test (UUT's) and sub-systems within this configuration, as well as the incoming feed from the Helium Purification System (HPS) or Helium Inventory and Pressure System (HIPCS) is routed back to the Blowers the main loop. The helium supply line from the HPS or HIPCS provides a helium flow into this facility.

8.7.4.1.3 Process flow and control description

Cooler C2

The temperature of the helium to the inlet of the Blower (B2) is controlled by means of water Coolers C2.

The maximum temperature set point for Blower B2 inlet is 250°C. A temperature transmitter measures the helium inlet temperature to Blower B2.

Refer to paragraph 8.7.1.1.2 for cooler control.

Filter F2

The cooled helium is routed to Filter F2 for removal of solid particles in the gas stream.

The pressure difference over the filter are recorded and replacement is suggested when the pressure differential reaches a certain value at maximum flow conditions.

Blower B2

The main function of the Blower B2 is to provide the main and secondary loops with helium at the required flow rates and pressures for the experiments in the test set-ups. Refer to paragraph 8.7.1.1.2 for blower control.

Heater H1 and H2 Segment:

8.7.4.1.4 Functional activities

Further electrical heating of the helium supply in the main loop in order to achieve the temperatures required for the different UUT's.
Further electrical heating of the helium supply in the secondary loop in order to achieve the temperatures required for the different UUT's.

8.7.4.1.5 Inputs and outputs

Inputs to Heater H1 are:

- the supply helium from intermediate heat exchangers IHX A and IHX B.

Inputs to Heater H2 are:

- the supply helium from secondary loop (Blower B2).

8.7.4.1.6 Process flow and control description

Heater H1

The helium supply line exits the intermediate Heat exchangers and is routed to Heater H1 (where the helium is further heated by the electrical elements of the heater). The outlet temperature (measured with thermocouple) of Heater H1 controls the heater. In the case that the helium temperature is lower than the set point, the thyristor control will increase the energy (kW) input to the heater elements to raise the helium outlet temperature, and vice versa (gas burners as a heat source is also a possibility). The set-point temperature will typically be different for specific configurations.

Heater H2

The helium supply from Blower B2 is routed to Heater H2 (where the helium is further heated by the electrical elements of the heater). The outlet temperature (measured with thermocouple) of Heater H2 controls the heater. In the case that the helium temperature is lower than the set point, the thyristor control will increase the energy (kW) input to the heater elements to raise the helium outlet temperature, and vice versa (gas burners as a heat source is also a possibility). The set-point temperature will typically be different for specific configurations.

Table 8-22: Units under test

Unit	Description
IHX A	Intermediate Heat exchanger
IHX B	Intermediate Heat exchanger
Test Group A	TBD
PCHX	Hydrogen Generator

8.7.4.1.7 Functional activities:

Hydrogen Generation

8.7.4.1.8 Inputs and outputs

The inputs to Test Group A are:

- the supply helium from main loop (Heater H1).

The inputs to the intermediate heat exchangers are:

- the supply helium from main loop (Heater H1), and
- the return helium from the secondary loop (Heater H2),

The inputs to the PCHX are:

- the supply helium from the IHXA's secondary side.

8.7.4.1.9 Process flow and control description

Helium at a specified temperature, pressure and flow rate will be supplied to these units from the main loop. A portion of the flow from the secondary side of IHXA will be re routed to the hydrogen generation UUT. The outlet flow from the PCHX will be re routed to heater H1 via Mixer M2.

These are units under test and the scope of control will be a customer input.

8.7.5 Configuration 1: C5-Brayton Cycle Test

Overall Functionality of configuration.

This configuration consists of the secondary loop diverted to the main loop through recuperator R1B to provide flow to a compressor-turbine machine under test. PFD TLDR-CQL2-SS-02-0005 (Reference [8-12]) for a schematic presentation of the plant configuration.

This configuration provides helium at high temperature and high pressure in order to simulate conditions to enable testing of various components. See Table 8-23 for main components of this loop.

Table 8-23: Main components of configuration C5

Component	Description
CM1	Compressor
TB1	Turbine
GS1/MT1	Generator /Motor
R1B	Recuperator
C2	Cooler
F2	Filter
H1	Heater

Compressor CM1-Turbine TB1 and Cooler C2

8.7.5.1.1 Functional activities

Provides helium at the required temperature, pressure and flow rate;
Traps solid particles in helium returning from sub-systems by means of Filter F2;
Cools Compressor CM1 inlet stream in order to achieve desired outlet temperatures;

8.7.5.1.2 Inputs and outputs

All the Helium returning from units under test (UUT's) and sub-systems within this configuration, as well as the incoming feed from the Helium Purification System (HPS) or Helium Inventory and Pressure System (HIPCS) is routed back to the Compressor (CM1)-Turbine (TB1) unit. This combination unit serves as the driving force within this configuration. The excess energy is converted into electricity via a generator (GS1) coupled directly to the compressor-turbine unit. The helium supply line from the HPS or HIPCS provides a helium flow into this facility.

Inputs to Compressor CM1 are:

- the supply helium from secondary loop (Cooler C2).

Outputs from Compressor CM1 are:

- the supply helium to main loop (Recuperator R1B).

Inputs to Turbine TB1 are:

- the supply helium from main loop (Heater H1).

Outputs from Turbine TB1 are:

- the supply helium to secondary loop (Recuperator R1B).

8.7.5.1.3 Process flow and control description

Cooler C2

The temperature of the helium to the inlet of compressor CM1 is controlled by means of water Cooler C2.

The maximum temperature set point for compressor inlet is $\pm 30^{\circ}\text{C}$. A temperature transmitter measures the helium inlet temperature to compressor CM1. Refer to 8.7.1.1.2 for cooler control.

Filter F2

The cooled helium is routed to Filter F2 for removal of solid particles in the gas stream.

The pressure difference over the filter are recorded and replacement is suggested when the pressure differential reaches a certain value at maximum flow conditions.

Compressor CM1

The main function of compressor CM1 is to provide the main loop with helium at the required flow rate and pressure for the experiments in the test set-ups. The controllability of the direct-coupled compressor-turbine-generator combination will also be tested.

Refer to Figure 8-27 for control. The maximum discharge pressure of each Compressor is 9000 kPa(g). This is the static control point and will be controlled via the HICPS system. To achieve the required flow rates and pressures, the differential pressure over the compressor is measured and then adjusted with the compressor speed (Load control). This is achieved by controlling valve (1).

The required anti-surge control of the compressor is achieved by measuring the pressure ratio over the compressor, the inlet flow rate and the inlet and outlet temperatures. These parameters are utilized to calculate the required bypass flow rate to achieve the working limits and the anti-surge control valve is manipulated accordingly.

The stonewall limiting is done by measuring the inlet and outlet temperatures and pressures, as well as the outlet flow rate of compressor CM1. If the compressor is nearing a possible stonewalling scenario, the set point of the Load Controller is adjusted. This is controlled via valve (2).

The maximum helium inlet temperature to the Compressor is specified as 30°C. Temperatures higher than 30°C may cause damage to the Compressors (TBC). A temperature transmitter is situated upstream from the Compressors but downstream of the Filter F2 to detect warm helium from the secondary loop (test set-ups) or the HPS.

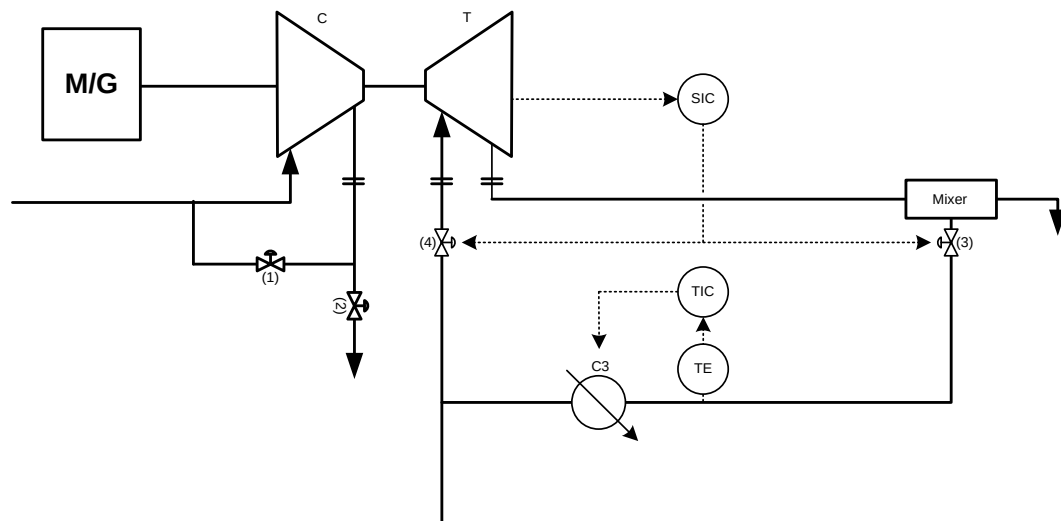


Figure 8-27: Compressor-Turbine-Generator control

Turbine TB1

The main function of turbine TB1 is to convert kinetic energy into shaft work when the helium impinges on blades attached to a rotating shaft (The same shaft is directly connected to the compressor and generator). The work is then applied to accomplish the required gas compression with compressor CM1. The turbine expands high temperature helium from Test group A into high velocity low pressure helium rerouted to exchange heat (cooled down) in recuperator R1B with gas from the compressor discharge (heated up).

A spill back valve in the turbine bypass line is used to control the amount of kinetic energy converted in to shaft work. A valve in the turbine suction line is also utilized to do load control (work output control) on the turbine.

Refer to Figure 8-27 for control.

Cooler C3 is inserted in the feedback control line to ensure safe operating conditions for valve (3). The input on the feedback is line can be 900°C and valves will be difficult to obtain.

Valve (4) is used to control the speed of Turbine TB1 by controlling the amount of gas to the turbine input as well as the amount of gas bypassing the turbine. This is controlled by the speed indicating controller (SIC) acting on valves (3) and (4).

A mixer is used to ensure that the feedback temperature through the spillback line and the warmer gas at the output of the turbine is mixed and provided at the correct input temperatures to Recuperator R1B.

Recuperator R1B and Heater H1 Segment:**8.7.5.1.4 Functional activities:**

To compromise the temperature lost/gained via the compressor (main loop) and turbine (secondary loop) respectively.

Further electrical heating of the helium supply in the main loop in order to achieve the temperatures required for the different UUT's.

8.7.5.1.5 Inputs and outputs

The inputs to the Recuperator R1B are:

- the supply helium from main loop (Compressor CM1), and
 - the return helium from the main loop (Turbine TB1),
- Inputs to Heater H1 are:
- the supply helium from main loop (Recuperator R1B).

8.7.5.1.6 Process flow and control description**Recuperator R1B**

The helium supply stream routed from Compressor CM1 enters the Recuperator where heat exchange takes place with the helium return from the Turbine TB1 in the secondary loop. The extent of the heat exchange between these lines is dependent on the respective flow-rates and the difference between the inlet temperatures. The passive heat exchange properties can therefore only be influenced indirectly by the velocity and mass flow through it.

The pressure differential measurement will be used to monitor the possibility of a blockage in the Recuperator flow path.

The temperature differentials over the Recuperator of the cross flow helium streams are also measured to determine the effectiveness of the Recuperator.

Heater H1

The helium supply line exits the Recuperator R1B and is routed to Heater H1 (where the helium is further heated by the electrical elements of the heater). The outlet temperature (measured by a thermocouple) of Heater H1 controls the heater. In the case that the helium temperature is lower than the set point, the thyristor control will increase the energy (kW) input to the heater elements to raise the helium outlet temperature, and vice versa (gas burners as a heat source is also a possibility). The set-point temperature will typically be different for specific configurations.

Table 8-24: Units under test

Unit	Description
CM1	Intermediate Heat exchanger
TB1	Intermediate Heat exchanger
GS1	Generator
Test Group A	TBD

8.7.5.1.7 Functional activities:

By customer.

8.7.5.1.8 Inputs and outputs

The inputs to Test Group A are:

- the supply helium from main loop (Heater H1).

The inputs to the Compressor-Turbine-generator are:

Refer to paragraph 8.7.5.1.2.

8.7.5.1.9 Process flow and control description

Helium at a specified temperature, pressure and flow rate will be supplied to these units from the main loop diverted to the secondary loop through recuperator R1B. These are units under test and the scope of control will be a customer input.

8.7.6 Configuration 1: C6-Basic Component Test

Overall Functionality of configuration

This configuration consists of the main loop diverted tot the secondary loop through recuperators R1A and R1B. See PFD TLDR-CQL2-SS-02-0006 (Reference [8-12]) for a schematic presentation of the plant configuration.

This configuration provides helium at high temperature and high pressure in order to simulate conditions to enable testing of various components. See Table 8-25for main components of this loop.

Table 8-25: Main components of configuration C6

Component	Description
B1a	Blower
B1b	Blower
R1A	Recuperator
R1B	Recuperator
C1	Cooler
F1	Filter
H1	Heater

Cooler C1 and Blower B1

8.7.6.1.1 *Functional activities*

Provides helium at high temperature at the required pressure and flow rate;
Traps solid particles in helium returning from sub-systems by means of Filter F1;
Cools common Blower inlet stream in order to achieve helium outlet temperature of 250°C;
Load control of Blowers;
Anti-surge control of Blowers;

8.7.6.1.2 *Inputs and outputs*

All the Helium returning from units under test (UUT's) and sub-systems within this configuration, as well as the incoming feed from the Helium Purification System (HPS) or Helium Inventory and Pressure System (HIPCS) is routed back to the Blowers in both the main and secondary loop. The helium supply line from the HPS or HIPCS provides a helium flow into this facility.

8.7.6.1.3 *Process flow and control description*

Cooler C1

The temperature of the helium to the inlet of Blowers B1 is controlled by means of water Coolers C1.

The maximum temperature set point for Blower B1's inlet is 250°C. A temperature transmitter measures the helium inlet temperature to Blower B1.

Refer to paragraph 8.7.1.1.2 for cooler control.

Filter F1

The cooled helium is routed to Filters F1 for removal of solid particles in the gas stream.

The pressure difference over the filter are recorded and replacement is suggested when the pressure differential reaches a certain value at maximum flow conditions.

Blower B1

The main function of Blowers B1 is to provide the main and secondary loop with helium at the required flow rates and pressures for the experiments in the test set-ups. Refer to paragraph 8.7.1.1.2 for blower control.

Recuperator R1A and R1B and Heater H1

8.7.6.1.4 *Functional activities*

To recover the energy input of the heater units after the different UUT's.

Further electrical heating of the helium supply in the main loop in order to achieve the temperatures required for the different UUT's.

8.7.6.1.5 Inputs and outputs

The inputs to the Recuperator are:

- the supply helium from main loop (Blower B1), and
- the return helium via the secondary loop (Heater H1 outlet),

Inputs to Heater H1 are:

- the supply helium from main loop (via Recuperators R1A and R1B).

8.7.6.1.6 Process flow and control description

Recuperator R1a and R1b

The helium supply stream routed from Blower B1 enters the Recuperator where heat exchange takes place with the helium return in the secondary loop. The extent of the heat exchange between these lines is dependent on the respective flow-rates and the difference between the inlet temperatures. The passive heat exchange properties can therefore only be influenced indirectly by the velocity and mass flow through it.

The pressure differential measurement will be used to monitor the possibility of a blockage in the Recuperator flow path.

The temperature differentials over the Recuperator of the cross flow helium streams are also measured to determine the effectiveness of the Recuperator.

Heater H1

The helium supply line exits the Recuperator R1A and is routed to Heater H1 (where the helium is further heated by the electrical elements of the heater). The outlet temperature of Heater H1 controls the heater. In the case that the helium temperature is lower than the set point, the thyristor control will increase the energy (kW) input to the heater elements to raise the helium outlet temperature, and vice versa. The set-point temperature will typically be different for specific configurations.

Table 8-26: Units under test

Unit	Description
Test Group A	TBD

8.7.6.1.7 Functional activities

By customer

8.7.6.1.8 Inputs and outputs

The inputs to Test Group A are:
the supply helium from main loop (Heater H1).

8.7.6.1.9 Process flow and control description

Helium at a specified temperature, pressure and flow rate will be supplied to these units from the main loop. These are units under test and the scope of control will be a customer input.

8.7.7 Configuration 1: C7-Steam Generator Coupled to Secondary Loop

8.7.7.1 Overall Functionality of Configuration

This configuration consists of 2 separate loops called the main and secondary loops, which provide simulated condition of the NGNP primary and secondary loops. The secondary loop is diverted to a steam and hydrogen generation unit. See PFD TLDR-CQL2-SS-02-0007 (Reference [8-12]) for a schematic presentation of the plant configuration.

This configuration provides helium at high temperature and high pressure in order to simulate conditions to enable testing of various components. See Table 8-27 for main components of this loop.

Table 8-27: Main components of configuration C7

Component	Description
B1a	Blower
B1b	Blower
B2a	Blower
B2b	Blower
R1A	Recuperator
R1B	Recuperator
IHXA	Intermediate Heat exchanger
IHXB	Intermediate Heat exchanger
C1	Cooler
C2	Cooler
F1	Filter
F2	Filter
H1	Heater
H2	Heater
H4	Steam Generator Pre heater
H5	Steam Generator
P1	Feed water pump
HT1	Hot well
CN1	Condenser
M1	Mixer

Cooler C1 and C2 and Blower B1 and B2

8.7.7.1.1 *Functional activities*

Provides helium at high temperature at the required pressure and flow rate;
Traps solid particles in helium returning from sub-systems by means of Filters F1 and F2;

Cools common Blower inlet stream in order to achieve helium outlet temperature of 250°C;
Load control of Blowers;
Anti-surge control of Blowers.

8.7.7.1.2 *Inputs and outputs*

All the Helium returning from units under test (UUT's) and sub-systems within this configuration, as well as the incoming feed from the Helium Purification System (HPS) or Helium Inventory and Pressure System (HIPCS) is routed back to the Blowers in both the main and secondary loop. The helium supply line from the HPS or HIPCS provides a helium flow into this facility.

8.7.7.1.3 *Process flow and control description*

Cooler C1 and Cooler C2

The temperature of the helium to the inlet of the Blowers (B1 and B2) is controlled by means of water Coolers C1 and C2.

The maximum temperature set point for Blower B1 and B2's inlet is 250°C. A temperature transmitter measures the helium inlet temperature to Blower B1 and B2.

Refer to paragraph 8.7.1.1.2 for cooler control.

Filter F1 and F2

The cooled helium is routed to Filters F1 and F2 for removal of solid particles in the gas stream.

The pressure difference over the filters are recorded and replacement is suggested when the pressure differential reaches a certain value at maximum flow conditions.

Blower B1 and B2

The main function of the Blower B1 and B2 is to provide the main and secondary loop with helium at the required flow rates and pressures for the experiments in the test set-ups. Refer to paragraph 8.7.1.1.2 for blower control.

Recuperator R1A and R1B and Heater H1 and H2 Segment:

8.7.7.1.4 Functional activities

To recover the energy input of the heater units after the different UUT's:

- Further electrical heating of the helium supply in the main loop in order to achieve the temperatures required for the different UUT's.
- Further electrical heating of the helium supply in the secondary loop in order to achieve the temperatures required for the different UUT's.

8.7.7.1.5 Inputs and outputs

The inputs to the Recuperator are:

- the supply helium from main loop (Blower B1), and
- the return helium from the secondary loop (Steam Generator),

Inputs to Heater H1 are:

- the supply helium from main loop (Recuperator R1A).

Inputs to Heater H2 are:

- the supply helium from secondary loop (Blower B2).

8.7.7.1.6 Process flow and control description

Recuperator R1a and R1b

The helium supply stream routed from Blower B1 enters the Recuperator where heat exchange takes place with the helium return from the condenser with in the steam generation unit in the secondary loop. The extent of the heat exchange between these lines is dependent on the respective flow-rates and the difference between the inlet temperatures.

The pressure differential measurement will be used to monitor the possibility of a blockage in the Recuperator flow path.

The temperature differentials over the Recuperator of the cross flow helium streams are also measured to determine the effectiveness of the Recuperator.

Heater H1

The helium supply line exits the Recuperator R1A and is routed to Heater H1 (where the helium is further heated by the electrical elements of the heater). The outlet temperature (measured with thermocouple) of Heater H1 controls the heater. In the case that the helium temperature is lower than the set point, the thyristor control will increase the energy (kW) input to the heater elements to raise the helium outlet temperature, and vice versa. The set-point temperature will typically be different for specific configurations.

Heater H2

The helium supply from Blower B2 is routed to Heater H2 (where the helium is further heated by the electrical elements of the heater). The outlet temperature (measured with thermocouple) of Heater H2 controls the heater. In the case that the helium temperature is lower than the set point, the thyristor control will increase the energy (kW) input to the heater elements to raise the helium outlet temperature, and vice versa. The set-point temperature will typically be different for specific configurations.

Table 8-28: Units under test

Unit	Description
IHXA	Intermediate Heat exchanger
IHXB	Intermediate Heat exchanger
Test Group A	TBD
Test Group B	TBD
H5 and PCHX	Steam and hydrogen generation unit

8.7.7.1.7 Functional activities:

By customer

8.7.7.1.8 Inputs and outputs

The inputs to Test Group A are:

- the supply helium from main loop (Heater H1).

The inputs to the intermediate heat exchangers are:

- the supply helium from main loop (Heater H1), and
- the return helium from the secondary loop (Heater H2),

The inputs to Test Group B are:

- the supply helium from intermediate heat exchanger IHX A.

The inputs to the Hydrogen Generator are:

- the supply helium from main loop (Heater H1). A portion of the flow is directed to the hydrogen generation plant.

The inputs to the Steam Generator are:

- the supply helium from main loop (Heater H1) mixed with outlet flow from the hydrogen generation plant in mixer M1.

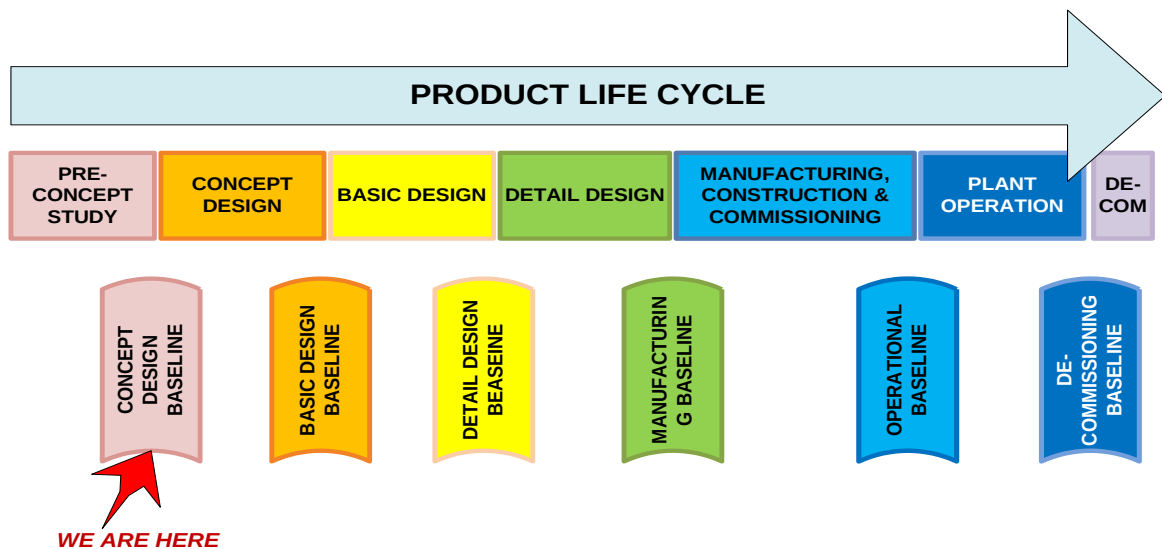
8.7.7.1.9 Process flow and control description

Helium at a specified temperature, pressure and flow rate will be supplied to the Steam and Hydrogen generation units. The excess heat will be recovered via recuperators R1A and R1B. These are units under test and the scope of control will be a customer input.

8.8 CQL2 Future Work

- The recommendations for future work relate only to the CTF main components/sub-systems and not to any of the units under test.
- Future work relates to the completion of the full scale conceptual and basic design of the CTF. The future activities for detail design are not mentioned.
- Basically, the CTF preconceptual proposal is based on well-proven industrial technologies and components but the actual capabilities to provide similar product today are uncertain.
- The future work defined below is meant to mitigate the uncertainties as defined in paragraph 8.1.1, minimize the risk to comply with the objectives of the CTF and to continue with the next design phase, as per the Product Life Cycle depiction below.

Figure 8-28 : Product Life Cycle Description



- The following general future work is defined:

8.8.1 System level

- Optimization of the individual loop component to end in the most economic proposal. Capital vs. operational cost should be considered.
- Space allowed for testing purposes should be closely studied. (For defined and postulated future needs).

- The proposed flexibility in the configuration with its associated implications /complications should be better understood.
- The size (mass flow) of the loop should be measured against the benefit e.g. to satisfy TRL 7 requirements.
- The availability of electric power supply on site may influence the heat source to be used.
- The general services on site and the effective “link-in” should be studied.
- The applicable laws, standards and procedures to be considered in the designs should be revisited.
- Temperature conditioning of hot pipes, pressure vessels and other pressure retaining components with a dedicated conditioning system should be studied to make sure there are no hidden difficulties.

8.8.2 Component level

- Transport of heavy components to be investigated.
- Availability and the level of technology readiness of major components e.g. blowers, recuperators, electric heaters etc to be investigated through discussion/negotiation with potential suppliers.
- Long lead items to be identified.
- The heating energy supply method to be studied (combination of pre-heating, gas heating and electric heating mentioned).

8.8.3 Technology/units Under Test Level

- The exact uncertainties and characteristics of the UUT, which should be to attend to, should be more closely studied in order to define the CTF needs more accurately.
- The time span of individual tests should be defined.
- Simultaneous tests to be performed, or which can be performed simultaneously should be defined.
- Insulation capability of insulation materials under hot helium conditions is uncertain.
- The effective cleaning of helium with oil contaminants is unsure.
- Heat transfer from heating elements to high temperature helium gas is not well proven in the industry.
- Cooler control via bypass streaming on coolers should be simulated.

8.9 References

- [8-1] “High Level Requirements High Temperature Gas Reactor (HTGR) - Component Test Facility (CTF),” INL/MIS-08-14156, dated April 2008;
- [8-2] “Technical and Functional Requirements - High Temperature Gas- Cooled Reactor (HTGR) Component Test Facility (CTF),” INL/EXT-08-14150
- [8-3] “Site Selection Study for the High Temperature Gas-Cooled Reactor (HTGR) Component Test Facility (CTF),” INL/EXT-08-14052
- [8-4] “HTGR Component test facility (CTF) Feasibility and recommendations,” NGNP-CTF, dated February 2008
- [8-5] “NGNP Technology Develop Roadmapping,” NGNP-CTF MTECH-TDRM, dated December 2008

8.10 Supporting Documents

- [8-6] Appendix A - External Interfaces
- [8-7] Appendix B - Internal Interfaces (Component Specification Sheets)
- [8-8] Appendix C - Safety base
- [8-9] Appendix D - Risk/hazard identification worksheet
- [8-10] Appendix E - Risk/hazard assessment worksheet
- [8-11] Appendix F - P&ID's
- [8-12] Appendix G - Process flow diagrams
- [8-13] Appendix H - Mechanical layout drawings
- [8-14] Appendix I - Electrical drawings

Appendix A: External Interfaces

NGNP-CTF External Interface Requirements Table

Property												
Item	Energy into plant						Flow	Temperatures		Mass	Elevation From Finished Floor Level for Crane	Sizes L=Length Diam = Outer Diameter W=Width H=Height t =Thickness
	Voltage [V]	Current [A]	Apparent Power [kVA]	Reactive Power [kVAR]	Real Power [kW]			T _{into plant} (°C)	T _{out of plant} (°C)			
							m³/hr			kg	m	mm
1	Cooling Water Supply						371.429	35	65			
2	Electricity Interface	6,600	2x 3,500A incomers									
2.1	- maximum operational demand			45,193	7,716	44,529						
2.2	- Blower 1B and Heater HT1 on 25MW, Blower B3 not operational			38,085	6,484	37,529						
2.3	- maximum expandable capability			80,000	21,200	77,000						
3	Support Systems for:											
3.1	Cooler C1/C2									14952	3.54	L=5245 Diam=950 t=50
3.2	Filters F1/F2									15000	4.697	Diam=1160 t=50
3.3	Blower 1a									30000(estimated)	3.283	Diam=2765 L=6348
3.4	Blower 1b									30000(estimated)	3.283	Diam=2765 L=6348
3.5	Blower 2a									30000(estimated)	3.283	Diam=2765 L=6348
3.6	Blower 2b									30000(estimated)	3.283	Diam=2765 L=6348
3.7	Blower B3									30000(estimated)	3.283	Diam=2765 L=6348
3.8	Blower B4									30000(estimated)	3.283	Diam=2765 L=6348
3.9	Steam Generator H5									368762	21.14	Diam= 2000mm L=20m t=75mm
	Heater H1:											
3.10	Bank 1									181000	11	L=11000 Diam=2800
3.11	Bank 2									181000	11	L=11000 Diam=2800
3.12	Bank 3									181000	11	L=11000 Diam=2800
3.13	Bank 4									181000	11	L=11000 Diam=2800
3.14	Bank 5									181000	11	L=11000 Diam=2800
3.15	Bank 6									181000	11	L=11000 Diam=2800
3.16	Heat Exchanger PCHX									10000	2.818	Diam=1700 L=6000
3.17	Recuperator R1B									175030	5.451	Diam=2860 L=8630
3.18	Recuperator R1A									309082	3.961	Diam=2800 L=17000
	Test Group A:											
3.19	Core Structure Test									25000	5	L=3000 Diam=2500
3.20	Hot Pipe Test									90000	3	L=15000 Diam=2000
3.21	Hot Valve Test									90000	2	L=15000 Diam=2000
	Test Group B:											
3.22	Heat Exchanger IHXA									126000	7.5	L=8268 Diam=2600
3.23	Heat Exchanger IHXB									105000	7.5	L=7908 Diam=2600
4	Compressed Air											
5	Instrument Air											
6	Containment Building											
7	Ventilation System to Building											
8	Emergency service/control											
9	Site Security											
10	Access to Roads											
11	Plant Maintenance Facility											
12	Trained Plant Operators											
13	Telecommunication facility											
14	Waste											
14.1	Wash Bay to clean used filters											
14.2	Domestic Waste Removal Service											

Appendix B: Internal Interfaces (Component Specification Sheets)

NGNP-CTF Internal Interface Requirements Table: Configuration 1: "Primary and Ultra High Temperature Test Loop"

Identification		Physical					Electrical			Instrumentation		Thermo hydraulic									
Equipment name and short description	Equipment number	Interface number	Nozzle number	Nozzle nominal size mm	Mass kg	Elevation from finished floor level m	Sizes L=Length Diam = Outer Diameter W=Width t =Thickness H=Height	Power usage kW	Duty(%) (Demand/ capability)	No of phases	Amps A	Volts V	Instrument type P, T, dP, F	Instrument Number	Flow kg/s	Temperature in (Primary Loop): °C	T ₁₀ (Primary Loop): °C	Temperature in (Secondary Loop): T ₁₀ °C	Temperature out (Secondary Loop): T ₁₀ °C	Fluid type	Notes
Cooler C1				600 (4 off)	14952	3.54	L=5245 Diam=950 t=50 L=825 W=120						T		25	337	250			He	
Cooler C1 Saddle Support(2 OFF)					15000(estimated)																
Filter F1					15000	4.697	Diam=1160 t=50						dP		25	250	250			He	
Blower 1a				600 (2 off) & 600 (2 off)	30000(estimated)	3.283	Diam=2765 L=6348	1000	100	3	105	6600	F		12.5	250	250			He	
Blower 1b				600 (2 off) & 100 (2 off)	30000(estimated)	3.283	Diam=2765 L=6348	1000	100	3	105	6600	F		12.5	250	250			He	
Recuperator R1B				600 (4 off)	175030	5.451	L=8630 Diam=2860 L=2500 W=200								25	250	<550	<550	350	He	
Recuperator R1B Saddle Support(2 OFF)					170000(estimated)																
Recuperator R1A				600 (4 off)	309082	3.961	L=17000 Diam=2800 L=2500 W=200								25	<550	800	900	<550	He	
Recuperator R1A Saddle Support(2 OFF)					170000(estimated)																
Heater H1(25MW thermal)*								30000	100	3	2975	6600	T		25	800				He	* see note at bottom of sheet
Bank 1				900 (2 off)	181000	11	L=11000 Diam=2800	5000	100	3	595	6600									
Bank 2				900 (2 off)	181000	11	L=11000 Diam=2800	5000	100	3	595	6600									
Bank 3				900 (2 off)	181000	11	L=11000 Diam=2800	5000	100	3	595	6600									
Bank 4				900 (2 off)	181000	11	L=11000 Diam=2800	5000	100	3	595	6600									
Bank 5				900 (2 off)	181000	11	L=11000 Diam=2800	5000	100	3	595	6600									
Bank 6				900 (2 off)	181000	11	L=11000 Diam=2800	5000	100	3	595	6600									
Heater H1 Leg Support					181000(estimated)		Skirt flange OD=3000														
Test Group A																					
Core Structure Test				762 (2 off)	25000	5	L=3000 Diam=2500														
Hot Pipe Test					90000	3	L=15000 Diam=2000														
Hot Valve Test				-	90000	2	L=15000 Diam=2000														
Test Group B																					
Heat Exchanger IHXA				1219 (4 off)	126000	7.5	L=8268 Diam=2600								25	950	760	710	900	He	
Heat Exchanger IHXB				1219 (2off) & 600(2off)	105000	7.5	L=7908 Diam=2600								25	760	337	287	710	He	
Cooler C2				600 (4 off)	14952	3.54	L=5245 Diam=950 t=50 L=825 W=120						T		25			350	250	He	
Cooler C2 Saddle Support(2 OFF)					15000(estimated)																
Filter F2					15000	4.697	Diam=1160 t=50						dP		25			250	250	He	
Blower 2a				600 (2 off) & 100 (2 off)	30000(estimated)	3.283	Diam=2765 L=6348	1000	100	3	105	6600	F		12.5			250	250	He	
Blower 2b				600 (2 off) & 100 (2 off)	30000(estimated)	3.283	Diam=2765 L=6348	1000	100	3	105	6600	F		12.5			250	250	He	
Heater H2 (4.810 MW thermal)				900 (2 off)	181000	11	L=11000 Diam=2800	5000	100	3	595	6600	T		25			250	287	He	
Heater H2 Leg Support					181000(estimated)																
HIPCS vessel 1					180000	18000	L = 18000 Diam=4000														
HIPCS vessel 2					180000	18000	L = 18000 Diam=4000														
HIPCS vessel 3					180000	18000	L = 18000 Diam=4000														
Width(mm) x depth(mm) x height(mm)																					
Uninterruptible power supply 1	UC1				850	2	1500x850x1800	20	1	3	19	460									
Uninterruptible power supply 2	UC2				850	2	1500x850x1800	20	1	3	19	460									
Analysier shelter	VP4				1200	2	1200x4500x1800	45	1	3	56	460									
Analysier shelter	VP5				1200	2	1200x4500x1800	45	1	3	56	460									
HVAC -system	VP6						160 x 1200 x 1800	160	1	3	201	460									
Fire fighting pump 1	P20A				1500	1	1500x2500x1000	55	1	3	82	460									
Fire fighting pump 2	P20B				1500	1	1500x2500x1000	55	1	3	82	460									
Fire fighting pump 3	P20C				1500	1	1500x2500x1000	55	1	3	82	460									
Instrument air supply 1	VP7				1500	2	1500x2000x2200	30	1	3	48	460									
Instrument air supply 2	VP8				1500	2	1500x2000x2200	30	1	3	48	460									
Helium compressor 1	CP1A				1200	1	1200x2000x1000	30	1	3	48	460									
Helium compressor 1 air fan	FA1A				90	1	1000x600x1200	3	1	3	5	460									
Helium compressor 2	CP1B				1200	1	1200x2000x1000	30	1	3	48	460									
Helium compressor 2 air fan	FA1B				90	1	1000x600x1200	3	1	3	5	460									
HPS heater 1	HT20A				2300	2	2000x2500x1800	55	1	3	69	460									
HPS heater 2	HT20B				2300	2	2000x2500x1800	55	1	3	69	460									
HPS heater 3	HT20C				2300	2	2000x2500x1800	55	1	3	69	460									
HPS heater 4	HT20D				2300	2	2000x2500x1800	55	1	3	69	460									
HPS chiller	VP1				1500	2	2000x2500x1800	30	1	3	38	460									
HPS cooling fan 1	FA3				90	1	500x500x1000	3	1	3	4	460									
HPS cooling fan 2	FA4				90	1	500x500x1000	3	1	3	4	460									
Motorised valves	DB1				850	2	3000x600x2200	45	1	3	56	460									
DSRS Compressor 1	CP2A				1200	1	1200x2000x1000	55	1	3	82	460									
DSRS Compressor 2	CP2B				1200	1	1200x2000x1000	55	1	3	82	460									
Overhead crane 1	VP2				-	-	-	38	1	3	48	460									
Overhead crane 2	VP2				-	-	-	55	1	3	69	460									
Overhead crane 3	VP3						-	tba				460									
Overhead crane 4	VP4						-	tba				460									
Overhead crane 5	VP5						-	tba				460									
Overhead crane 6	VP6						-	tba				460									
Overhead crane 7	VP7						-	tba				460									
Lighting and small power DB 1	LSP1				150	1	1200x300x600	22	1	3	28	460									
Lighting and small power DB 2	LSP2				150	1	1200x300x600	22	1	3	28	460									
Lighting and small power DB 3	LSP3				150	1	1200x300x600	55	1	3	69	460									
Lighting and small power DB 4	LSP4				150	1	1200x300x600	55	1	3	69	460							</		

NGNP-CTF Internal Interface Requirements Table: Configuration 1: "Primary and Ultra High Temperature Test Loop"

Identification		Physical						Electrical					Instrumentation		Thermo hydraulic						
Equipment name and short description	Equipment number	Interface number	Nozzle number	Nozzle nominal size	Mass	Elevation from finished floor level	Sizes L=Length Diam = Outer Diameter W=Width H=Height t =Thickness	Power usage kW	Duty(%) (Demand/ capability)	No of phases	Amps	Volts	Instrument type	Instrument Number	Flow	Temperature in (Primary Loop):	Temperature out (Primary Loop):	Temperature in (Secondary Loop):	Temperature out (Secondary Loop):	Fluid type	Notes
				mm	kg	m	mm	kW			A	V	P, T, dP, F		kg/s	°C	°C	°C	°C		
Blower B2A Variable speed drive	VSD2A				6500	2	6000x1000x2200	1200kVA	1	3	105	6600									
Blower B2B Variable speed drive	VSD2B				6500	2	6000x1000x2200	1200kVA	1	3	105	6600									
Blower B4 Variable speed drive	VSD4				6500	2	6000x1000x2200	1200kVA	1	3	105	6600									
Blower B3 Variable speed drive	VSD3				40000	2	10000x1600x2200	18000kVA	1	3	980	6600									
Heater H1																					
Bank 1 control panel	HTCP1				30000	2	7000x1600x2200	6.8MVA	1	3	3300	6600									
Bank 2 control panel	HTCP2				30000	2	7000x1600x2200	6.8MVA	1	3	3300	6600									
Bank 3 control panel	HTCP3				30000	2	7000x1600x2200	6.8MVA	1	3	3300	6600									
Bank 4 control panel	HTCP4				30000	2	7000x1600x2200	6.8MVA	1	3	3300	6600									
Bank 5 control panel	HTCP5				30000	2	7000x1600x2200	6.8MVA	1	3	3300	6600									
Heater H2																					
Bank 1 control panel	HTCP6				30000	2	7000x1600x2200	6.8MVA	1	3	3300	1200									
Blower B5A Variable speed drive	VSD5A				4200	2	4000x1000x2200	400kVA	1	3	105	6600									
Blower B5B Variable speed drive	VSD5B				4200	2	4000x1000x2200	400kVA	1	3	105	6600									
Cooling water pump 1	P1				2500	1500	1200x2500x1500	132	1	3	198	460									
Cooling water pump 2	P2				2500	1500	1200x2500x1500	132	1	3	198	460									
Air compressor 1	CA1				2000	2000	2000x1500x2000	50		3											
Air compressor 2	CA2				2000	2000	2000x1500x2000	50		3											
Air dryer 1	AD1				4000	3000	2000x1500x3000	15		3											
Air dryer 2	AD2				4000	3000	2000x1500x3000	15		3											

* Electrical Power Consumption is based upon the Thermal Effectiveness of the Recuperators. These Electrical values are based on an Recuperator effectiveness of 83%

Appendix C: Safety Base

C1INTRODUCTION:

Nuclear power plants the safety analysis is based on the classification of initiating events associated with different plant conditions (PC1 to 5). Plant conditions are defined in different categories bases on the probability of occurrence of the initiating events. These categories can also related to plant states e.g. Norman operation, Upset conditions, Emergency and Faulted condition.

Normally the acceptance criteria for the different PC are well defined e.g. the allowable dose to workers and public (risk), allowable stresses as defined in the ASME III code, temperatures of concrete structure etc.

C2CTF PLANT CONDITIONS RECOMMENDATION:

It is recommended that the following plant conditions, for the non-nuclear CTF, be used:

- o **Normal Operational** condition (N). (= Frequent)
This include normal operational transients and maintenance scenarios
- o **Upset condition** (U) (=Often)
- o **Emergency** (E) (= Remote and Unlikely)

C3GENERAL CRITERIA (RULES) APPLIED AS BASIS FOR THE SAFETY ASSESSMENT:

- o **Passive product** designed for the postulated “events-loadings” e.g. thermal, pressure, seismic, mechanical etc. and which are build to the acceptable prescribed codes, do not fail during and following the event.
- o Active systems can fail at any time i.e. as initiating event or as a result of an event. Redundancy should be provided where safety functions are needed.
- o The single failure criteria are not applicable to the CTF.
- o Human /operators errors are possible. It is however assumed that the CTF protection system prevents accidents or mitigates the effect.
- o Co-incidents simultaneous with initiating events are possible

Appendix D: Risk/Hazard Identification Worksheet

PLANT ITEM/SYSTEM DESCRIPTION	Concept 2 CTF (=L-CTF)					
AREA NO.	New building					
FLOWSHEET/DRAWING NO.	Refer PFD/s and layout proposal					
POSSIBLE? TICK YES COMPLETE WORKSHEET	NO	YES	W/S NO:	NO	YES	W/S NO:
EXTERNAL FIRE		X				
INTERNAL FIRE (In equipment)		X				
PHYSICAL BURST		X small pipes only				
INTERNAL EXPLOSION (In equipment)		X e.g. blower impellor)				
CONFINED EXPLOSION (In building/structure)	?					
UNCONFINED EXPLOSION (Outside in open)	?					
INTEGRITY LOSS		X Full inventory of helium				
ACUTE HARMFUL/ NOXIOUS EXPOSURE	X					
ACUTE HARMFUL/ PHYSICAL EXPOSURE	X					
CHRONIC HARMFUL/ NOXIOUS EXPOSURE	X					
SPILLS		X Waist from purification system				
POLLUTION	X					

PLANT ITEM/SYSTEM DESCRIPTION	Concept 2 CTF (=L-CTF)					
AREA NO.	New building					
FLOWSHEET/DRAWING NO.	Refer PFD/s and layout proposal					
POSSIBLE? TICK YES COMPLETE WORKSHEET	NO	YES	W/S NO:	NO	YES	W/S NO:
NOISE		X Running machines				
VIOLENT RELEASE OF ENERGY		X Only with Beyond design basis accidents (BDBE's)				
MOMENTUM CHANGE	X					
VISUAL IMPACT	X					
UNAVAILABILITY	X no safety issue					
SECURITY BREACH		X High energy system				
FINANCIAL PROBLEM	?					

Appendix E: Risk/Hazard Assessment Worksheet

Frequency of event: N= normal operational condition events
 U= upset condition events
 E= Emergency condition events

Consequence Severity : Cat = catastrophic
 Crit = Critical
 Marg = Marginal
 Neg = Negligible

SYSTEM: Concept 2 Large component test facility (L-CTF)				CONTRACT: NGNP-CTF			
Flow Sheet/Drawing nr: PFD's . layout, thermo-hydraulic design Worksheet nr. Area: New building				Worksheet nr: Review Team Members:			

Ref Nr	Hazardous Event	Causes	Frequency of event	Consequences	Severity of event	Mitigative Measures	Risk Level	Comments

1 Normal operational condition:

1.1	Plant trip	Electronic part failure	N	Plant may shut down	Neg	System protection will take over		
1.2	Single measurement wrong reading	Sensor failure	N	Warning signal	NEG	Replace		
1.3	Small leak from high energy pipe	Leaking seal	N	Skin burning, damaging of instruments etc	Neg	Repare		

Ref Nr	Hazardous Event	Causes	Frequenc y of event	Consequences	Severity of event	Mitigative Measures	Risk Level	Comments

1 Normal operational condition:

2 Upset condition:

2.1	Instrument pipe failure	Fatigue or bad fitting	U	Loose inventory	Neg	Close isolation valve		
2.2	Total measure function failure	Common failure of redundant instruments	U	Control system react wrong	Neg	Protection system will recover situation		
2.3	Grid separation	Incoming power cut, transformer failure etc.	U	Large power consumer equipment stop functioning	Marg	UPS provide power for control room and emergency diesel-generator starts		
2.4	Control system failure, emergency shutdown system respond	Internal fire or short-circuit in con PLC cabinet	U	Completely lost of normal control		Emergency shut-down control system takes over		
2.5	Large flange seal failure	Lack of correct tightening of bolts, erosion by small leak stream etc.	U	Workers burn, instrument damage, other plant or experimental equipment damage,	Marg	Provide early warning system (acoustic, helium detection, inspection)		
2.6	Fire in control room	Short circuiting	U	Loose of normal control, damaging of equipment and or	Crit	Correct fire protection system or equipment		

Ref Nr	Hazardous Event	Causes	Frequency of event	Consequences	Severity of event	Mitigative Measures	Risk Level	Comments

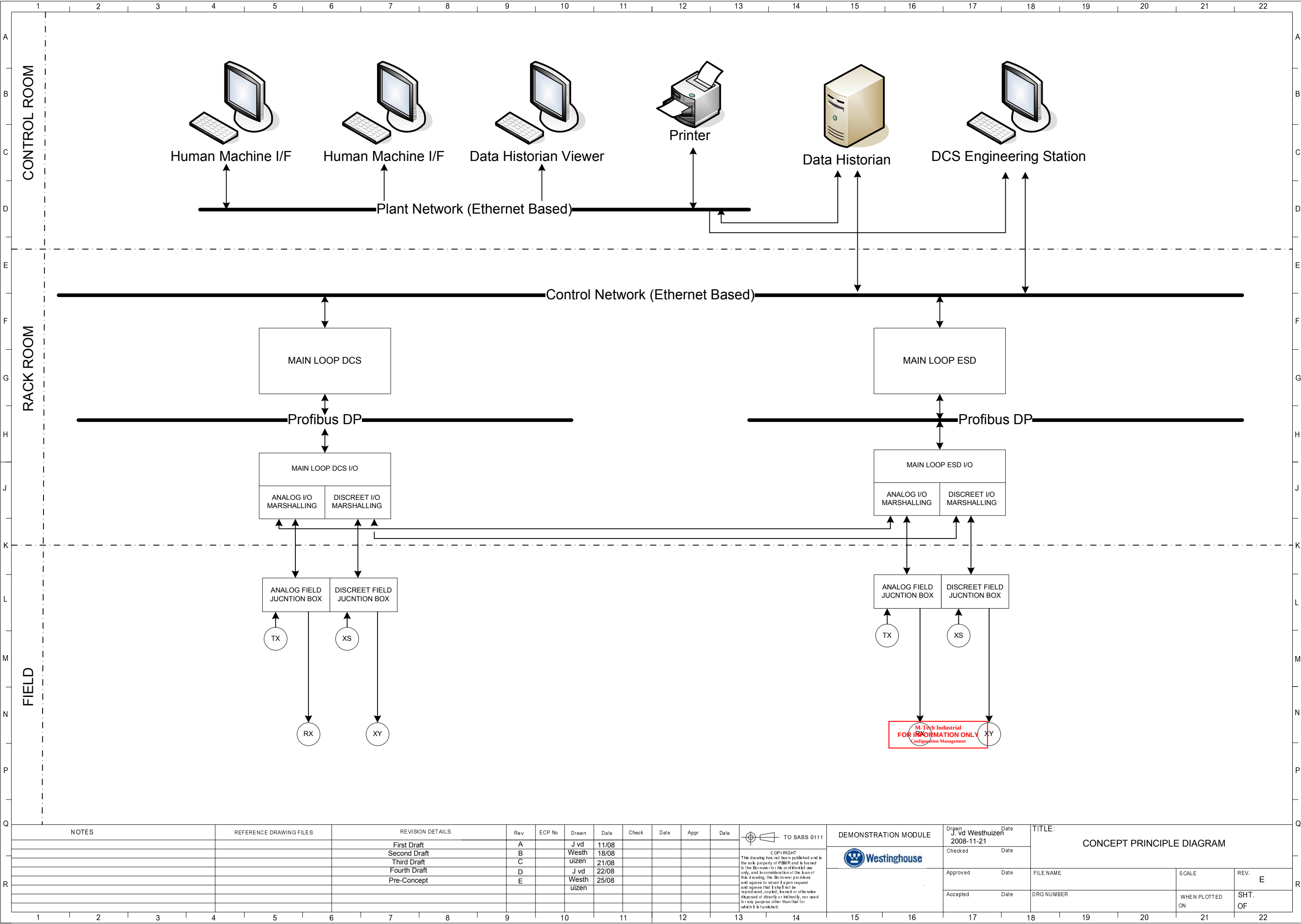
1 Normal operational condition:

				plant				

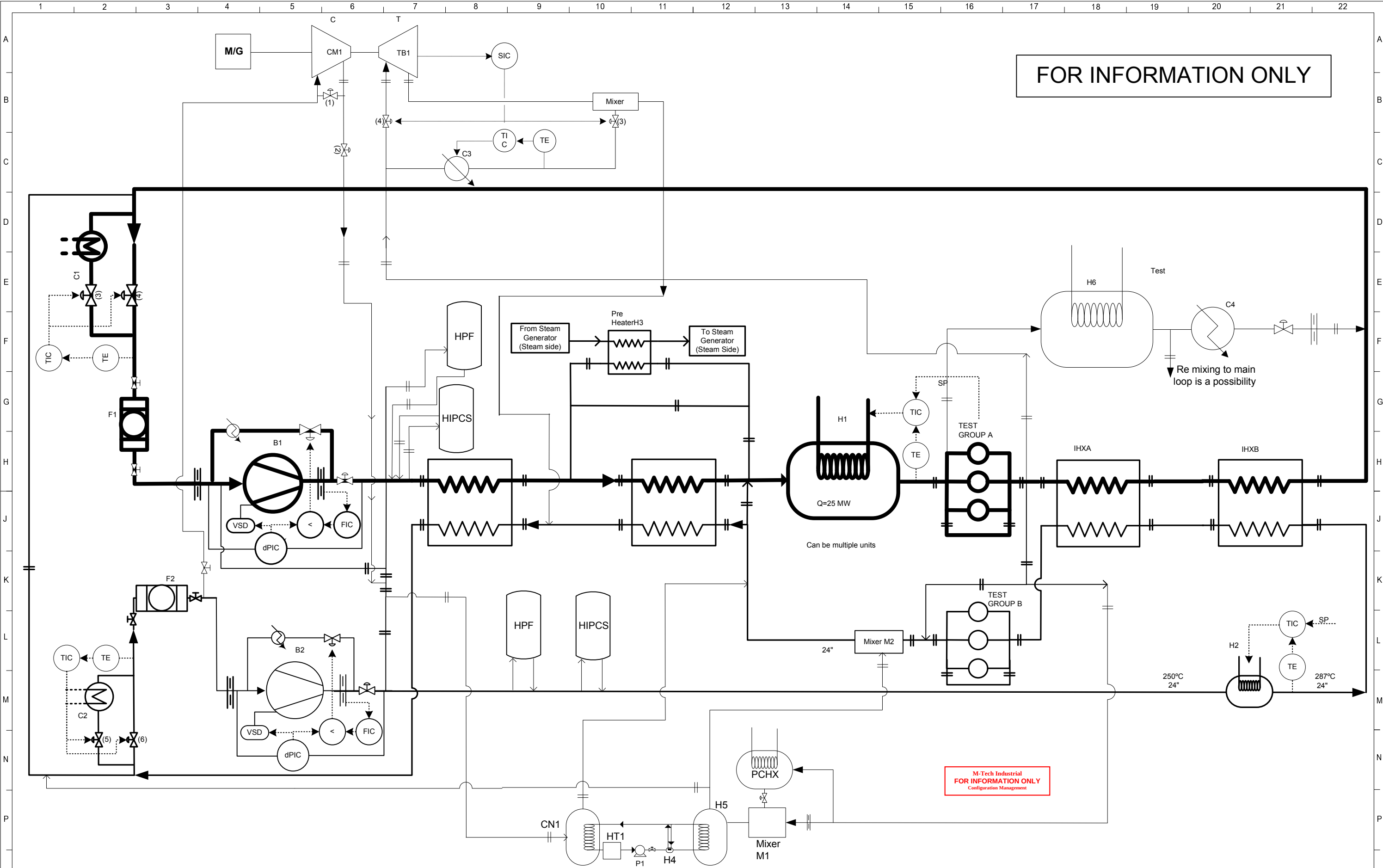
3 Emergency condition:

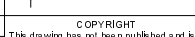
3.1	Medium size pipe break (, 6" dia)	Fatigue or wrong design	E	Large damage to plant, serious injuries	Cat	Large ventilation/gas escape rout		
3.2	Complete blackout, emergency backup also fails	Grid isolation together will diesel-gen refuse to start	E	Plant stop functioning	Crit	Control system and conditioning system on UPS power will shut down plant safely.		
3.3	Larger than postulated earthquake	Natural phenomena	E	High energy components can fail	Cat	Emergency plan		
3.4	Sabotage	Panic objective	E	Undefined	Can be Cat	Emergency plan		
3.5	Impellor failure	Fatigue	E	Blower casing damage	Cat	Isolation where possible		
3.6	Drop of heavy mass on high energy systems	Crane/hoisting failure or wrong operation	E	Damaging of high energy components	Cat	Isolation, switch off, emergency plan		

Appendix F: P&ID's

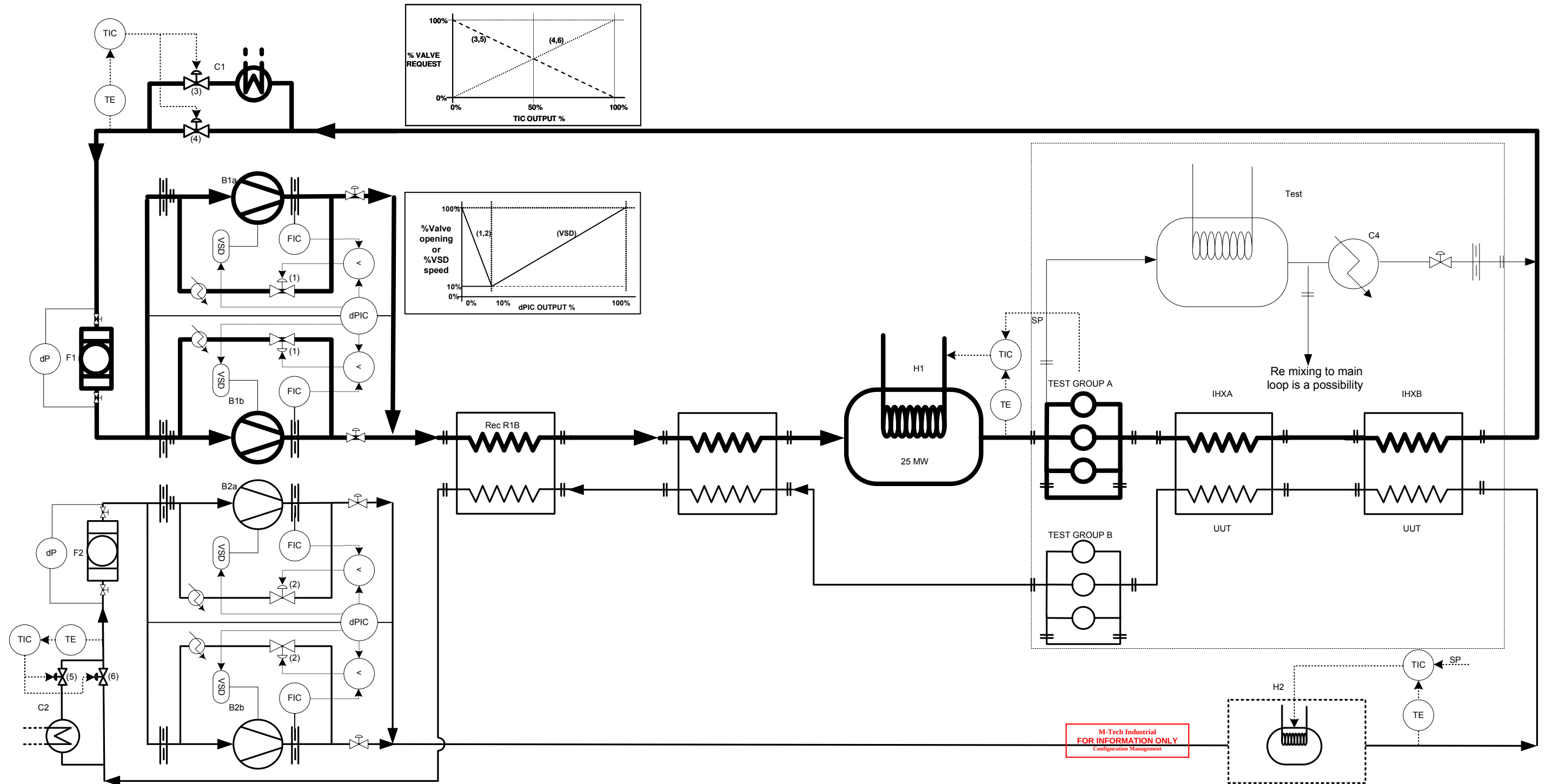


NOTES		REFERENCE DRAWING FILES		REVISION DETAILS		Rev	ECP No	Drawn	Date	Check	Date	Appr	Date	 TO SABS 0111	DEMONSTRATION MODULE		Drwn	Date	TITLE:			
				First Draft	A			J vd	11/08					 COPYRIGHT This drawing has not been published and is the sole property of P&M R and is loaned to the Borrower for his confidential use only, and in consideration of the loan of this drawing, the Borrower promises and agrees to return it upon request and agrees that it shall not be reproduced, copied, loaned or otherwise disposed of directly or indirectly, nor used for any purpose other than that for which it is furnished.		J. vd Westhuizen	2008-11-21	CONCEPT PRINCIPLE DIAGRAM				
				Second Draft	B			Westh	18/08						Checked	Date						
				Third Draft	C			uizen	21/08							Date	FILE NAME	SCALE	REV.			
				Fourth Draft	D			J vd	22/08							Approved	Date			E		
				Pre-Concept	E			Westh	25/08							Accepted	Date	DRG NUMBER	WHEN PLOTTED ON	SHT. OF		



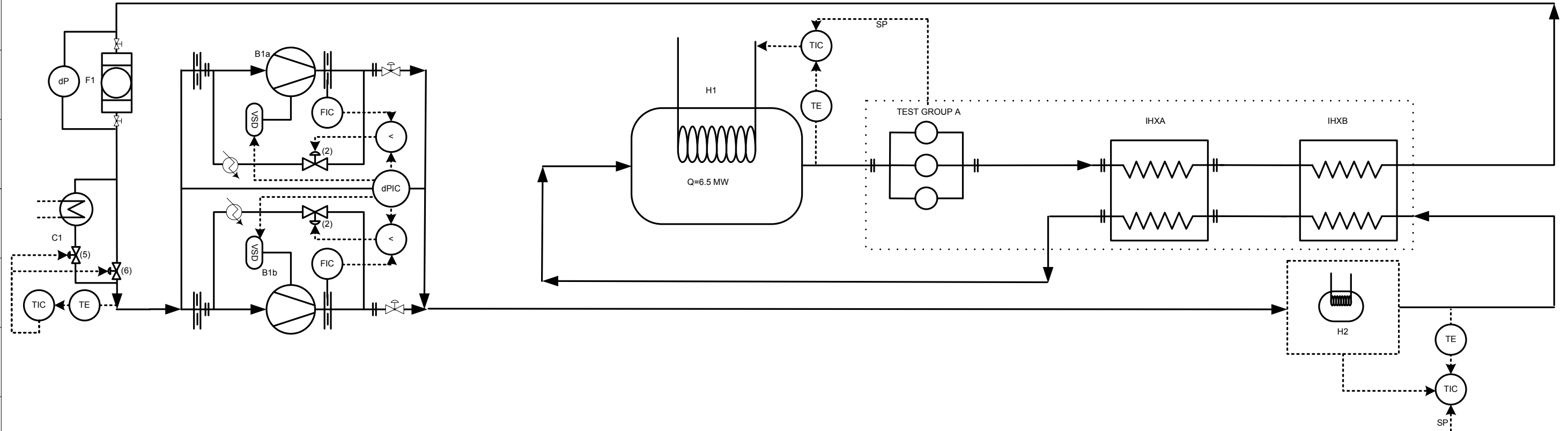
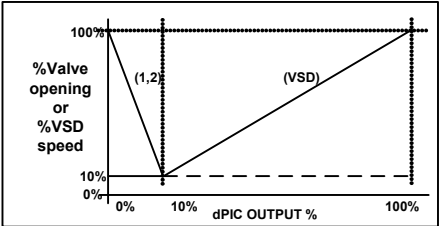
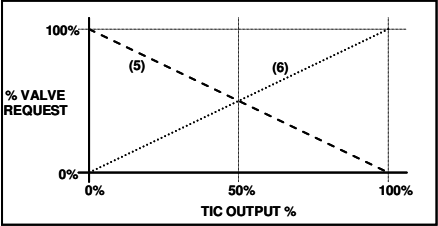
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					First Draft				A		J vd	11/08								J. vd Westhuizen		2008-11-21								
					Second Draft				B		Westh	18/08						Checked		Date										
					Third Draft				C		uizen	21/08							Approved	Date		FILE NAME	SCALE	REV.						
					Fourth Draft				D		J vd	22/08							Accepted	Date		DRG NUMBER	WHEN PLOTTED ON	SHT. OF						
					Pre-Concept				E		Westh	25/08											TLDR-CQL2-SS-03-0000		E					
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				First Draft	A		J vd	11/08									Checked C Dent	Date 17/11/2008	FILE NAME		SCALE	REV. E
				Second Draft	B		Westh	18/08								Approved N Scholtz	Date 17/11/2008	DRG NUMBER		WHEN PLOTTED ON	SHT. 1	
				Third Draft	C		uizen	21/08								Accepted M Fox	Date 17/11/2008	TLDR-CQL2-SS-03-0001			OF 1	
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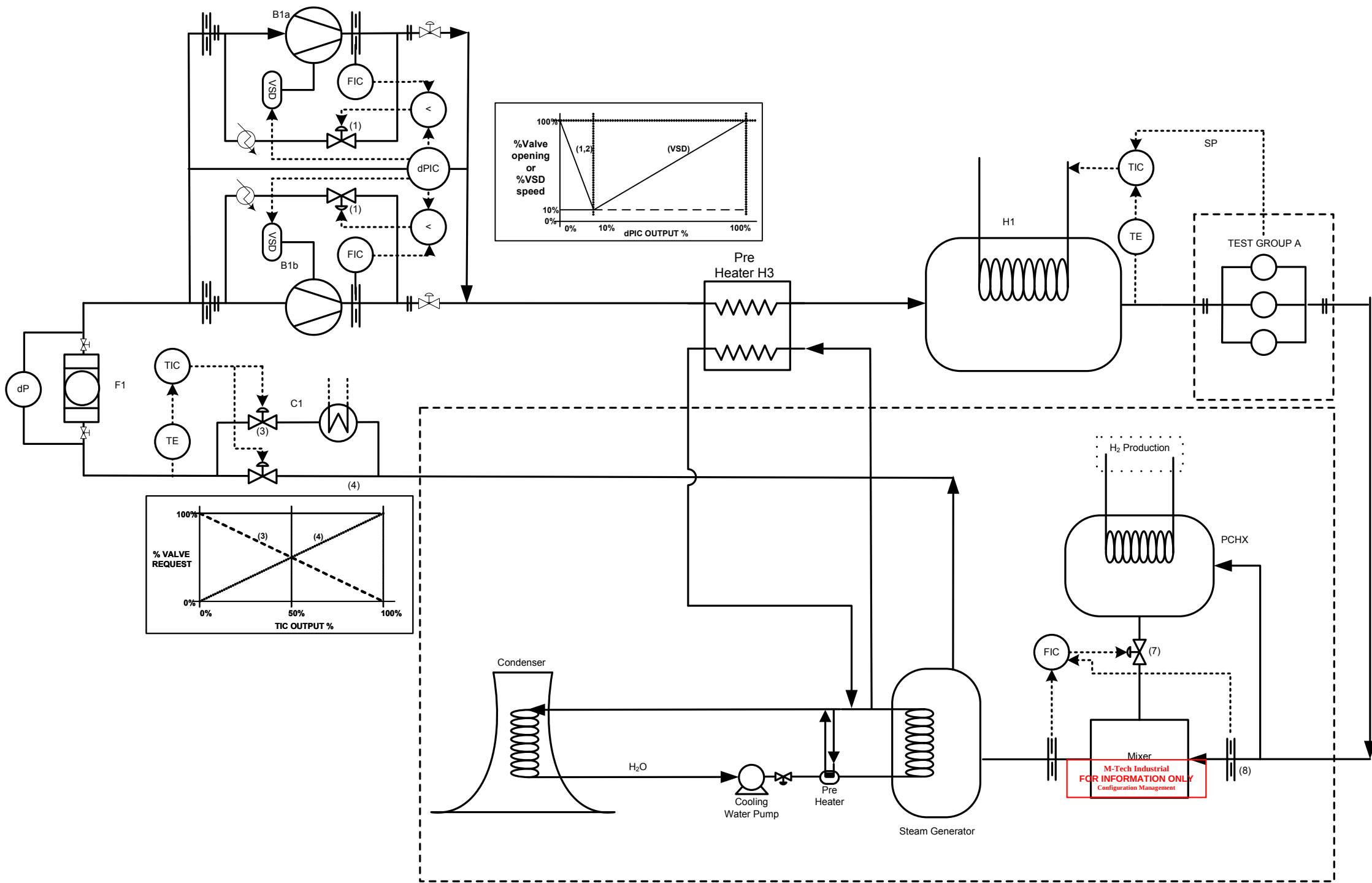
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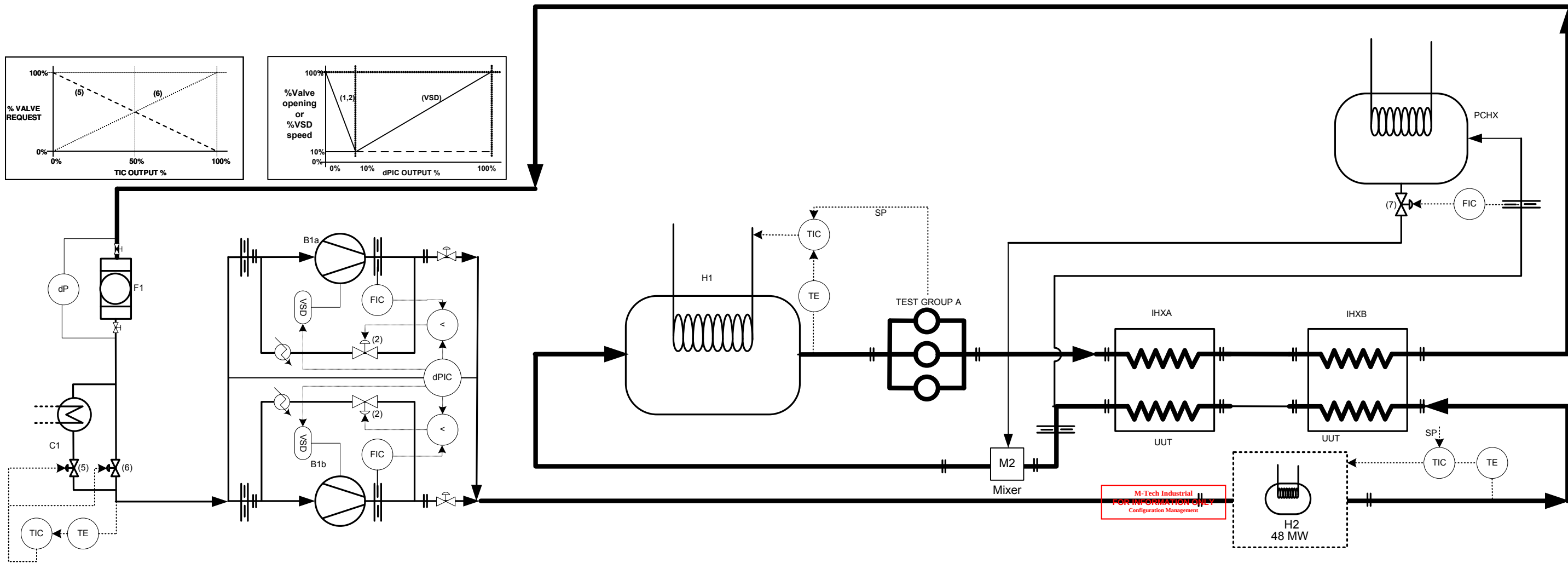
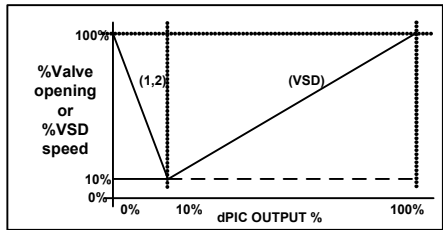
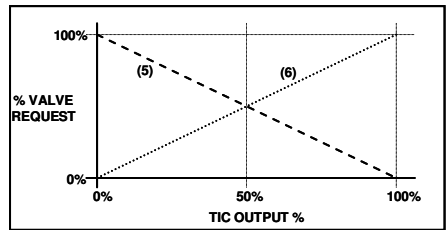
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		First Draft	A		L. Smith	11/08					COPYRIGHT  This drawing has not been published and is the sole property of PWR and is loaned to the Borrower for his confidential use only, and in consideration of the loan of this drawing, the Borrower promises and agrees to return it upon request and agrees that it shall not be reproduced, copied, loaned or otherwise disposed of directly or indirectly, nor used for any purpose other than that for which it is furnished.	Checked	Date				
		Second Draft	B		Westh	18/08						Approved	Date	FILE NAME	SCALE	REV. E	
		Third Draft	C		uizen	21/08											
		Fourth Draft	D		J vd	22/08											
		Pre-Concept	E		Westh uizen	25/08											
												Accepted	Date	DRG NUMBER TLDR-CQL2-SS-03-0002	WHEN PLOTTED ON	SHT. OF	

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NOTES	REFERENCE DRAWING FILES	REVISION DETAILS	Rev	ECP No	Drawn	Date	Check	Date	Appr	Date	 TO SABS 0111	DEMONSTRATION MODULE	Drawn	Date	TITLE: PIPING AND INSTRUMENTATION DIAGRAM (P&ID) NEW GENERATION NUCLEAR PLANT (NGNP) C3-MAINLOOP-PROCESS HEAT COMPONENT (STEAM GENERATOR)				
		First Draft	A		L. Swart	11/08							2008-11-21						
		Second Draft	B		Westhuizen	18/08							Checked						
		Third Draft	C		uizen	21/08							Approved				FILE NAME	SCALE	REV. E
		Fourth Draft	D		J vd	22/08							Accepted				DRG NUMBER	WHEN PLOTTED	SHT. OF
		Pre-Concept	E		Westhuizen	25/08									TLDR-CQL2-SS-03-0003	ON	OF		

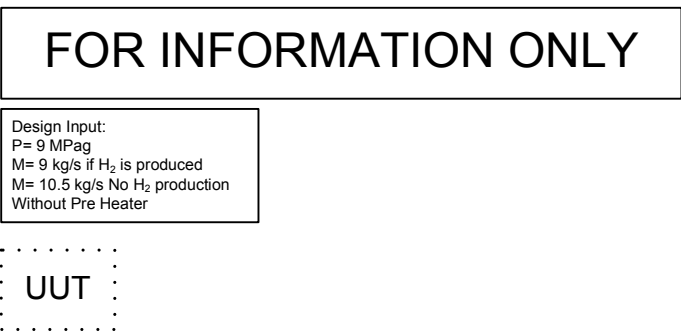
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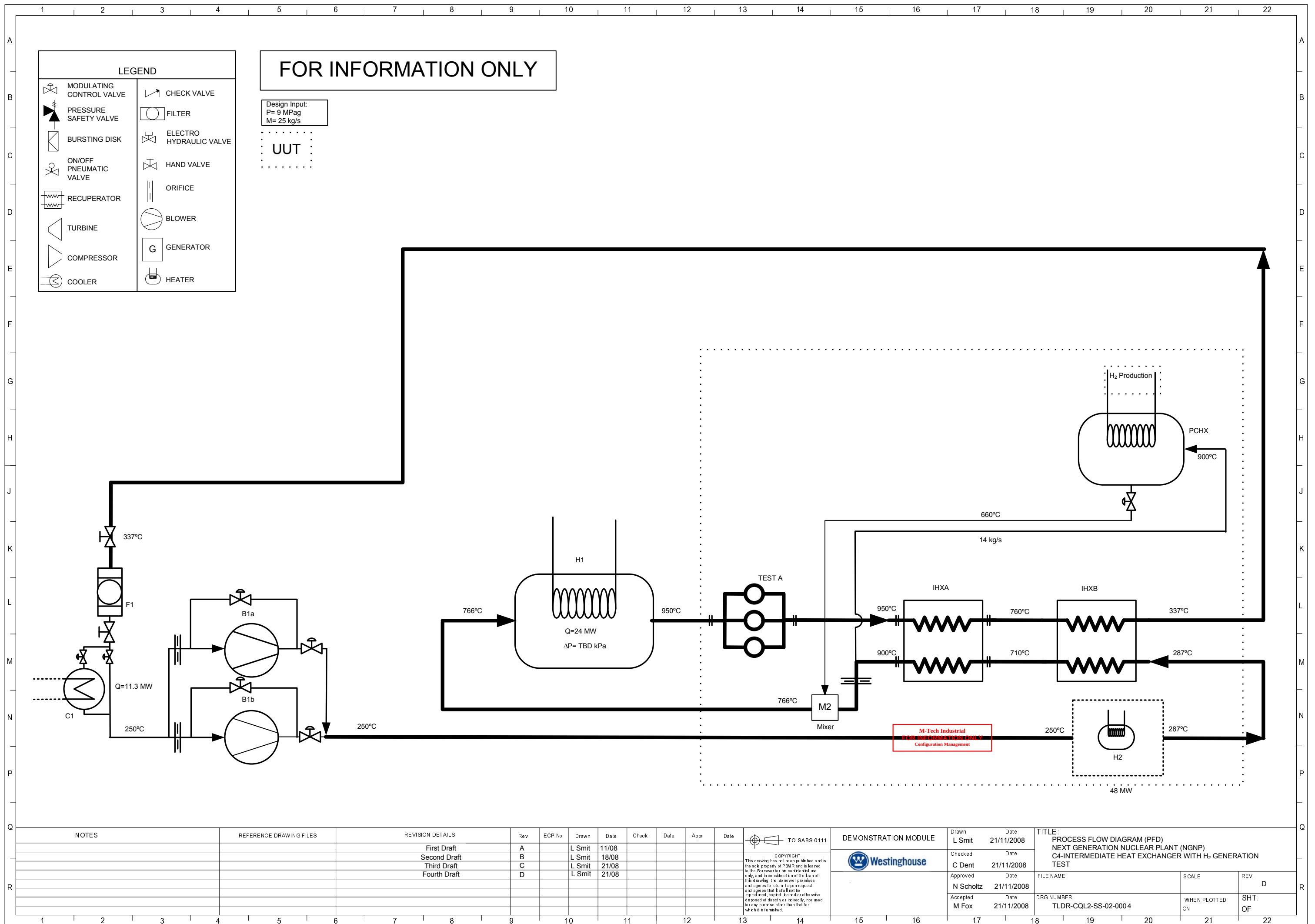
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				Rev	ECP No	Drawn	Date	Check	Date	Appr	Date				Checked	Date				
						First Draft	11/08													
						Second Draft	18/08													
						Third Draft	21/08													
						Fourth Draft	22/08													
						Pre-Concept	25/08													

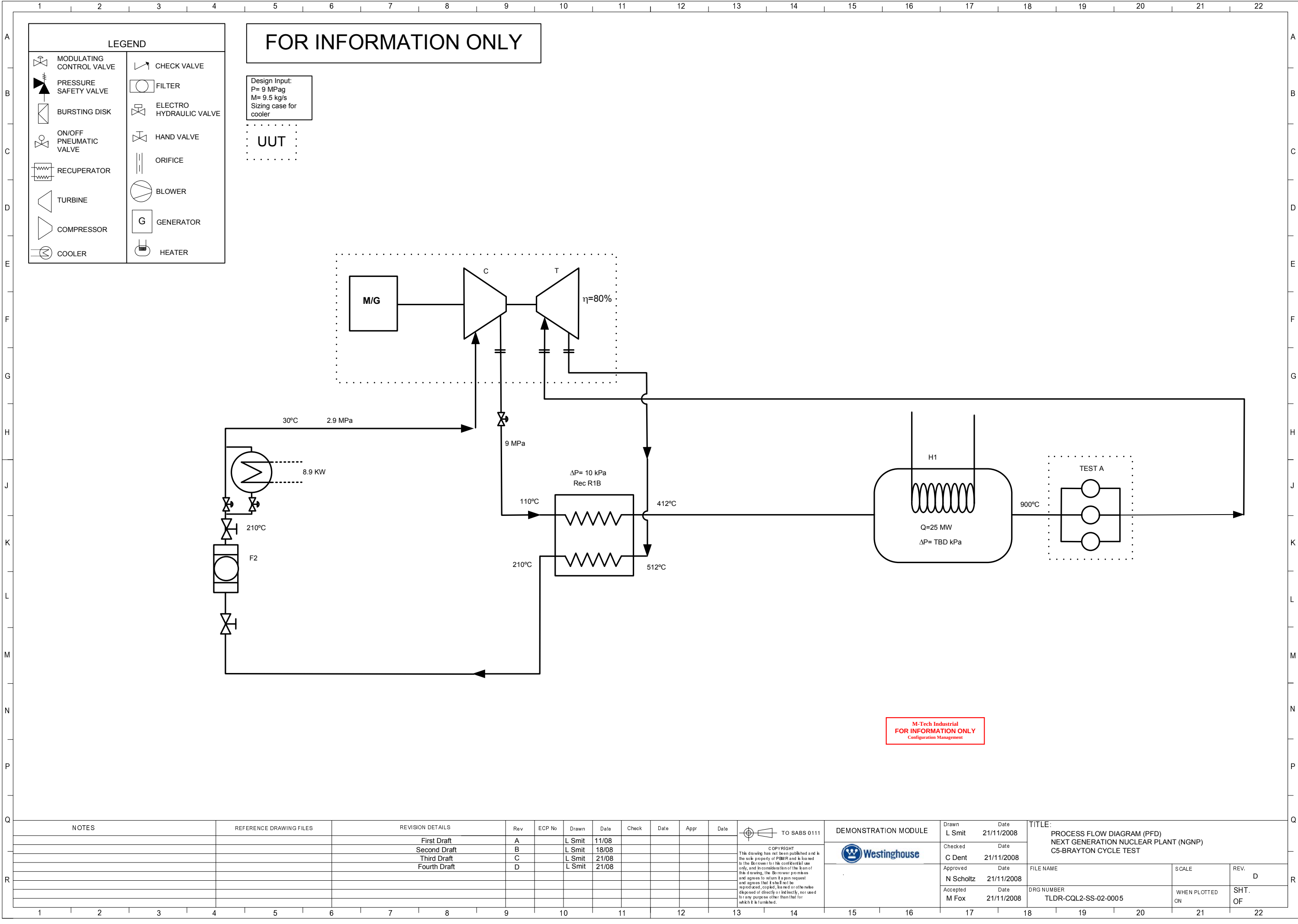
Appendix G: Process flow Diagrams

NOTES	REFERENCE DRAWING FILES	REVISION DETAILS	Rev	ECp No	Drawn	Date	Check	Date	Appr	Date	 TO SABS 0111	DEMONSTRATION MODULE	Drawn L Smit	Date 21/11/2008	TITLE: PROCESS FLOW DIAGRAM (PFD) NEXT GENERATION NUCLEAR PLANT (NGNP) C2-HIGH EFFICIENCY COMPONENT TEST		
		First Draft	A		L Smit	11/08					 COPYRIGHT This drawing has not been published and is the sole property of PBMR and is loaned to the Borrower for his confidential use only, and is inconsistent for the form of this drawing, the Borrower promises and agrees to return it upon request and agrees that it shall not be reproduced, copied, loaned or otherwise disposed of directly or indirectly, nor used for any purpose other than that for which it is furnished.	 Westinghouse	Checked C Dent	Date 21/11/2008	FILE NAME	SCALE	REV. D
		Second Draft	B		L Smit	18/08				Approved N Scholtz			Date 21/11/2008				
		Third Draft	C		L Smit	21/08				Accepted M Fox			Date 21/11/2008				
		Fourth Draft	D		L Smit	21/08											
															DRG NUMBER TLDR-CQL2-SS-02-000 2	WHEN PLOTTED ON	SHT. OF



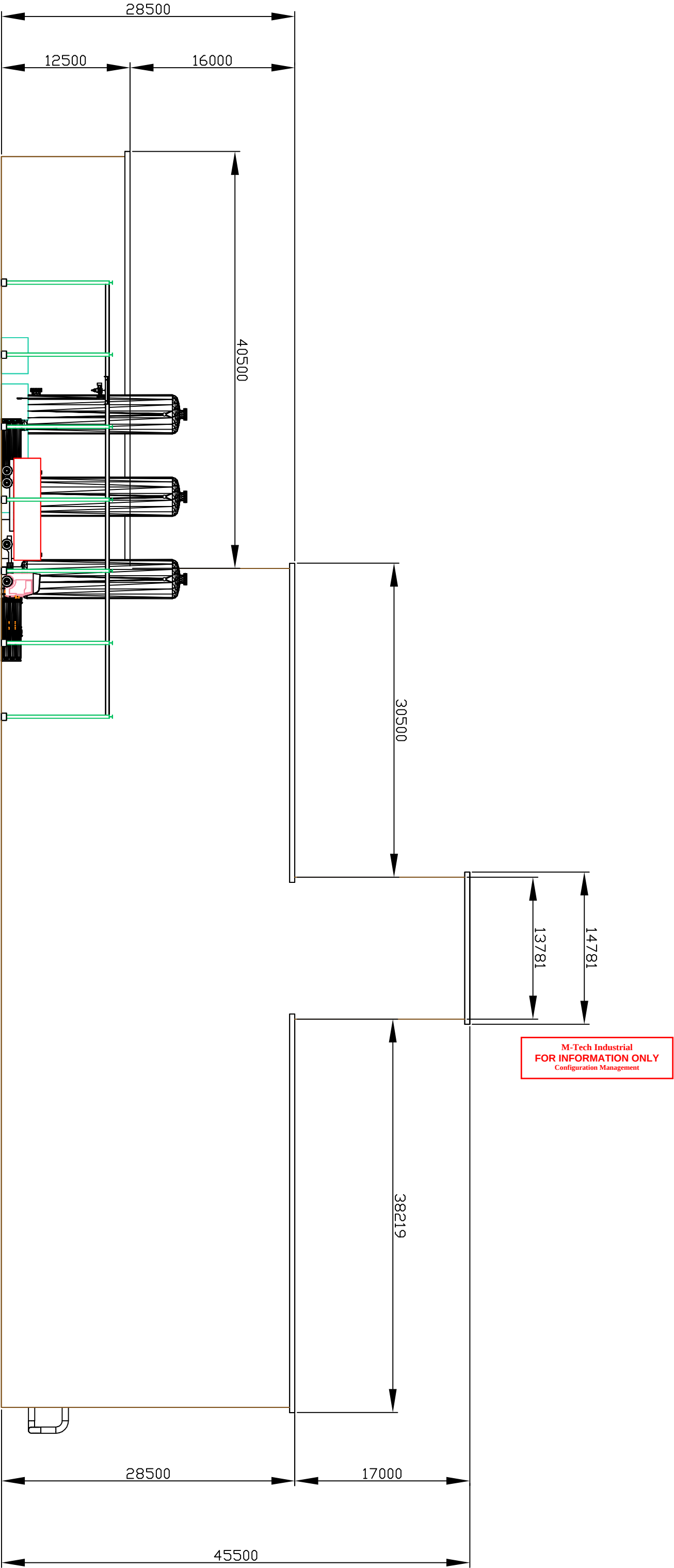
NOTES	REFERENCE DRAWING FILES	REVISION DETAILS	Rev	ECP No	Drawn	Date	Check	Date	Appr	Date	 TO SABS 0111  COPYRIGHT This drawing has not been published and is the sole property of PBMR and is loaned to the Borrower for his confidential use only, and in consideration of the loan of this drawing, the Borrower promises and agrees to return it upon request and agrees that it shall not be reproduced, copied, loaned or otherwise disposed of directly or indirectly, nor used for any purpose other than that for which it is furnished.	DEMONSTRATION MODULE	Drawn L Smit Date 21/11/2008	TITLE: PROCESS FLOW DIAGRAM (PFD) NEXT GENERATION NUCLEAR PLANT (NGNP) C3-MAINLOOP-PROCESS HEAT COMPONENT TEST (STEAM GENERATOR)		
		First Draft	A		L Smit	11/08						Checked C Dent Date 21/11/2008				
		Second Draft	B		L Smit	18/08						Approved N Scholtz Date 21/11/2008	FILE NAME	SCALE	REV. D	
		Third Draft	C		L Smit	21/08						Accepted M Fox Date 21/11/2008	DRG NUMBER TLDR-CQL2-SS-02-0003	WHEN PLOTTED ON	SHT. OF	
		Fourth Draft	D		L Smit	21/08										





NOTES	REFERENCE DRAWING FILES	REVISION DETAILS	Rev	ECP No	Drawn	Date	Check	Date	Appr	Date	TO SABS 0111	DEMONSTRATION MODULE	Drawn	Date	TITLE:		
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		Second Draft	B	L Smit	18/08					Cent			21/11/2008				
		Third Draft	C	L Smit	21/08					N Scholtz			21/11/2008	FILE NAME		SCALE	REV.
		Fourth Draft	D	L Smit	21/08					M Fox			21/11/2008	DRG NUMBER		WHEN PLOTTED ON	SHT. OF

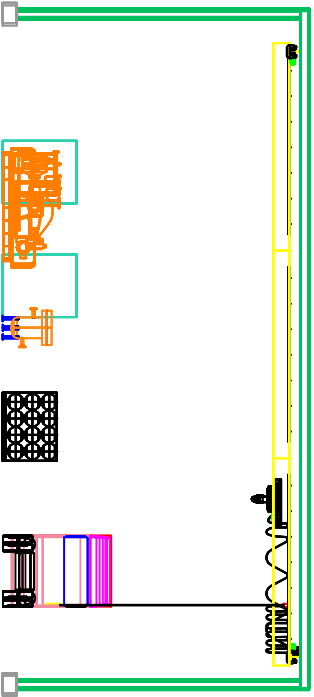
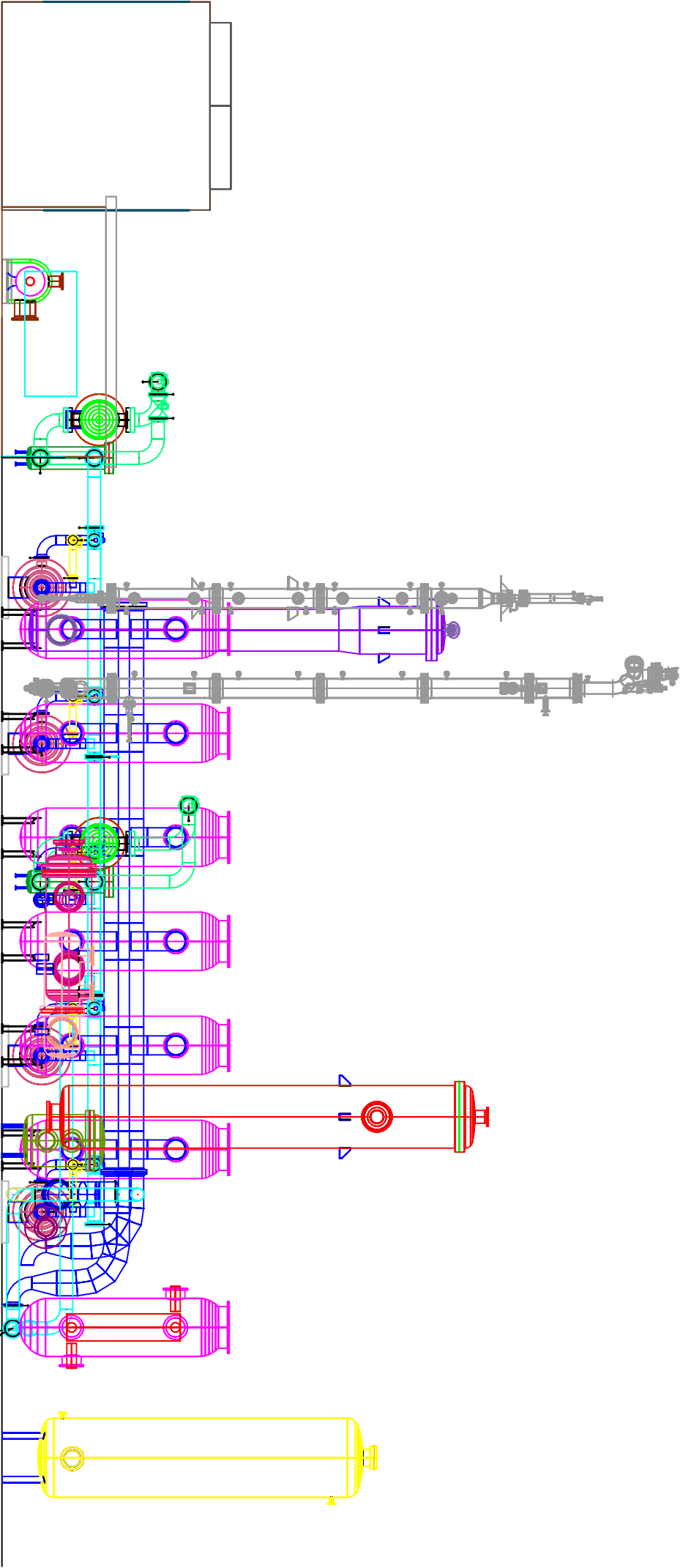
Appendix H: Mechanical layout drawings



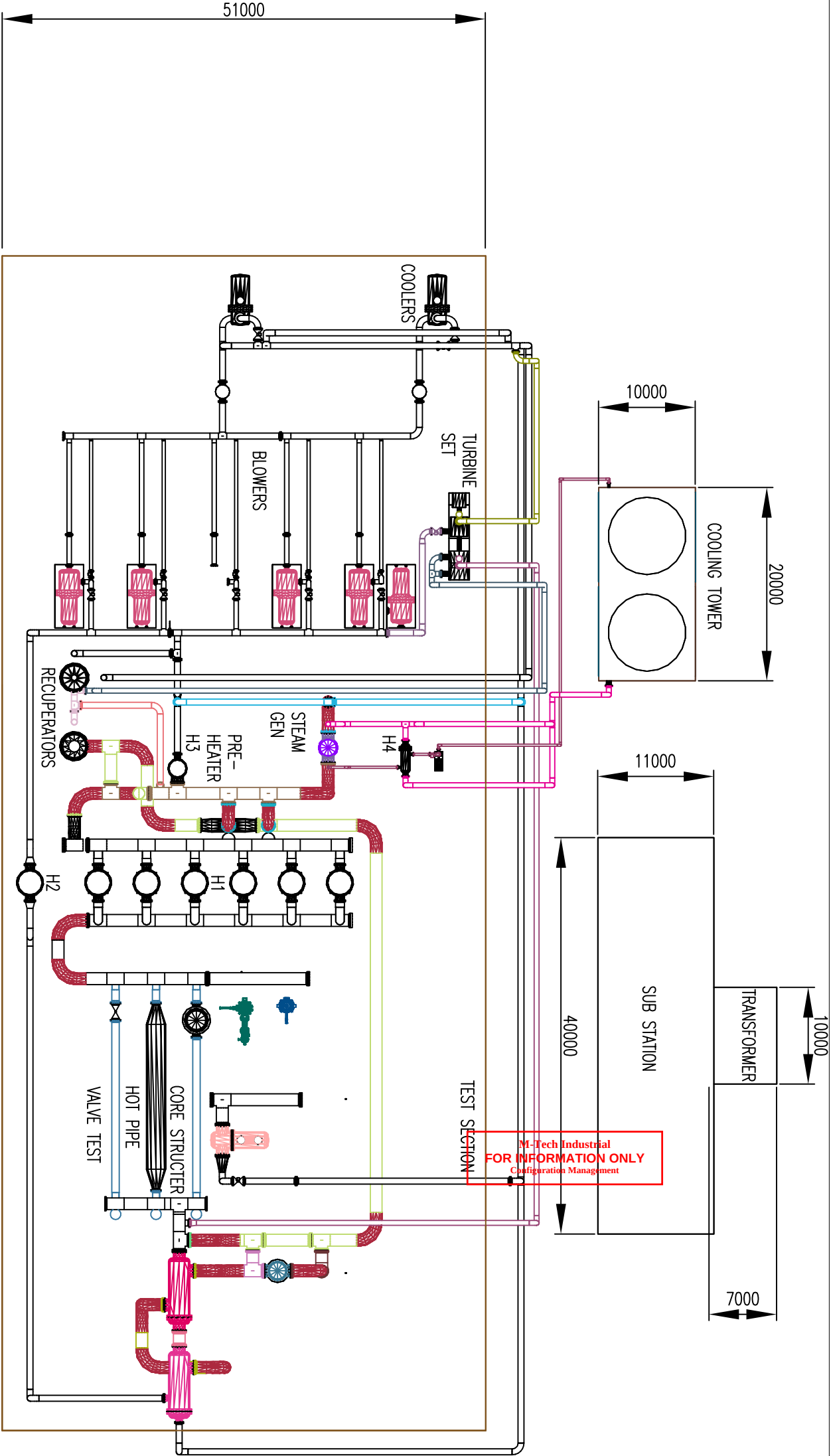
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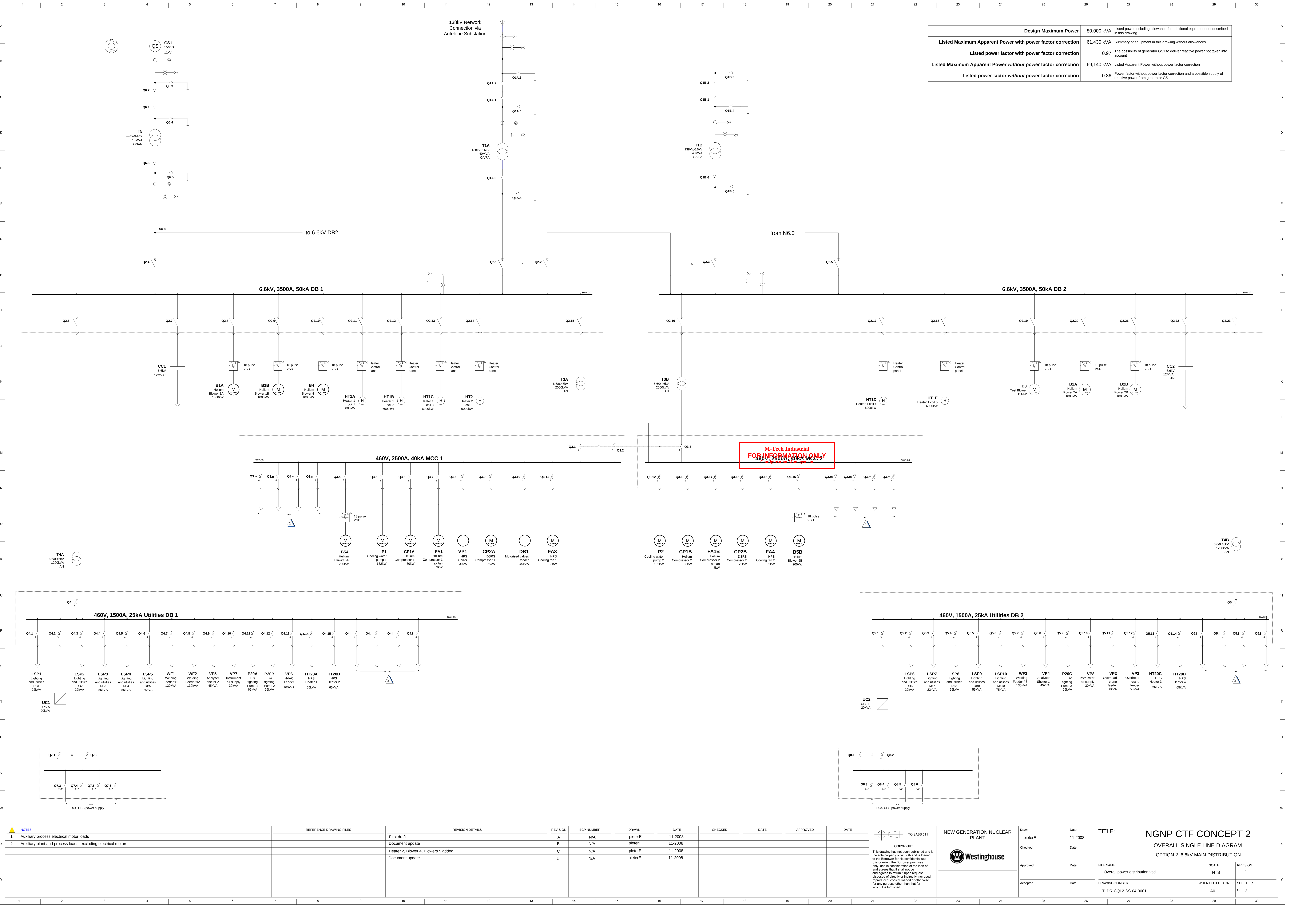


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Appendix I: Electrical drawings

Load	Description	Apparent Power (Maximum) [kVA]	Apparent Power (Nominal design) [kVA]	Reactive Power [kVAr]	Real Power [kW]	Voltage [V]	Nominal Operating Current [A]	Maximum design Current [A]	Power factor
T1	Main power transformer -p	75,000	60,430	11,117	59,399	138,000	253	314	0.982933
T2	Main power transformer -s	75,000	60,430	11,117	59,399	13,800	2,530	3,140	0.982933
	13.8kV DB1	48,000	29,101	4,160	28,802	13,800	1,217	2,000	0.989732
GS1	Turbo machinery Generator	-15,000	-15,000	0	-15,000	13,800	-628	-630	1.00
CC1	Capacitor bank 1	12,000	12,000	-12,000	0	13,800	502	360	0.00
T2A	13.8/6.6kV Transformer 2A -p	40,000	30,785	14,790	27,000	13,800	1,289	1,680	0.88
T2A	13.8/6.6kV Transformer 2A -s	40,000	30,785	14,790	27,000	6,600	2,694	3,500	0.88
	6.6kV DB3	40,000	30,785	14,790	27,000	6,600	2,694	3,500	0.88
B1A	Helium Blower 1A	1,200	1,200	663	1,000	6,600	105	105	0.83
B1B	Helium Blower 1B	1,200	1,200	663	1,000	6,600	105	105	0.83
B4	Helium Blower 4	1,200	1,200	663	1,000	6,600	105	105	0.83
HT1A	Heater 1 heating coil 1	6,800	6,800	3,200	6,000	6,600	595	595	0.88
HT1B	Heater 1 heating coil 2	6,800	6,800	3,200	6,000	6,600	595	595	0.88
HT1C	Heater 1 heating coil 3	6,800	6,800	3,200	6,000	6,600	595	595	0.88
HT2	Heater 2 coil 1	6,800	6,800	3,200	6,000	6,600	595	595	0.88
T3A	13.8/0.46kV Transformer 3A -p	2,000	1,222	811	913	13,800	52	84	0.75
T3A	13.8/0.46kV Transformer 3A -s	2,000	1,222	811	913	460	1,571	2,500	0.75
	460V MCC1	2,000	1,222	811	913	460	1,571	2,500	0.75
P1	Cooling water pump 1	158	158	87	132	460	198	198	0.84
CP1A	Helium compressor 1	38	38	23	30	460	48	48	0.79
FA1A	Helium compressor 1 air fan	4	4	3	3	460	5	5	0.75
B5A	Helium Blower B5A	400	400	346	200	460	502	502	0.50
VP1	HPS chiller	38	38	23	30	460	48	48	0.79
FA3	HPS cooling fan 1	4	4	3	3	460	5	5	0.75
DB1	Motorised valves	45	45	28	35	460	56	56	0.78
	Auxiliary process electrical motor loads	500	500	263	425	460	628	628	0.85
CP2A	DSRS Compressor 1	65	65	35	55	460	82	82	0.85
T3A	13.8/0.46kV Transformer 4A -s	1,200	1,050	558	889	13,800	44	50	0.85
T3A	13.8/0.46kV Transformer 4A -p	1,200	1,050	558	889	460	1,320	1,500	0.85
	460V Utilities DB1	1,200	1,050	558	889	460	1,320	1,500	0.85
UC1	Uninterruptible and conditioned power supply 1	20	20	16	12	460	25	25	0.60
HT20A	HPS heater 1	65	65	35	55	460	82	82	0.85
HT20B	HPS heater 2	65	65	35	55	460	82	82	0.85
LSP1	Lighting and small power DB 1	22	22	13	18	460	28	28	0.82
LSP2	Lighting and small power DB 2	22	22	13	18	460	28	28	0.82
LSP3	Lighting and small power DB 3	55	55	27	48	460	69	69	0.87
LSP4	Lighting and small power DB 4	55	55	27	48	460	69	69	0.87
LSP5	Lighting and small power DB 5	75	75	37	65	460	94	94	0.87
WF1	Welding feeder 1	130	0	0	0	460	0	0	1.00
WF2	Welding feeder 2	130	0	0	0	460	0	0	1.00
VP4	Analyser shelter	45	45	28	35	460	56	56	0.78
VP6	HVAC	160	160	77	140	460	201	201	0.88
P20A	Fire fighting pump 1	65	65	35	55	460	82	82	0.85
P20B	Fire fighting pump 2	65	65	35	55	460	82	82	0.85
	Auxiliary plant and process electrical loads, excluding	300	300	158	255	460	377	377	0.85
VP7	Instrument air supply 1	38	38	23	30	460	48	48	0.79
	13.8kV DB2	48,000	31,378	6,957	30,597	13,800	1,313	2,000	0.975108
GS1	Turbo machinery Generator	-15,000	-15,000	0	-15,000	13,800	-628	-630	1.00
CC2	Capacitor bank 2	12,000	12,000	-12,000	0	13,800	502	418	0.00
T2B	13.8/6.6kV Transformer 2B -p	40,000	33,963	17,677	29,000	13,800	1,422	1,680	0.85
T2B	13.8/6.6kV Transformer 2B -s	40,000	33,963	17,677	29,000	6,600	2,974	3,500	0.85
	6.6kV DB4	40,000	33,963	17,677	29,000	6,600	2,974	3,500	0.85
B2A	Helium Blower 2A	1,200	1,200	663	1,000	6,600	105	105	0.83
B2B	Helium Blower 2B	1,200	1,200	663	1,000	6,600	105	105	0.83
HT1D	Heater 1 heating coil 4	6,800	6,800	3,200	6,000	6,600	595	595	0.88
HT1E	Heater 1 heating coil 5	6,800	6,800	3,200	6,000	6,600	595	595	0.88
B3	Test Blower	18,000	18,000	9,950	15,000	6,600	1,575	1,575	0.83
T3B	13.8/0.46kV Transformer 3B -p	2,000	1,139	760	848	13,800	49	84	0.74
T3B	13.8/0.46kV Transformer 3B -s	2,000	1,139	760	848	460	1,467	2,500	0.74
	460V MCC2	2,000	1,139	760	848	460	1,467	2,500	0.74
P2	Cooling water pump 2	158	158	87	132	460	198	198	0.84
CP1B	Helium compressor 2	38	38	23	30	460	48	48	0.79
FA1B	Helium compressor 2 air fan	4	4	3	3	460	5	5	0.75
B5B	Helium Blower B5B	400	400	346	200	460	502	502	0.50
FA4	HPS cooling fan 2	4	4	3	3	460	5	5	0.75
	Auxiliary process electrical motor loads	500	500	263	425	460	628	628	0.85
CP2B	DSRS Compressor 2	65	65	35	55	460	82	82	0.85
T3B	13.8/0.46kV Transformer 4B -p	1,200	912	521	749	13,800	40	40	0.82
T3B	13.8/0.46kV Transformer 4B -s	1,200	912	521	749	460	1,155	1,500	0.82
	460V Utilities DB2	1,200	912	521	749	460	1,155	1,500	0.82
VP2	Overhead crane 1	38	38	23	30	460	48	48	0.79
VP3	Overhead crane 2	55	55	32	45	460	69	69	0.82
UC2	Uninterruptible and conditioned power supply 2	20	20	16	12	460	25	25	0.60
HT20C	HPS heater 3	65	65	35	55	460	82	82	0.85
HT20D	HPS heater 4	65	65	35	55	460	82	82	0.85
LSP6	Lighting and small power DB 6	22	22	13	18	460	28	28	0.82
LSP7	Lighting and small power DB 7	22	22	13	18	460	28	28	0.82
LSP8	Lighting and small power DB 8	55	55	27	48	460	69	69	0.87
LSP9	Lighting and small power DB 9	55	55	27	48	460	69	69	0.87
LSP10	Lighting and small power DB 10	75	75	37	65	460	94	94	0.87
WF3	Welding feeder 3	130	0	0	0	460	0	0	1.00
VP5	Analyser shelter	45	45	28	35	460	56	56	0.78
P20C	Fire fighting pump 3	65	65	35	55	460	82	82	0.54
	Auxiliary plant and process electrical loads, excluding	300	300	158	255	460	377	377	0.85
VP8	Instrument air supply 2	38	38	23	30	460	48	48	0.79

Load	Description	Apparent Power (Maximum) [kVA]	Apparent Power (Nominal design) [kVA]	Reactive Power [kVAr]	Real Power [kW]	Voltage [V]	Nominal Operating Current [A]	Maximum design Current [A]	Power factor
T1	Main Supply	80,000	60,567	11,166	59,529	138,000	254	336	0.982859
	Main Supply	80,000	60,567	11,166	59,529	138,000	254	336	0.982859
T2A	138/6.6kV Transformer 1A -p	40,000	29,101	4,160	28,802	138,000	122	168	0.99
T2A	138/6.6kV Transformer 1A -s	40,000	29,101	4,160	28,802	6,600	2,546	3,500	0.99
SWB-01	6.6kV DB1	40,000	29,101	4,160	28,802	6,600	2,546	3,500	0.99
GS1	Turbo machinery Generator	-15,000	-15,000	0	-15,000	6,600	0	0	1.00
CC1	Capacitor bank 1	12,000	12,000	-12,000	0	6,600	0	0	0.00
B1A	Helium Blower 1A	1,200	1,200	663	1,000	6,600	105	105	0.83
B1B	Helium Blower 1B	1,200	1,200	663	1,000	6,600	105	105	0.83
B4	Helium Blower 4	1,200	1,200	663	1,000	6,600	105	105	0.83
HT1A	Heater 1 heating coil 1	6,800	6,800	3,200	6,000	6,600	595	595	0.88
HT1B	Heater 1 heating coil 2	6,800	6,800	3,200	6,000	6,600	595	595	0.88
HT1C	Heater 1 heating coil 3	6,800	6,800	3,200	6,000	6,600	595	595	0.88
HT2	Heater 2	6,800	6,800	3,200	6,000	6,600	595	595	0.88
T3A	6.6/0.46kV Transformer 3A -p	2,000	1,222	811	913	6,600	110	175	0.75
T3A	6.6/0.46kV Transformer 3A -s	2,000	1,222	811	913	460	1,571	2,500	0.75
SWB-03	460V MCC1	2,000	1,222	811	913	460	1,571	2,500	0.75
P1	Cooling water pump 1	158	158	87	132	460	198	198	0.84
CP1A	Helium compressor 1	38	38	23	30	460	48	48	0.79
FA1A	Helium compressor 1 air fan	4	4	3	3	460	5	5	0.75
B5A	Helium Blower B5A	400	400	346	200	460	502	502	0.50
VP1	HPS chiller	38	38	23	30	460	48	48	0.79
FA3	HPS cooling fan 1	4	4	3	3	460	5	5	0.75
DB1	Motorised valves	45	45	28	35	460	56	56	0.78
	Auxiliary process electrical motor loads	500	500	263	425	460	628	628	0.85
CP2A	DSRS Compressor 1	65	65	35	55	460	82	82	0.85
T3A	6.6/0.46kV Transformer 4A -s	1,200	1,050	558	889	6,600	92	105	0.85
T3A	6.6/0.46kV Transformer 4A -p	1,200	1,050	558	889	460	1,320	1,500	0.85
SWB-05	460V Utilities DB1	1,200	1,050	558	889	460	1,320	1,500	0.85
UC1	Uninterruptible and conditioned power supply 1	20	20	16	12	460	25	25	0.60
HT20A	HPS heater 1	65	65	35	55	460	82	82	0.85
HT20B	HPS heater 2	65	65	35	55	460	82	82	0.85
LSP1	Lighting and small power DB 1	22	22	13	18	460	28	28	0.82
LSP2	Lighting and small power DB 2	22	22	13	18	460	28	28	0.82
LSP3	Lighting and small power DB 3	55	55	27	48	460	69	69	0.87
LSP4	Lighting and small power DB 4	55	55	27	48	460	69	69	0.87
LSP5	Lighting and small power DB 5	75	75	37	65	460	94	94	0.87
WF1	Welding feeder 1	130	0	0	0	460	0	0	1.00
WF2	Welding feeder 2	130	0	0	0	460	0	0	1.00
VP4	Analyser shelter	45	45	28	35	460	56	56	0.78
VP6	HVAC	160	160	77	140	460	201	201	0.88
P20A	Fire fighting pump 1	65	65	35	55	460	82	82	0.85
P20B	Fire fighting pump 2	65	65	35	55	460	82	82	0.85
	Auxiliary plant and process electrical loads, excluding	300	300	158	255	460	377	377	0.85
VP7	Instrument air supply 1	38	38	23	30	460	48	48	0.79
T2B	138/6.6kV Transformer 1B -p	40,000	31,516	7,007	30,727	138,000	132	168	0.97
T2B	138/6.6kV Transformer 1B -s	40,000	31,516	7,007	30,727	6,600	2,757	3,500	0.97
SWB-02	6.6kV DB2	40,000	31,516	7,007	30,727	6,600	2,757	3,500	0.97
GS1	Turbo machinery Generator	-15,000	-15,000	0	-15,000	6,600	-1,312	-1,312	1.00
CC2	Capacitor bank 2	12,000	12,000	-12,000	0	6,600	1,050	1,050	0.00
B2A	Helium Blower 2A	1,200	1,200	663	1,000	6,600	105	105	0.83
B2B	Helium Blower 2B	1,200	1,200	663	1,000	6,600	105	105	0.83
HT1D	Heater 1 heating coil 4	6,800	6,800	3,200	6,000	6,600	595	595	0.88
HT1E	Heater 1 heating coil 5	6,800	6,800	3,200	6,000	6,600	595	595	0.88
B3	Test Blower	18,000	18,000	9,950	15,000	6,600	1,575	1,575	0.83
T3B	6.6/0.46kV Transformer 3B -p	2,000	1,267	829	958	6,600	111	175	0.76
T3B	6.6/0.46kV Transformer 3B -s	2,000	1,267	829	958	460	1,590	2,500	0.76
SWB-04	460V MCC2	2,000	1,267	829	958	460	1,590	2,500	0.76
P2	Cooling water pump 2	158	158	87	132	460	198	198	0.84
CP1B	Helium compressor 2	38	38	23	30	460	48	48	0.79
FA1B	Helium compressor 2 air fan	4	4	3	3	460	5	5	0.75
B5B	Helium Blower B5B	400	400	346	200	460	502	502	0.50
HT20C	HPS heater 3	65	65	35	55	460	82	82	0.85
HT20D	HPS heater 4	65	65	35	55	460	82	82	0.85
FA4	HPS cooling fan 2	4	4	3	3	460	5	5	0.75
	Auxiliary process electrical motor loads	500	500	263	425	460	628	628	0.85
CP2B	DSRS Compressor 2	65	65	35	55	460	82	82	0.85
T3B	6.6/0.46kV Transformer 4B -p	1,200	918	501	769	6,600	80	105	0.84
T3B	6.6/0.46kV Transformer 4B -s	1,200	918	501	769	460	1,152	1,500	0.84
SWB-06	460V Utilities DB2	1,200	918	501	769	460	1,152	1,500	0.84
VP2	Overhead crane 1	38	38	23	30	460	48	48	0.79
VP3	Overhead crane 2	55	55	32	45	460	69	69	0.82
UC2	Uninterruptible and conditioned power supply 2	20	20	16	12	460	25	25	0.60
HT20C	HPS heater 3	65	65	35	55	460	82	82	0.85
HT20D	HPS heater 4	65	65	35	55	460	82	82	0.85
LSP6	Lighting and small power DB 6	22	22	13	18	460	28	28	0.82
LSP7	Lighting and small power DB 7	22	22	13	18	460	28	28	0.82
LSP8	Lighting and small power DB 8	55	55	27	48	460	69	69	0.87
LSP9	Lighting and small power DB 9	55	55	27	48	460	69	69	0.87
LSP10	Lighting and small power DB 10	75	75	37	65	460	94	94	0.87
WF3	Welding feeder 3	130	0	0	0	460	0	0	1.00
VP5	Analyser shelter	45	45	28	35	460	56	56	0.78
P20C	Fire fighting pump 3	65	65	35	55	460	82	82	0.85
	Auxiliary plant and process electrical loads, excluding	300	300	158	255	460	377	377	0.85
VP8	Instrument air supply 2	38	38	23	30	460	48	48	0.79



Design Maximum Power	80,000 kVA	Listed power including allowance for additional equipment not described in this drawing
Listed Maximum Apparent Power with power factor correction	61,430 kVA	Summary of equipment in this drawing without allowances
Listed power factor with power factor correction	0.97	The possibility of generator GS1 to deliver reactive power not taken into account
Listed Maximum Apparent Power without power factor correction	69,140 kVA	Listed Apparent Power without power factor correction
Listed power factor without power factor correction	0.86	Power factor without power factor correction and a possible supply of reactive power from generator GS1

M-Tech Industrial
FOR INFORMATION ONLY
460V, 2500A, 40kA MCC 2
Not to be used for design purposes



- NOTES
- Auxiliary process electrical motor loads
 - Auxiliary plant and process loads, excluding electrical motors

REFERENCE DRAWING FILES

REVISION DETAILS

REVISION

ECP NUMBER

DRAWN

DATE

CHECKED

DATE

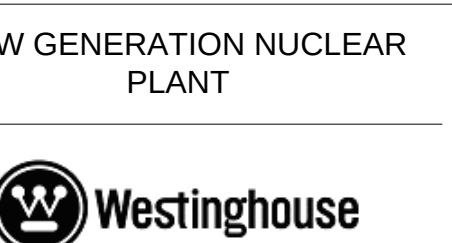
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Drawn	pieterE	Date	11-2008
Checked		Date	
Approved		Date	
Accepted		Date	

TITLE: **NGNP CTF CONCEPT 2**
OVERALL SINGLE LINE DIAGRAM
OPTION 2: 6.6kV MAIN DISTRIBUTION

FILE NAME	SCALE	REVISION
Overall power distribution.vsd	NTS	D
DRAWING NUMBER	WHEN PLOTTED ON	SHEET 2
TLDR-CQL2-SS-04-0001	A0	OF 2

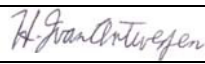
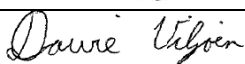
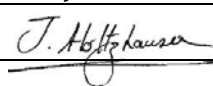
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NGNP and Hydrogen Production Conceptual Design Study

NGNP CTF Test Loop Preconceptual Design Report

Section 9: Circulator Test Loop (CTL)

APPROVALS

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Lucas Pitso; M-Tech Industrial (Pty) Ltd.	December 12, 2008

BACKGROUND INTELLECTUAL PROPERTY CONTENT

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B	H.J. van Antwerpen	First release to BEA	November 26, 2008
C	H.J. van Antwerpen	Updated release to BEA	November 29, 2008
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E	H.J. van Antwerpen	Updated for consistency with regards to references and nomenclature	December 10, 2008
0	H.J. van Antwerpen	Document for final release to BEA	December 17, 2008

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ACRONYMS

Abbreviation or Acronym	Definition
A	Accelerometer
A-E-C	Architecture – Engineering -Construction
AGR	Advanced Gas-cooled Reactor
AHJ	Authority Having Jurisdiction
AICE	American Institute of Chemical Engineers
AISC	American Institute of Steel Construction
AISI	American Iron and Steel Institute
ALARA	As Low As Reasonable Achievable
AMB	Active Magnetic Bearing
ANSI	American National Standards Institute
API	American Petroleum Institute
ASHRAE	American Society of Heating Refrigeration and Air Conditioning Engineers
ASME	American Society of Mechanical Engineers
AWS	American Welding Society
BEA	Battelle Energy Alliance
BIL	Basic Impulse Insulation Level
BIM	Building Information Management
BS	British Standard
Btu/hr	British thermal unit per hour
CAD	Computer Aided Design
CAE	Computer Aided Engineering
CBCS	Core Barrel Conditioning System
CCS	Core Conditioning System
CFR	Code of Federal Regulations
CH	Cold Header
CMAA	Crane Manufacturers Association of America
COR	Client Observation Room
COTS	Commercial Off-The-Shelf (Commercial Grade Items)
CQL	Component Qualification Loop
CQL1	Component Qualification Loop 1
CQL2	Component Qualification Loop 2
CTF	Component Test Facility
CTL	Circulator Test Loop
CV	Valve Flow Coefficient
DAQ	Data Acquisition
db	Dry Bulb
DB	Distribution Board

Abbreviation or Acronym	Definition
DC	Direct Current
DCD	Design Criteria Document
DCS	Distributed Control System
DDN	Design Data Need
DOE	Department of Energy
dP	Differential Pressure
DPP	Demonstration Power Plant
EDMS	Engineering Data Management System
EHR	Essener Hochdruck Rohrleitung
EIA	Electronic Industry Alliance
EMB	Electro-magnetic Bearing
ENS	Emergency Notification System
EPACT	Energy Policy Act (of 2005)
EPC	Engineering Procurement and Construction
ER	Environmental Requirement
ES&H	Environmental, Safety and Health
ESD	Emergency Shutdown
F	Flow Rate
FDD	Facility Design Description
FHA	Fire Hazard Analysis
FIPS	Federal Information Processing Standards
FM	Factory Mutual
FMS	Facility Monitoring System
FS	Flow rate (switch)
GA	Gas analyzer (composition)
GHEP	Guidelines for Hazard Evaluation Procedures
gpm	Gallon per minute (US)
GR	General Requirements
H ₂	Hydrogen Production Test (Specifically referring to H ₂ SO ₄ Decomposition Reactor Test)
H ₂ SO ₄	Sulfuric Acid
HAZOP	Hazard and Operational Study
HDBK	Handbook
HGD	Hot Gas Duct
HGDs	Hot Gas Ducts
HH	Hot Header
HICS	Helium Inventory Control System
HIPCS	Helium Inventory and Pressure Control System
HIRA	Hazard and Risk Identification Analysis
HLR	High Level Requirement
HMI	Human Machine Interface

Abbreviation or Acronym	Definition
HPS	Helium Purification System
HT	Heat Transfer
HTF	Helium Test Facility
HTGR	High Temperature Gas -Cooled Reactor
HTS	Heat Transport System
HTSE	High Temperature Steam Electrolysis
HTTR	High Temperature Test Reactor
HTTU	High Temperature Test Unit
HV	High Voltage (>132 000V)
HVAC	Heating, Ventilation, & Air Conditioning
HX	Heat Exchanger
HyS	Hybrid Sulfur
I&C	Instrumentation and Control
I/O	Input/Output
IBC	International Building Code
ICC	International Code Council
ICD	Initial Conceptual Design
ICEA	Insulated Cable Engineers Association
IDAPA	Idaho Administrative Procedure Act
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IFC	International Fire Code
IFGC	International Fuel Gas Code
IHX	Integrated Heat Exchanger
IHXA	Intermediate Heat Exchanger A
IHXB	Intermediate Heat Exchanger B
IMC	International Mechanical Code
IMS	Information Management Systems
INL	Idaho National Laboratory
IPMC	International Property Maintenance Code
ISA	International Society of Automation
ISO	International Organization for Standardization
JB	Junction Box
kg/s	Kilogram per second
kV	Kilovolt (1000 Volts)
kl/h	Kilolitre per hour
kPa	Kilopascal (1000 Pascal)
kW	Kilowatt (1000 Watts)
LCD	Liquid Crystal Display
LCP	Local Control Panel
LRFDS	Load and Resistance Factor Design Specification

Abbreviation or Acronym	Definition
LV	Low Voltage (<1000 V)
MBMA	Metal Building Manufacturers Association
MCC	Motor Control Center
MCR	Mission Critical Requirement
MDB	Main Distribution Board
MES	Manufacturing Execution System
MPa	Megapascal = million Pascal
MTI	M-Tech Industrial (Pty) Ltd.
MV	Medium Voltage (>1000V< 132 000V)
MW	Megawatt (Million Watts)
N	Speed
NBIMS	National BIM Standards Project Committee
NEC	National Electrical Code
NEMA	National Electrical Manufacturers Association
NEPA	National Environmental Policy Act
NESC	National Electrical Safety Code
NFPA	National Fire Protection Association
NGNP	Next Generation Nuclear Plant
NHI	National Hydrogen Institute
NIST	National Institute of Standards and Technology
NQA-1	ASME NQA-1 2000, Quality Assurance for Nuclear Facilities
OPC	Operating Procedure Checklist
OSHA	Occupational Safety and Health Administration
P	Pressure
P&ID	Piping and Instrument Diagram
PBMR	Pebble Bed Nuclear Reactor (RSA)
PCDR	Preconceptual Design Report
PCFC	Preconceptual Facility Configurations
PCHX	Printed Circuit Heat Exchanger
PCS	Process Control System
PDA	Potential Deviation Analysis
PDMS	Project Data Management System
PDS	Plant Design System
PFD	Process Flow Diagram
PHA	Preliminary Hazard Analysis
PHTS	Primary Heat Transport System
PLC	Programmable Logic Controller
PLCs	Programmable Logic Controllers
PMN	Support Manager
PRV	Pressure Relief Valve
psig	Pound per square inch gauge

Abbreviation or Acronym	Definition
PSM	Support Modeler
QC	Quality Control
QCP	Quality Control Plan
RCS	Reactivity Control System
RIS	Relational Interface System
RPV	Reactor Pressure Vessel
RSA	Republic of South Africa
SBS	System Breakdown Structure
SCADA	Supervisory Control and Data Acquisition System
scfm	Standard cubic feet per minute
SDD	System Design Description
SDI	Steel Door Institute or Steel Deck Institute
SG	Steam Generator
SHEQ	Safety, Health, Environmental and Quality
SHTS	Secondary Heat Transport System
SI	Sulfur Iodine
SIL	Safety Integrity Level
SIS	Safety Instrument System
SJI	Steel Joist Institute
SNM	Special Nuclear Materials
SPEL	SmartPlant Electrical
SPF	SmartPlant Foundation
SPMat	SmartPlant Material
SPR	SmartPlant Review
SPS	Standby Power System
SR	Safety Requirement
SRM	System Requirement Manual
SSC	Systems Structures and Components
SSDT	Small Scale Development Test
SSS	Site Selection Study
SSSB	Specification for Structural Steel Buildings
STD	Standard
T	Temperature
T&FR	Technical and Functional Requirement
TBD	To Be Determined
TDL	Technology Development Loop
TDRM	Technology Development Road Map
TEDS	Transducer Electronic Data Sheet
TEMA	Tubular Exchanger Manufacturers Association
THTR	Thorium High Temperature Reactor
TIA	Telecommunications Industry Association

Abbreviation or Acronym	Definition
TRL	Technology Readiness Level
TSR	Technical Safety Requirement
UL	Underwriters Laboratories
UL	Underwriters' Laboratories
UPC	Uniform Plumbing Code
UPS	Uninterruptable Power Supply
UUT	Unit Under Test
V&V	Verification and Validation
VHTGR	Very High Temperature Gas-Cooled Reactor
VL	Valve
VSD	Variable Speed Drive
wb	Wet Bulb
WBS	Work Breakdown Structure
WEC	Westinghouse Electric Company
WE-SA	Westinghouse Electric - South Africa
ϵ	Strain

SUMMARY AND CONCLUSIONS

The Circulator Test Loop (CTL) comprises a Test Station for a full-scale circulator for the NNGP, which operates at 160kg/s helium flow rate, at a maximum temperature of 350°C and a pressure of 9MPa. Due to the availability of a high flow rate of helium at a high pressure drop (450kPa total), several other tests can be conducted in the CTL. These include: the calibration of flow meters for the full-scale NNGP, testing of flow-induced vibrations in the full-scale Heat Transport System piping (hot gas ducts), testing of vibration damping devices in the mixing chamber and determination of the pressure drop coefficient of a full-scale check valve.

The Test Test Loop is heated by means of the Circulator energy input into the fluid, while loop temperature control is done by a controlled water cooler.

9. CIRCULATOR TEST LOOP (CTL)

9.1 CTL: Design Inputs and Requirements

The CTF is required to perform all the tests listed in reference [9-1], as derived in during the Technology Development Road Mapping, reference [9-13]. In the abovementioned list, the tests that require full-scale NGNP mass flow rates at 9 MPa are listed in Table 9-1.

Table 9-1: List of tests that require high flow rates, as will be available in the Circulator Test Loop.

Section	Description	Test number
Circulator	Partial of Full scale circulator Model Test	WEC-TS-CIRC-003
Piping	Performance and environmental testing of prototypical high-temperature and low-temperature piping/insulation system	WEC-TS-PIP-009
Mixing chamber	Vibration Damping Devices Test	WEC-TS-MC-002
Piping	One-way “flapper” valve: operation test and pressure drop characterization	From NGNP-PCDR Section 6
	Full-scale NGNP flow meter calibration	From INL F&OR's

The primary purpose of this loop is to provide a test environment for full-scale prototypes of the NGNP Circulator. Because of the availability of the high flow rate, other tests have been incorporated into the Circulator Test Loop (CTL), such as the HTS Piping Hot Gas Duct (Hot Gas Duct (HGD) vibration velocity limit test, mixing chamber vibration damping device test and a full-scale flow meter calibration facility.

9.1.1 Prototype Circulator Test

This section refers to the following test specification(s): WEC-TS-CIRC-003

The largest NGNP circulator (SHTS, PCDR design) operates at 350°C, 160kg/s, 9 MPa and 450kPa pressure rise, as given in reference [9-2]. The compressor gas dynamic performance under steady-state full-load and part-load conditions is required.

9.1.2 HTS Piping (Hot Gas Duct): Vibration

This section refers to the following test specification(s): WEC-TS-PIP-009

The formal test description is “Performance and environmental testing of prototypical high-temperature and low-temperature piping/insulation system”.

One of the objectives of this test is to determine the hot gas duct maximum gas velocity experimentally, as limited by the onset of flow induced vibrations. The effect of possible flow induced vibrations on the liner and insulation integrity must also be established.

While the CTL will not operate at high temperature, it provides the highest possible flow rate in the CTF and will therefore be capable of the largest scale flow effects tests.

9.1.3 Mixing Chamber: Vibration Damping Devices

This section refers to the following test specification(s): WEC-TS-MC-002

Due to the fact that the CTL provides the largest possible scale flow tests, it is the best suited to perform close to full-scale tests on the Mixing Chamber vibration damping devices. In order to arrive at a density and Reynolds number that corresponds to 900°C, a full-scale mixer test may have to be done at a lower pressure than 9 MPa and could require a higher volume flow than the circulator nominal design value.

9.1.4 Flow Meter Calibration

The INL Technical and Functional Requirement for the CTF requires “space for the testing, qualification and calibration of instrumentation” (reference [9-3]). In order to calibrate flow meters for NGNP duty (i.e. nominal 160kg/s, 9 MPa, 350°C), a high-integrity flow measurement facility is included in the CTL proposal.

9.1.5 One-Way “Flapper” Valve

In reference [9-4], a one-way “flapper” valve is required. This valve is installed on the “cold” section of the NGNP PHTS. It has to close when the Circulator is not in operation so that the reactor core cooling flow from the Core Conditioning System (CCS) does not bypass the reactor through the PHTS. The automatic operation and pressure drop of such a full-scale valve can be tested in the CTL at actual conditions of 160kg/s, 9 MPa and 350°C. The leak rate or sealing effectiveness of this valve will have to be tested in one of the Small-Scale Development Tests (reference [9-5]). Currently, there is not yet a design for such a one-way valve.

9.2 CTL: Thermal Hydraulic Design

9.2.1 System-Level Process Design

The primary requirement of the CTL is to provide the test environment for a full-scale NGNP Circulator at 160kg/s, 350°C, 9 MPa pressure level and 450kPa pressure rise.

Therefore, the CTL has to provide a flow loop with a variable pressure loss characteristic.

A process-gas cooling device is required to control the gas temperature and remove the heat added by the circulator and in the loop. The cooler heat load and gas temperatures, as well as the heat loss to the environment were calculated as described in reference [9-14]. The design process described in this section resulted in the Process Flow Diagram (PFD) shown in reference [9-15].

9.2.1.1 Pressure Loss

The pressure loss section comprises an orifice (which serves as a pressure dissipater) in parallel with several small, standard open/close valves and a single continuously controlled valve. The open/close valves and the control valve have the same flow coefficient (C_v) which avoids the development of a custom large sized control valve. Due to the high flow rate, it is a possibility that the throat velocity in a single orifice could exceed the erosion limit. It is, therefore, recommended that this possibility be ruled out during detail design phases of the CTL. If erosion poses a problem, several larger sized orifices (meaning a larger throat to outer diameter ratio) can be used in series to accomplish the required pressure drop.

9.2.1.2 Cooling and Temperature Control

The pressure rise of 450kPa for the given volume flow represents a heat addition of about 12.3MW; therefore it is not necessarily required to install a separate heater to reach the working temperature in the CTL. In order to control the temperature level in the CTL, a shell-and-tube type water cooled heat exchanger is proposed.

Temperature level control in the CTL is to be done by matching the heat removal from the cooler with the heat input by the circulator. In this way, the water flow rate is varied to reach the desired heat removal. This avoids additional large helium control valves, or a specific helium flow rate through the cooler.

It is assumed that the cooling water is supplied at a temperature around 20°C and it may not be returned at a temperature above 45°C. Based on this assumption, the cooling water requirement for a nominal heat removal of 13MW was calculated as 155 kg/s at 20°C supply and 40°C return temperature (reference [9-14]).

In order to control the heat removal rate from the loop, the heat transfer has to be dependent on the water mass flow rate, such that the water return temperature stays below 45°C. This is accomplished by passing only 10kg/s helium through the heat exchanger, with the remaining flow of 150kg/s bypassing the heat exchanger. This results in a heat exchanger helium outlet temperature of 100°C, so that, for the required heat removal, the temperature difference between the helium and the water is reduced from (334°C – 40°C) to (100°C – 40°C). Any variation in water flow rate will now cause a much more significant change in helium outlet temperature and, consequently, in heat transfer. There is also a 5°C control margin between the water nominal return temperature of 40°C and the maximum return temperature of 45°C.

The placement of the cooler and the pressure drop section in the loop has to be revised during detail design, as the most appropriate re-entry place for a blower surge protection pipeline (if required by the circulator design) is at the cooler inlet.

9.2.1.3 Pipe Sizing

As a rule of thumb, pipe sizes for gas flow applications are sized such that a flow velocity of 20m/s or less (to reduce pressure losses) is reached in the pipes. A gas velocity of 40m/s, instead of 20m/s, is assumed in the CTL to reduce the size of the pipes from 1.22m to 0.85m. A further consideration is that there is excess pressure drop available so that the pressure loss associated with high gas velocity is no problem.

From an operational point of view, the pipes are not required to be insulated on the inside or the outside. However, plant requirements may specify the installation of shrouds to prevent access to hot surfaces.

Based on first estimates for pipe lengths, the helium inventory is 604kg.

The estimated heat loss from the pipe surface (if uninsulated) to the environment is 1.66MW (at 30°C ambient temperature). When the pipes are insulated such that the cladding temperature is 50°C, the heat loss to the environment reduced to 92kW, as calculated in reference [9-14].

9.2.1.4 Flow Meter Calibration

The philosophy behind the construction of the flow meter calibration section is that a reference flow standard can be obtained by installing orifice flow meters according to easily verifiable geometric standards (such as ISO 5167 or BS1042) specifications. The calibration of the pressure drop (ΔP) across the orifice station can easily be done onsite with a secondary standard. All other types of flow meters (vortex, ultrasonic, etc.) require calibration against a reference flow measurement and are usually not as simple as the calibration of an orifice measurement station. It is proposed that these types of flow measurement devices be installed in Test Station TS 4_1.2 for calibration against the reference measurement provided by the orifice flow meters.

The placement of the flow meter calibration Test Station is described in the Process Flow Diagram in reference [9-15].

The average volume flow measurement Q for n number of flow meters in series is calculated with Eq.(9.1).

$$Q = \frac{Q_1 + Q_2 + \dots + Q_n}{n} \quad (9.1)$$

According to reference [9-9], the uncertainty on the measurement $u(Q)$ is calculated with Eq.(9.2):

$$u(Q) = \sqrt{\left(\frac{\partial Q}{\partial Q_1} \cdot u(Q_1)\right)^2 + \dots + \left(\frac{\partial Q}{\partial Q_n} \cdot u(Q_n)\right)^2} \quad (9.2)$$

From Eq.(9.1), it is apparent that the derivative of Q with respect to any flow measurement Q_i is given by Eq.(9.3):

$$\frac{\partial Q}{\partial Q_1} = \frac{\partial Q}{\partial Q_2} = \dots = \frac{\partial Q}{\partial Q_n} = \frac{1}{n} \quad (9.3)$$

So that Eq.(9.2) simplifies to Eq.(9.4).

$$u(Q) = \frac{1}{n} \cdot u(Q_i) \quad (9.4)$$

Eq.(9.4) states that the uncertainty of the combined flow measurement $u(Q)$ is inversely proportional to the number n of flow meters in series.

Depending on pipe layout and construction tolerances, an uncertainty of one percent (1%) is feasible, as was found at the High Pressure Test Unit (HPTU) in South Africa. An uncertainty of 1.1 percent was calculated for an orifice flow meter operating in 5 MPa nitrogen (100mm nominal pipe diameter, 50mm orifice diameter).

If a flow uncertainty of one percent is assumed for one of the orifices in the CTL, Eq.(9.4) implies that a theoretical uncertainty of 0.33 percent can be claimed on the average flow measurement for the CTL setup with three orifice flow measurement devices.

This highlights the fact that the desired flow meter calibration accuracy must be specified by the client before the flow meter calibration facility design can commence. Once the measurement accuracy has been prescribed, the facility size can be minimized by optimal configuration of flow straighteners, pipe lengths, flow restrictions (elbows, valves, reducers etc.) and possibly using a number of parallel flow meter pipes.

A tradeoff study should also be performed to determine the optimum number of flow meters and the greatest attainable accuracy.

Thus, in the absence of detailed flow meter calibration specifications for the NGNP, the current proposed design is only a minimum-effort workable concept for calibrating full-scale flow meters for the NGNP.

For consideration during detail design:

- An evaluation of the type of flow meter to be used as reference, i.e. orifice, venturi or nozzle type.
- An evaluation of flow meter accuracy and number of orifice flow meters.
- Facility minimization by optimal configuration of flow restrictions (elbows, valves, reducers etc.), flow straighteners, pipe lengths and possibly using a number of parallel flow meter pipes.

Applicable standards for flow-restriction-based flow meters are given in references [9-9] to [9-12].

9.2.1.5 Heat Transport System (HTS) Piping (Hot Gas Duct) And Mixing Chamber Tests

Provision is made for the HTS Piping HGD vibration test and the Mixing Chamber vibration damper test by adding spool pieces in the section after the flow meter calibration section.

The experimental design for these tests has to take into account that the CTL tests will be at a low temperature compared to the normal working temperature of the hot gas duct and the mixing chamber. During the experimental design, the characterizing non-dimensional parameters for a specific test will have to be determined. For results from a low-temperature experiment to apply to a high-temperature case, the appropriate non-dimensional parameters will have to be equal. As an example, the gas density at 9MPa, 950°C can be reached by testing at a lower pressure level at 350°C.

9.2.1.6 Allocation of Pressure Drop and Component Sizing

The pressure drop of 450kPa available from the circulator was assigned to the various components as follows:

Flow meter calibration section:	~200kPa
Pressure dissipating section:	~200kPa
Hot gas duct, Mixing chamber, “flapper” valve, piping, Cooler:	~50kPa

A significant pressure drop (200kPa) is assigned to the pressure dissipating section in order to reduce the size of valves that are required for that duty and to ensure a wide range of controllability. A significant pressure drop is also assigned to the flow meter calibration section in order to reduce the required absolute sensitivity of the differential pressure drop sensors.

9.2.2 System Breakdown Structure

The System Breakdown Structure (SBS) for the Circulator Test Loop is shown in Figure 9-1, with the subsystems divided into Test Stations and Loop components.

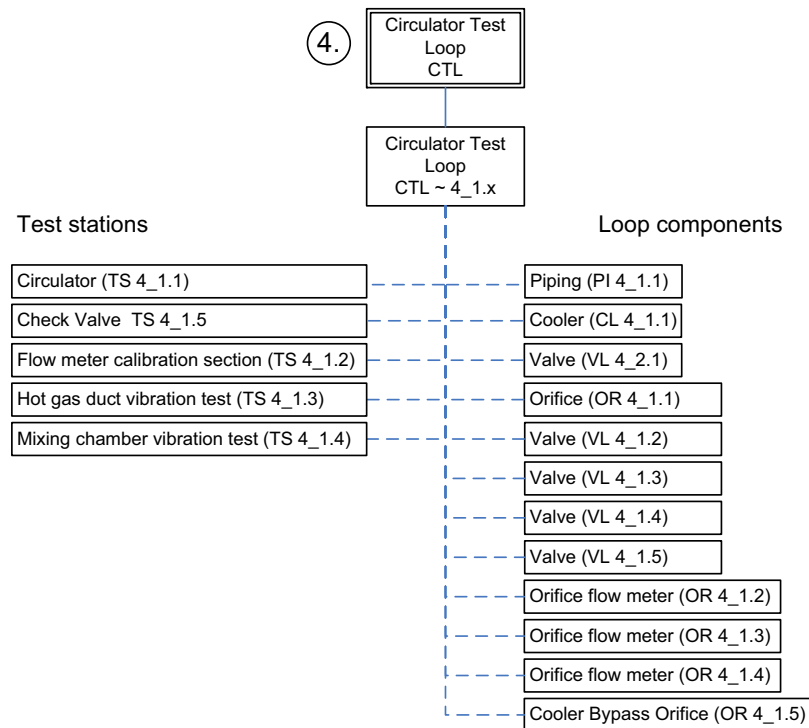


Figure 9-1: System Breakdown Structure for the Circulator Test Loop

9.2.3 Component Performance Specifications

The components listed in the System Breakdown Structure (SBS) are specified according to the envelopes determined during the system-level process thermal-hydraulic design.

9.2.3.1 Circulator Performance Specification

This section refers to the following test specification(s): TS 4_1.1

For low pressure rise, the mass flow of a typical centrifugal turbomachine could increase up to 50% higher than nominal. Accordingly, the power consumption will also increase by about 50% so that the electrical supply should cater for an increased electrical demand. Similarly, the maximum mass flow in the CTL could go as high as 240kg/s. This has to be reviewed during detail design. In the absence of a circulator design, the nominal flow rate of 160kg/s is used as design reference.

9.2.3.2 Piping Performance Specification

This section refers to the following test specification(s): PI 4_1.1

Due to the fact that there are no high-temperature or low-temperature loops in the CTL, the same piping can be used for the entire loop.

Description	Unit	Value
P_{he}	kPa	9,600
$T_{he\ in}$	°C	350
$d_{internal}$	m	0.85
m_{he}	kg/s	160

9.2.3.3 Cooler Performance Specification

This section refers to the following test specification(s): CL 4_1.1

Circulator Test Loop cooler.

Description	Unit	Value
P_{he}	kPa	9,000
$T_{he\ in}$	°C	350
$T_{he\ out}$	°C	100
m_{he}	kg/s	10
P_w	kPa	120
$T_{w\ in}$	°C	20
$T_{w\ out}$	°C	40
m_w	kg/s	155
Q_{th}	MW	13

9.2.3.4 Valve Performance Specification

This section refers to the following test specification(s): VL 4_2.1

Circulator Test Loop cooling water control valve.

Description	Unit	Value

Description	Unit	Value
P_w	kPa	200
$T_{w\text{ in}}$	°C	20
m_{he}	kg/s	155

9.2.3.5 Orifice Performance Specification

This section refers to the following test specification(s): OR 4_1.1

Circulator Test Loop pressure dissipating orifice

Description	Unit	Value
P_{he}	kPa	9,600
$T_{he\text{ in}}$	°C	350
$d_{\text{internal pipe}}$	m	0.85
dP	kPa	200

9.2.3.6 Valves Performance Specification

This section refers to the following test specification(s): VL 4_1.2, VL 4_1.3, VL 4_1.4

These are actuated open/close valves which provide a varying pressure drop characteristic for the CTL.

Description	Unit	Value
P_{he}	kPa	9,600
$T_{he\text{ in}}$	°C	350
dP	kPa	200

9.2.3.7 Valve Performance Specification

This section refers to the following test specification(s): VL 4_1.5

This is a control valve which provides a varying pressure drop characteristic for the CTL.

Description	Unit	Value
P_{he}	kPa	9,600
$T_{he\text{ in}}$	°C	350
dP	kPa	200

9.2.3.8 Orifice Flow Meters Performance Specification

This section refers to the following test specification(s): OR 4_1.2, OR 4_1.3, OR 4_1.4

These flow meters are for calibrating the flow meter in Test Station TS4_1.2.

Description	Unit	Value
P_{he}	kPa	9,600
$T_{he\ in}$	°C	350
$d_{internal\ pipe}$	m	0.85
m_{he}	kg/s	160
dP	kPa	50

9.2.3.9 Cooler Bypass Orifice Performance Specification

This section refers to the following test specification(s): OR 4_1.5

This orifice is to ensure a mass flow through the Cooler.

Description	Unit	Value
P_{he}	kPa	9,600
$T_{he\ in}$	°C	350
$d_{internal\ pipe}$	m	0.85
m_{he}	kg/s	150
dP	kPa	10

9.3 CTL: Component Design

This paragraph describes the thermal-hydraulic and mechanical design or specification of individual components in the CTL. All component thermal- hydraulic sizing calculations are described in reference [9-14].

9.3.1 Circulator

This section refers to the following test specification(s): TS 4_1.1

The circulator is connected to the CTL by means of two flanged connections. The flanges are installed on parallel supply and demand pipes so that the CTL does not impose a physical size limit on the Circulator unit under test. The pipes and flanges are of the standard size used in the CTL.

9.3.2 Test Stations

Nominal conditions available at the following test stations are as follows:

Description	Unit	Value
P_{he}	kPa	9,000

Description	Unit	Value
$T_{he\ in}$	$^{\circ}C$	350
d_{pipe}	m	0.85
m_{he}	kg/s	160

By proper selection of the dissipation orifice, a total pressure drop of up to 200kPa is achievable over the following test stations.

Valve

This test station (TS 4_1.5) has a spool piece of one meter length that can be replaced with the unit under test. The pipes and flanges are of the standard size used in the CTL.

Flow meter calibration section

This test station (TS 4_1.2) has a spool piece of one meter length that can be replaced with the unit under test. The pipes and flanges are of the standard size used in the CTL.

HTS Piping (Hot gas duct) vibration test

This test station (TS 4_1.3) has a spool piece of five meter length that can be replaced with the unit under test. The pipes and flanges are of the standard size used in the CTL.

Mixing chamber vibration test

This test station (TS 4_1.4) has a spool piece of three meter length that can be replaced with the unit under test.

9.3.3 Process Piping

This section refers to the following test specification(s): PI 4_1.1

As there are no high-temperature or low-temperature loops in the CTL, the same piping can be used for the whole loop.

Description	Unit	Value
P_{he}	kPa	9,600
$T_{he\ in}$	$^{\circ}C$	350
$d_{internal}$	m	0.85
m_{he}	kg/s	160
V_{he}	m/s	40

The surface temperature of the piping is roughly equal to the internal gas temperature, namely 334 $^{\circ}C$ to 350 $^{\circ}C$. An initial estimate of the total length of pipe came to 151m. The pressure drop caused by the pipe wall friction was calculated as 11.3 kPa.

If the pipes are not insulated, the heat loss to the environment is calculated as 2.375 MW. If the pipes are insulated such that the cladding temperature is around 50°C, the heat loss reduces to about 92kW. Thus, it is recommended to insulate the CTL piping. This heat loss calculation is described in reference [9-14].

During the mechanical design of the piping, it was found that the largest standard commercial pipe size that is capable of 9 MPa at 350°C, is 24 inch seamless pipe. This is a serious issue for the CTF and the NNGP, because; if it is decided to use standard commercially available pipe, the flow velocity is 80m/s at 350°C. In the HTS piping with internal insulation, the gas densities are much lower resulting in a velocity that is much higher than 80m/s. If it is decided to have lower flow velocities for the NNGP, each pipe section will have to be custom built and treated as a pressure vessel.

For the purposes of this preconcept design, the CTL pipe diameter is selected as 0.85m, but with a note that it has to be updated during the detail design phase.

The calculation sheet for the pipe wall thickness and diameter is attached in reference [9-23], with a preliminary data sheet for the piping attached in reference [9-24].

9.3.4 Cooler

This section refers to the following test specification(s): CL 4_1.1

The CTL cooler was designed to accommodate only a portion of the total helium mass flow through it. This was done to have a control margin on the cooling water side while keeping the cooling water return temperature below 45°C.

Description	Unit	Value
P_{he}	kPa	9,000
$T_{he\ in}$	°C	350
$T_{he\ out}$	°C	100
m_{he}	kg/s	10
P_w	kPa	120
$T_{w\ in}$	°C	20
$T_{w\ out}$	°C	40
m_w	kg/s	155
Q_{th}	MW	13

A shell-and-tube type heat exchanger with a u-tube configuration is proposed. The data sheet and outline drawings of the cooler is available in references [9-17] to [9-20].

9.3.5 Water Control Valve

This section refers to the following test specification(s): VL 4_2.1

The Circulator Test Loop cooling water control valve is used to control the heat removal from the helium loop such that the helium temperature after mixing with the main stream is 334°C.

Description	Unit	Value
P_w	kPa	200
$T_{w \text{ in}}$	°C	20
d_{pipe}	m	0.32
m_w	kg/s	155

The data sheet for this valve is attached in reference [9-27].

9.3.6 Orifice

This section refers to the following test specification(s): OR 4_1.1

The Circulator Test Loop pressure dissipating orifice was sized such that when the circulator runs at nominal operating point, 50 percent of the flow goes through the dissipating orifice, while the rest goes through two open valves. In this way, the four valves provide roughly a 50 percent variation in flow rate.

Description	Unit	Value
P_{he}	kPa	9,600
$T_{\text{he in}}$	°C	350
m_{he}	kg/s	80
dP	kPa	220
Beta ratio	-	0.6

From the above inputs, the dissipating orifice pipeline diameter was calculated as 0.43m and the orifice diameter itself as 0.256m. Its data sheet is available in reference [9-21].

9.3.7 Open/Close Valves

This section refers to the following test specification(s): VL 4_1.2, VL 4_1.3, VL 4_1.4

These are actuated open/close valves which provide a varying pressure drop characteristic for the CTL. According to the design philosophy described in the previous paragraph, the thermal-hydraulic specifications are as follows:

Description	Unit	Value
P _{he}	kPa	9,600
dP	kPa	220
T _{he in}	°C	350
m _{he}	kg/s	40

The Cv-value for one valve was calculated to be 1358 [USGPM/sqrt(psi)] (K_v = 1,174.64 [m³/h bar]). A 150mm pipe is recommended for these valves as the maximum Cv-value available in 150mm valves is around 2000 [USGPM/sqrt(psi)] for a butterfly valve.

The data sheet is attached in reference [9-25].

9.3.8 Control Valve

This section refers to the following test specification(s): VL 4_1.5

This is a control valve which serves to provide a finely adjustable pressure drop characteristic for the CTL. It works in parallel with the abovementioned valves and its sizing similar.

Description	Unit	Value
P _{he}	kPa	9,600
dP	kPa	220
T _{he in}	°C	350
m _{he}	kg/s	40

The data sheet is attached in reference [9-26].

9.3.9 Orifice Flow Meters

This section refers to the following test specification(s): OR 4_1.2, OR 4_1.3, OR 4_1.4

These flow meters are for calibrating the flow meter in Test Station TS4_1.2. Beta (β), the ratio between the inner diameter of the pipe and the diameter of the orifice ($d_{orifice}/d_{pipe}$) is typically in the range of 0.4 to 0.6. The discharge coefficient (Cd) typically ranges between 0.6 and 0.7. A fixed value of 0.65 was used for Cd, while β was fixed at 0.6 to have a pressure drop of around 52kPa per orifice. This resulted in a sufficient available pressure drop margin for other components in the loop.

Description	Unit	Value
P _{he}	kPa	9,600

Description	Unit	Value
$T_{he\ in}$	$^{\circ}C$	350
$d_{internal\ pipe}$	m	0.85
m_{he}	kg/s	160

The data sheet for these orifices is attached in reference [9-22].

9.3.10 Cooler Bypass Orifice

This section refers to the following test specification(s): OR 4_1.5

The Cooler Bypass Orifice has to ensure a pressure drop of 10kPa on a helium mass flow of 150kg/s at 350°C. Its design procedure is the same as for the other orifices and has to be included in a following design phase.

9.3.11 Critical Systems, Structures And Components (SSC)

The SSCs are listed in Table 9-2 and their development status indicated accordingly.

Table 9-2: Critical SSC's for the CTL

SSC	COTS/Require development
Pressure dissipating valves	COTS
Orifices	COTS
Piping	COTS
Cooler	COTS

None of the SSCs in the CTL require any development, all are available as Commercial Off-The-Shelf (COTS) items.

9.4 CTL 3D Mechanical Layout

The mechanical layout was greatly determined by two factors, namely the orifice flow meters' requirement for long upstream and downstream pipe lengths and furthermore, the decision for the loop to have a footprint no larger than 5m by 45m. The resulting layout without the circulator is shown in Figure 9-2.

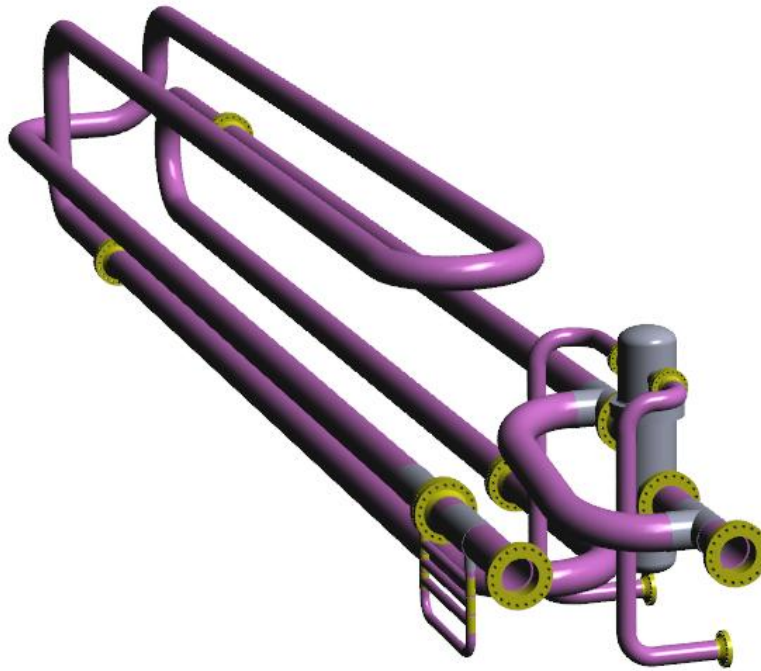


Figure 9-2: Proposed physical layout for the CTL.

Depending on the redesign of the flow meter calibration facility, the physical layout will also have to be updated.

9.5 CTL Instrumentation and Control (I&C) Design

9.5.1 Standard Operating Procedure

The CTL has to be pressurized to 4.5 MPa before heating. This is to prevent over pressurization due to the thermal expansion of gas during heat-up.

The HICS is required to control the pressure level in the CTL, i.e. the pressure set point is given to the HICS, with no pressure control on the side of the CTL.

9.5.2 Typical Modes and Transitions

The modes and transitions of the CTL loop can be subdivided into the stream sequences', process sequences' and system sequences' modes and transitions respectively as discussed in the control and instrumentation philosophy. The sequences of the different tests will typically look the same especially on stream sequence level. Figure 9-3, Figure 9-4 and Figure 9-5 respectively portray a stream, process and system sequence for a typical test.

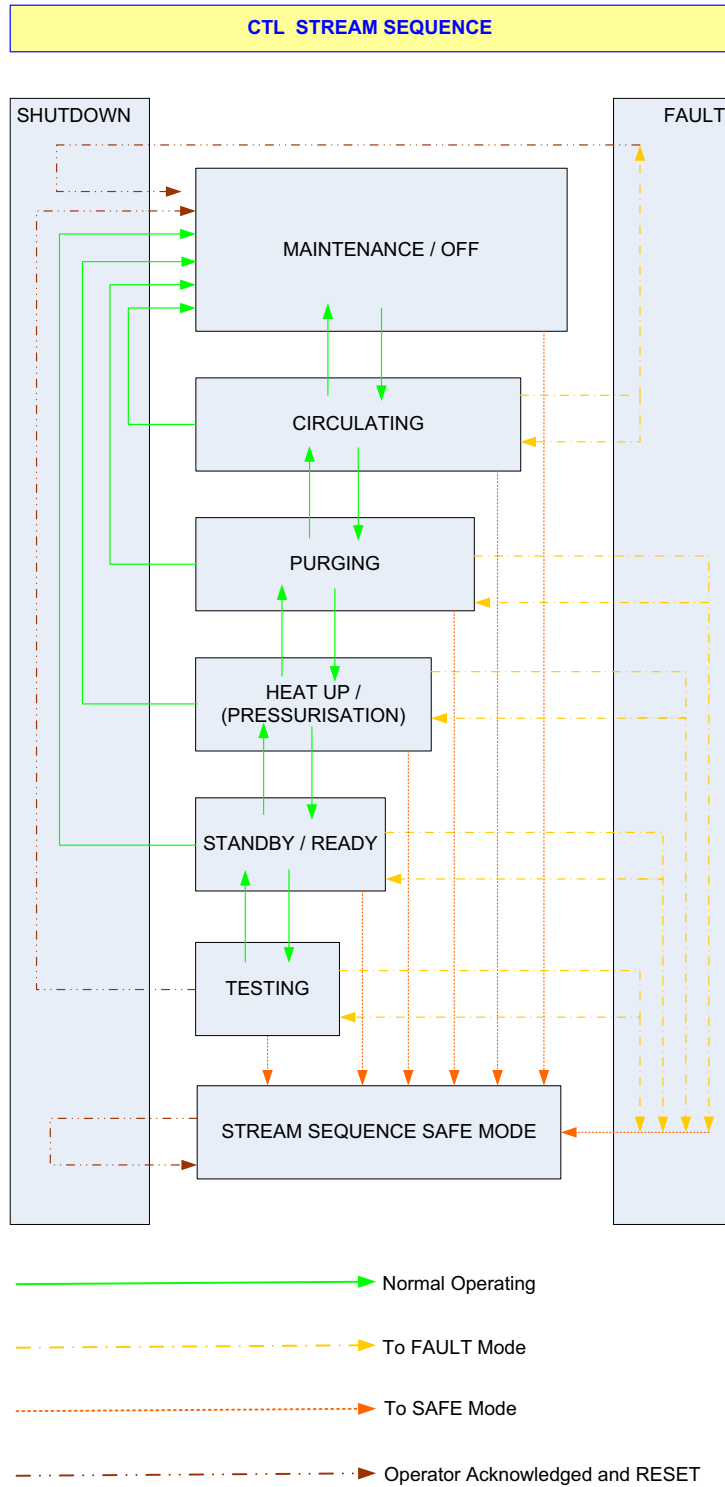


Figure 9-3: Typical CTL stream sequence

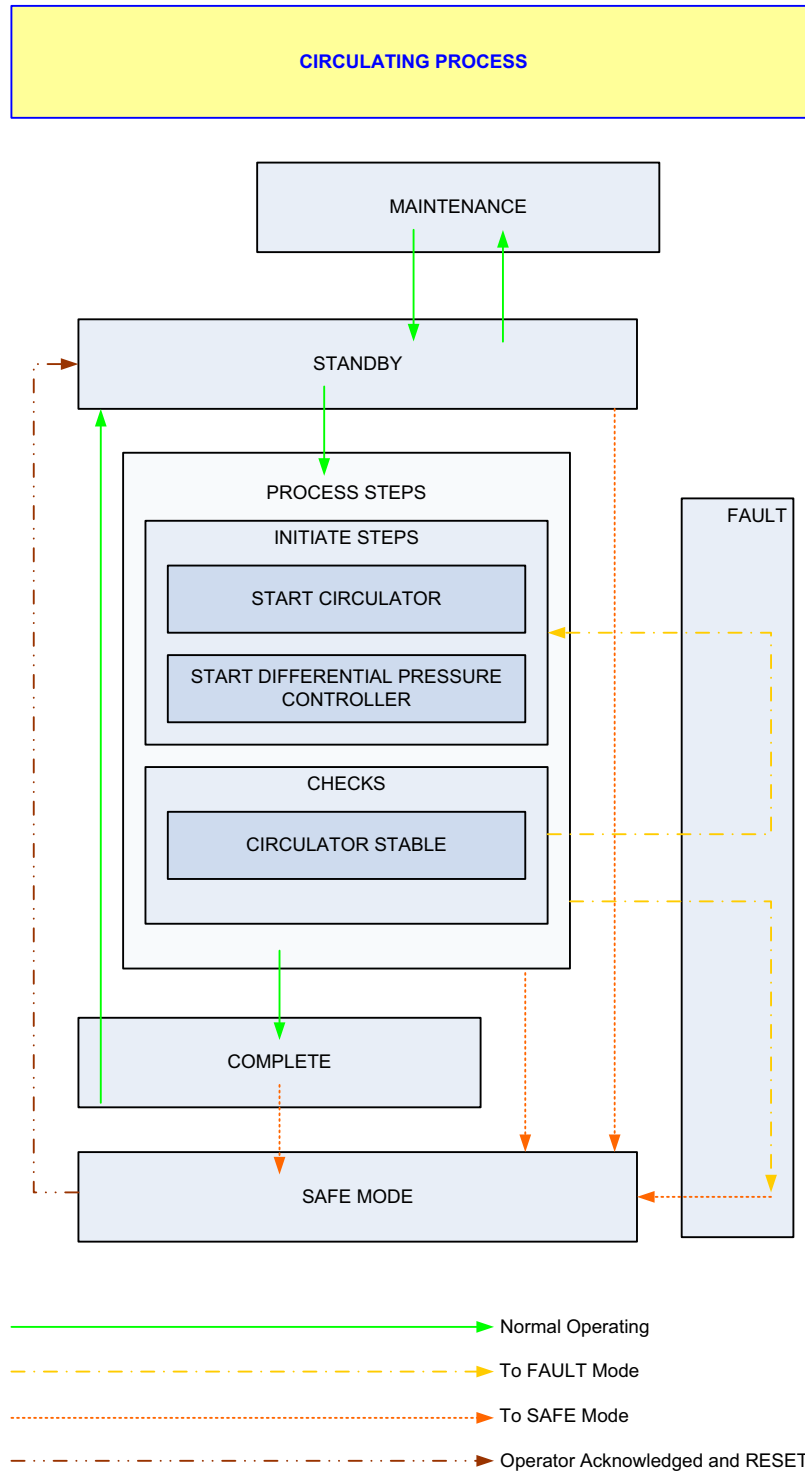


Figure 9-4: Typical CTL process sequence

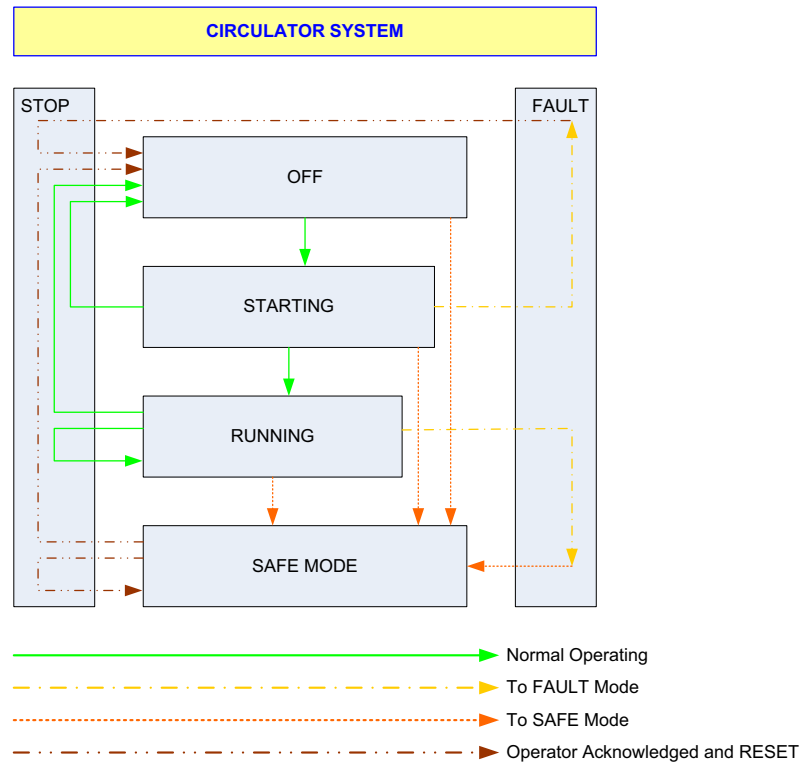


Figure 9-5: Typical CTL system sequence

9.5.3 Control Loops

With reference to the Process and Instrumentation Diagram (P&ID's) (reference [9-16]) for the CTL the following types of controllers are discussed:

- Pressure differential control
- Temperature control

The pressure control is similar to pressure control of the Technology Development Loops (TDLs) (reference [9-8]) and will be incorporated for the CTL in design phases to come.

9.5.3.1 Differential Pressure Control

The differential pressure over the circulator (TS4_1.1) will be controlled by the opening and closing of valves; VL4_1.2, VL4_1.3 and VL4_1.4, in conjunction with adjusting the control valve (VL4_1.5) that is in parallel with the open/close valves and the orifice (OR4_1.1) as shown in Figure 9-6.

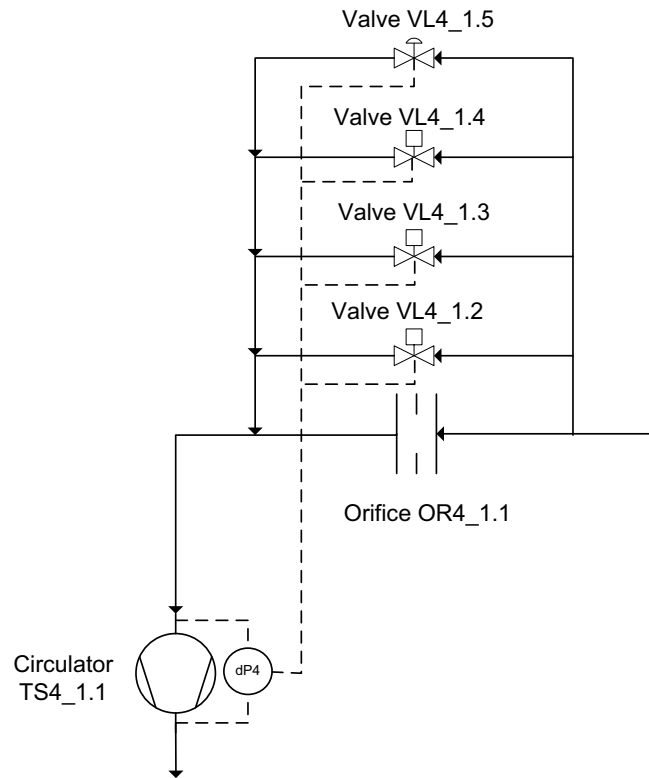


Figure 9-6: Control loop for differential pressure control on the circulator.

9.5.3.2 Pressure Level Control

Refer to paragraph 9.5.1 Standard Operating Procedure on this subject.

9.5.3.3 Temperature Control

The temperature of the gas will be controlled in two phases as follows (refer to Figure 9-7):

- During startup: while the cooler gas side upstream temperature (T4) is below a given temperature 350°C. During this phase the water line valve (VL4_2.1) will be adjusted to control the cooler water side outlet temperature (T8) at 45 °C, for minimal heat removal, i.e. faster heat-up.
- During operation: when the cooler gas-side upstream temperature (T4) is equal to or above a temperature of 350°C as mentioned above. During this phase the water line valve (VL4_2.1) will be adjusted to control the cooler gas-side outlet temperature at the outlet of the bypass line (T5) at 334 °C.

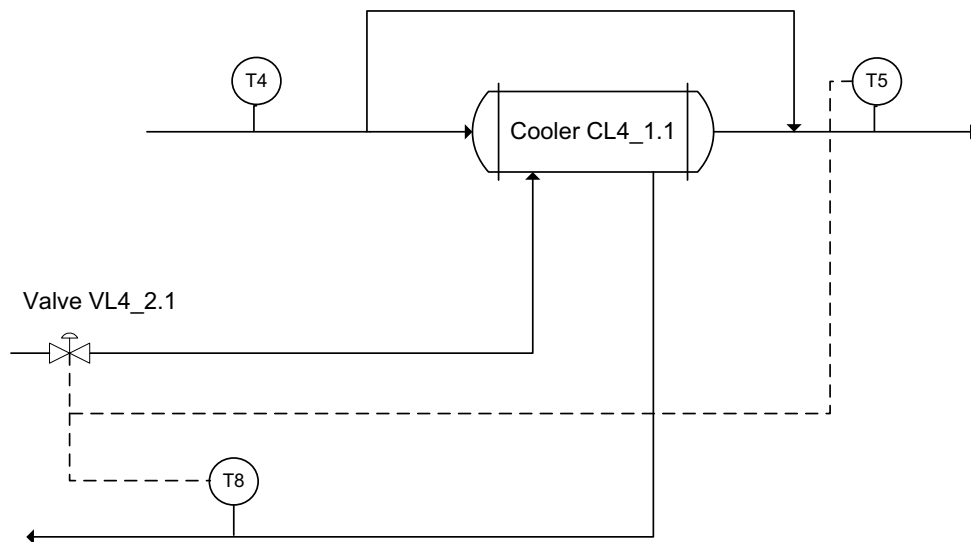


Figure 9-7: Circulator Test Loop Temperature control loops.

9.5.4 Initial Instrumentation Specification

Table 9-3 shows the minimum instrumentation instrument requirements with an indication of whether the instrument will be used for protection, control or validation and verification and whether it is required for a certain test specification. The maximum nominal conditions are given at which each instrument will be operating. Preliminary operating ranges for each instrument were obtained from the maximum nominal conditions.

Table 9-3: CTL Initial Instrumentation Specification

Component	Instrument	Protection	Control	V&V	Test spec	Temperatures (°C)		Mass flows (kg/s)		Pressures (MPa)		Diff Press (kPa)		Other	
						Max nom	Range	Max nom	Range	Max nom	Range	Max nom	Range	Max nom	Range
OR 4_1.2	T1	x	x		INL F&OR	350				9.5	0-11				
	P1	x	x		INL F&OR	350				9.5	0-11				
	dP1	x	x		INL F&OR	350				9.5	0-11				
OR 4_1.3	T2	x	x		INL F&OR	350				9.5	0-11				
	P2	x	x		INL F&OR	350				9.5	0-11				
	dP2	x	x		INL F&OR	350				9.5	0-11				
OR 4_1.4	T3	x	x		INL F&OR	350				9.5	0-11				
	P3	x	x		INL F&OR	350				9.5	0-11				
	dP3	x	x		INL F&OR	350				9.5	0-11				
TS 4_1.2	F4				INL F&OR	350		160		9.5	0-11				
	T4		x		INL F&OR	350				9.5	0-11				
	T5		x		INL F&OR	350				9.5	0-11				
CL 4_1.1	T6				INL F&OR	350				9.5	0-11				
	T7	x	x			20	0-40	135	0-150	0.3	0-0.4				
	T8	x	x			45	0-60	135	0-150	0.15	0-0.4				
VL 4_2.1	F5		x			20	0-40	135	0-150	0.3	0-0.4				
	P6	x				45	0-60	135	0-150	0.15	0-0.4				
	P5	x				20	0-40	135	0-150	0.3	0-0.4				
VL 4_1.1	VL 4_2.1	x	x			20	0-40	135	0-150	0.3	0-0.4				
	dP9				PCDR Section 6	350				9.5	0-11				
	T9					350				9.5	0-11				
TS 4_1.1	T10					350				9.5	0-11				
	T11					350				9.5	0-11				
	P4				WEC-TS-CIRC-003	350				9.5	0-11				
	dP4					350				9.5	0-11				
	N1	x				350				9.5	0-11				
	A1					350				9.5	0-11				

Component	Instrument	Protection	Control	V&V	Test spec	Temperatures (°C)		Mass flows (kg/s)		Pressures (MPa)		Diff Press (kPa)		Other	
						Max nom	Range	Max nom	Range	Max nom	Range	Max nom	Range	Max nom	Range
VL 4_1.2	A2					350				9.5	0-11				
	VL 4_1.2					350				9.5	0-11				
	VL 4_1.3		x			350				9.5	0-11				
	VL 4_1.4		x			350				9.5	0-11				
VL 4_1.5	VL 4_1.5		x		WEC-TS-CIRC-003	350				9.5	0-11				
OR 4_1.1	dP5			x		350				9.5	0-11				
TS 4_1.4	dP6				WEC-TS-MC-002	350				9.5	0-11				
	dP7					350				9.5	0-11				
	A3					350				9.5	0-11				
	dP8					350				9.5	0-11				
TS 4_1.3	A4				WEC-TS-PIP-009	350				9.5	0-11				
	A5					350				9.5	0-11				

9.6 CTL: Electrical Design

9.6.1 Power Requirements

The only large-scale power consuming component in the CTL is the circulator for which the nominal continuous operation electrical power rating is 13MW.

The power requirement for the measurement instrumentation is in addition to the circulator requirement.

9.6.2 One-Line Diagrams

An electrical one-line diagram including the required voltages and interface requirements for each system is available as part of the NGNP-CTF design in reference [9-7] .

9.7 CTL: Future Work

The CTL loop (excluding the Circulator itself) does not require specific Research and Development to perform the required test as all items are commercially readily available.

- An evaluation of flow meter accuracy and number of orifice flow meters can be performed during detail design. The monetary value of accuracy has to be traded against the cost of helium and steel pipe per meter.
- An important geometric aspect of an orifice flow meter is that it requires upstream and downstream pipe lengths for velocity profile development. The total length of these flow development sections can be reduced by using more than one smaller orifice flow line in parallel. This can also be considered during detail design.
- The placement of the cooler and the pressure drop section in the loop have to be revised during detail design, as the most appropriate re-entry place for the blower surge control line is at the cooler inlet. The cooler could also be integrated into the Mixing Chamber Test Station
- The maximum power rating for the Circulator Test Station (13MW) has to be revised, as the current design is for continuous nominal power rating only. Depending on the design, the power consumption can increase to 150 percent of nominal when testing at higher flow rates. This also depends on the test requirement, whether any higher flow rates are required for the circulator designs to be tested. One possible mitigating measure is to design the Circulator control system such that the maximum electrical power supplied is always 13MW, i.e. if the pressure drop decreases, the Circulator speed will be automatically decreased such that the electrical power consumption is still 13MW at a slightly higher

volume flow rate. This issue highlights the necessity of doing the Circulator design.

- The CTL pipe diameter has to be revised. The largest commercially available seamless pipe capable of 9 MPa and 350°C, is a 24" pipe, which will cause flow velocities in excess of 80m/s. It is currently not known what the practical limit on helium pipe flow velocity is. Previous high-temperature helium test setups had velocities up to 65m/s. Flow velocity could be limited by flow-induced vibration damage to the liner/insulation system, or there could be liner erosion at 950°C. If neither of these are a problem, it becomes a plant design optimization task, i.e. a tradeoff study needs to be performed done between pipe size and circulator pressure rise as these are linked by the pressure drop.
- Test specifications have to be drawn up for other components of the NGNP Heat Transport System. These typically include isolation and relief valves that can be tested full-scale in the CTF.
- For future work on improving the energy efficiency of the entire CTF plant, a gas to gas heat exchanger can be installed between the CTL and some of the other test loops, such as the Technology Development Loops (TDLs) in order to heat the gas in the TDL with the waste heat from the CTL. This integration should be done in such a way that operation of the two loops is not dependent on each other, so that each can still operate when the other is out of service. The added plant complexity and cost of the gas-gas heat exchanger will also have to be discounted against the cost of electricity for heating.

9.8 Interface Specification / Requirements

Cooling water

The cooling water requirement is 155 kg/s at 20°C supply and 40°C return temperature.

Helium Inventory Control System

Based on first estimates for pipe lengths, the helium inventory is 604kg. The HICS system is required to control the pressure level in the CTL, i.e. the pressure set point is given to the HICS system, with no pressure control on the side of the CTL.

Electrical power requirement

The CTL continuous operation electrical power rating is 13MW.

Heating, Ventilation and Air Conditioning (HVAC)

The estimated heat loss from the insulated piping to the environment is 92kW (at 30°C ambient temperature), as calculated in reference [9-14].

Hoisting/Crane requirement

The circulator is expected to be the heaviest component in the CTL, but it has not yet been designed, so that no specification can yet be given for the maximum lifting capacity.

NGNP-CTF Interface Requirements Table: "CIRCULATOR TEST LOOP"

Identification		Physical					Electrical				Instrumentation		Thermo hydraulic						
Equipment name and short description	Equipment number	Interface number	Nozzle number	Nozzle nominal size Inch	Mass kg	Elevation from finished floor level m	Sizes XxYxZ* or Diam.xZ mm	Power usage kW kW	Duty(%)	No of phases	Amps A	Volts V	Instrument type P, T, dP, F	Instrument Number	Flow kg/s	Temperature in °C	Temperature out °C	Heat transfer kW	Fluid type
Circulator	TS4.1.1			0.85m (2 off)				13000	100%	3		13800	P, T, Dp, F		160		334	350	He
Cooler	CL4.1.1												T, F		155	155	20	40	13000 water

9.9 References

- [9-1] “NGNP-CTF-MTECH-TLDR-0004. NGNP CTF Test Loop Pre-Conceptual Design Report. Section 4: System Requirement Manual”, dated December 2008.
- [9-2] “NGNP-PCDR Section 3, Plant Level Design Integration,” Figure 3.1-6, p3-18 of 107, dated May 2007
- [9-3] “INL Technical and Functional Requirements, INL/EXT-08-14150,” Paragraph 3.1.3.0, p8 of 21
- [9-4] “NGNP-PCDR Section 6, Heat Transport System,” p6-18 of 100, dated May 2007
- [9-5] “NGNP-CTF-MTECH-TLDR-0005. NGNP CTF Test Loop Pre-Conceptual Design Report. Section 5: Small-Scale Development Tests (SSDT)”, dated December 2008
- [9-6] “Quantifying Uncertainty in Analytical Measurement,”
<http://www.measurementuncertainty.org/mu/QUAM2000-1.pdf>
- [9-7] “NGNP-CTF-E-WIR-001-2 NGNP CTF Electrical One-Line Diagram,” dated December 2008
- [9-8] “NGNP-CTF-MTECH-TLDR-0006. NGNP CTF Test Loop Pre-Conceptual Design Report. Section 6: Technology Development Loop (TDL),” dated December 2008

“Measurement of fluid flow by means of pressure differential devices inserted in circular-cross section conduits running full:”
- [9-9] ISO 5167-1: Part 1: General principles and requirements
- [9-10] ISO 5167-2: Part 2: Orifice plates
- [9-11] ISO 5167-3: Part 3: Nozzles and Venturi nozzles
- [9-12] ISO 5167-4: Part 4: Venturi tubes
- [9-13] “NGNP Technology Development Road Mapping Report” NGNP-CTF MTECH-TDRM, dated December 2008

9.10 Appendices: Supporting Documentation

The following files are associated with this document:

- [9-14] Appendix A.1 CTL Calculation Sheet
- [9-15] Appendix A.2 CTL Process Flow Diagram
- [9-16] Appendix A.3 CTL Process and Instrumentation Diagram
- [9-17] Appendix B.1 Cooler Data Sheet
- [9-18] Appendix B.2 Cooler CL4_1.1 Outline Model
- [9-19] Appendix B.3 Cooler CL4_1.1 Sectional Model
- [9-20] Appendix B.4 Cooler CL4_1.1 Tube Layout Model
- [9-21] Appendix C Pressure dissipation orifice data sheet
- [9-22] Appendix D Flow measurement orifice data sheet
- [9-23] Appendix E.1 CTL Piping Calculation Sheet
- [9-24] Appendix E.2 CTL Piping data sheet
- [9-25] Appendix F Open-Close Valve data sheet
- [9-26] Appendix G Control Valve data sheet
- [9-27] Appendix H Water Control Valve data sheet

Appendix A



M - T e c h
i n d u s t r i a l

***Attachment to Section 9: Circulator Test Loop
(CTL)
Appendix A.1 CTL Calculation Sheet***

Document number: MT-TLDR-CAL-F-T-0901

Revision: 1

Status: Approved

H.J. van Antwerpen

November 2008

CHANGE HISTORY

Configuration Control	
Client Name:	Westinghouse Electric Company
Project Number:	NGNP-CTF MTECH-TLDR
Project Name:	NGNP-CTF-Test Loop Preconceptual Design
Calculation Title:	CTL Calculation Sheet
Calculation Identification Number:	MT-TLDR-CAL-F-T-0901
Quality Level:	3

Template No: MT-TLDR-CAL-REP rev 1

Authorisation			
Action	Name	Signature	Date
Preparer	H J van Antwerpen	_____	November, 29, 2008
Reviewer	D J Viljoen	_____	November, 29, 2008
Approver	R de Bruyn	_____	November, 29, 2008

Original Signed Copy at CMC

Distribution					
Discipline	Name	Discipline	Name	Discipline	Name

Confirmation Required Status			
Calculation Page	Input/Assumption that Requires Confirmation	Preparer and Date Input/Assumption Confirmed	Reviewer and Date Input/Assumption Approved
5	Helium gas velocity in the CTL process pipes: 40m/s.		

Record of Changes	
Revision	Description of Changes
A	Initial Draft
1	Document Approved

References to this document
NGNP-CTF MTECH-TLDR-0009

Change Forecast

The document format and contents have been approved.

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1. Objective

The objective of the calculation is to perform sizing calculations for the CTL pipes, valves and orifices according to pressure drops in the Circulator Test Loop. The heat loss to the environment, helium inventory as well as flow temperatures and heat loads around Cooler C1 is also calculated.

2. Methodology

2.1 APPROACH

The nominal Circulator performance specification is used as input to determine heat loads, flow rates and pressure drops in other components. As information becomes available in the calculation results, it serves as input to other calculations.

2.2 COMPUTER PROGRAMS

The computer program used is Engineering Equation Solver (EES). EES automatically recognizes the relationships between variables in the various equations and uses an iterative Newton-Raphson algorithm to solve sets of simultaneous equations. Therefore, it is not necessary for equations to be arranged such that the calculated variable is the subject of the equation, or for equations to be entered in a specific order. This has to be kept in mind when reviewing the equations in this document.

EES also has built-in thermodynamic property tables for many fluids. This built-in fluid property database is used as the source for thermodynamic and heat transfer properties in these calculations.

3. Inputs and Assumptions

3.1 ASSUMPTIONS

- Environment temperature is taken as 30°C in order to calculate the highest possible pressure vessel wall temperature
- The convection heat transfer coefficient to ambient conditions is assumed to be 10W/m²K. From previous experience on the Helium Test Facility in South Africa, this was found to be quite accurate.
- The radiative heat transfer view factor from vessel surface to environment equals one.
- Radiative Area_{environment} is infinitely large. This simplifies the radiation heat transfer calculation.
- Cladding: polished stainless steel: emissivity: $\epsilon_{\text{clad}} = 0.3$
- The above emissivity values are from: Heat and Mass Transfer, Incropera and De Witt, Fifth Edition, 2002
- Helium gas velocity in the CTL process pipes: 40m/s. This is considerably below historical values for hot gas ducts, of around 65m/s
- Water velocity in the cooling water piping: 2m/s [Recommended velocity to prevent water hammer (www.wikipedia.org)]

- A typical ratio between the orifice diameter and the pipe diameter: $\text{Beta}_{\text{orifice\_flowmeter}} = 0.6$
- A typical discharge coefficient for an orifice: $C_d = 0.65$
- The pressure drop allowance for the hot gas duct: $dP_{\text{hot gas duct}} = 2 \text{ kPa}$
- The pressure drop allowance for the mixer: $dP_{\text{mixer}} = 10 \text{ kPa}$
- The pressure drop allowance for the cooler: $dP_{\text{cooler}} = 10 \text{ kPa}$
- Pipe inner surface roughness: $e = 67.5 \text{e-6m}$. Commercial steel pipe roughness according to http://www.engineeringtoolbox.com/major-loss-ducts-tubes-d_459.html
- Water cooler helium outlet temperature $T_{\text{He}} = 100^\circ\text{C}$

3.2 INPUTS

- Circulator heat input to loop: $Q_{\text{th}} = 13\,000 \text{ kW}$
- Circulator mass flow: $m_{\text{he}} = 160 \text{ kg/s}$
- Maximum temperature of the gas stream: $T_{\text{sys}} = 350^\circ\text{C}$
- Circulator pressure rise: $dP_{\text{circulator}} = 450 \text{ kPa}$

All the above inputs from [NGNP Preconceptual Design Report Section 3, p3-19 of 107]

All fluid properties were calculated by the internal database in EES, as follows:

Fluid properties:

cp_water	4.183	[kJ/kg-K]
cp_helium	5.187	[kJ/kg-K]
cv_helium	3.121	[kJ/kg-K]
gamma	1.662	[-]
mu	3.323e-5	[kg/m-s]
rho	6.831	[kg/m^3]
R_helium	2.065	[kJ/kg-K]

4. Equations Used and Calculations

The following equations are used:

Radiative heat transfer between two opaque, grey, diffuse surfaces.
 [Heat and Mass Transfer, Incropera and De Witt, Fifth Edition, 2002]

Orifice sizing equations

[Measurement of fluid flow by means of pressure differential devices inserted in circular-cross section conduits running full. ISO 5167-2: Part 2: Orifice plates]

Valve sizing equations

[Control Valve Sizing Standard: ISA-75.01.01-2002 Flow Equations for Sizing Valves]

Darcy-Weisbach pressure drop equation for fully-developed turbulent, incompressible flow.

[Mechanics of fluids, Shames, Third Edition, McGraw-Hill, 1992]

Conservation of mass for cooler energy balance

Conservation of energy for cooler energy balance

[Fundamentals of Thermodynamics, Sonntag et al, Fifth edition, 1998]

The equations are described in Attachment A.

5. Results

The most important results are summarised in Figure 5-1, while additional results are given below.

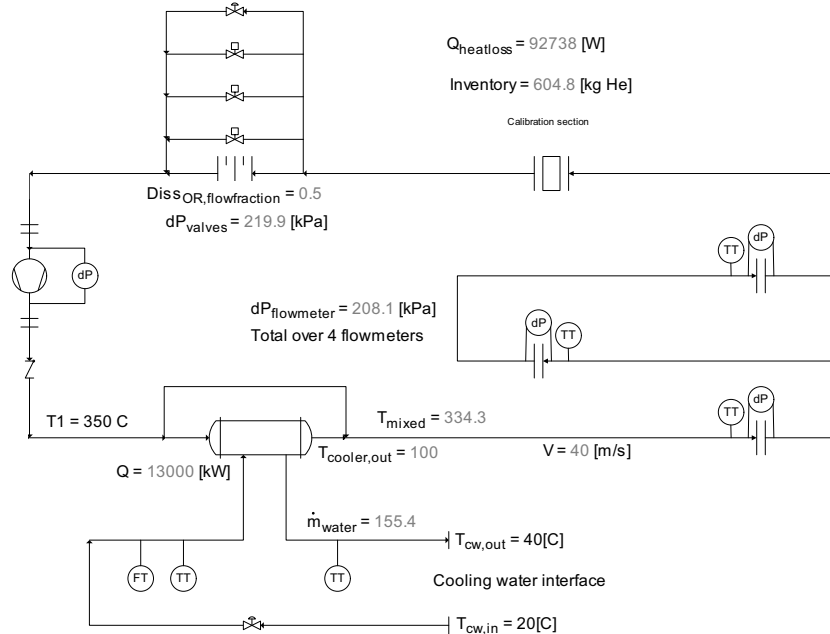


Figure 5-1. Calculated parameters in the CTL.

5.1 GEOMETRY

Pipe diameter: 0.85m
 Total pipe length: 151m

5.2 COOLER

Cooler water mass flow: 155kg/s
 Mixed helium temperature after cooler: 334°C.
 Cooling water pipe diameter: 0.315 m

5.3 HICS REQUIREMENT

The helium inventory is estimated at 604kg.

5.4 HEAT LOSS

Heat loss to the environment is calculated to be 2.375 MW from uninsulated pipes.
 For insulated pipes, assuming a cladding temperature of 50°C (typical value for insulated pipe cladding), the heat loss to the environment is calculated as 100kW.

5.5 PIPEWORK

The pressure drop through the pipe work was calculated as 11.3kPa.

5.6 ORIFICE FLOW METERS

The pressure drop across one orifice was calculated as 52kPa.

5.7 PRESSURE DISSIPATING VALVES

The required Cv value per valve was calculated as 1358 [USGPM/sqrt(psi)].

5.8 PRESSURE DISSIPATING ORIFICE

With the Beta-value, the pressure drop (dP_{valves}) and the mass flow fixed, the pipeline size for the dissipation orifice was calculated as 0.43m.

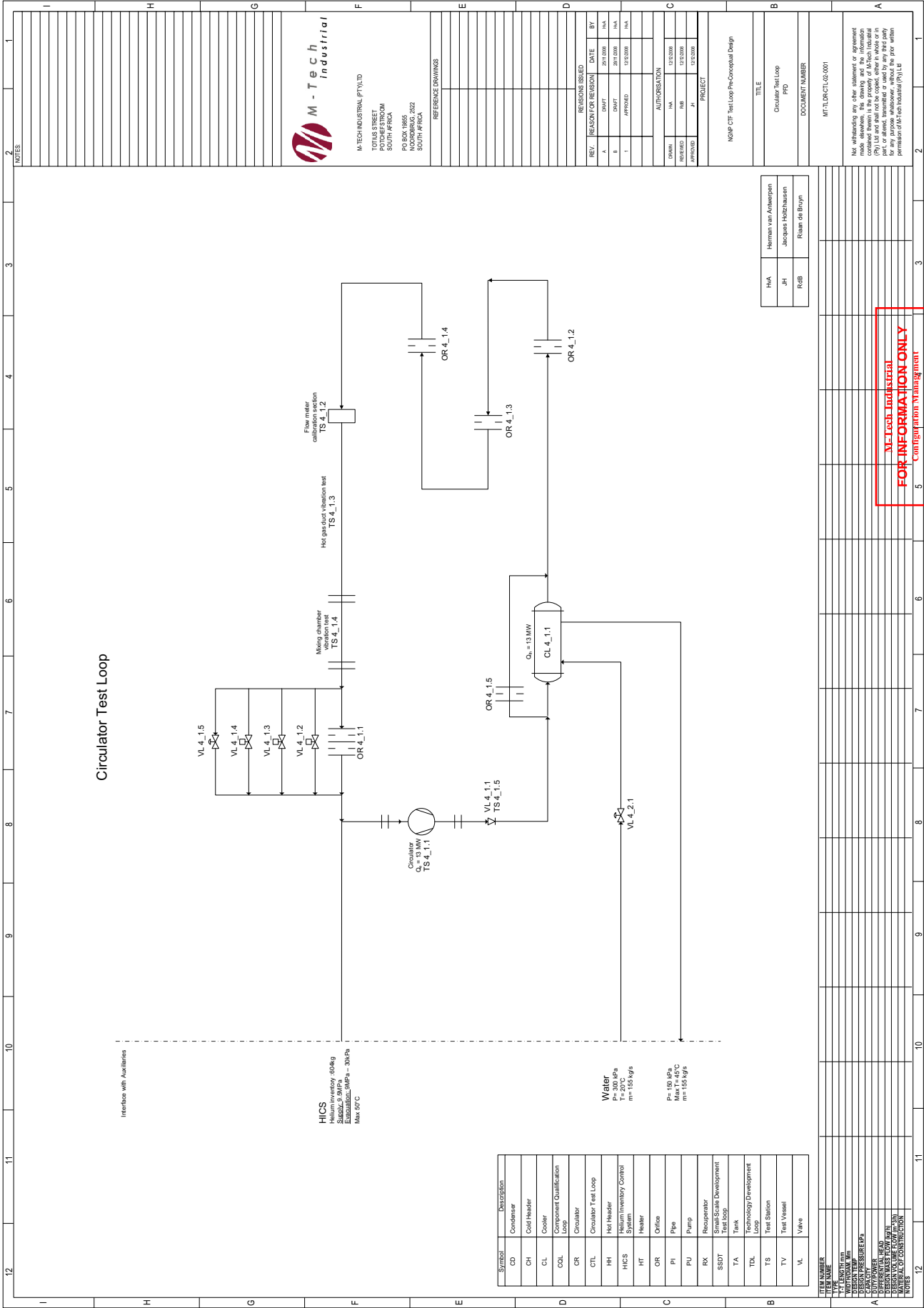
The Mach number was calculated as 0.16 (which is smaller than 0.3), so that it is valid to use and incompressible approach for calculation.

6. Conclusions

All relevant component sizes have been calculated in an integrated manner, thereby taking ensuring proper matching of component sizes in the context of the system.

Attachment A

CTL Calculation Sheet EES Model



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Configuration Management

M - T e c h Industrial

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REFERENCE DRAWINGS

REV.	REASON FOR REVISION	DATE	BY
A	ISSUED	2010/08	N/A
B	ISSUED	2010/08	N/A
C	APPROVED	12/03/08	N/A

AUTHORISATION	DATE
ISSUED	12/03/08
REVIEWED	12/03/08
APPROVED	12/03/08

NGMP CTF Test Loop Pre-Conceptual Design

TITLE	Circulator Test Loop
PROJECT	PROJECT
DOCUMENT NUMBER	MTL-DR-CT1-02-0001

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Appendix B

Appendix B.1

Component Specification Sheet

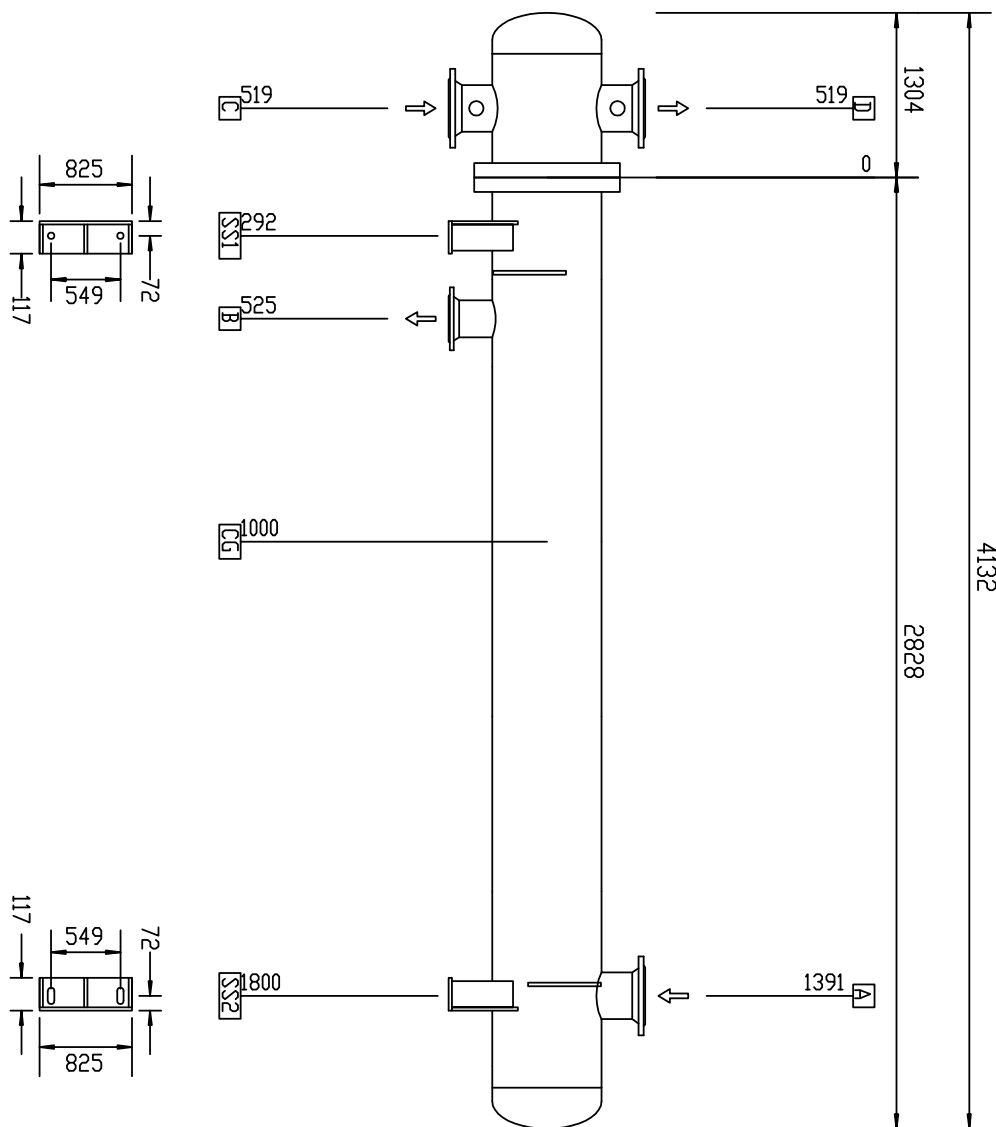
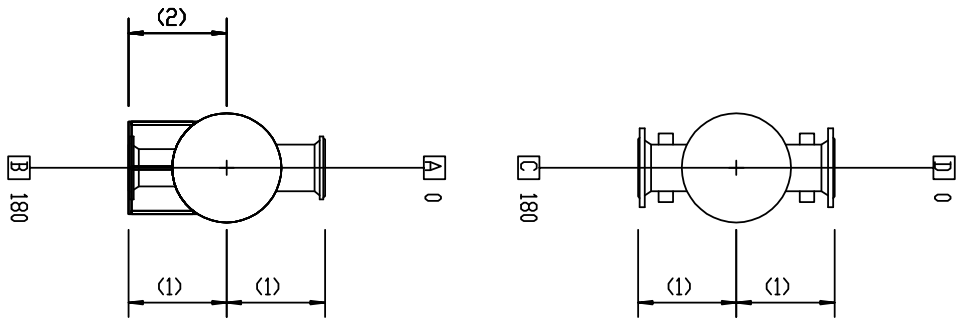
Company:	M-Tech Industrial (Pty) Ltd		
Location:	Potchefstroom, South Africa		
Document Number:	MT-TLDR-CTL-CMPT-05-0002		
Component:	CTL Cooler (CL 4_1.1)		
Date:	11 December 2008	Rev. No.:	2

Authorisation			
Action	Name	Signature	Date
Preparer	Bennie Nel		December 11, 2008
Reviewer	David Viljoen		December 11, 2008
Approver	Riaan de Bruyn		December 17, 2008

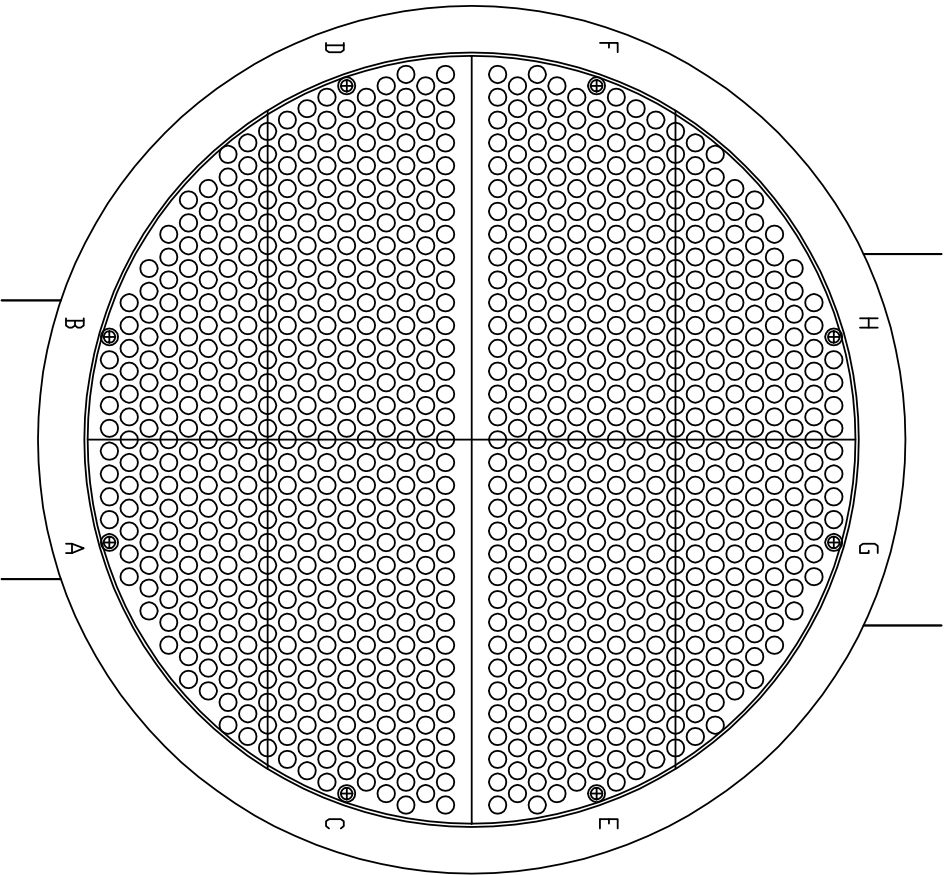
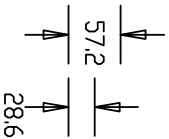
Record of Changes	
Revision	Description of Changes
A	Initial Draft
1	Document Approved
2	Configuration tables added

CL 4_1.1 Component Specification Sheet		
<u>Shell side:</u>	<u>Value & Unit</u>	<u>Remarks</u>
P_{he} :	9 000 kPa	Nominal pressure.
$T_{he\ in}$:	350 °C	Inlet temperature.
$T_{he\ out}$:	100 °C	Outlet temperature.
ΔP_{he} :	8.02 kPa	Pressure loss.
V_{he} :	8.93 m/ s	Velocity.
m_{he} :	10 kg/s	
Passes:	1	
T_{design} :	387.78 °C	
P_{design} :	9 790 kPa	
<u>Tube side:</u>		
P_w :	120 kPa	Nominal pressure.
$T_{w\ in}$:	20 °C	Inlet temperature.
$T_{w\ out}$:	40.14 °C	Outlet temperature.
ΔP_w :	22.454kPa	Pressure loss.
V_w :	2.23 m/ s	Velocity.
m_w :	155 kg/s	
Passes:	2	
T_{design} :	77 °C	
P_{design} :	517 kPa	
Q:	13.079 MW	Heat Exchanged.
<u>Tubes:</u>		
No. of tubes:	463 U's	
Outside diameter:	19.05 mm	
Thickness _{avg} :	2.6 mm	
Length:	200	

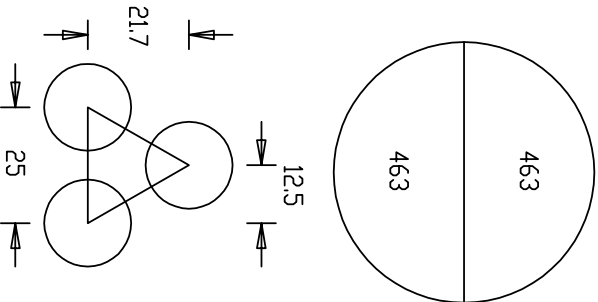
Pitch:	25 mm	
<u>Body Shell:</u>		
Length:	4 132 mm	Total length, head to head.
Outside diameter:	950 mm	
Wall thickness:	51 mm	
Corrosion allowance:		
<u>Nozzles:</u>		
No. of protrusions:	4	
Connections:	Flanged	
Length:		
Outside diameter:		
Wall thickness:		
<u>Elliptical Head:</u>		
Head ratio:		
Height:		
Wall thickness before:		
Wall thickness after:		
Skirt:		
<u>Total Mass:</u>	11 648 kg	
<u>Material:</u>		
Shell material:	SA-516 Gr 70	
Tube material:	SA-214 Wld Tube	



Row	Holes
36	8
35	13
34	16
33	19
32	22
31	23
30	26
29	27
28	28
27	29
26	30
25	31
24	30
23	31
22	32
21	32
20	33
19	33
18	33
17	32
16	32
15	32
14	31
13	30
12	31
11	29
10	30
9	28
8	27
7	26
6	23
5	22
4	19
3	16
2	13
1	8



Shell ID 848 mm
D.T.L. 840.9 mm
Baffle cut to C/E23.4 mm



Appendix C

Appendix C

Component Specification Sheet

Company:	M-Tech Industrial (Pty) Ltd		
Location:	Potchefstroom, South Africa		
Document Number:	MT-TLDR-CTL-CMPT-05-0007		
Component:	CTL Pressure Dissipating Orifice (OR 4_1.1)		
Date:	11 December 2008	Rev. No.:	2

Authorisation			
Action	Name	Signature	Date
Preparer	Bennie Nel		December 11, 2008
Reviewer	David Viljoen		December 11, 2008
Approver	Riaan de Bruyn		December 17, 2008

Record of Changes	
Revision	Description of Changes
A	Initial Draft
1	Document Approved
2	Configuration tables added

OR 4_1.1		
Component Specification Sheet		
	<u>Value & Unit</u>	<u>Remarks</u>
P_{he} :	9 600 kPa	Nominal Pressure.
$T_{he\ in}$:	350 °C	Inlet temperature.
$d_{internal\ pipe}$:	0.43 m	
$d_{orifice}$:	0.256 m	Orifice to be sized such that when circulator runs at nominal operating point, half of the flow goes through dissipating orifice, while the rest goes through 2 open valves. Thus four valves would provide roughly a 50% variation in flow rate.
m_{he} :	80 kg/s	
ΔP_{he} :	220 kPa	Pressure loss across orifice.
β ratio:	0.6	
Fluid:	Helium	
T_{design} :		
P_{design} :		
<u>Material:</u>		
Body material:		
Connection:	Flanged	

Appendix D

Appendix D

Component Specification Sheet

Company:	M-Tech Industrial (Pty) Ltd		
Location:	Potchefstroom, South Africa		
Document Number:	MT-TLDR-CTL-CMPT-05-0004		
Component:	CTL Flow Measuring Orifice (OR 4_1.2; OR 4_1.3; OR 4_1.4)		
Date:	11 December 2008	Rev. No.:	2

Authorisation			
Action	Name	Signature	Date
Preparer	Bennie Nel		December 11, 2008
Reviewer	David Viljoen		December 11, 2008
Approver	Riaan de Bruyn		December 17, 2008

Record of Changes	
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A	Initial Draft
1	Document Approved
2	Configuration tables added

OR 4_1.2; OR 4_1.3; OR 4_1.4
Component Specification Sheet

	<u>Value & Unit</u>	<u>Remarks</u>
P_{he} :	9 600 kPa	Nominal pressure.
$T_{he\ in}$:	350 °C	Inlet temperature.
Fluid:	Helium	
$d_{internal\ pipe}$:	0.85 m	
$d_{orifice}$:	0.51 m	
m_{he} :	160 kg/s	
ΔP_{he} :	52 kPa	Pressure loss across orifice.
β ratio:	0.6	
<u>Material:</u>		
Body material:		
Connection:	Flanged	

Appendix E

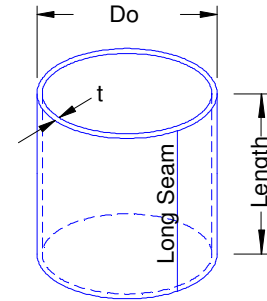
Pipe and Shell CTL

ASME Code VIII Div I 2001 edition no addenda

ASME L-2.2.1 <- BM **1** <- BM Item #
Verification Calc #3 <- Vessel, description

1 <- BM Qty**Dimensions:**

24.000 <- Do - Outside Diameter
1.219 <- t - Nominal Wall Thickness
78.740 <- Length
0.000 <- Corr, Corrosion Allowance

**Material and Conditions:**

SA-516 <- Material
20,000 <- S, Allowable Stress Level (psi)
0.85 <- E1 - Longitudinal Efficiency (circ. stress)
0.65 <- Ec - Circ. Connecting Efficiency (longitudinal stress)
0.0% <- UTP, Undertolerance allowance (%) **16.64** <- Volume (cubic ft)
0.000 <- UTI, Undertolerance allowance (inch) **1,948.3** <- Material Weight (lbs cs)
1392.4 <- P, Interior Pressure
0.0 <- Pa, Exterior Pressure
1 <- B, From exterior pressure curve **0.004317** <- A (use to lookup B)

Variables:

UT = $t \cdot \text{UTP} + \text{UTI}$ = $1.219 \cdot 0 + 0$ undertolerance UT = **0.000**
 Ri = $\text{Do} / 2 - t + \text{corr}$ = $24 / 2 - 1.219 + 0$ inside radius Ri = **10.781**
 nt = $t - \text{Corr} - \text{UT}$ = $1.219 - 0 - 0$ nominal thick nt = **1.219**
 LDo = L / Do = $78.74 / 24$ LDo = **3.281**
 DoT = Do / nt = $24 / 1.219$ DoT = **19.688**

Interior Pressure UG-27 (c) (1,2)

ta = $P \cdot \text{Ri} / (S \cdot E1 - 0.6 \cdot P)$ = $1392.4 \cdot 10.781 / (20000 \cdot 0.85 - 0.6 \cdot 1392.4)$ ta = **0.929**
 tb = $P \cdot \text{Ri} / (2 \cdot S \cdot \text{Ec} + 0.4 \cdot P)$ = $1392.4 \cdot 10.781 / (2 \cdot 20000 \cdot 0.65 + 0.4 \cdot 1392.4)$ tb = **0.565**
 tmin = $\text{Max}(ta, tb) \leq nt$ **Okay** tmin = **0.929**
 PMaxA = $(S \cdot E1 \cdot nt) / (\text{Ri} + 0.6 \cdot nt)$ = $(20000 \cdot 0.85 \cdot 1.219) / (10.781 + 0.6 \cdot 1.219)$ PMaxA = **1800.1**
 PMaxB = $(2 \cdot S \cdot \text{Ec} \cdot nt) / (\text{Ri} - 0.4 \cdot nt)$ = $(2 \cdot 20000 \cdot 0.65 \cdot 1.219) / (10.781 - 0.4 \cdot 1.219)$ PMaxB = **3079.1**
 PMax = $\text{Min}(\text{PMaxA}, \text{PMaxB})$ **Okay** PMax = **1800.1**
 tr1 = $P \cdot \text{Ri} / (S \cdot 1 - 0.6 \cdot P)$ = $1392.4 \cdot 10.781 / (20000 \cdot 1 - 0.6 \cdot 1392.4)$ tr1 = **0.783**

Exterior Pressure UG-28 (c)

A = Interpolated from IID Part D Table G A = **0.004317**
 PaMax = $4 \cdot B / (3 \cdot \text{DoT})$ = $4 \cdot 1 / (3 \cdot 19.688)$ **Okay** PaMax = **0.1**
 tre = $(3 \cdot \text{Do} \cdot \text{Pa}) / (4 \cdot B)$ = $(3 \cdot 24 \cdot 0) / (4 \cdot 1)$ tre = **0.000**

Shell stress relief -UCS-79(d), UNF-79(d), UHA-44(d)

Rf = $(\text{do} - t) / 2$ = $(24 - 1.219) / 2$ **11.3905**
 % elong = $(50 \cdot t / \text{Rf}) \cdot (1 - 0)$ = $(50 \cdot 1.219 / 11.391) \cdot (1 - 0)$ % elongation = **5.4**

0.1% <- Max Elongation**Yes** <- Cold formed **5.4%** <- Elongation**no** <- Vessel carries lethal substances (Yes/no)**no** <- Impact testing is required (Yes/no)**no** <- Greater than 10% reduction in thickness**no** <- Formed between 250 and 900 Degrees F**YES** <- Shell is greater than 5/8" thick before forming

Required	Yes ?
no	no
no	no
no	no
no	no
no	no
Stress Relieve ?	no



M - T e c h
i n d u s t r i a l

***Attachment to Section 9: Circulator Test Loop
(CTL)
Appendix E.1 CTL Piping Calculation Sheet***

Document number: MT-TLDR-CAL-M-0902

Revision: 1

Status: Approved

H.J. van Antwerpen

December 2008

CHANGE HISTORY

Configuration Control	
Client Name:	Westinghouse Electric Company
Project Number:	NGNP-CTF MTECH-TLDR
Project Name:	NGNP-CTF-Test Loop Preconceptual Design
Calculation Title:	CTL Piping Calculation Sheet
Calculation Identification Number:	MT-TLDR-CAL-M-0902
Quality Level:	3

Template No: MT-TLDR-CAL-REP rev 1

Authorisation			
Action	Name	Signature	Date
Preparer	H J van Antwerpen	_____	December, 4, 2008
Reviewer	D J Viljoen	_____	December, 4, 2008
Approver	R de Bruyn	_____	November, 29, 2008

Original Signed Copy at CMC

Distribution					
Discipline	Name	Discipline	Name	Discipline	Name

Confirmation Required Status			
Calculation Page	Input/Assumption that Requires Confirmation	Preparer and Date Input/Assumption Confirmed	Reviewer and Date Input/Assumption Approved

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Revision	Description of Changes
A	Initial Draft
1	Document Approved

References to this document
NGNP-CTF MTECH-TLDR-0009

Change Forecast

The document format and contents have been approved.

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1. Objective

The objective of the calculation is to perform sizing calculations for the CTL pipes according to the required flow velocity, pressure and temperature.

2. Methodology

2.1 APPROACH

The prescribed calculation methods of the applicable ASME code were used to set up a general calculation sheet that has as inputs: the inner diameter, length, pressure and temperature of the required pressure vessel.

2.2 COMPUTER PROGRAMS

The calculation is performed in Microsoft Excel, using Visual Basic Macros. In this way, only the inputs and the results are visible but the calculation method can not be altered from the spreadsheet.

3. Inputs and Assumptions

3.1 ASSUMPTIONS

- All pressure boundary calculations are done using a MS Excel spreadsheet incorporating ASME Code VIII Div 1 2001, No Addenda
- No corrosion allowance was included
- All pressure boundary outside temperatures are taken as 200°C

3.2 INPUTS

- Proposed material is SA-516 Gr.70
- Allowable stress was taken as 20 KSI at 204°C (400°F) from ASME material property database
- Internal pressures taken as 9.6 MPa
- All other related input can be found in the attached calculation spreadsheet and are included in sections: **Dimensions** and **Material and Conditions**

4. Equations Used and Calculations

All equations used are included in the calculation spreadsheet.

5. Results

The largest pipe diameter capable of handling 9.6 MPa at 350°C is a 24 inch (610mm) pipe with a 1.219 inch (31mm) wall thickness.

The mass per length is calculated as 1948 lbs per 78.75 inch (442 kg/m).

6. Conclusions

A pipe was calculated that is capable of handling the required pressure and temperature. There were no special cases to be calculated or designed so that the pipe design is considered well within the current state of the art.



Attachment A

Pipe and Shell CTL

Appendix E.2

Component Specification Sheet

Company:	M-Tech Industrial (Pty) Ltd		
Location:	Potchefstroom, South Africa		
Document Number:	MT-TLDR-CTL-CMPT-05-0005		
Component:	CTL Piping (CL 4_1.1)		
Date:	11 December 2008	Rev. No.:	2

Authorisation			
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Record of Changes	
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2	Configuration tables added

PI 4_1.1		
Component Specification Sheet		
	<u>Value & Unit</u>	<u>Remarks</u>
P _{he} :	9 600 kPa	Nominal pressure.
T _{he in} :	350 °C	Inside temperature.
d _{internal} :	0.85 m	
m _{he} :	160 kg/s	
V _{he} :	40 m/s	
Roughness _{inner surface}	67.5e-06	The pressure drop caused by the pipe wall friction was calculated as 11.3 kPa.
Q _{heat loss} :	2.375 (0.1) MW	Values inside () is if the pipes are insulated, and the cladding temperature is kept around 50 °C. Insulating is recommended.
Fluid:	Helium	
T _{design} :	350 °C	The surface temperature of the piping is roughly equal to the internal gas temperature, namely 334°C to 350°C.
P _{design} :	9 600 kPa	
<u>Pipes:</u>		
Length:	151 m	Estimated total length.
Outside diameter:		
Wall thickness:		
Mass per meter:		
Corrosion allowance:		
<u>Nozzles:</u>	0	
<u>Elliptical Head:</u>	N / A	
<u>Material:</u>		
Component material:	SA-516 Gr.70	
Allowable stress:	115.14 MPa	

Appendix F

Appendix F

Component Specification Sheet

Company:	M-Tech Industrial (Pty) Ltd		
Location:	Potchefstroom, South Africa		
Document Number:	MT-TLDR-CTL-CMPT-05-0006		
Component:	CTL Open / Close Valves (CL 4_1.1)		
Date:	11 December 2008	Rev. No.:	2

Authorisation			
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Record of Changes	
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VL 4_1.2; VL 4_1.3; VL 4_1.4 Component Specification Sheet		
	<u>Value & Unit</u>	<u>Remarks</u>
P _{he} :	9 600 kPa	Nominal pressure.
T _{he in} :	350 °C	Inlet temperature.
d _{internal pipe} :	0.15 m	
m _{he} :	40 kg/s	
Cv:	1 358	USGPM/sqrt(psi).
ΔP _{he} :	220 kPa	Pressure loss across valve.
Fluid:	Helium	
<u>Physical:</u>		
Type:		
Nominal diameter:		
<u>Material:</u>		
Body material:		
Disc seating surface:		
Seat surface:		
Stem:		
Connection:		

Appendix G

Appendix G

Component Specification Sheet

Company:	M-Tech Industrial (Pty) Ltd		
Location:	Potchefstroom, South Africa		
Document Number:	MT-TLDR-CTL-CMPT-05-0003		
Component:	CTL Control Valve (VL 4_1.5)		
Date:	11 December 2008	Rev. No.:	2

Authorisation			
Action	Name	Signature	Date
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Approver	Riaan de Bruyn		December 17, 2008

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VL 4_1.5 Component Specification Sheet		
	<u>Value & Unit</u>	<u>Remarks</u>
P_{he} :	9 600 kPa	Nominal pressure.
$T_{he\ in}$:	350 °C	Inlet temperature.
$d_{internal\ pipe}$:	0.15 m	
m_{he} :	40 kg/s	
C_v (90%):	1 358	USGPM/sqrt(psi).
ΔP_{he} :	220 kPa	Pressure loss across valve.
Fluid:	Helium	
T_{design} :		
P_{design} :		
<u>Physical:</u>		
Type:		
Outside diameter:		
<u>Material:</u>		
Body material:		
Disc seating surface:		
Seat surface:		
Stem:		
Connection:		

Appendix H

Appendix H

Component Specification Sheet

Company:	M-Tech Industrial (Pty) Ltd		
Location:	Potchefstroom, South Africa		
Document Number:	MT-TLDR-CTL-CMPT-05-0008		
Component:	CTL Water Control Valves (VL 4_2.1)		
Date:	11 December 2008	Rev. No.:	2

Authorisation			
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VL 4_2.1 Component Specification Sheet		
	<u>Value & Unit</u>	<u>Remarks</u>
P _w :	200 kPa	Nominal pressure.
T _{w in} :	20 °C	Inlet temperature.
d _{internal pipe} :	0.32 m	
m _w :	155 kg/s	
Cv:		USGPM/sqrt(psi).
ΔP _{he} :		
Fluid:	Water	
T _{design} :		
P _{design} :		
<u>Physical:</u>		
Type:		
Outside diameter:		
<u>Material:</u>		
Body material:		
Disc seating surface:		
Seat surface:		
Stem:		
Connection:		