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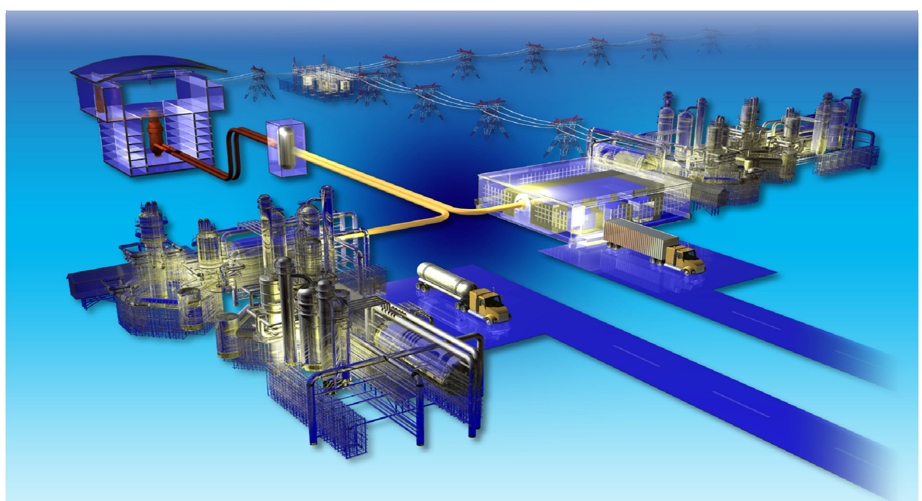
NGNP with Hydrogen Production Preconceptual Design Study, HTGR Component Test Facility (CTF) Feasibility and Recommendations

Prepared by Westinghouse Electric Company, LLC for the Next Generation Nuclear Plant Project

Jacques Holtzhausen

February 2008



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NGNP and Hydrogen Production Preconceptual Design Study

HTGR Component Test Facility (CTF) Feasibility and Recommendations

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[1] "High Temperature Fluid Flows Test Facility White Paper," NGNP Engineering, INL, September 2007	INL/EXT-07-13146

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ACRONYMS

ASME	American Society of Mechanical Engineers
BEA	Battelle Energy Alliance
COTS	Commercial Off the Shelf
CTF	Component Test Facility
CTL	Circulator Test Loop
CQL	Component Qualification Loop (as incorporated in Concept 1)
CQL 2	Large Scale Component Qualification Loop (Concept 2)
CTP	Component Testing Program
DDN	Design Data Need
DOE	Department of Energy
DRL	Design Readiness Level
FHS	Fuel Handling System
FOAKE	First-Of-A-Kind-Engineering
F&OR	Functional and Operational Requirements
HTF	Helium Test Facility
HTTF	High Temperature Test Facility
HTTU	High Temperature Test Unit
HPS	Helium Purification System
HPTU	High Pressure Test Unit
IET	Integrated Effects Tests
IHX	Intermediate Heat Exchanger
INL	Idaho National Laboratory
ISI	In-Service Inspection
LWR	Light Water Reactor
MSS	Main Support System
NHS	Nuclear Heat Source
NGNP	Next Generation Nuclear Plant
PHTS	Primary Heat Transport System
PCDR	Pre-Conceptual Design Report
PCS	Power Conversion system
PBMR DPP	Pebble Bed Modular Reactor, Demonstration Power Plant
PBMM	Pebble Bed Micro Model
RCS	Reactivity Control System
RFC	Ready For Commissioning
SET	Separate Effect Tests
SG	Steam Generator
SHTS	Secondary Heat Transport System
TBD	To be defined
TDL	Technology Development Loop (as incorporated in Concept 1)
TQC	Testing, Qualification and Commissioning
TRL	Technology Readiness Level
UUT	Unit Under Test
V&V	Verification & Validation

SUMMARY AND CONCLUSIONS

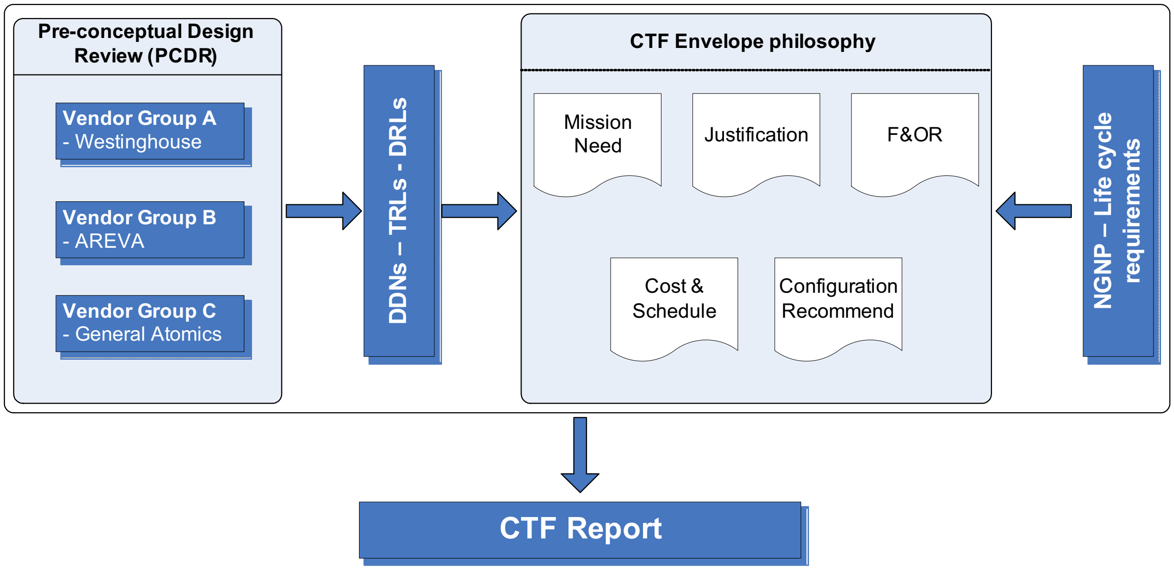
The Next Generation Nuclear Plant (NGNP) project is a US-based initiative to demonstrate the viability of using High Temperature Gas-Cooled Reactors (HTGR) in the production of heat for usage in a wide range of energy producing technologies. These technologies typically include electricity production, hydrogen production, salt water desalination and the like. This forms part of DOE's long term vision of acknowledging the potential of using nuclear energy as opposed to burning fossil fuels to meet the growing demand for energy. This task was authorized by EPAct 2005 and charged Idaho National Laboratories (INL) with the responsibility of investigating and selecting the appropriate technology for supplying process heat at high temperatures (~950°C) using a nuclear heat source.

As part of this responsibility, INL initiated three pre-conceptual designs for the NGNP by different vendor teams. These designs included proposals for the complete system as well as related technology development and testing requirements. The vendor teams identified the major elements of developmental testing and the vendor reports focused mainly on the different heat transport systems and their associated components. In order to support the development of some of the high risk components that were identified in the reports, a dedicated component test facility (CTF) was proposed. Such a facility would be supportive of the NGNP with regard to technology development and risk mitigation in terms of schedule requirements and equipment qualification. Typical applications include primary and secondary heat transport systems testing, demonstration and developmental testing of commercial high temperature process heat applications (e.g., hydrogen production) and testing of NGNP specific control, maintenance and inspection philosophies.

The purpose of this study was to evaluate the feasibility of this envisioned CTF with regards to the following key areas:

- CTF Mission Need
- CTF Justification
- CTF Functional and Operational Requirements (F&ORs)
- CTF Configuration Recommendations
- CTF Cost Estimate and Schedule

The study was conducted by means of a work plan as illustrated in the figure below. The Design Data Needs, Technology Readiness Levels as well as Design Readiness Levels (DDNs, TRLs, DRLs) of all three vendor groups and the NGNP lifecycle requirements were used as inputs to establish the CTF Enveloping Philosophy.

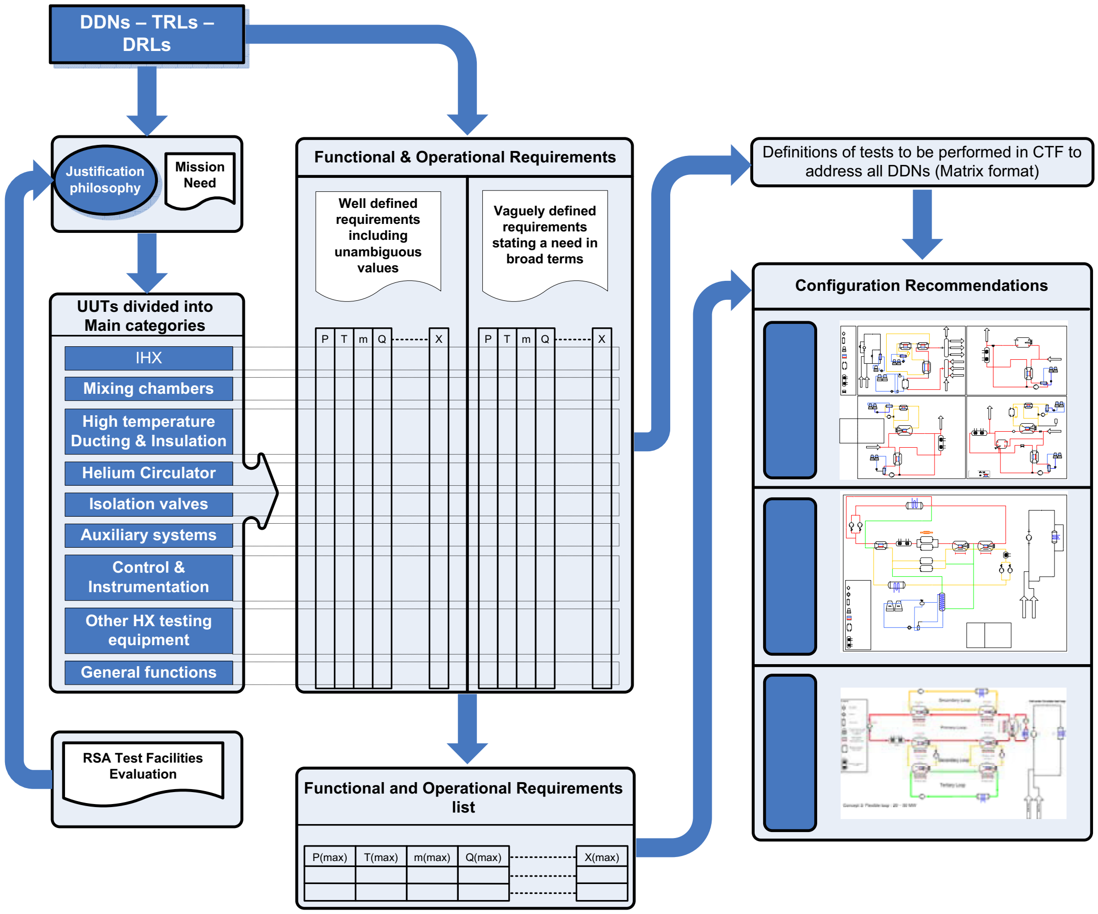


Component Test Facility Feasibility Study Work Plan Outline

The CTF Enveloping Philosophy was defined as:

The CTF is a technology development platform for components and systems in support of the NGNP program. In order for these technologies to be integrated into the NGNP, it will be required that full scale, representative size component tests be conducted on certain items or assemblies. These tests need to be done at NGNP representative conditions, with regards to pressure, flow rate and temperature.

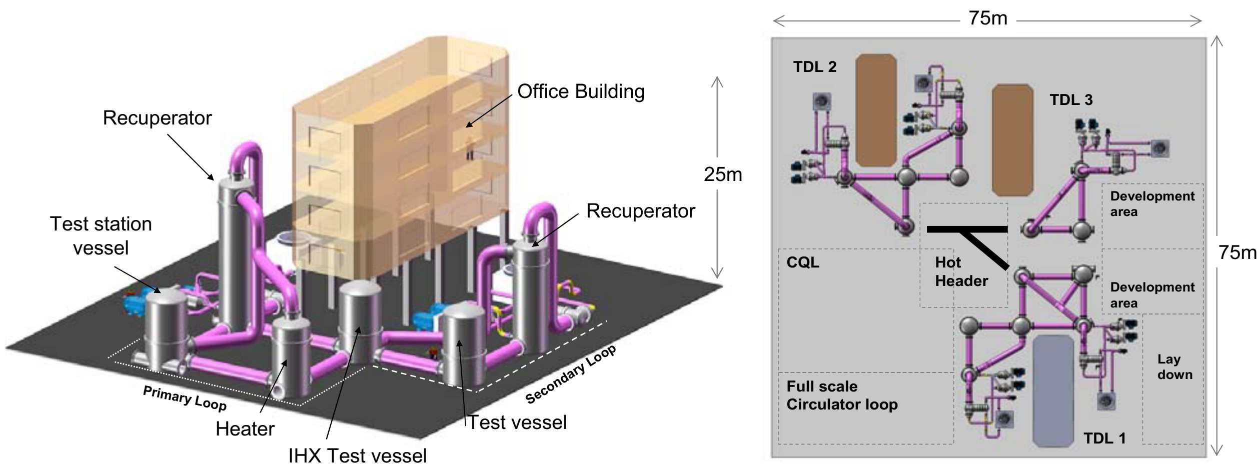
The justification process for the CTF basically consisted of an in depth review of the mission need with specific reference to the Functional and Operational Requirements (F&ORs) that were developed as part of this task. The South African PBMR test facilities were used as basis for the analysis against the F&ORs and Mission Need. The analysis was performed in terms of the technical capability, timeframe utilization and possible modifications to these facilities to meet the CTF requirements. The nine main categories into which the Units Under Test (UUTs) resorted were also defined as part of the analysis. The result of the analysis indicated that none of the RSA test facilities that were evaluated sufficed as a CTF candidate and it was proposed that different concepts be developed that will in fact address all CTF Mission Need requirements. The figure below provides a flow diagram of this process.



Work flow diagram of the process that was followed to attain the Functional & Operational Requirements resulting in the Configuration Recommendation

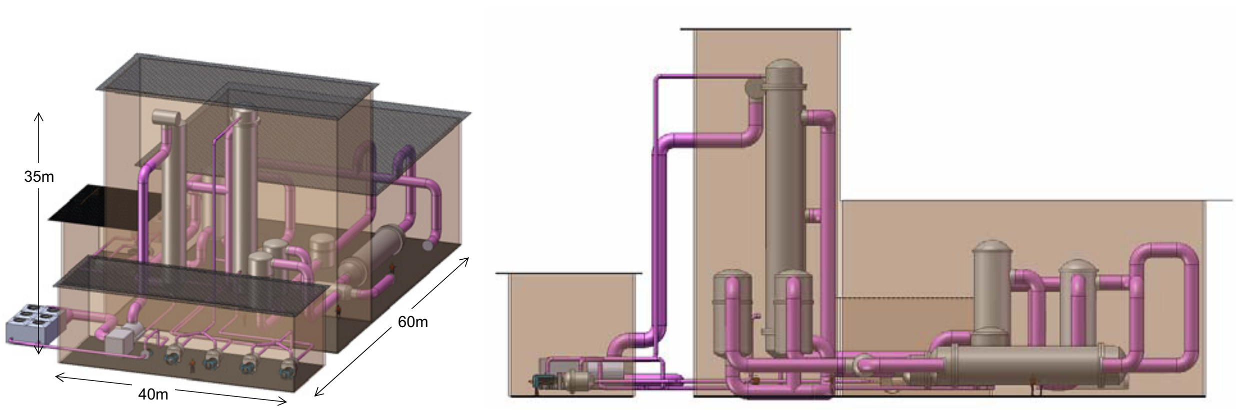
A concept deriving philosophy was formulated with the Mission Needs, DDNs, NGNP lifecycle requirements as well as anticipated time schedules as basis. Three concepts were developed accordingly and a high level trade-off analysis was performed to determine the most feasible concept. The trade-off analysis comprised aspects such as minimizing risk through maximum utilization of commercially available components to improve reliability, minimizing the simultaneous use of two or more units under test, etc.

The first concept (Concept 1) consists of three small, completely independent test facilities which are referred to as Technology Development Loops (TDLs). These individual loops are inter-connectable to a common manifold/header. This interconnected facility can then provide high temperature (950°C), high pressure (9MPa) helium to a single large Component Qualification Loop (CQL) at the combined operational envelopes of all the individual smaller TDLs and can then be used for larger scale component qualification. In addition to the TDLs and CQL, this concept also includes a completely independent and separate, full scale (in terms of the NGNP) Circulator Test Loop (CTL). The two figures below illustrate a 3D layout of a single TDL (on the left) and a plausible footprint size of a complete Concept 1 facility (with all three TDLs and CTL on the right).



Concept 1 Layout

Concept 2 differs from Concept 1 and comprises mainly one large facility plus a separate full-scale CTL, instead of multiple smaller facilities. This large facility's sizing is driven by a mass flow rate recommendation of approximately 15 percent of the maximum NGNP circulating mass flow which relates to roughly 25 kg/s for the concept. A preliminary 3D layout of such a facility is provided in the figures below.



Concept 2 Layout

Lastly, a third concept (Concept 3) was proposed which consists of one large primary loop (20 – 50 MW_t) with numerous secondary loops connected to it as well as a separate CTL. The connection of the primary and secondary loops is established by means of heat transfer testing

UUTs. It is anticipated that the secondary loops are in turn connected to tertiary loops for testing and evaluating of commercial high temperature application items for example hydrogen production systems. This concept was, however, not recommended due to several risks, which could be detrimental when imposed on the NGNP lifecycle requirements, in terms of the Mission Need that was mentioned earlier.

Both Concepts 1 and 2 are feasible options to consider as being CTF candidates; however Concept 1 was recommended. This is mainly due to the fact that it complies with the Mission Need, addresses almost all of the DDNs and F&ORs and aligns better with the NGNP lifecycle requirements in terms of cost and schedule. One of the typical advantages associated with this concept is the higher level of reliability by using commercial-off-the-shelf (COTS) components as opposed to first-of-a-kind engineering (FOAKE) components used in Concept 2 (such as the circulators that still need to be developed). Other advantages include the ability to facilitate a large development audience due to the concurrent, parallel testing capabilities and separate CTL. Another advantage of Concept 1 is the utilization of the manifold/header that enables large scale testing; however this component in itself could provide some design challenges that will be investigated in future studies. Opposed to Concept 1, Concept 2 has the ability to test even larger scale components up to 15 percent of the NGNP scale.

The cost and schedule of both Concepts 1 and 2 were prepared at a feasibility level. Each of the cost estimates were determined as baseline models and a techno-economic trade-off study between Concept 1 and 2 still needs to be performed in the pre-conceptual design phase. Cost estimates were based on applicable South African quotes and experience gained from the PBMR test facilities as well as US-based inputs regarding civil works and the like. Some assumptions were made where not enough information could be gathered and are listed in more detail in the relevant section of this document.

The total cost for Concept 1 amounts to approximately US$ 243 million while that of Concept 2 amounts to approximately US$ 250 million. Both these cost models include expenditure for civil work, hardware components, vessels, structures, utilities, construction management (i.e. distributables) and engineering design costs. The confidence level of the cost estimates that are presented herein is expressed as a 50:50-confidence level which implies a balanced probability of being over or under budget. A contingency amount was also included and ranged between 10 percent and 20 percent for Concept 1 and 2 respectively. A preliminary schedule was prepared for both concepts where construction commenced in the 4th quarter of 2009 and an envisaged duration of 20 to 24 months for Concept 1 and 2 respectively.

It is the conclusion of this feasibility study that a Component Test Facility is definitely required. More specifically, the approach of Concept 1 addresses the NGNP lifecycle requirements best and it is therefore recommended. However, it is proposed that an optimization of the recommended layout be performed during the pre-conceptual design phase to determine whether Concept 1 is most suited or possibly even a combination of the Concepts 1 and 2.

INTRODUCTION

The Next Generation Nuclear Plant (NGNP) project is a US-based initiative to demonstrate the technical, licensing, operational, and commercial viability of High Temperature Gas-Cooled Reactor (HTGR) technology for the production of high temperature (up to 950°C) heat for any combination of process heat, process steam and cogeneration applications, including utilization of the low temperature waste heat for applications such as water desalination. The HTGR can be used as a substitute for the burning of fossil fuels for a wide range of industrial process applications. Substitution of the HTGR for burning fossil fuels conserves these hydrocarbon resources for other uses, reduces uncertainty in the cost and supply of natural gas and oil, and eliminates the emissions of greenhouse gases attendant with the burning of these fuels. The HTGR also provides enhanced safety features that permit substantially reduced emergency planning requirements and improved siting flexibility compared to current and advanced light water reactors (LWRs).

During FY07, pre-conceptual designs were developed for the NGNP by three competing vendor teams, along with related technology development and testing requirements and associated plans. Major elements of the development-related testing identified by the teams are focused on the main heat transport systems and their associated components. To support these needs, a test facility is envisioned, which is herein referred to as the High Temperature Gas-Cooled Reactor (HTGR) – Component Test Facility or "CTF". The purpose of this facility is to support the development of high temperature gas thermal-hydraulic technologies (e.g., helium, helium-nitrogen, CO_2) as applied in heat transport and heat transfer applications. Such applications include but are not limited to, primary coolant, secondary coolant, direct cycle power conversion, intermediate, secondary and tertiary heat transfer, and demonstration of processes requiring high temperatures (e.g., hydrogen production).

The initial focus of the CTF will be in support of the NGNP project. However, it is envisioned that the CTF will be open for use by the full range of suppliers, end-users, facilitators, government laboratories and others in the domestic and international community supporting the development and application of HTGR technology. Currently, it is envisioned that the CTF will be a DOE-owned facility sited at the Idaho National Laboratory (INL).

The purpose of this special study is to evaluate the feasibility of the envisioned CTF concept and covers five key areas, as identified in [1], namely:

- CTF Mission Need
- CTF Justification
- CTF Functional and Operational Requirements (F&ORs)
- CTF Configuration Recommendations
- CTF Cost Estimate and Schedule

The work plan outline is presented in Figure 1 where the Design Data Needs, Technology Readiness Levels and Design Readiness Levels (DDNs, TRLs and DRLs) were used to formulate the CTF envelope philosophy. The five key areas were then addressed within this philosophy as well as the NGNP life cycle requirements to finally result in this report.

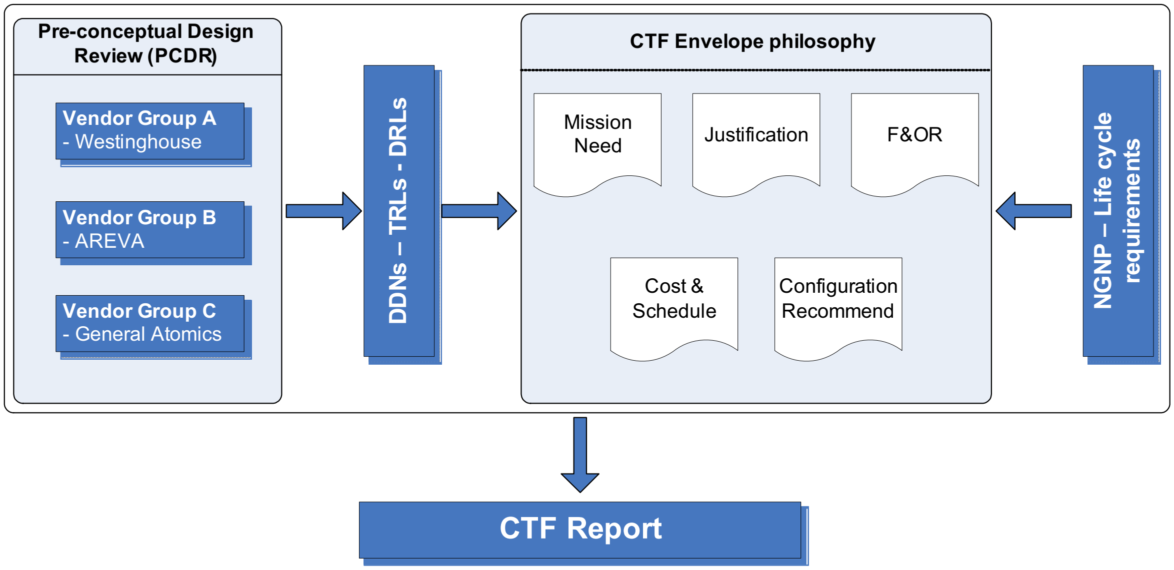


Figure 1: Component Test Facility Feasibility Study Work Plan Outline

1. CTF MISSION NEED

During various life cycle stages of the NGNP project, a number of systems, sub-systems, assemblies, and components need to be developed. Concurrently with this development, verifications and validations need to be performed via tests as a risk mitigation strategy. Active testing of complete NGNP systems at full scale is not achievable in all cases due to several practical and physical constraints. Rather, a more practical approach would be to test certain identified engineering scale components/assemblies that exemplify a representative sample of the actual items to be used in the NGNP. These components are typically found in the Primary and Secondary Heat Transport Systems (PHTS and SHTS) and some tertiary loops that may include the Hydrogen Production System and Power Conversion System (PCS). Items to be tested are typically heat exchangers, circulators, valves and gas piping.

The earlier mentioned pre-conceptual design reports (PCDRs) were performed under leadership of three vendor teams, namely AREVA, General Atomics and Westinghouse Electrical Company. Special studies that were performed by the vendor teams during the pre-conceptual design resulted in the identification of several design data needs (DDNs). In addition, an initial effort was made to establish the technology readiness levels and design readiness levels (TRLs and DRLs) of key systems and components. These DDNs, TRLs and DRLs essentially stated the requirements and needs during the complete lifecycle of the NGNP. They addressed aspects ranging from materials engineering, material qualification and laboratory scale component testing up to and including full scale components. These DDNs were used as the basis for the development of the mission needs of the CTF.

A total of nearly 400 DDNs, using the PCDRs of the three vendor teams as basis, were identified and are listed in Appendix A as part of the input matrix to this study. After closer evaluation of the DDNs, it was found that it will not be feasible to address all the DDNs with the CTF and the complete spectrum of DDNs will rather be addressed within a larger Component Test Program (CTP). The DDNs within the CTP were classified (“binned”) into three different types: Task Groups, Specialized Laboratories and the CTF.

1. Task Groups will develop and establish the procedures and work plans that are not normally associated with Specialized Laboratory work and will include compilation of code cases, etc. The Task Groups will typically be made up of expert consultants.

2. Specialized Laboratories will be utilized to address certain DDNs in their fields of expertise and these will typically include material certification, validation and testing. These are envisaged to be accredited to relevant standards and can be on-site or off-site from INL, or even abroad.

3. The CTF will be used to test the components that were constructed/developed from the work done by the Task Groups and Specialized Laboratories.

The DDNs, TRLs and DRLs served as input to address the complete lifecycle requirements of the NGNP, which will include the CTP and the CTF. The NGNP lifecycle is defined as:

1. Research, development and design
2. NRC licensing
3. Long lead procurements
4. Construction
5. Commissioning, initial operations and testing
6. Operation, training and verification
7. Certification and commercial deployment application

With all the DDNs, TRLs, DRLs and NGNP lifecycle requirements taken into account, the CTF Envelope Philosophy can be given as:

The CTF is a technology development platform for components and systems in support of the NGNP program. In order for these technologies to be integrated into the NGNP, it will be required that full scale, representative size component tests be conducted on certain items or assemblies. These tests need to be done at NGNP representative conditions, with regards to pressure, flow rate and temperature.

By employing this philosophy, the risks in the NGNP life cycle, which can be addressed in the CTF, can be mitigated in a structured, value adding and timely manner. In defining the Mission Statement of the CTF, cognizance must be taken of the Envelope Philosophy to ensure that a comprehensive needs requirement is formulated.

The Mission Statement of the CTF is defined as being a facility that:

- Must support the complete NGNP lifecycle as outlined above.
- Must be available to the entire nuclear community that contributes to the NGNP.
- Must provide the required test conditions including secondary loop conditions to support process heat application testing and hydrogen production using various technologies.
- Must facilitate testing of laboratory and engineering scale components.
- Must facilitate testing of representative size components that are to be used in the NGNP.
- Must facilitate testing for component characterization and qualification including primary fluids.
- Must have the capability to do Verification and Validation (V&V) of computer codes and must, therefore, have the required traceability in terms of data capturing, storing and presenting for all of its main systems, including ancillary systems where necessary. The CTF instrumentation selection and quantity must also facilitate this need.
- Must have to ability to do simultaneous testing in support of the NGNP milestone and key dates.
- Must have the ability to do both steady-state and transient tests in support of the previously mentioned points.

- Most provide for the testing, qualification and calibration of instrumentation under comparable conditions to that of the envisaged NGNP operating conditions.
- Must provide for the testing of control philosophies.
- Must provide for inventory control and testing under certain contamination conditions including loop-to-loop leak detection.
- Must provide for control room human factors.
- Must be able to facilitate and support the NGNP maintenance and support program with regards to development of installation and maintenance procedures.
- Must provide the opportunity to test and develop control room simulators.
- Must enable the sourcing and evaluation of different suppliers to the NGNP with regards to their component quality, customer service, etc.
- Must support code cases (new and updating of existing ones)
- Must support V&V of heat transfer correlations
- Must support development of ISI (In Service Inspection) requirements and methodologies of IHX and other components
- Must support NGNP commercial and operational phases
- Must support investigations into other heat transport fluids (i.e., molten salts, etc.)

As part of the Work Description, it was indicated that in addition to the NGNP project phases, the CTF Mission Need will also be evaluated to address the following items:

- Development, ownership and operation by DOE
- Location at the Idaho National Laboratory (INL)
- Potential interface with NGNP for interactive testing with the nuclear heat source (e.g., to evaluate radionuclide contamination transmission, cleanup and control).

While it is recommended that the first two items be addressed by BEA, the Westinghouse team supports the location of a DOE owned CTF at the Idaho National Laboratory (INL). With regards to the potential interface with the NGNP for interactive testing with a nuclear heat source, the Westinghouse team does not see any reason why the CTF cannot be located close to the NGNP (if also located at INL) and will evaluate the location of the CTF and the possible interface with the NGNP as part of the project. The integration aspects and issues, such as licensing, will need to be evaluated in more detail as part of the conceptual design of both the CTF and NGNP to ensure optimum integration and to minimize risks.

2. CTF JUSTIFICATION

Justification of the CTF will be discussed in this section. The philosophy (presented in Figure 2) that was followed during the justification of the CTF mainly revolved around the following points:

- Determine what is actually required of the CTF (Mission Need).
- Evaluate existing facilities' capabilities to meet CTF requirements.
- Suggest possible modifications to these facilities if the complete Mission Need is not addressed.
- Re-evaluate the feasibility after modifications.
- Propose utilization.

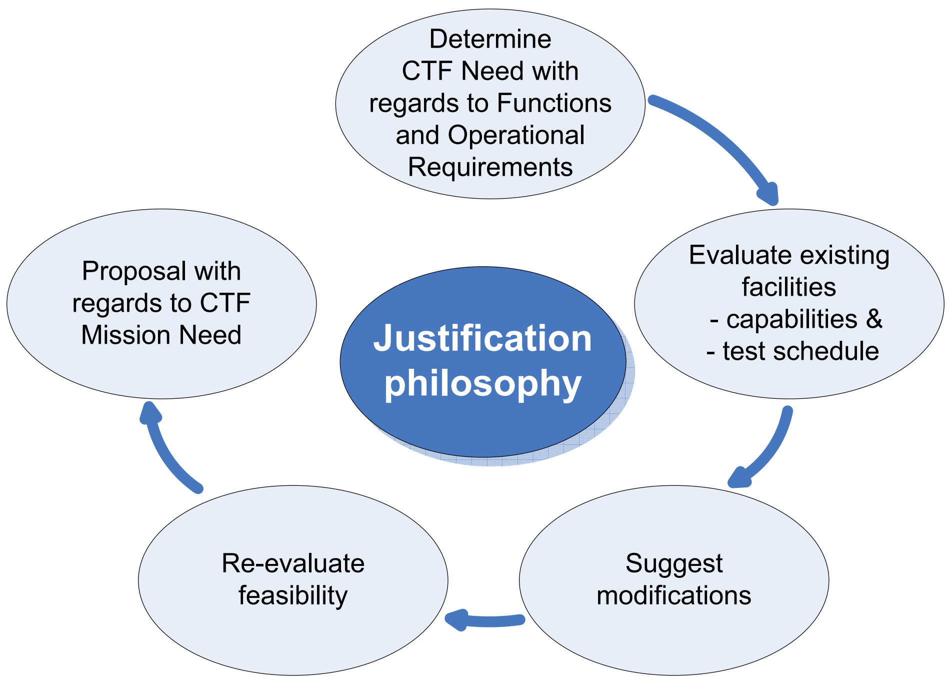


Figure 2: Component Test Facility Justification Philosophy

A fundamental understanding of the CTF Mission Need is crucial. If this is not unambiguously presented, the possibility of motivating an under-specified, too small, non-value adding test facility is evident. It is specifically for this reason that the Mission Need was derived from *ALL* the needs as discussed in Section 1.

The motivation for evaluating existing test facilities was to determine whether it would be possible to reduce the cost and time for meeting the CTF Mission Need. It could be much more economical to use existing facilities or modifications of them, instead of building a complete new facility. Furthermore, it can be assumed that existing facilities have already established a broad knowledge base of operations in high pressure and temperature helium which is an advantage for the NGNP program. However, it can be assumed that modifications to existing facilities generally do not deliver the required performance in terms of the Mission Need of the conceptualized facility. This is purely because existing facilities were typically designed and developed for another purpose and scope and more often than not experience has shown that the modification costs vs. outcome are not always justifiable. Therefore, the justification philosophy includes the re-evaluation of a facility's capabilities after a proposed modification and how this addresses the CTF Mission Need. It is only hereafter that a proposal can be made to whether the CTF is justifiable in the greater NGNP life cycle need.

The CTF Mission Need from Section 1 can be elaborated further, and areas where such a facility will be applicable include:

- 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 and
  - Helium circulators.
- Design code development Verification & Validation collaboration.
- Materials development and qualification.
- Manufacturer and supplier evaluation and development.

Other less tangible aspects[1] justify the CTF due to the fact that:

- It will facilitate the role of Idaho National Laboratory (INL) in the coordination, consolidation and leading of the development of heat transfer and transport technologies to establish and advance the application of HTGR technology.
- It will ensure the availability of a facility to serve the development phases of the NGNP and beyond. The possible limited capacity and availability of other facilities (most of which are outside of the USA and supporting other projects) could adversely affect the NGNP schedule.
- It will improve the efficiency of technology development for the NGNP and follow-on technology upgrades.
- It provides a means for off-line trouble shooting of component and system problems and for the development of programs and processes to ultimately support a growing commercial HTGR fleet.

[1] Some of these areas that are mentioned served as motivation for the CTF and can be found in [1]

- It provides a long-term US-based facility for continued development of advanced technologies to increase the capabilities and broaden the applications of the HTGR.
- It serves in the development of human capital and skills for the HTGR NGNP environment.
- It provides insights in the identification of shortfalls in the CTF design that can be taken into account in the NGNP design.
- It provides an environment where Quality Assurance, safety and procurement systems can be tested and verified and where shortfalls/enhancements can be identified.
- It provides a means for the testing and evaluation of manufacturing technologies for large scale manufacturing of First-of-a-Kind Engineering (FOAKE) systems and long lead time components.
- It will provide the opportunity to understand and test phenomena that prevail in transients of critical hot components at a CTF scale for both experimental results and V&V of codes.
- It will provide vast amounts of test data that will be beneficial for operation of the NGNP.

Before an evaluation of any facility could be done, it was important to define a measuring unit to which the facilities will be evaluated to. To define this measuring unit, the Functional and Operational Requirements (F&ORs) for the CTF needed to be laid down.

The process that was followed to determine F&ORs is discussed in the next section, after which the justification process continues with the evaluation of existing (or modified) facilities.

3. CTF FUNCTIONAL AND OPERATIONAL REQUIREMENTS

Figure 3 illustrates the method that was followed in determining the F&ORs from the DDNs, TRLs and DRLs as presented in the DDNs Matrix in Appendix A. The sorted DDNs were further binned into main categories of components/systems to be tested. These are:

- Intermediate heat exchanger (IHX)
- Mixing chambers
- High temperature ducting and insulation
- Steam generator (SG)
- Helium circulator
- Isolation valves
- Auxiliary systems
- Control and Instrumentation
- Other heat exchanger (HX) equipment
- General functions

The requirements from all three vendor groups' DDNs were distilled into process parameters such as pressure, temperature, mass flow, energy required, etc. Some of the DDNs process parameter requirements were well defined in terms of units and magnitudes while others were very vague and mentioned needs in general and in very broad terms. These process parameters were sorted in matrix format with the aim to result in a Functional and Operational Requirements list that indicated the maximum values of the operational envelope of the CTF. These maximum values were useful to determine a first order sizing and conceptual layout of the CTF. This first order layout implied a facility that could possibly be equivalent in size to the NGNP itself due to requirements of full scale testing of some of the components. Also, at this stage in the process, it was not clear whether to provide for single component testing or assemblies of these components (such as the IHX). For obvious schedule and financial reasons, a facility of this scale is not feasible and a process of optimization was followed during which the categorized components/systems' individual F&ORs were combined in such a fashion to define the tests that need to be performed in the CTF.

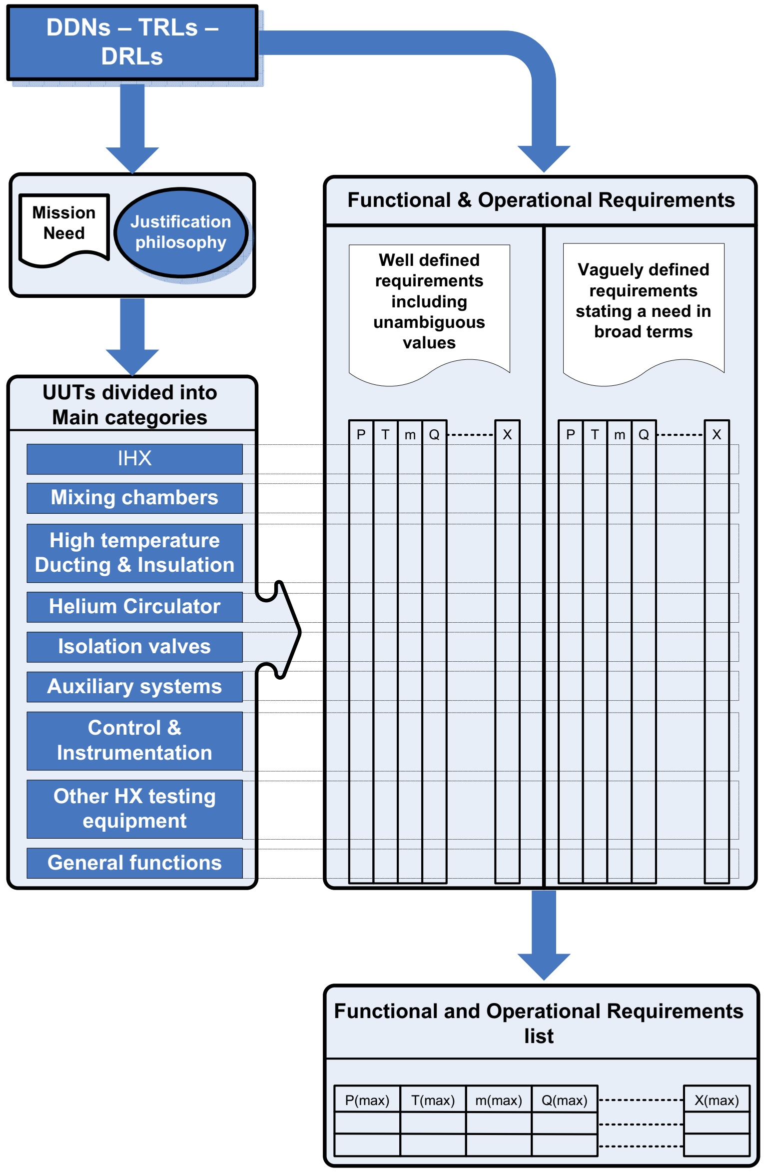


Figure 3: Work flow diagram of the process that was followed to attain the Functional & Operational Requirements resulting in the Configuration Recommendation

The F&ORs for the tests in terms of energy balances, layouts and configurations were determined in the context of the *Facility Philosophy* (explained in Section 4) and resulted in three possible concepts. Concept 1 (which consists of three *Technology Development Loops (TDLs) as well as a Component Qualification Loop (CQL) and* full scale *Circulator Test Loop (CTL)*) was configured into fourteen (14) different setups to enable testing of all the required DDNs. Energy balances were performed on all the setups to determine the operational envelope of the system components. This resulted in a first order specification and sizing of the system elements. The same process was followed for Concept 2 where a total of three different setups, including energy balances were defined. The same process was not performed in as much detail for Concept 3 for reasons that will be discussed later in this section.

The Main categories into which the Units Under Test (UUTs), as listed in the DDNs, were divided are discussed in the next points with their individual F&ORs. A summary of a typical UUT, such as the IHX, together with Test Modes and a Test Specification is provided in Appendix G.

3.1 MAIN CATEGORIES OF UNITS UNDER TEST

3.1.1 IHX Component Tests

The CTF should have the flexibility to test a range of IHX designs, configurations, operating conditions and heat transport fluids. The heat transport fluids might have controlled levels of impurities in some tests. In the absence of a specific NGNP design, the options proposed by the three vendor teams were used as the basis for evaluating the potential range of development requirements.

Mockups or scaled representative IHX concepts are required to be tested in operating conditions comparable to anticipated NGNP conditions. The functionality for large scale testing at representative conditions should not be excluded.

The main tests to be conducted include:

- IHX performance verification testing, which could serve as empirical validation for thermal-hydraulic design methods and analysis.
- Life prediction and durability testing to evaluate design and fabrication methods, as well as data generated by material laboratories. Thermal-mechanical aspects of concepts should be evaluated during these tests, which typically include interface development.
- Seals tests on various sealing interfaces, as well as the influence on leak rates due to various process parameters.
- Flow induced vibration tests and tests on IHX configurations and its associated piping, together with frequency spectra and sound pressure levels caused by different flow velocities.

3.1.1.1 CTF IHX Operational Requirements: Westinghouse Vendor Team

The following provides a list of operational requirements for the CTF as imposed by IHX development and testing requirements from the Westinghouse Vendor Team.

- Primary helium inlet temperature of 950ºC (nominal)
- Primary outlet temperature of 337ºC (nominal)
- Secondary helium inlet temperature of 290ºC (nominal)
- Secondary outlet temperature of 900ºC (nominal)
- The CTF should provide for long-term testing, sufficient to provide confidence in the operating life of the IHX components
- IHX-A Primary Heat Transport System (PHTS) inlet pressure shall be 8,750 kPa
- PHTS to Secondary Heat Transport System (SHTS) ΔP and interior to exterior ΔP near zero (essentially pressure balanced at <200 kPa)
- IHX-B SHTS inlet pressure shall be 9,100 kPa.
- The working fluid in both the PHTS and the SHTS shall be helium, with controlled impurity levels which are still To Be Defined (TBD).

- Pressure drop across primary side and also across secondary side of IHX shall be smaller than 1.23 percent of its respective inlet pressure (e.g. [Primary IHX-A inlet - Primary IHX-B outlet] < 108 kPa)
- A summary of the representative cores to be tested for both IHX A and B are provided in the following tables:

IHX-A (1 x Test Core) Requirements		
	PRIMARY	**SECONDARY**
m	1.15 [kg/s] (138 total cores)	1.15 [kg/s] (138 total cores)
T_in	950 [°C]	710 [°C]
T_out	760 [°C]	900 [°C]
Pressure_in	8.750 [MPa]	9.011 [MPa]
Delta T	190 [°C]	
Q	1.134 [MW]	
Dimensions:	1000 x 56 x 275 [mm]	

IHX-B (1 x Test Core) Requirements		
	PRIMARY	**SECONDARY**
m	0.938 [kg/s] (170 total cores)	0.938 [kg/s] (170 total cores)
T_in	760 [°C]	287 [°C]
T_out	337 [°C]	710 [°C]
Pressure_in	8.683 [MPa]	9.10 [MPa]
Delta T	423 [°C]	
Q	2.058 [MW]	
Dimensions:	1000 x 56 x 420 [mm]	

- The IHX test cores would need to be subjected to the transient testing to be defined
- Cooling helium should be provided to the IHX test vessel if required by the unit under test [TBD].

3.1.1.2 CTF IHX Operational Requirements: General Atomics Vendor Team

The following is a list of operational requirements for the CTF as imposed by IHX development and testing requirements from the General Atomics Vendor Team.

- It is necessary to confirm by experiment the flow distribution throughout the IHX (both primary and secondary inlets and outlets) accompanied by analytical evaluation.
- Data are needed to produce frequency spectra and sound pressure levels that may be generated by the IHX as a function of flow velocities.
- Physical and operational characteristics of insulation are required relative to thermal cycling, mechanical and acoustic vibrations, and effects of flow and thermal gradients.
- The CTF should be able to measure leak rates under operating conditions and should be configured in such a way to investigate the influence of various parameters in the leak rates.

- The flow induced excitation mechanisms of concern are turbulent buffeting, vortex shedding and fluid elastic instability.

3.1.1.3 CTF IHX Operational Requirements: AREVA Vendor Team

The following is a list of operational requirements for the CTF as imposed by tubular IHX development and testing requirements from the AREVA Vendor Team. These values represent the anticipated values for the full-scale heat exchanger and only representative parameters would need to be provided in the CTF.

Primary side (shell Side)

- IHX inlet temperature: 900°C
- IHX outlet temperature: 489.5°C
- Primary side inlet pressure: 5 MPa
- Pressure drop: 11.33 kPa
- Fluid: Helium

Secondary side (tube side)

- IHX inlet temperature: 449.1°C
- IHX outlet temperature: 850°C
- Secondary side inlet pressure: 5.46 MPa
- Pressure drop: 260 kPa
- Fluid: Helium – Nitrogen (He-N_2)
- The IHX test modules would need to be subjected to the following transients
  - Cool-down transients of 300°C in 5 sec.
  - Heat-up transients of 300°C in 120 sec
- Representative geometry [TBD]
- Testing of IHX concepts is proposed to be conducted in the following steps:
  - Mock-up scaled versions to be tested in ~1 MW loop facility
  - Qualification tests of full-scale mock-up in ~10 MW loop facility
- All tests should be conducted with sufficient flow for representative flow distribution in headers, as well as providing all the representative conditions at the same time.

3.1.2 Mixing Chamber Test

The CTF should be capable of performing various predefined tests on representative helium mixing chamber designs and configurations.

The main tests to be conducted are:

- Performance verification test on a prototype mixing chamber.
- Thermal cycling effects testing.
- Nominal operating life of the mixing chamber [equivalent to NGNP plant life].
- Working fluid shall be helium.
- Different size fixed orifice testing for mixing of gas.

3.1.2.1 CTF Mixing Chamber Operational Requirements: Westinghouse Vendor Team

The following is a list of operational requirements for the CTF as imposed by helium-mixing chamber development and testing requirements from the Westinghouse Vendor Team.

- Inlet pressure of 8.5 MPa for SHTS
- Helium inlet temperature of 900°C
- Process Coupling Heat Exchanger (PCHX)
  - T-outlet: 660°C (Hydrogen Production System in operation)
  - T-outlet: 900°C (Hydrogen Production System not in operation)
- Mixing chamber outlet: 840°C
- Total HTS flow: 159.6 kg/s
  - Flow to PCHX: 39.9 kg/s
  - Flow to SG: 119.7 kg/s (NGNP required flow)
- Split of 75 percent hot gas (900°C) and 25 percent cold gas(660°C)

3.1.3 High Temperature Duct & Insulation Testing

The CTF should provide the capabilities to verify and experimentally validate the designs for high temperature ducts and insulation (HTD&I) which are to be used for fluid transport in both primary and secondary heat transfer loops. Experimental testing and validation will need to be performed on prototype samples and emphasis needs to be placed on long-term validations.

3.1.3.1 CTF HTD&I Operational Requirements: Westinghouse Vendor Team

The following is a list of operational requirements for high temperature duct and insulation design validation as required by the Westinghouse Vendor Team.

- PHTS ducts and insulation up to 950°C
- SHTS ducts and insulation up to 900°C
- Fluid: Helium
- Piping prototypes need to be tested at full temperature and pressure (Pressures equal to the requirements of the WEC IHX requirements need to be provided).
- Flow rates: It is suggested to provide the same boundary velocity by means of an annulus design. Final size and velocity TBD
- Prototype tests include:
  - Mechanical properties evaluation
  - Investigation of environmental effects on proposed designs
  - Long-term tests [TBD] for the validation of acceptability and continued effectiveness (performance) of proposed designs under normal operating conditions.

3.1.3.2 CTF HTD&I Operational Requirements: AREVA Vendor Team

The following is a list of operational requirements for high temperature duct and insulation design validation as required by the AREVA Vendor Team.

- PHTS ducts and insulation up to 900°C
- SHTS ducts and insulation up to 850°C
- In order to address the risk of the high temperature ducts and insulation AREVA proposed a qualifications process constituting of the following CTF related steps:
  - Subscale mock-up tests in helium of about 1 MW for validation purposes
  - Full scale mock-up test in ~10 MW test facilities.
- The tests should include:
  - Depressurization tests
  - Pressure drop, heat loss
  - Leak tightness of connections
  - Temperature measurement needs to be taken at various locations during operating conditions.

3.1.4 Steam Generator Testing

The CTF should provide the capabilities to perform various tests on steam generator (SG) designs which include:

- Acoustic response testing under different flow conditions as well as flow induced vibrations due to various excitation mechanisms.
- Thermal and mechanical performance of steam generator related insulation.
- Demonstration tests of certain design aspects in steam generators such as tube retention and wear protection devices, and the non-helical transition tubes. These tests would typically be used for determining adequacy of existing designs, as well as evaluating new proposals.
- Seal-related tests in order to evaluate designs and validate performance-related criteria with varying parameters.
- Feed water related tests which include aspects such as orifice performance verifications, as well as design and manufacturing configurations.
- Steam generator instrumentation related mock-up tests need to be conducted.
- Steam generator performance tests need to be conducted in order to evaluate the heat transfer characteristics of certain regions.

3.1.4.1 CTF SG Operational Requirements: Westinghouse Vendor Team

The following is a list of operational requirements for the steam generator tests as required by the Westinghouse Vendor Team.

- **Hot Side:**
  - Fluid: Helium
  - Inlet pressure: 8.2 MPa
  - Pressure drop: ~ 0.1 MPa (NGNP requirement)
  - Inlet temperature: 900°C
  - Helium flow: 159.6 kg/s (NGNP requirement)
  - Outlet temperature: 272°C

  - Design pressure: > 13.2 MPa

- **Cold Side:**
  - Fluid: water / steam
  - Feed water / steam flow: 206.3 kg/s
  - Feed water temperature: 219°C
  - Feed water pressure: 18.9 MPa
  - Steam pressure: 12.78 MPa

- Empirical data is needed to investigate the noise on large steam generator surfaces as a function of varying frequencies. Acoustical response of the tube bundle and cavity also need to be measured as a result of primary flow. Data to be generated include representative frequency spectra and sound pressure levels generated by the steam generator bundle as a function of velocities and geometry variations.

- Physical and operational characteristics of the insulation are to be verified as a result of:
  - Thermal cycling [cycles TBD]
  - Mechanical and acoustic vibrations
  - Flow and thermal gradients

- Accelerated wear tests to demonstrate existing tube-retention device designs.

- Operating requirements that influence the seal test are:
  - Performance verification and leak rates measurements under prototypical conditions.
  - Influence of leak rates under differential pressures.

- Testing of non-helical portions of the tube bundle is needed to determine:
  - Spatial envelope
  - Characteristics of thermal movement
  - Interactions of tubes and supports to evaluate adequacy of clearances.

- Test should be conducted to accurately determine flow induced vibration characteristics of the helical tube bundle, lead-in/out tubes and transition tubes.

- Test data is needed to design and size orifices to be used in the individual tube circuits. Performance verification regarding erosion/corrosion resistances to be evaluated as well as fabrication and assembly performances. Data requirements include:
  - Pressure drop measurement
  - All data measurements in accordance with validation requirements

- Testing of steam generator mock-ups to confirm the design and assembly techniques of critical instrumentation. Ease of removal and replacement must be in accordance with requirements for experimental data and validation for non-safety related components.

3.1.4.2 CTF SG Operational Requirements: General Atomics Vendor Team

Data required once the design has developed further and materials have been selected.

3.1.5 Helium Circulator

The CTF should provide for full scale integrated tests of various circulator configurations which could assist in the verification of circulator component designs and adequacy of support systems. Typical tests will include:

- Circulator design verification tests
- Circulator performance empirical verification
- Circulator control system testing.

3.1.5.1 CTF Circulator Operational Requirements: Westinghouse Vendor Team

The following is a list of operational requirements for the CTF as imposed by helium circulator development and testing requirements from the Westinghouse Vendor Team:

- Primary helium loop pressure of 9MPa
- Primary inlet temperature of 350°C exit conditions
- Secondary helium loop pressure of 9MPa
- NGNP Design: 10.8 MW Circulator

3.1.5.2 CTF Circulator Operational Requirements: General Atomics Vendor Team

The following is a list of operational requirements for the CTF as imposed by helium circulator development and testing requirements from the General Atomics Vendor Team.

- Primary helium circulator
- Secondary helium circulator (Secondary circulator DDNs are covered by primary helium circulator DDNs due to design similarity)
- Shutdown cooling circulator
- Primary and secondary 5 MPa.

3.1.5.3 CTF Circulator Operational Requirements: AREVA Vendor Team

The following is a list of operational requirements for the CTF as imposed by helium circulator development and testing requirements from the AREVA Vendor Team.

- Scale: Full scale recommended
- NGNP proposal
    - 3 x 5 MW circulators & 1 x 1.5 MW circulator
    - At full power required, the circulator should run at maximum of 90 percent
- Primary and secondary pressure of 5MPa.

3.1.6 Valves Testing

The CTF should provide the capabilities to do performance and structural verification on high temperature valves for maintenance and/or isolation, albeit design requirements are still TBD.

3.1.6.1 CTF Valves Operational Requirements: General Atomics Vendor Team

The following is a list of operational requirements as obtained from the General Atomics PCDR:

- CTF should provide large scale facilities for valve testing at 950°C in representative primary loop environment.
- Tests to be used for component qualification

3.1.7 Auxiliary Systems

The CTF should provide a complete array of auxiliary systems in support of the tests to be conducted. These auxiliary systems should include, but are not limited to the following:

- Helium purification system
- Helium inventory control system
- Heat rejection systems (typically air cooled condensers instrumented to enable full energy balances)
- Control instrumentation air system

3.1.8 Control & Instrumentation

The CTF must be used for instrumentation and control philosophy development as well as adequacy verification for certain applications.

3.1.8.1 CTF C&I Operational Requirements: General Atomics Vendor Team

Typical requirements for the CTF regarding instrumentation include the following:

- Capabilities to measure and verify helium mass flow measurements
- Verify conduction cool down temperature monitoring instrumentation
- All instrumentation to be used for verification and validation purposes

3.1.9 Other Helium Heat Exchanger Testing Requirements

The CTF should be capable of performing various predefined tests on representative supporting component designs and configurations, including the shutdown heat exchanger. The main tests to be conducted in support of the shutdown heat exchanger are:

- Insulation verification tests
- Vibrational fretting wear and sliding wear of tube restraint
- Devices for bare tubes
- Instrumentation attachment test
- Bare tubes inspection methods and equipment
- Shroud seal test
- Acoustical response of the helical bare tube bundle

- Inlet flow and temperature distribution test
- Tube bundle local heat transfer and flow resistance characteristics

3.1.9.1 CTF Operational Requirements: General Atomics Vendor Team

All other heat exchanger test requirements relate to DDNs as determined by the General Atomics Vendor Team. Detailed requirements are TBD once the design is further developed.

3.1.10 General Functions

The following is a list of general functions that should be addressed by the CTF.

- The CTF should provide data and measurements that could be utilized for verification and validation purposes of thermal-fluid related software.
- The CTF should also be used for qualifications control as well associated program requirements development.
- Control room human factors are also envisaged to be tested and developed using the CTF.
- Specific hydrogen production testing is not defined yet but should be included in the future.

The F&ORs for the CTF have been determined in this section and provide a set of requirements that existing facilities can be measured against. The next section describes the South African facilities and their ability to meet the requirements of the CTF.

3.2 SOUTH AFRICAN TEST FACILITIES

The PBMR facilities were identified and used in the justification of the CTF primarily because they have the ability to test under high temperature and pressure helium conditions. Other facilities located or planned elsewhere in the world which are listed in [1] were excluded in this evaluation due to time and resource constraints. However, a literature study on some German facilities (Appendix C) was conducted to determine what was done on other typical test facilities with similar mission needs. The literature study also served as guidance to establish the Envelope Philosophy (e.g., full scale testing vs. laboratory scale testing, etc.) that was followed in the justification of the CTF.

The South African PBMR test facilities were designed, built and operated specifically for the technology development of the PBMR Demonstration Power Plant (PBMR DPP). The following facilities were reviewed:

- The Helium Test Facility (HTF)
- The Heat Transfer Test Facility (HTTF), which consists of two units:
  - The High Pressure Test Unit (HPTU) and
  - The High Temperature Test Unit (HTTU)
- The Pebble Bed Micro Model (PBMM).

(Refer to Appendix B for detailed descriptions of these facilities.)

The assessment of the facilities concurred with the justification philosophy (presented in Section 2) in terms of the evaluation with regard to their capabilities, test schedule, possible modifications, current configuration and ability to address the CTF Mission Need. The outcome of the assessment is briefly presented in the following sections.

3.2.1 The Helium Test Facility

The Helium Test Facility (HTF) was mandated to do design/development/functional/integrated and performance testing on the PBMR Main Support Systems (MSS) up to delivery of the MSS to the first demonstration plant. The main focus of the HTF hereafter is full scale, non nuclear tests on the Fuel Handling System (FHS), Reactivity Control System (RCS) and Reserve Shutdown System (RSS). These systems are termed Units Under Test (UUTs).

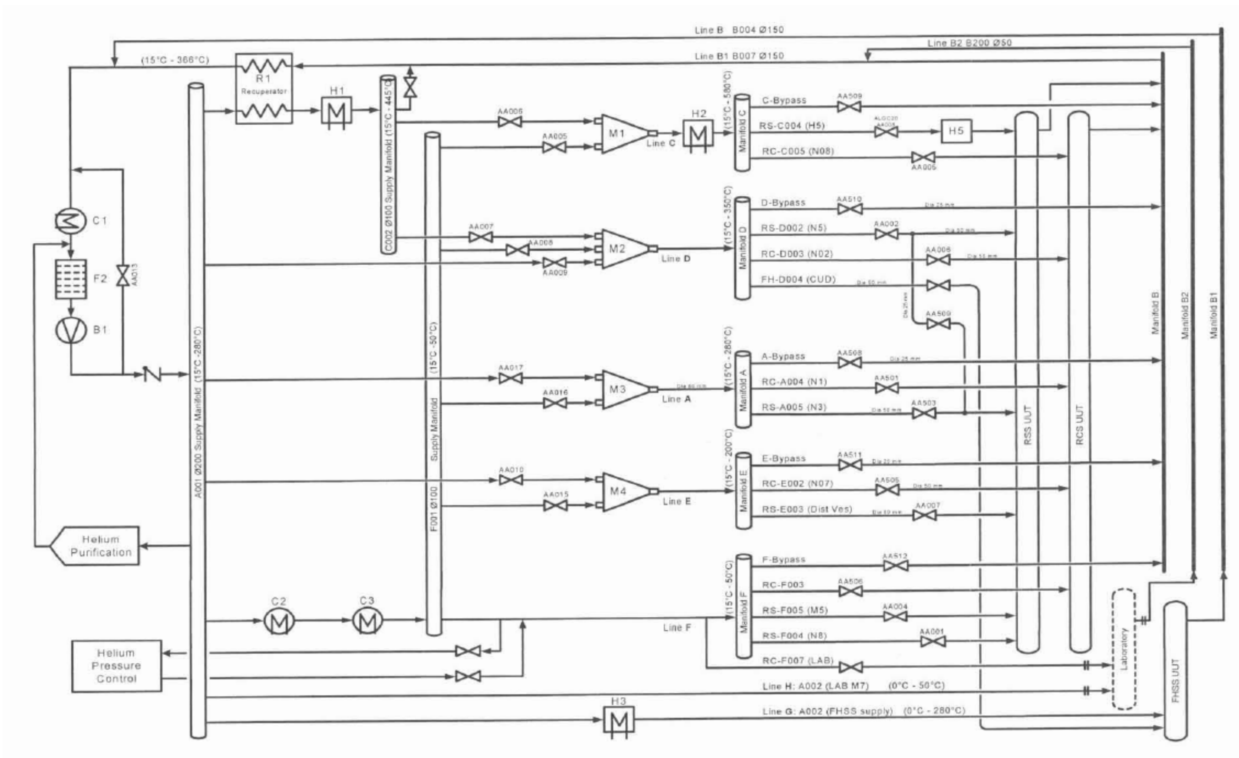


Figure 4: High level process flow diagram of the Helium Test Facility Main Loop

3.2.1.1 Capabilities

The HTF supports the development, verification and non-nuclear testing of critical prototype components of the PBMR MSS. It provides the capability to test components and sub-assemblies in a high-temperature and high-pressure helium environment that is similar to the operating conditions expected for the PBMR DPP. The operational envelope of the HTF is provided in Table 1 and Figure 5. From this table, it is evident that the maximum usable flow rate and temperature are on the order of 1kg/s and 900°C respectively. (NOTE: These conditions cannot be attained simultaneously; see Appendix B for more details.)

Table 1: Helium Test Facility (HTF) Operational Conditions

No.	Description	Phase I	Phase II	Phase III	Manifold													Lab Availibilty		
					Pressure	C		D		A		E		F		Line G		Lab Availibilty		
					[MPa]	[kg/s]	[°C]	[kg/s]	[°C]	[kg/s]	[°C]	[kg/s]	[°C]	[kg/s]	[°C]	[kg/s]	[°C]	kg/s	[°C]	Date
1	FHSS @ **1 MPa** Line D, **T = 280°C** (via FHS system)		X		1	-	-	0.051	280	-	-	-	-	-	-	-	-	0.051	280	[TBD]
2	FHSS @ **1 MPa** Line G, **T = 200 - 250°C** (via equalisation line)	X			1	-	-	-	-	-	-	-	-	-	-	0.03	250	0.03	250	[TBD]
3	FHSS @ **1 MPa** Line G, **T = 280°C** (via FHS system)		X		1	-	-	-	-	-	-	-	-	-	-	0.13	280	0.13	280	[TBD]
4	RSS @ **2.2 MPa** & **T_max ≤ 250°C**	X			2.2	0.05	250	0.05	60	0.05	60	0.15	100	0.05	50	-	-	0.05	250	[TBD]
5	RSS @ **6.5 MPa** & **T_max ≤ 300°C**	X			6.5	0.05	300	0.05	100	0.05	100	0.03	100	0.05	50	-	-	0.05	300	[TBD]
6	RSS @ **6.5 MPa** & **T_max ≤ 600°C**		X		6.5	0.05	500	0.05	100	0.05	100	0.03	100	0.05	50	-	-	0.05	500	[TBD]
7	RSS @ **9.0 MPa** & **T_max ≤ 300°C** (SAS transport)	X			9	0.05	300	0.05	280	0.05	280	0.4	150	0.05	50	-	-	0.05	300	[TBD]
8	RSS @ **9.0 Mpa** & **T_max ≤ 600°**C (SAS transport)		X		9	0.05	580	0.05	280	0.05	280	0.4	150	0.05	50	-	-	0.05	580	[TBD]
9	RSS @ **9.0 Mpa** & **T_max ≤ 900°C** (SAS transport)			X	9	0.05	750	0.05	280	0.05	280	0.4	150	0.05	50	-	-	0.05	750	[TBD]
10	RSS @ **9.0 Mpa** & T_max **≤ 600°C** (Manifold D for lower RSS vessel conditioning at **350°C**)		X		9	0.05	580	0.1	350	0	-	0	-	0.05	50	-	-	0.05	580	[TBD]
11	RSS @ **9.0 Mpa** & **T_max ≤ 900°C** (Manifold D for lower RSS vessel conditioning at **350°C**)			X	9	0.05	750	0.1	350	0	-	0	-	0.05	50	-	-	0.05	750	[TBD]
12	RCS @ **9.0 MPa** & **T_max ≤ 300°C**	X			9	0.2	300	0.06	280	0.05	280	0.05	120	0.05	50	-	-	0.2	300	[TBD]
13	RCS @ **9.0 MPa** & **T_max ≤ 600°C**		X		9	0.2	580	0.06	280	0.05	280	0.05	200	0.05	50	-	-	0.2	580	[TBD]
14	RCS @ **9.0 MPa** & **T_max ≤ 600°C**			X	9	0.05	900	0.05	280	0.05	280	0.4	150	0.05	50	-	-	0.05	900	[TBD]
15	RCS @ **9.0 MPa** & **T_max ≤ 300°C** (No manifold C flow)	X			9	0	-	0.06	280	0.05	180	0.05	120	0.05	50	-	-	0.06	280	[TBD]
16	RCS @ **9.0 MPa** & **T_max 600°C** (No manifold C flow)		X		9	0	-	0.06	350	0.05	180	0.05	120	0.05	50	-	-	0.06	350	[TBD]
17	RCS @ **9.0 MPa** & **T_max ≤ 600°C** (No manifold A & E flow)		X		9	0.22	580	0.06	350	0	-	0	-	0.05	50	-	-	0.22	580	[TBD]
18	RCS @ **9.0 MPa** & **T_max ≤ 900°C** (No manifold A & E flow)			X	9	0.22	900	0.06	350	0	-	0	-	0.05	50	-	-	0.22	900	[TBD]
19	Combined RCS & RSS @ **9.0 MPa** & **T_max ≤ 300°C**	X			9	0.25	300	0.11	0.1	0.9	280	0.35	120	0.9	50	-	-	0.25	300	[TBD]
20	Combined RCS & RSS @ **9.0 MPa** & **T_max ≤ 600°C**		X		9	0.25	580	0.11	280	0.9	280	0.35	120	0.1	50	-	-	0.25	580	[TBD]
21	FHSS @ **9.0 MPa**, **T=280°C** (via equalisation line)	X			9	-	-	-	-	-	-	-	-	-	-	0.6	280	-	0	-
22	FHSS @ **9.0 MPa, T=280°C** (via FHS system)		X		9	-	-	-	-	-	-	-	-	-	-	0.58	280	-	0	-
	Maximum Conditions				9	0.25	900	0.11	350	0.9	280	0.4	200	0.9	50	0.6	280			

Notes
1 Temperature measured at manifold C
2 Temperature at nozzle of RSS test set-up vessel (N6)
3 Manifold D used for conditioning of RSS vessel bottom
4 Temperature at nozzle of RSS test set-up vessel (N8)
5 Temperature at nozzle of RSC test set-up vessel (N8)
6 Temperature at nozzle of RSS (N6) and RCS (N8) test set-up vessels
Temperature within boring (to be achived with heater H1, H2 and H5 or
7 internal RSS heating)
8 Boring temperature above 580 to be achieved with H6

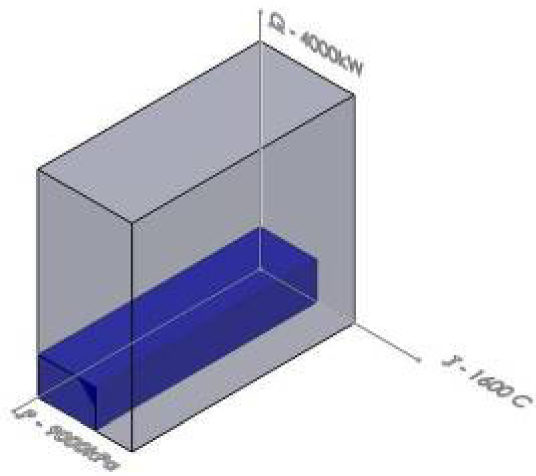


Figure 5: Helium Test Facility (HTF) operational envelope (dark blue area) compared against a facility that will typically address the CTF F&ORs (grey area)

3.2.1.2 Test Schedule

Currently, the HTF team works closely with PBMR Testing, Qualification and Commissioning (TQC) to develop and implement test and qualification strategies for the development and testing of the previously mentioned systems. On this basis, a total of 275 tests were defined and need to be completed on a priority basis in support of these systems. Based on what is contained in the qualification strategies, the HTF management estimated the number of tests that need to be completed per annum to allow designers to deliver these PBMR DPP systems on time. Currently 25 critical design/development tests have been scheduled for completion during 2008, with the rest of the 275 scheduled for the following year and in the future. The latest forecast indicated that the HTF will be committed to PBMR DPP MSS tests until at least 2012. This schedule takes into account the current availability of resources and plant capability.

3.2.1.3 Possible Modifications

In essence, it must be understood that the HTF is actually a "cold" system with locally heated hot spots for testing the three UUTs. Essentially the HTF consists of a main loop with heaters, a helium circulator, coolers, etc. and three UUTs coupled thereto (refer to Figure 4). It is therefore not a facility that can easily be modified to suit the CTF Mission Need. However, a HTF Laboratory is being designed where some lab-scale tests can be conducted on components such as valves. A proposal for a secondary loop in the laboratory area with an operating envelope of ±1 kg/s at 9 MPa and localized heating to ~950 °C can be found in Appendix B and is depicted in Figure 6.

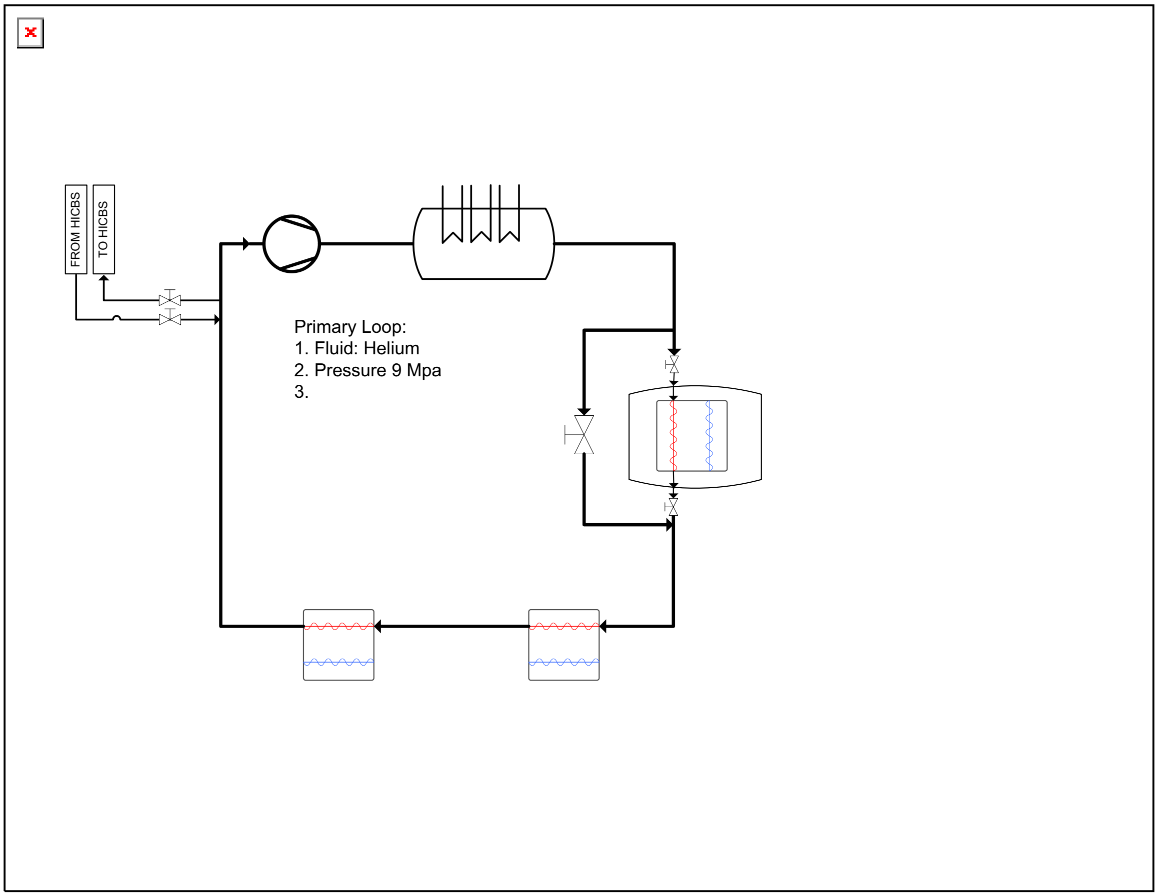


Figure 6: High level process flow diagram of the possible modifications to the HTF Laboratory

3.2.1.4 Current Configuration

The HTF, as a complete facility, is currently not configured to support major changes. The only foreseeable changes are the addition of the HTF Laboratory and possible increases in temperature in the localized heating in the UUTs to represent the NGNP conditions.

3.2.1.5 Ability To Address CTF Mission Need

When the HTF capability envelope is compared to the CTF Envelope Philosophy and F&ORs, it is found the HTF cannot address the requirements due to capability constraints on components, current and future test schedules and physical space constraints. Due to established test schedules, this facility will not be available for use within the required timeframe to achieve the 2018 NGNP startup.

The HTF cannot accommodate full scale testing of HTS components, but rather specialized testing of materials or scaled components at diluted requirements when compared with the NGNP F&ORs.

An important aspect that also came out of the investigation is the fact that nowhere in the DDNs were the PBMR DPP related tests that are currently underway at the HTF mentioned. It is evident that the assumption was made that these tests do not need further investigation by the WEC NGNP team due to the fact that PBMR was already committed to obtaining the results for PBMR DPP purposes. These results could, in the future, be offered in kind, but will require further investigation and negotiations among the relevant parties.

It must also be noted that the PBMR DPP and NGNP have slightly different operating conditions in terms of inlet and outlet temperatures. The PBMR DPP has a core outlet temperature of 900°C compared to the 950°C of the NGNP. This would imply that the HTF test conditions are only set up to reach NGNP requirements that fall within the range of the PBMR DPP. It is proposed that a separate study be done on exactly what modifications need to be made, if any, to the HTF to test and verify that the MSS components that are under test will suffice for the NGNP reactor as well.

3.2.2 The Pebble Bed Micro Model

The purpose of the Pebble Bed Micro Model (PBMM) was to demonstrate the concept and controllability of the PBMR three-shaft recuperated closed Brayton Cycle. The PBMM was also utilized to demonstrate the Flownex computer code's ability to accurately predict the dynamic behavior of the system. The operational envelope of the PBMM is found in Table 2. From this table it is evident that the maximum usable flow rate and temperature is in the order of 2kg/s and 700°C, respectively, with Nitrogen as the working fluid. (NOTE: These conditions cannot be attained simultaneously; see Appendix B for more details.)

3.2.2.1 Capabilities

Table 2: Pebble Bed Micro Model Operational Conditions

Variable	Unit	Min	Max
System Pressure	MPa (abs)	0	0.9
System Mass Flow Rate	kg/s	0	2
System Heater Power	kW	0	350
Heater Temperature	°C	0	700
Fluid	---	Nitrogen	Nitrogen

3.2.2.2 Test Schedule

The PBMM is currently not in use.

3.2.2.3 Possible Modifications And Current Configuration

Extensive modifications are needed to change the current facility for use as a component test facility or laboratory. The major changes will include a blower, pipe work, a new control system and instrumentation. The use of helium in the facility must be investigated further as sealing of the vessel will be of concern.

3.2.2.4 Ability To Address CTF Mission Need

When the PBMM capability envelope is compared to the CTF Envelope Philosophy and F&ORs, it is found the PBMM cannot address the requirements. It is not foreseen that the PBMM will suffice for use as a CTF in terms of the CTF Envelope Philosophy.

3.2.3 The Heat Transfer Test Facility

The Heat Transfer Test Facility (HTTF) consists of two clearly distinguishable test units, namely the High Temperature Test Unit (HTTU) and the High Pressure Test Unit (HPTU). The purpose of the facility is twofold namely:

- To validate the correlations that are currently used to model the relevant heat transfer and fluid flow phenomena required for the integrated simulation of the pebble bed core, via a comprehensive set of separate effects tests.
- To generate results that may be used to validate the different simulation methodologies applied in the integrated models that represent the entire pebble bed core, via a comprehensive set of integrated effects tests.

3.2.3.1 High Temperature Test Unit

HTTU Capabilities

The HTTU is an integrated effects test facility that represents a section of the pebble bed reactor. The HTTU pebble annulus is the same width and geometrically similar to the actual PBMR reactor core and it will be used to measure the heat transfer characteristics of the pebble bed as a whole. Some of the tests that will be conducted with the HTTU will be used to validate correlations currently employed by PBMR for the determination of the pebble-to-pebble effective conductivity, pebble-to-reflector conductivity and temperature profiles through the core for different gas flow rates. These tests include steady-state and transient experiments with nitrogen and helium under different conditions. The high temperature pebble bed core or test section forms the heart of the HTTU plant. The test section contains about 28,000 graphite spheres of size similar to that of the PBMR fuel spheres. The operational envelope of the HTTU is found in Table 3 and Figure 7. From this table it is evident that the maximum usable flow rate and temperature are on the order of 4kg/s and 1200°C in the flow configuration and 1600°C in the near vacuum and natural convection configurations. The fluids that can be used in the HTTU are Helium (Natural Convection) and Nitrogen (Natural and Forced Convection) at pressures ranging from 10-100kPa (abs).

NOTE: These conditions cannot be attained simultaneously (see Appendix B for more details).

Table 3: High Temperature Test Unit (HTTU) Operational Conditions

Variable	Unit	Min	Max
System Pressure	kPa (abs)	10	100
System Mass Flow Rate - Nitrogen	kg/s	0	0.5
System Heater Power	kW	0	500
Heater Temperature	ºC	Ambient	1600
Heat Exchanger Power	kW	0	157

Fluid		Helium & Nitrogen

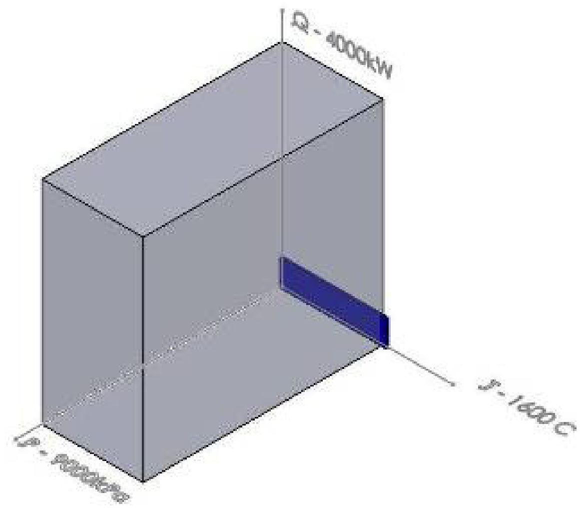


Figure 7: High Temperature Test Unit (HTTU) operational envelope (dark blue area) compared against a facility that will typically adress the CTF F&ORs (grey area)

HTTU Test Schedule

The HTTU is currently utilized for PBMR tests and it is foreseen that it will be available in 2010 for other work.

HTTU Possible Modifications And Current Configuration

It is not foreseen that modification to the HTTU configuration can be made to further address the CTF Mission Need. However, the results obtained from the HTTU will be relevant to the NGNP as it forms the basis for the PBMR design and will be used to V&V the correlation used in the simulation of the PBMR reactor.

HTTU Ability To Address CTF Mission Need

When the HTTU capability envelope is compared to the CTF Envelope Philosophy and F&ORs, it is found the HTTU cannot address the requirements due to its inability to meet operational requirements. The tests that are currently being conducted could possibly be presented in-kind from PBMR to contribute to the NGNP's success and vice-versa.

3.2.3.2 High Pressure Test Unit

HPTU Capabilities

The HPTU operates at a system pressure of 5.0 MPa and a temperature of 75°C, using nitrogen as the working fluid. The HPTU consists of a number of test sections, each evaluating different parameters and reactor phenomena.

The aim of the HPTU is to validate the correlations that are used for different heat transfer and fluid flow phenomena through comprehensive Separate Effects Tests (SET), and to validate the different simulation methodologies used in the integrated models through comprehensive Integrated Effects Tests (IET). It should be noted that the HPTU is not an exact scale model of the actual reactor core or any other reactor structures. It is merely an assortment of representative sections of a pebble bed core, suitable for conducting SET and IET.

The operational envelope of the HPTU is found in Table 4 and Figure 8. From Table 4, it is evident that the maximum usable flow rate is on the order of 2.9kg/s. The fluid that is used in the HPTU is Nitrogen at pressures ranging from 100 to 5,000kPa (abs).

Table 4: High Pressure Test Unit (HPTU) Operational Conditions

Variable	Unit	Min	Max	Completion date
System Pressure	kPa	100	5000	Jan '08
System Mass Flow Rate	kg/s	0.01117	2.888	Jan '08
Braiding Mass Flow Rate	kg/s	0.001532	0.12480	Jan '08
System Heater Power	kW	0.03491	9.668	Jan '08
Braiding Heater Power	kW	0.127	5.481	Jan '08
Heat Exchanger Power	kW	0.04507	0.04507	Jan '08

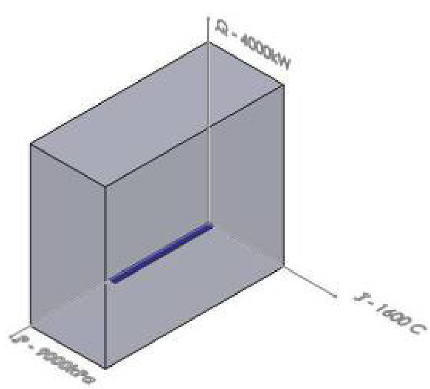


Figure 8: High Pressure Test Unit (HPTU) operational envelope (dark blue area) compared against a facility that will typically adress the CTF F&ORs (grey area).

HPTU Test schedule

The HPTU is fully operational and at the end of its testing phase. The tests for the PBMR were completed at the end of February 2008.

HPTU Possible Modifications and Current Configuration

Extensive modifications (localized heating and cooling) are required to reach high temperatures (T>900 ºC) and that at only 5.0 MPa. It is therefore not foreseen that modification to the HTTU configuration can be made to further address the CTF Mission Need. However, the results obtained from the HPTU will be relevant to the NGNP.

HPTU Ability to Address CTF Mission Need

When the HPTU capability envelope is compared to the CTF Envelope Philosophy and F&ORs, it is found the HPTU cannot address the requirements due to the fact that it was designed to be a high pressure, low temperature and flow rate, Nitrogen operated facility. The tests that are currently being conducted could possibly be presented in-kind from PBMR to contribute to the NGNP's success and vice-versa.

3.2.4 Justification Conclusion

In conclusion, it can be said that after employing the Justification Philosophy to evaluate the South Africa test installations, these facilities do not meet the Mission Statement, Functional and Operational Requirements or Envelope Philosophy and will, therefore, not be suitable as Component Test Facility candidates.

This implies that a completely new facility must be designed and constructed to serve the life cycle requirements of the NGNP. The new facility must be specified in terms of what the F&ORs dictate to result in a solution that will meet the imposed CTF Mission.

The following section presents the recommendations for three concepts of the CTF that should meet the requirements listed in the preceding sections.

4. CTF CONFIGURATION RECOMMENDATIONS

Using the DDNs, together with additional requirements, a *Functional and Operational Requirements List* was created, which basically dictated a number of different test configurations (refer to Figure 9 for the process that was followed). The different concepts were evaluated and will be discussed in this section. Detail descriptions on all the concepts can be found in Appendix F.

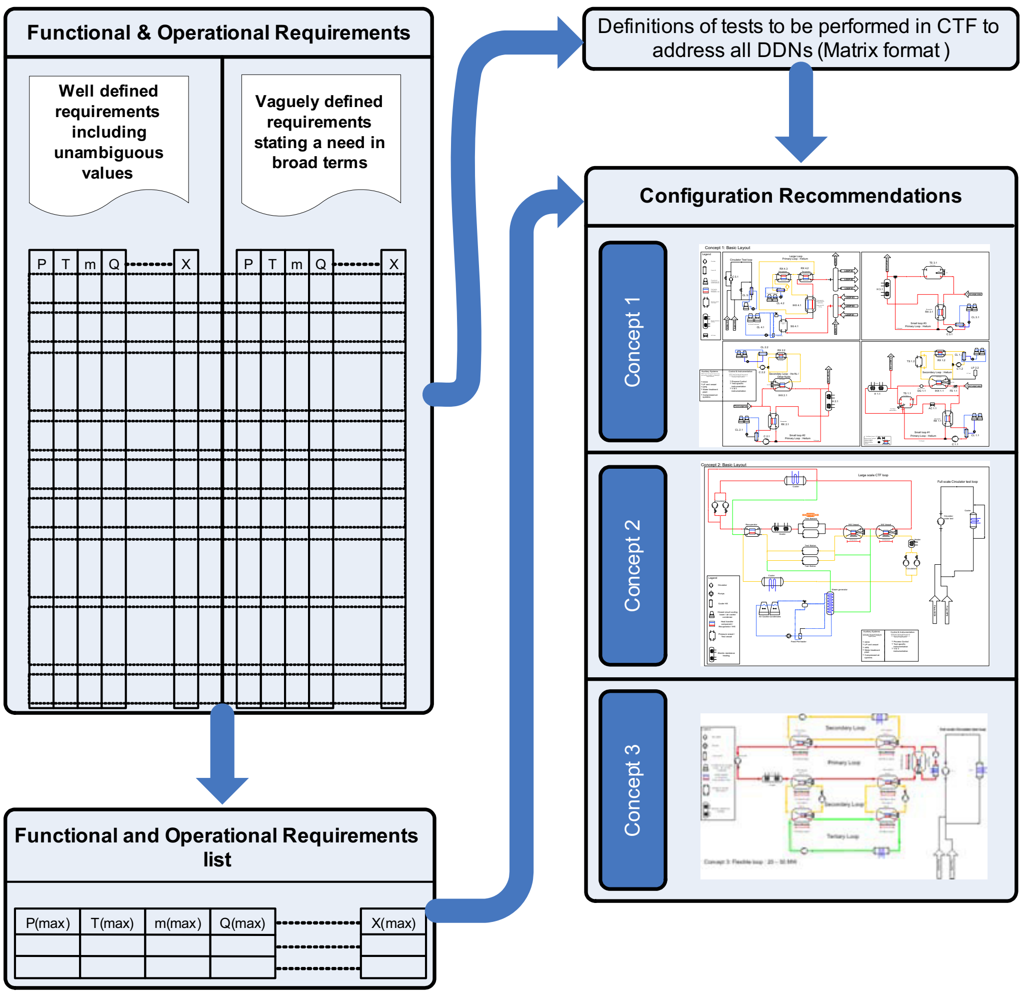


Figure 9: Work flow diagram of the process that was followed to recommend configurations of the CTF that will address all Mission Needs.

From the different F&ORs in the previous section, it is clear that the capability to test a vast array of components and configurations needs to be provided for in the recommended facility concepts. In addition to these verification tests, it is also required to perform long-term life prediction and durability tests on either representative mock-up models or larger scaled components. Keeping this in mind, a *Facility Philosophy* was derived to enable the proposal for such a facility with different concepts.

The *Facility Philosophy* dictates that recommended concepts of the facility:

- Should have the capability of performing numerous tests at the same time. This is needed to address the various long-term testing requirements from different vendors.
- Need to accommodate further development work in terms of coupling commercial process demonstrations via high temperature heat exchangers.
- Should provide test capability for mock-up / scaled versions of certain components under test, while also allowing for full scale testing on circulators.
- Need to provide the capability to investigate different fluids (gases) in secondary loops.
- Should provide sufficient auxiliary systems to perform tests and become familiar with the working of these systems.
- Need to provide an environment where control philosophies can be tested.
- Need to provide an environment where development work can be performed on certain instrumentation.
- Should strive to utilize components that are one order more reliable than the components under test, typically commercial-off-the-shelf (COTS) items.
- An additional requirement is that the complete facility should be constructed and instrumented with Verification and Validation (V&V) in mind.
- Endeavor to possibly facilitate connection to a Nuclear Heat Source (NHS). If the connection to a NHS is required, the facility would need to be designed and built according to ASME III which will lead to a steep increase in cost.

Three different concepts are proposed in this report, based on the *Facility Philosophy,* above. Each of these concepts will be described with reference to its layout, the enveloping values as determined from the different test configurations and some additional considerations.

4.1 CONCEPT 1

Concept 1 consists of three small, completely independent test facilities which can be referred to as Technology Development Loops (TDLs). Each of these three loops could be connected to a common header in order to provide high temperature helium to a single large Component Qualification Loop (CQL). The large loop could then be used for larger scale component qualification by using the combined mass flows and heat energies from the TDLs. In addition to the TDLs and CQL, this concept also includes a completely independent and separate full scale Circulator Testing Loop (CTL).

A process flow diagram of the complete facility for Concept 1, which includes the three different TDLs, CQL and a full scale circulator loop, is provided in Figure 10. Please refer to Appendix D for a more detailed description of Concept 1.

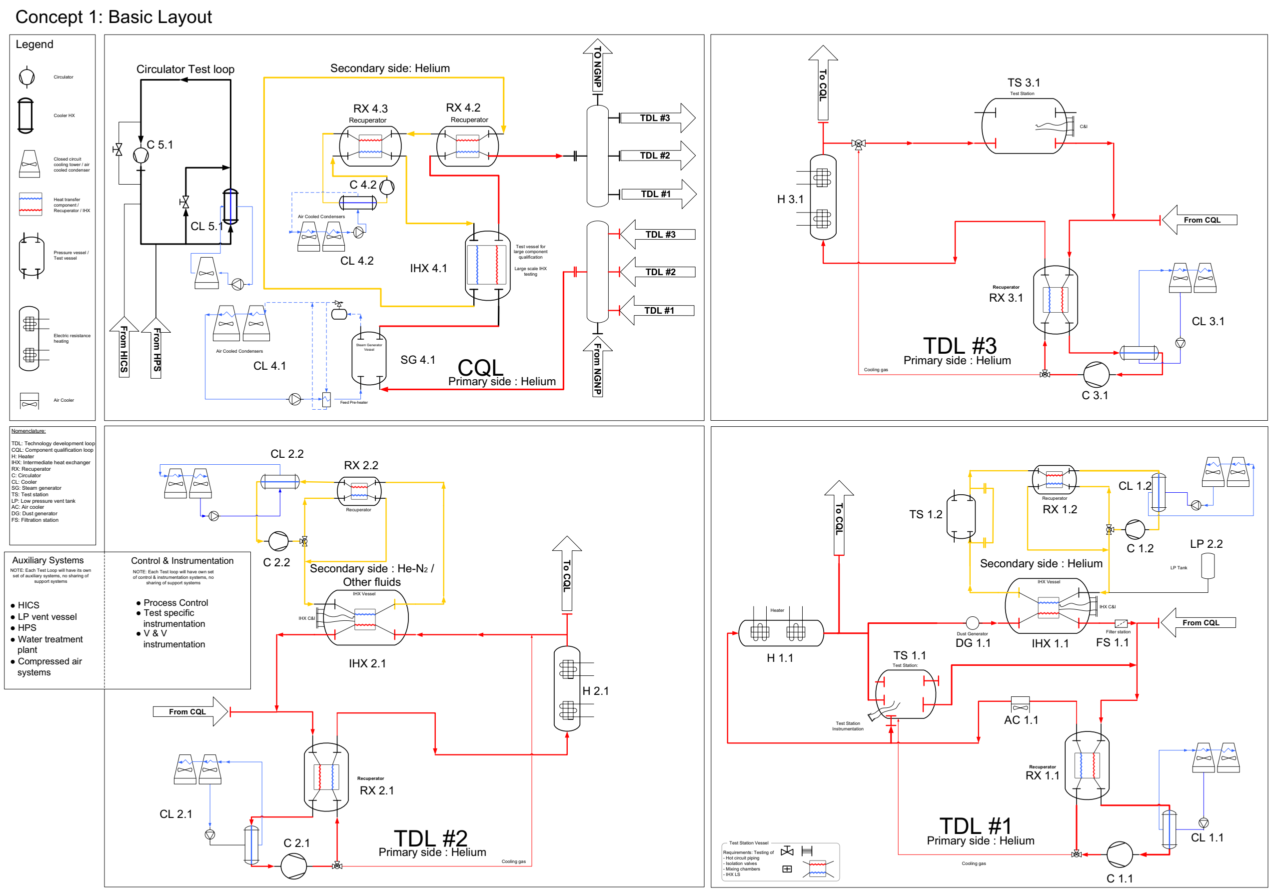


Figure 10: High level Process Flow Diagram of Concept 1 indicating all Technology Development Loops, Component Qualification Loop & Full Scale Circulator Loop

4.1.1 Facility Layout

A preliminary facility layout of TDL 1 is presented in Figure 11, Figure 12 and Figure 13. This layout does not represent an optimized facility and was only created to obtain a feel for possible sizes of a single facility and related equipment. Although the complete facility is portrayed outside a building, it is recommended that it be housed inside a large building, utilizing overhead cranes with sufficient space for future development and lay down areas.

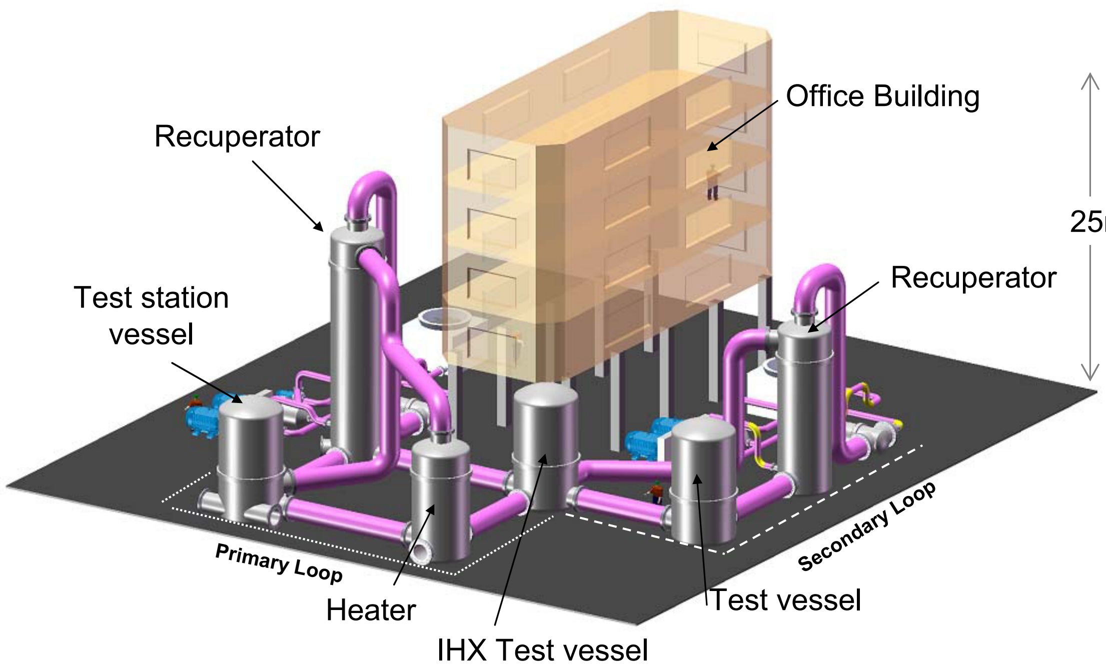


Figure 11: Conceptual physical layout of Technology Development Loop 1 indicating major components as found in the Process Flow diagram

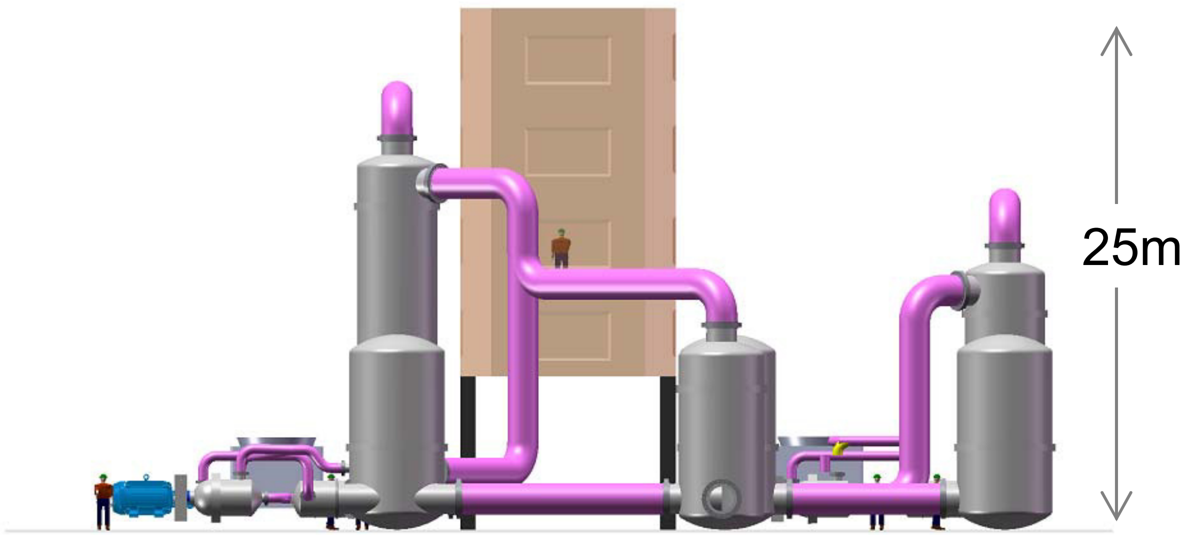


Figure 12: Conceptual layout side view of Technology Development Loop 1

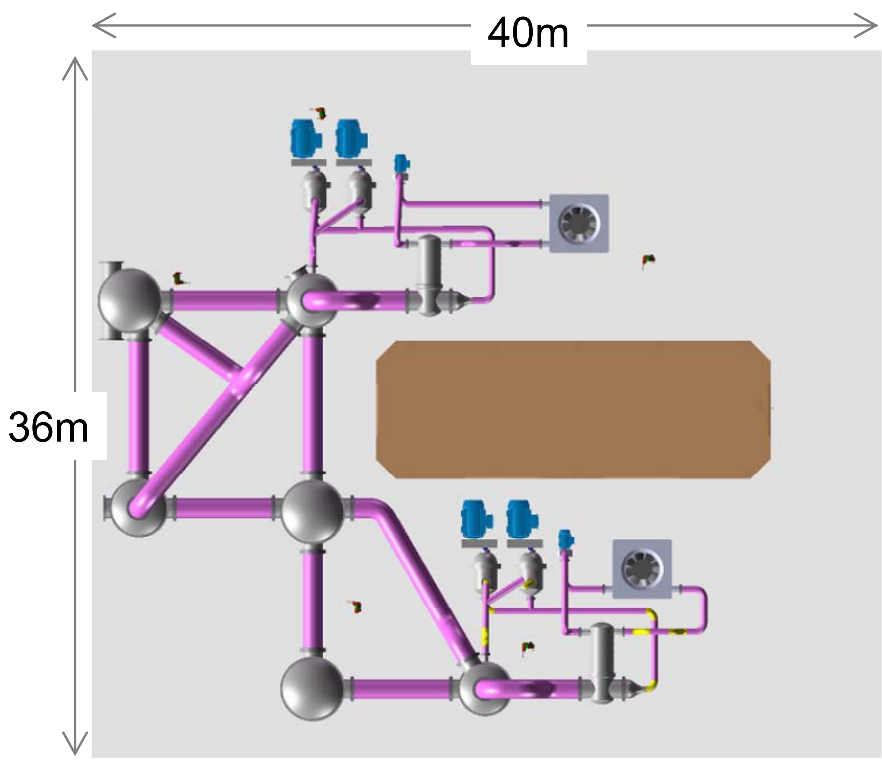


Figure 13: Conceptual floor plan view of Technology Development Loop 1

An envisaged layout of the entire Concept 1 is illustrated in Figure 14. Specific consideration was given to the following:

- The facility layout should have large open / undeveloped areas in the vicinity of the test vessels. This is to accommodate later development work with regards to either liquid salt secondary loops, or process coupling for commercial applications.
- The facility layout should be such that the heaters from the three smaller loops are in close proximity to each other, in order to reduce the common hot header for a possible large loop.
- Auxiliary systems should be located to the rear of each facility in order to ease access.
- Dedicated laydown areas should be provided.

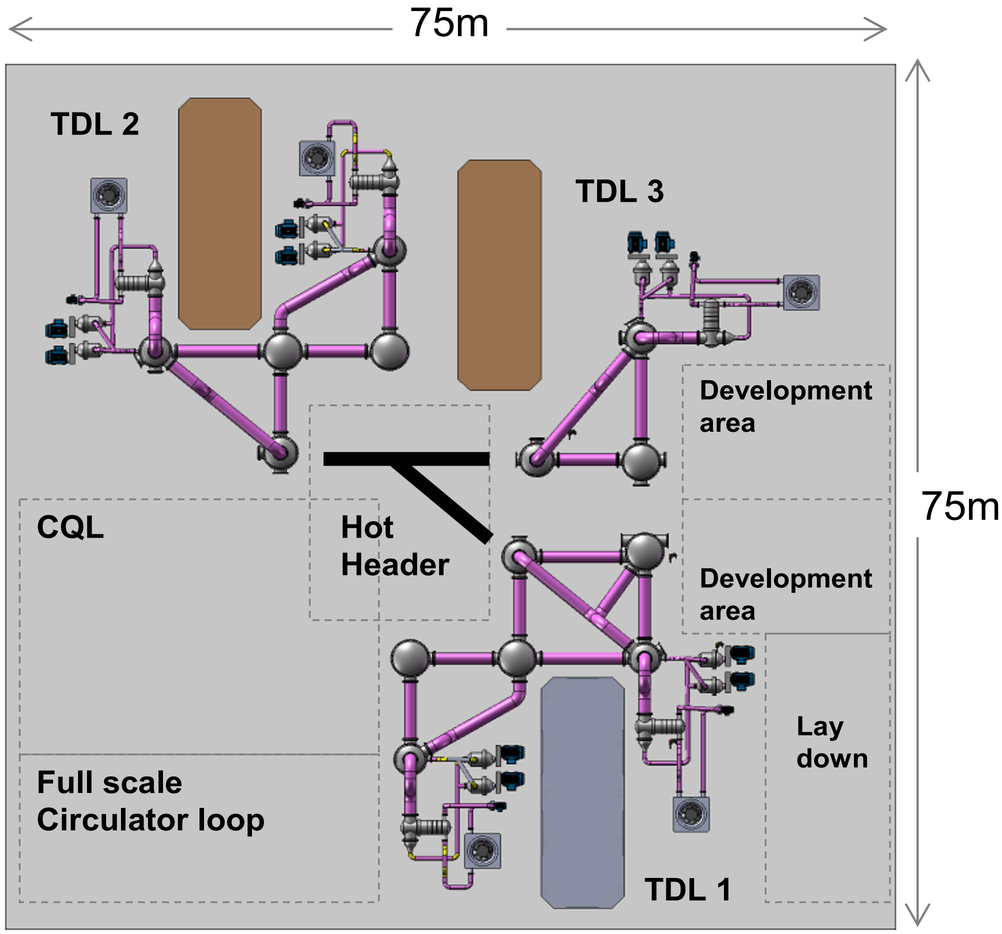


Figure 14: Physical layout of Concept 1 showing the TDL, interconnecting Hot Header, CQL, CLT, allocated floor space and lay down areas

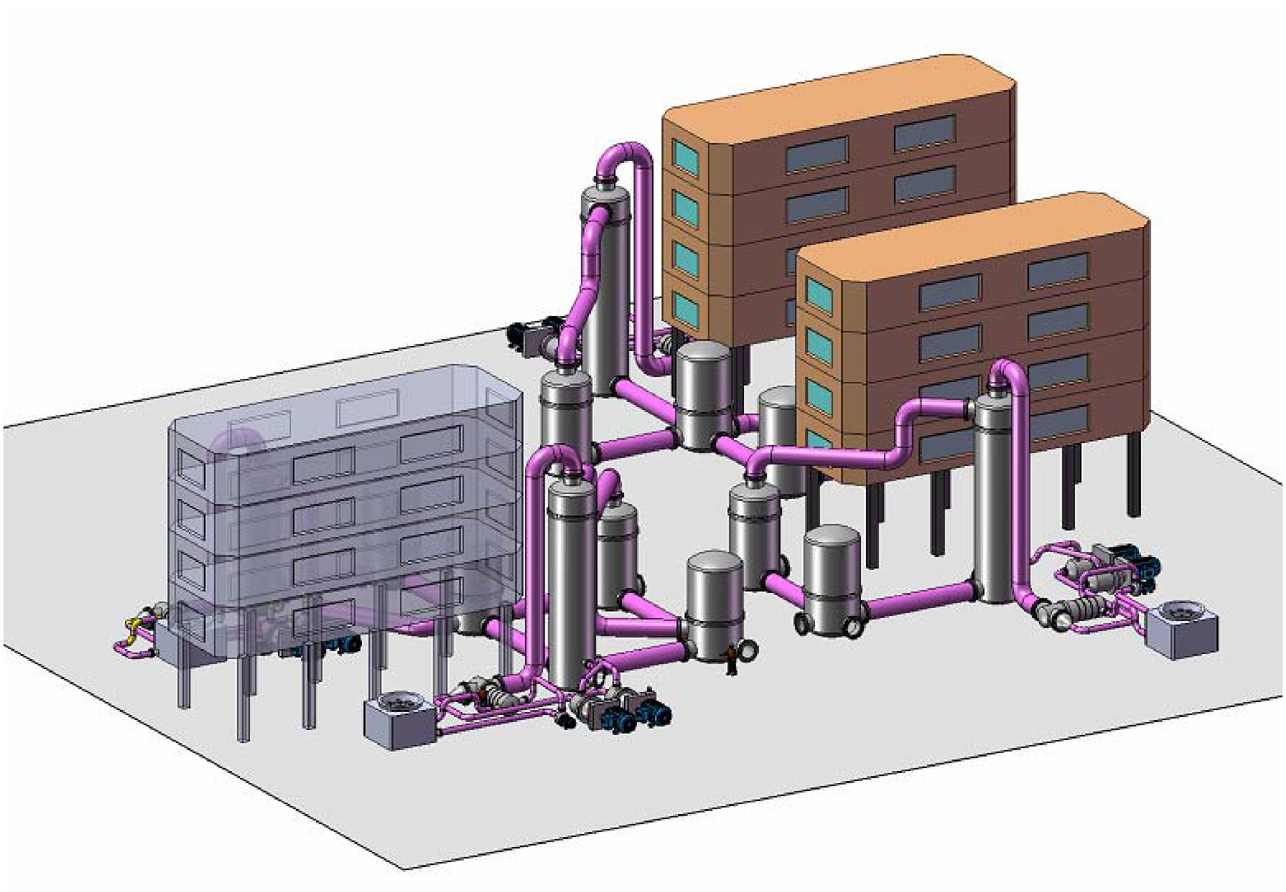


Figure 15: Perspective view of the physical layout of Concept 1

4.1.2 Pros And Cons

A few additional considerations that are regarded as advantages for this concept include:

- Three small test loops provide independent testing capability of various components from different vendors at the same time.
- Smaller, less complex facilities tend to utilize standard off-the-shelf components, as is or with minor modifications.
- The TDLs can be built in succession and lessons learned from one could be transferred to another, without impairing the NGNP time schedule.
- Risks are mitigated in terms of complexity and manufacturing lead times, while allowing an overall footprint that is quite compact.
- Utilizing the smaller loops for larger scale testing is accommodated by means of the common header configuration.
- Smaller loops provide independent connectivity for potential commercial application testing utilizing hot helium heat exchangers.
- Smaller facilities tend to favor transients in terms of lower thermal inertia and smaller gas volumes for depressurization.

- Multiple independent loops spread the risk in terms of availability and redundancy of the test facility as a whole.

The disadvantages or aspects that need further investigation include:

- Limited mass flow and heating capacity of the smaller facilities.
- This concept includes complex inlet and outlet headers which need to operate at high temperatures. The complexity of the outlet header might, however, be decreased by means of defining test configurations which always include a heat transfer testing component while also testing non-heat transfer components.
- Possibility of long lengths of hot pipes. Could be addressed by optimized routing.

4.2 CONCEPT 2

Concept 2 differs from Concept 1 in that it comprises of one large facility instead of multiple smaller facilities and is used as a large scale Component Qualification Loop (CQL 2). This large facility is driven by a mass flow recommendation of ~15 percent of the maximum NGNP circulating mass flow which relates to ~25 kg/s. This recommendation came as a result of various discussions with the engineering team of the HTF and component specialists. The process layout is similar to that of the Concept 1, in that it also utilizes a primary, secondary and dedicated steam generating loop. In addition to these, it is again proposed to have a separate full scale circulator testing circuit (as in Concept 1).

A process flow diagram of the complete facility for Concept 2, which includes the primary, secondary and steam generator loop is indicated in Figure 16. This also illustrates the separate full scale CTL. Please refer to Appendix E for a more detailed description of Concept 2.

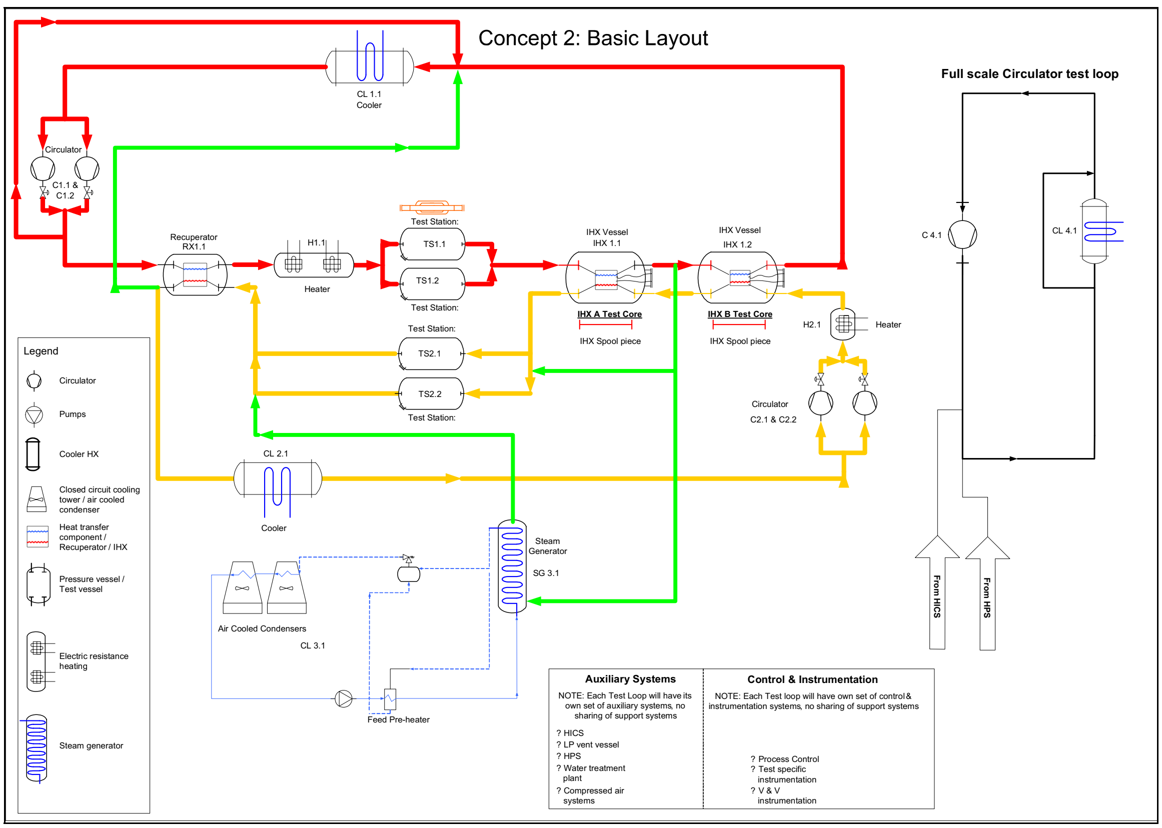


Figure 16: High level Process Flow Diagram of Concept 2 indicating Primary Loop, Secondary Loop, Steam Generator Loop & Full Scale Circulator Loop

4.2.1 Facility Layout

A preliminary facility layout of Concept 2 is presented in Figure 17. This layout does not necessarily indicate all minor details of the proposed concept, but merely provides an idea of expected sizes. The circulator loop is not included in this illustration and is expected to accommodate a footprint size of approximately 50m x 25m.

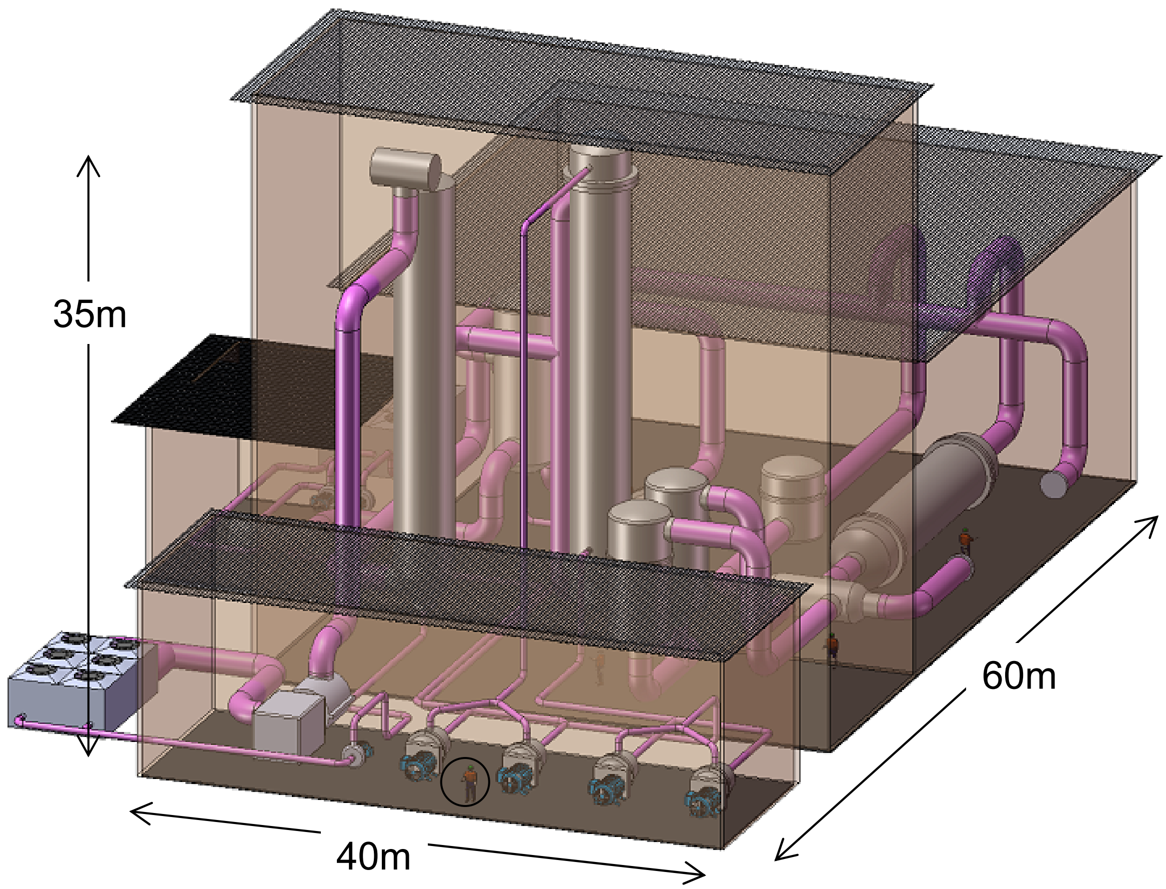


Figure 17: Physical layout of Concept 2 (CQL 2)

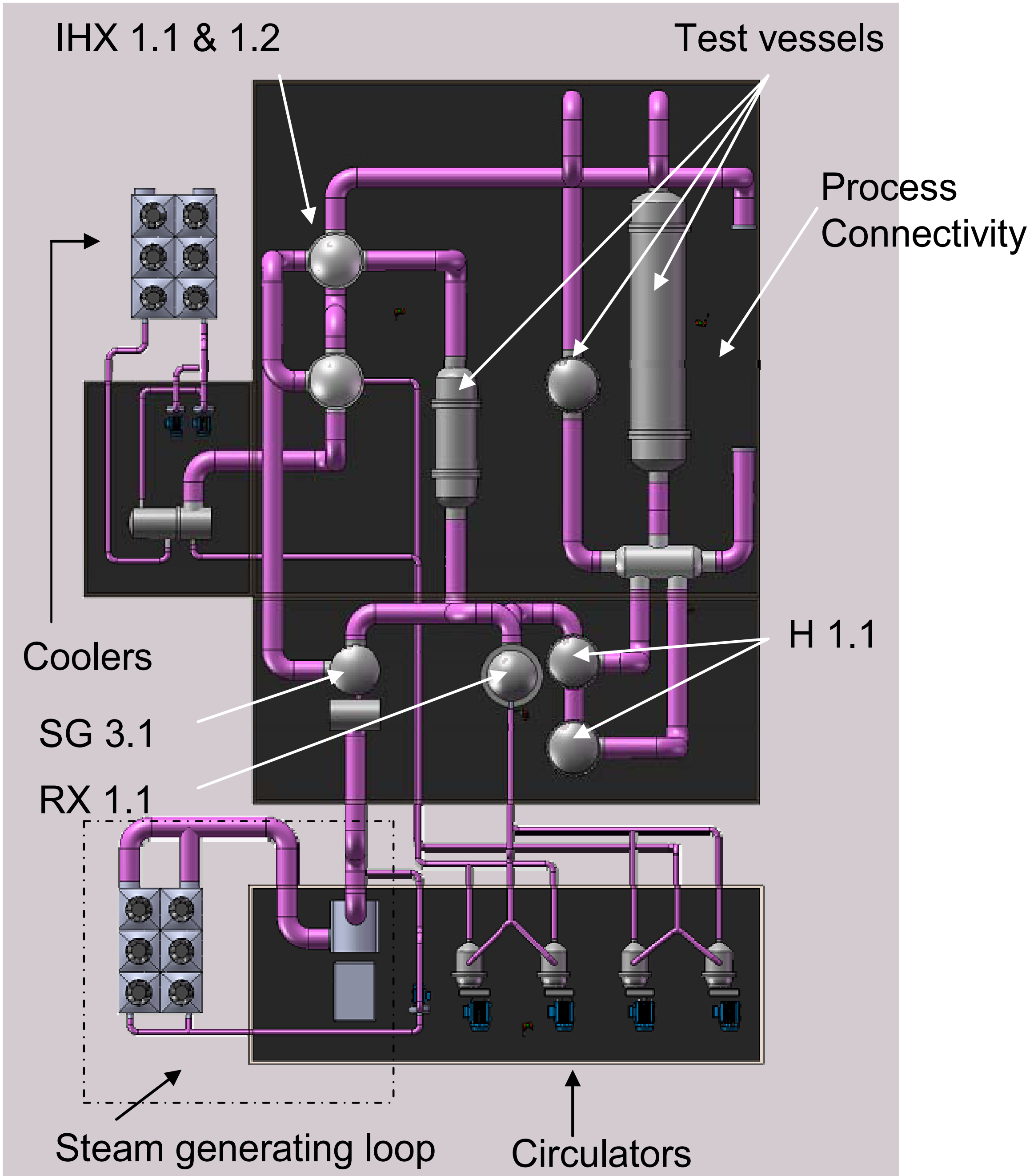


Figure 18: Floor plan layout of Concept 2(CQL 2) indicating major components as can be found in the Process Flow diagram

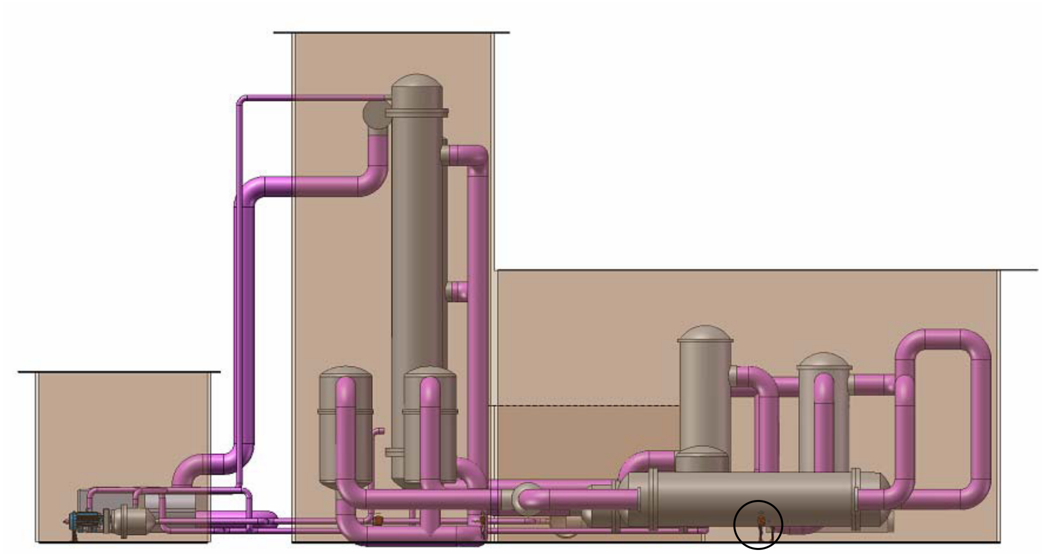


Figure 19: Side view layout of Concept 2 (CQL 2)

4.2.2 Pros And Cons

Additional considerations that are regarded as advantages are:

- The capability to perform large scale testing (maximum sizes are provided in the loop descriptions in Appendix E).
- Provision should be made for future development in terms of coupling of commercial high temperature processes.
- A large test facility could provide conditions closer to that of the NGNP with regards to fault finding, program development, safety programs, maintenance programs and in-service inspections.
- The lesson learned from a facility such as this could be more easily transferred to the NGNP design and construction phases.
- Quality assurance programs (such as NQA-1) on a large facility could be of more relevance to NGNP related programs than from smaller facilities.

With these added benefits, the following disadvantages are also to be mentioned:

- The complexity associated with a large facility immediately increases the risk in terms of non standard components and long manufacturing lead times.
- Some major components, such as the circulator, need to be developed. This implies that a unit under test is supplied by certain process conditions by another unit under test which is contrary to the *Facility philosophy*.
- A large facility makes complete independent testing from various parties quite difficult, which translates back to possible time scheduling risks. Testing of numerous components at the same time can be obtained but with a high level of complex control.
- The facility would be less amenable to scaled testing or module testing, which may be more cost effective than large-scale testing, when otherwise technically acceptable.

4.3 CONCEPT 3

Concept 3 is an alternative for Concept 2 and will only be discussed via a high level process flow diagram. This concept basically consists of one large primary loop (20 – 50 MW_t) with numerous secondary loops connected to it, plus the separate CTL. The connection of the primary and secondary loops is established by means of heat transfer testing components. It is further anticipated that the secondary loops are in turn connected to tertiary loops for testing and evaluating of commercial high temperature applications items. A representative process flow diagram of such a facility is provided in Figure 20, while a list of associated advantages and disadvantages is presented thereafter.

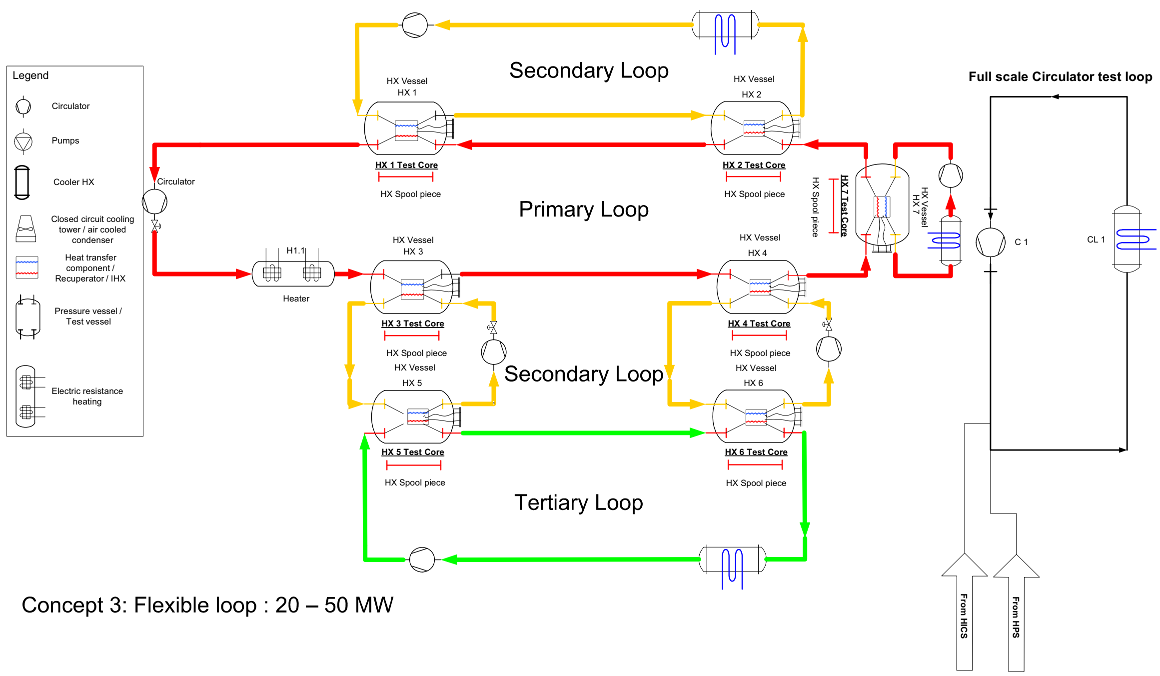


Figure 20: High level process flow diagram of Concept 3 indicating the Primary Loop, Secondary and Tertiary Loops as well as the Full Scale Circulator Test Loop

4.3.1 Pros And Cons

Advantages associated with this concept include:

- The flexibility to perform numerous tests at the same time by means of various connectivity possibilities in both secondary and tertiary loops.
- Large capacity in terms of mass flow and heating capability which provides for large scale component testing.
- Large scale facilities will provide more relevant information with regard to program development, fault finding and in-service training.
- The lessons learned from such a facility could be more easily transferred to the NGNP design and construction phases.
- Quality assurance programs (such as NQA-1) on a large facility could be of more relevance to NGNP related programs than from smaller facilities.

Apart from these advantages, this concept is not highly recommended due to the following aspects:

- The complexity associated with a large facility immediately increases the risk in terms of non-standard components and long manufacturing lead times.
- Some major components such as the circulator need to be developed. This developed component is now utilized in testing components under development which increases the risk of potential non-operating conditions.
- A large facility makes complete independent testing from various parties quite difficult, which translates back to possible time scheduling risks. Testing of numerous components at the same time can be obtained, but with high level of complex control.
- Due to the fact that this facility is also quite large and that several secondary loops need to be supplied by hot gas, it could increase the price of primary loop hot pipes dramatically.

4.4 CONCEPT RECOMMENDATION

Three different concepts were discussed in the previous section and a recommendation regarding the most desirable concept that addresses the CTF Mission Need and F&ORs is presented below.

Concept 1 consists of three independent small test facilities which are specifically sized to address explicit DDNs as obtained from the PCDR of the three vendor teams. These three smaller facilities can in general be considered as Technology Development Loops (TDL) (for smaller components), while they are capable of being integrated via a common header. The common header allows for large mass flows and heating capability which could be used as a Component Qualification Loop (CQL) (up to ~10 MW_t) as per specific design needs. The advantage of the separate, but interconnecting loops lies in the manner in which different components can be tested at the same time using different loops. Also, the smaller loops require less engineering challenges during design and a staged technology growth path can be followed, where lessons learned from the first loop can be applied in the succeeding loops. It can also be advantageous that, when the first loop has been constructed and commissioned, testing can already commence while the other loops in the facility are being built. This is in favor of the NGNP schedule and is one of the primary reasons why Concept 1 is recommended as the concept of choice.

Concept 2 consists of a large loop used for component qualification (CQL 2) with the basic sizing being driven by a ~15 percent NGNP mass flow recommendation. This facility will be able to address almost all DDNs but has the limitation of performing a singular, long term durability test which entirely commits the plant to one specific test that could negatively impact on the greater NGNP schedule. Together with this disadvantage are the added risk, due to complexity, the higher operating costs of a single large plant and, specifically, the research and development (R&D) that is required for most of the loop components. The required R&D work on the loop components might affect the target completion date of 2011. Concept 2 is the second choice in recommending a test loop configuration for the CTF.

Concept 3 utilizes a singular primary hot loop with numerous secondary and tertiary loops connecting to it. Although the flexibility might seem to be an advantage, it is foreseen that the complexity in control philosophies with various independent experiments might be problematic. If the functionality of testing different UUT simultaneously is encumbered, it is foreseen that the Mission Need will not be satisfied. More specifically, it is required that the CTF be available to a huge community of contributors that has a large number of envisaged tests (as per DDNs) which will probably entail a comparable waiting list if the facility cannot accommodate parallel testing. This would put the NGNP schedule at risk and is one of the reasons why Concept 3 is not recommended to be a feasible concept for the CTF.

Despite its disadvantages, the ability to have a larger test loop such as that of Concept 2 (excluding the CTL) later on in the component qualification stages of the NGNP lifecycle does make sense. It is possible that the common header proposal of Concept 1 could prove to be more complex or costly than can be anticipated now. It might turn out that construction of the loop configuration of Concept 2 should follow after construction of TDL2 or TDL3 of Concept 1.

This is also why Concept 1 is attractive; it provides flexibility in testing as well as a staged approach in financial expenditure.

5.2 SCHEDULE

The schedule for the CTF was done in line with the cost estimate and the following assumptions were used:

- The final mile-stone is RFC in FY2011
- Schedules are provided for Concepts to stand as singular independent units that do not share utilities.
- Manpower will not be a constraint during any phase of the project.
- Based on construction and design time of PBMR facilities such as HTF and HTTF.
- *Force Majeure* was not catered for in these estimates.

The two envisaged schedules are presented in the next paragraphs.

5.2.1 Schedule - Concept 1

Figure 21 below depicts the schedule of Concept 1 and illustrates that in light of meeting the FY2011 deadline, the concept design phase must start in December 2008. After approval of the concept design, the preliminary design will follow thereafter, but must be completed no later than December 2009 to start support of the civil work. This provides a 20 month period during which to complete Concept 1.

ID	Task Name	Duration	Start	Finish
2	**Component Test Facility (CTF) - Concept 1**	**660 days**	**Mon 08/12/01**	**Fri 11/06/10**
3	**Civils**	**240 days**	**Mon 09/12/28**	**Fri 10/11/26**
4	Site preperation	2 mons	Mon 09/12/28	Fri 10/02/19
5	Road work	1 mon	Mon 10/02/22	Fri 10/03/19
6	Buildings & Cranes	8 mons	Mon 10/03/22	Fri 10/10/29
7	Paving	1 mon	Mon 10/11/01	Fri 10/11/26
8	**Utilities**	**340 days**	**Mon 09/12/28**	**Fri 11/04/15**
9	Water treatment	6 mons	Mon 10/03/22	Fri 10/09/03
10	Electrical	6 mons	Mon 09/12/28	Fri 10/06/11
11	HPS	6 mons	Mon 10/11/01	Fri 11/04/15
12	HICS	6 mons	Mon 10/11/01	Fri 11/04/15
13	Compressed air	1 mon	Mon 10/11/01	Fri 10/11/26
14	Fire protection	1 mon	Mon 10/11/01	Fri 10/11/26
15	**Technology Development Loop 1 (TDL 1)**	**660 days**	**Mon 08/12/01**	**Fri 11/06/10**
16	Concept Design	6 mons	Mon 08/12/01	Fri 09/05/15
17	Preliminary Design	8 mons	Mon 09/05/18	Fri 09/12/25
18	Procure Long lead Items	18 mons	Mon 09/08/03	Fri 10/12/17
19	Final Design	12 mons	Mon 09/12/28	Fri 10/11/26
20	Construction	8 mons	Mon 10/11/01	Fri 11/06/10
21	**Technology Development Loop 2 (TDL 2)**	**500 days**	**Mon 09/05/18**	**Fri 11/04/15**
22	Concept Design	4 mons	Mon 09/05/18	Fri 09/09/04
23	Preliminary Design	5 mons	Mon 09/09/07	Fri 10/01/22
24	Procure Long lead Items	18 mons	Mon 09/08/03	Fri 10/12/17
25	Final Design	6 mons	Mon 10/01/25	Fri 10/07/09
26	Construction	6 mons	Mon 10/11/01	Fri 11/04/15
27	**Technology Development Loop 3 (TDL 3)**	**500 days**	**Mon 09/05/18**	**Fri 11/04/15**
28	Concept Design	4 mons	Mon 09/05/18	Fri 09/09/04
29	Preliminary Design	5 mons	Mon 09/09/07	Fri 10/01/22
30	Procure Long lead Items	18 mons	Mon 09/08/03	Fri 10/12/17
31	Final Design	6 mons	Mon 10/01/25	Fri 10/07/09
32	Construction	6 mons	Mon 10/11/01	Fri 11/04/15
33	**Circulator Test Loop (CTL)**	**460 days**	**Mon 09/05/18**	**Fri 11/02/18**
34	Concept Design	2 mons	Mon 09/05/18	Fri 09/07/10
35	Preliminary Design	2 mons	Mon 09/07/13	Fri 09/09/04
36	Procure Long lead Items	18 mons	Mon 09/08/03	Fri 10/12/17
37	Final Design	4 mons	Mon 09/09/07	Fri 09/12/25
38	Construction	4 mons	Mon 10/11/01	Fri 11/02/18
39	**Component Qualification Loop (CQL)**	**520 days**	**Mon 09/05/18**	**Fri 11/05/13**
40	Concept Design	4 mons	Mon 09/05/18	Fri 09/09/04
41	Preliminary Design	6 mons	Mon 09/09/07	Fri 10/02/19
42	Procure Long lead Items	18 mons	Mon 09/08/03	Fri 10/12/17
43	Final Design	6 mons	Mon 10/02/22	Fri 10/08/06
44	Construction	7 mons	Mon 10/11/01	Fri 11/05/13

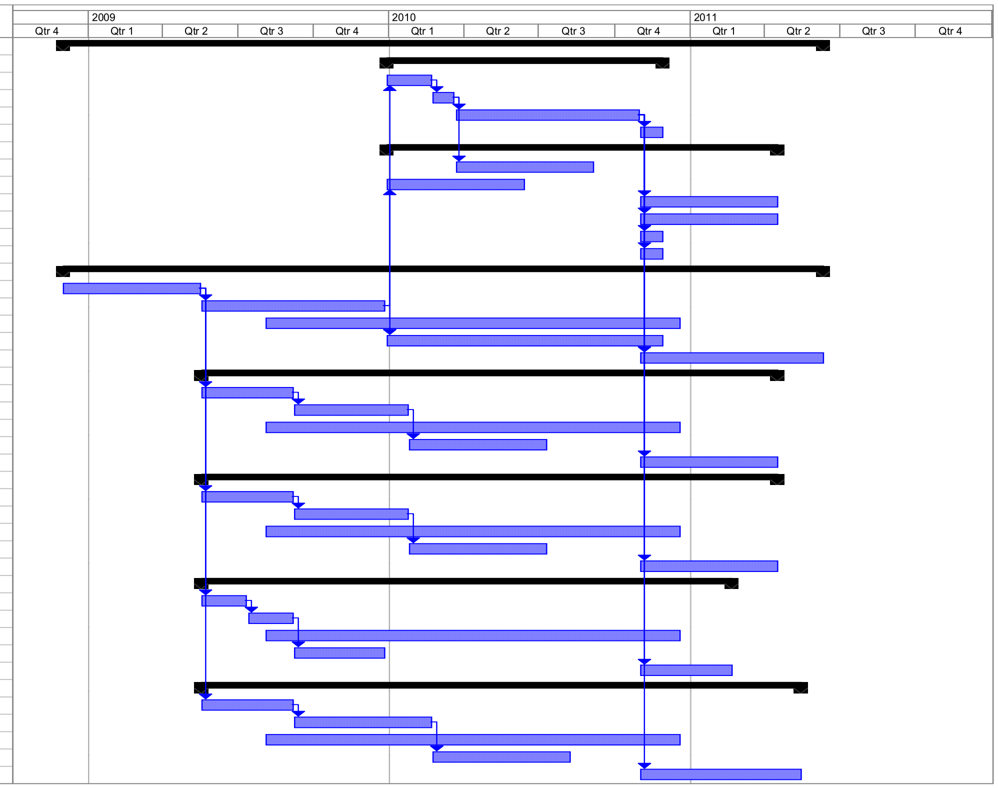


Figure 21: Schedule for Concept 1 indicating key dates and dependants

5.2.2 Schedule - Concept 2

Figure 22 presents the schedule for Concept 2 and dictates that it will take an estimated 720 days, i.e. two years, to complete, i.e. from concept phase to RFC. The fact that R&D is required in developing some of the components is clear from the long design and construction time. The circulator loop will be built in parallel with the large CQL 2.

ID		Task Name	Duration	Start	Finish
2		**Component Test Facility (CTF) - Concept 2 (CQL2)**	**720 days**	**Mon 08/12/01**	**Fri 11/09/02**
3		**Civils**	**240 days**	**Mon 09/02/02**	**Fri 10/01/01**
4		Site preperation	2 mons	Mon 09/02/02	Fri 09/03/27
5		Road work	1 mor	Mon 09/03/3C	Fri 09/04/24
6		Buildings & Cranes	8 mons	Mon 09/04/27	Fri 09/12/04
7		Paving	1 mor	Mon 09/12/07	Fri 10/01/01
8		**Utilities**	**249 days**	**Tue 09/09/01**	**Fri 10/08/13**
9		Water treatment	6 mons	Mon 10/03/01	Fri 10/08/13
10		Electrical	6 mons	Tue 09/09/01	Mon 10/02/15
11		HPS	6 mons	Mon 09/12/07	Fri 10/05/21
12		HICS	6 mons	Mon 09/12/07	Fri 10/05/21
13		Compressed air	1 mor	Mon 09/12/07	Fri 10/01/01
14		Fire protection	1 mor	Mon 09/12/07	Fri 10/01/01
15		**Circulator Test Loop (CTL)**	**340 days**	**Mon 09/02/02**	**Fri 10/05/21**
16		Concept Design	2 mons	Mon 09/02/02	Fri 09/03/27
17		Preliminary Design	2 mons	Mon 09/03/3C	Fri 09/05/22
18		Final Design	4 mons	Wed 09/07/01	Tue 09/10/2C
19		Construction	6 mons	Mon 09/12/07	Fri 10/05/21
20		**Component Qualification Loop 2 (CQL 2)**	**720 days**	**Mon 08/12/01**	**Fri 11/09/02**
21		Concept Design	6 mons	Mon 08/12/01	Fri 09/05/15
22		Preliminary Design	9 mons	Mon 09/05/1E	Fri 10/01/22
23		Procure long lead items	18 mons	Wed 09/07/01	Tue 10/11/16
24		Final Design	20 mons	Thu 09/10/01	Wed 11/04/13
25		Construction	12 mons	Mon 10/10/04	Fri 11/09/02

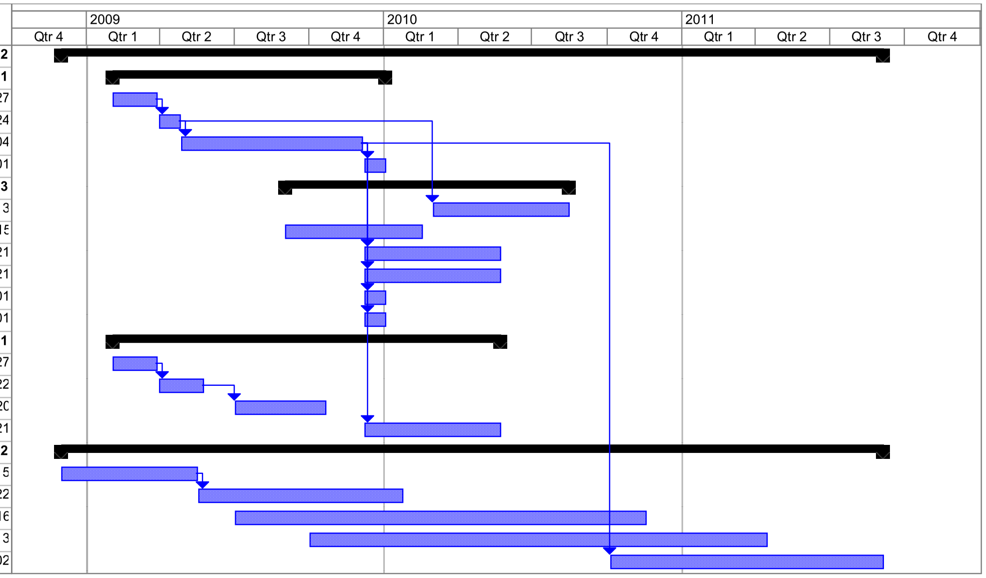


Figure 22: Schedule for Concept 2 indicating key dates and dependants

APPENDIX A: DESIGN DATA NEEDS MATRIX

The following DDN's are specific to a CTF

Vendor	Group	DDN #	(3.1) Mission Need		(3.3) Functional and Operational requirements														(3.2) Facility				(3.5) Life Cycle							rating		
					FOR-001	FOR-002	FOR-003	FOR-004	FOR-005	FOR-006	FOR-007	FOR-008	FOR-009	FOR-010	FOR-011	FOR-012	FOR-013	FOR-014	FAC-005	FAC-002	FAC-003	FAC-006	R&D	NRC Licensing	Long Lead Items	Construction	Commission	Operation	Commercial Appl.	DDL	TEL	Doc#
					P (Prim)	P (Secon)	P (Delta)	T (Prim)	T (Secon)	T (Other)	m	Q	Fluid	(Other)	(Other)	(Other)	(Other)	(Other)	HTF	HTTU	HPTU	PBMM	I	II	III	IV	V	VI	VII			
WEC	CTF	HTS-01-17	Metallic: IHX Performance Verification	1	9 Mpa	9MPa	< 200 kPa	T_inlet: 950C T_outlet: 331C	T_inlet: 280C T_outlet: 900C	N/A	TBD	TBD	Helium / TBD	IHX Life prediction	Controlled impurity levels	IHX Material testing	IHX Durability Testing	IHX Performance testing	Yes, see note	No	No	No	1	1	1			1		1	2	017, 018
WEC	CTF	HTS-02-04	Ceramic: IHX Performance Verification	1	9 Mpa	9MPa	< 200 kPa	T_inlet: 950C T_outlet: 331C	T_inlet: 287C T_outlet: 900C	N/A	TBD	TBD	Helium / TBD	IHX Life prediction	Controlled impurity levels	IHX Material testing	IHX Durability Testing	IHX Performance testing	Yes, see note	No	No	No	1	1	1	1		1		1	2	020, 021, 022
WEC	CTF	HTS-03-01	Mixing Chamber Performance Test	2	N/A	8.5MPa	N/A	IHX A T_outlet 800C	PCHX T_outlet 850C (HPS in ops) T_outlet 800C (HPS out ops)	N/A	Total HTS flow: 150.8 kg/s. Flow to PCHX: 39.8 kg/s. Flow to SG: 110.7 kg/s	N/A	Helium	Performance verification test on a prototype mixing chamber	Nominal operating life of the mixing chamber (equivalent to plant life)	N/A	N/A	N/A	Yes, see note	No	No	No	1	1	1			1		1	2	022
WEC	CTF	HTS-04-01	Evaluation of High Temperature Ducts and Insulation Systems	3	8.8 Mpa	8.4 Mpa	N/A	Reactor T_outlet 950°C	IHX T_outlet 900°C	N/A	TBD	N/A	Helium	Nominal operating life of the hot duct and other high temperature piping systems equivalent to plant life	N/A	N/A	N/A	N/A	Yes, see note	Yes, see note	No	No	1	1	1	1		1		3	6	034 , 036, 039
WEC	CTF	SG-01-04	Acoustic Response of Helical Bundle	4	N/A	8.2 MPa	N/A	N/A	T_inlet: 600C T_outlet: 270C	FW T_inlet 220C Steam T_outlet 540C	TBD	N/A	Helium	The design service life is 60 equivalent full-power years.	N/A	N/A	N/A	Predict the excitation frequency for a given tube array.	Yes, see note	No	No	No	1			1				3	6	040,048
WEC	CTF	SG-01-07	Insulation Verification Test	4	N/A	8.2MPa	N/A	N/A	T_inlet: 600C T_outlet: 270C	N/A	TBD	N/A	Helium	Thermal and mechanical performance of the insulation located in the active flow region (i.e., helium inlet plenum and outer shroud) of the steam generator needs to be verified.	Thermal cycling of fibrous insulation	Effects of mechanical and acoustic vibrations	Effects of flow and thermal gradients	Thermal conductivity at 8.2 Mpa	Yes, see note	No	No	No	1			1				3	6	040,048
WEC	CTF	SG-01-08	Fretting & Sliding Wear Protection Tests	4	N/A	8.2MPa	N/A	N/A	T_inlet: 600C T_outlet: 270C	FW T_inlet 220C Steam T_outlet 540C	TBD	N/A	Helium	demonstrate that the existing TRD design	Thermal cycling might be a requirement	N/A	N/A	N/A	Yes, see note	No	No	No	1			1				3	6	040,048
WEC	CTF	SG-01-10	Shroud Seal Test	4	N/A	8.2MPa	N/A	N/A	T_inlet: 600C T_outlet: 270C	FW T_inlet 220C Steam T_outlet 540C	N/A	N/A	Helium	Test of two types of seals designs to validate design features.	Measure leak rates	Measure Pressure diff	Sealing load measure	N/A	Yes, see note	No	No	No	1			1				3	6	040,048
WEC	CTF	SG-01-11	Lead-in/Lead-out/Transition/Expansion Loop Mockups	4	N/A	8.2MPa	N/A	N/A	T_inlet: 600C T_outlet: 270C	FW T_inlet 220C Steam T_outlet 540C	TBD	N/A	Helium	Thermal movement characteristics	N/A	N/A	N/A	N/A	Yes, see note	No	No	No	1							3	6	040,048
WEC	CTF	SG-01-12	Flow Induced Vibration Testing of Helical Bundle	4	N/A	8.2MPa	N/A	N/A	T_inlet: 600C T_outlet: 270C	FW T_inlet 220C Steam T_outlet 540C	TBD	N/A	Helium	Flow-induced vibration characteristics of the steam generator helical tube bundle, lead-out tubes and transition tubes.	N/A	N/A	N/A	N/A	Yes, see note	No	No	No	1			1				3	6	040,048
WEC	CTF	SG-01-13	Orifice Qualification Test	4	N/A	N/A	N/A	FW inlet temperature of nominally 220°C	N/A	N/A	TBD	N/A	Water	Erosion / Corrosion resistance test for orifice	Orifice pressured rop performance validation	N/A	N/A	N/A	Yes, see note	No	No	No	1							3	6	040,048
WEC	CTF	SG-01-14	Instrumentation Attachment Test	4	N/A	8.2MPa	N/A	N/A	T_inlet: 600C T_outlet: 270C	FW T_inlet 220C Steam T_outlet 540C	N/A	N/A	Helium	N/A	N/A	N/A	N/A	N/A	Yes, see note	No	No	No	1			1		1		3	6	040,048
WEC	CTF	SG-01-16	Helical Bundle and Transition Region Heat Transfer Test	4	N/A	8.2MPa	N/A	N/A	T_inlet: 600C T_outlet: 270C	FW T_inlet 220C Steam T_outlet 540C	TBD	TBD	Helium	Heat transfer coefficients on the outside of tubes in the transition region from cross flow in a helical tube bundle to axial flow along parallel straight tubes.	Heat transfer coefficient circumferential variation around the outside of a tube at the entrance region of a helical tube bundle.	Average heat transfer coefficients on the outside of tubes for the entrance region of a helical tube bundle	Tube bundle friction factors for tube bundles with variation from a square pitch to a staggered pitch.	N/A	Yes, see note	No	No	No	1							3	6	040,048
ARE	CTF	AREVA-023	- Circulators	5	TBD	TBD	TBD	TBD	TBD	N/A	TBD	N/A	Helium	Determine specific requirements for circulator					Yes, see note	No	No	No								3	6	014, 028
ARE	CTF	AREVA-024	- Tube type IHX	1	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	Helium	Areva specifications / requirements TBD					Yes, see note	No	No	No								1	2	018, 020
ARE	CTF	AREVA-025	- Plate type IHX	1	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	Helium	Areva specifications / requirements TBD					Yes, see note	No	No	No								1	2	018, 020
ARE	CTF	AREVA-026	- Isolation valves (High temperature)	8	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	Helium	Areva specifications / requirements TBD					Yes, see note	No	No	No								3	6	015
ARE	CTF	AREVA-027	- Helium purification system	7	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	Helium	Areva specifications / requirements TBD					Yes, see note	No	No	No								3	6	012
ARE	CTF	AREVA-033	- Hot Gas Duct	3	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	Helium	Areva specifications / requirements TBD					Yes, see note	No	No	No								3	6	034

The following DDN's are specific to a CTF

Vendor	Group	DDN #	(3.1) Mission Need		(3.3) Functional and Operational requirements														(3.2) Facility				(3.5) Life Cycle							rating		
					FOR-001 P (Prim)	FOR-002 P (Secon)	FOR-003 P (Delta)	FOR-004 T (Prim)	FOR-005 T (Secon)	FOR-006 T (Other)	FOR-007 m	FOR-008 Q	FOR-009 Fluid	FOR-010 (Other)	FOR-011 (Other)	FOR-012 (Other)	FOR-013 (Other)	FOR-014 (Other)	FAC-005 HTF	FAC-002 HTTU	FAC-005 HPTU	FAC-006 PBMM	R&D I	NRC Licensing II	Long Lead Items/Procurement III	Construction IV	Commissioning V	Operation VI	Commercial Appl. VII	DRL	TRL	Doc#
ARE	CTF	AREVA-034	- Instrumentation	8	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	Helium	Areva specifications / requirements TBD					Yes, see note	No	No	No								1		1DHT
GA	CTF	N.13.01	Primary Helium Circulator (PHC)	5	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	Helium						Yes, see note	No	No	No	TBD	TBD	TBD	TBD	TBD	TBD	TBD			
GA	CTF	N.13.01.02	Circulator Magnetic and Catcher Bearings Design Verification	5	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	Helium	static and dynamic axial thrust load capacities, stiffness and damping coefficients of radial bearings for the entire operating speed range.	sensitivity of electronic control system to outside disturbances.	rotor dynamic response to externally induced unbalance loads	useful life of catcher bearings.		Yes, see note	No	No	No	TBD	TBD	TBD	TBD	TBD	TBD	TBD			
GA	CTF	N.13.01.03	Circulator Prototype Design Verification	5	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	Helium	Data on the functional capability of the entire circulator system including motor/control-circulator compatibility are required.	aerodynamic performance of the inlet, loop shutoff valve, circulator impeller and diffuser;	motor/thrust bearing performance, (3) overspeed capability,	Structural integrity of rotating parts and supports	noise levels and frequencies, vibration characteristics and critical speeds, shutdown and hot restart capability including hot seals.	Yes, see note	No	No	No	TBD	TBD	TBD	TBD	TBD	TBD	TBD			
GA	CTF	N.13.02.04	Confirmation of PCHE Core Temperature Distribution	9	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	Helium	As applied to the IHX, it is necessary to confirm by experiment the temperature distribution accompanied by analytical evaluation					Yes, see note	No	No	No	TBD	TBD	TBD	TBD	TBD	TBD	TBD			
GA	CTF	N.13.02.05	Confirmation of IHX Thermal Hydraulic Characteristics	1	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	Helium	It is necessary to confirm by experiment the flow distribution throughout the IHX (both primary and secondary inlets and outlets) accompanied by analytical evaluation.					Yes, see note	No	No	No	TBD	TBD	TBD	TBD	TBD	TBD	TBD			
GA	CTF	N.13.02.06	IHX Acoustic Test	1	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	Helium	Data are needed to predict frequency spectra and sound pressure levels that may be generated by the IHX as a function of flow					Yes, see note	No	No	No	TBD	TBD	TBD	TBD	TBD	TBD	TBD			
GA	CTF	N.13.02.07	IHX Insulation Verification Tests	1	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	Helium	Physical and operational characteristics of insulation are required relative to thermal cycling, mechanical and acoustic vibrations.					Yes, see note	No	No	No	TBD	TBD	TBD	TBD	TBD	TBD	TBD			
GA	CTF	N.13.02.08	IHX Seal Tests	1	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	Helium	Various sliding seals, expansion joints, and other seals joining surfaces are expected in the IHX design for installation and replacement purposes.	Data are needed to confirm the design feasibility, measure leak rates under operating conditions, and measure the influence of various factors on seal performance.				Yes, see note	No	No	No	TBD	TBD	TBD	TBD	TBD	TBD	TBD			
GA	CTF	N.13.02.09	IHX Flow Induced Vibration Test	1	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	Helium	Data are needed to accurately determine the flow-induced vibration characteristics around the IHX and its associated piping.	The flow-induced excitation mechanisms of concern are turbulent buffeting, vortex shedding and fluid elastic instability				Yes, see note	No	No	No	TBD	TBD	TBD	TBD	TBD	TBD	TBD			
GA	CTF	C.14.01	Shutdown Circulator	5	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	Helium	No info available					Yes, see note	No	No	No	TBD	TBD	TBD	TBD	TBD	TBD	TBD			
GA	CTF	C.14.01.01	SCS Circulator Magnetic and Catcher Bearings Design Verification	5	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	Helium	No info available					Yes, see note	No	No	No	TBD	TBD	TBD	TBD	TBD	TBD	TBD			
GA	CTF	C.14.01.02	SCS Circulator Prototype Impeller Aerodynamic and Acoustic Test Data	5	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	Helium	No info available					Yes, see note	No	No	No	TBD	TBD	TBD	TBD	TBD	TBD	TBD			
GA	CTF	C.14.01.03	SCS Circulator Prototype Test in High Pressure Test Facility (HPTF)	5	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	Helium	No info available					Yes, see note	No	No	No	TBD	TBD	TBD	TBD	TBD	TBD	TBD			
GA	CTF	C.14.01.04	Shutdown Circulator Loop Shut-off Valve (SLSV) Life Cycle Test Data	8	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	Helium	No info available					Yes, see note	No	No	No	TBD	TBD	TBD	TBD	TBD	TBD	TBD			
GA	CTF	C.14.04	Shutdown Heat Exchanger (SHE)	9	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	Helium	No info available					Yes, see note	No	No	No	TBD	TBD	TBD	TBD	TBD	TBD	TBD			
GA	CTF	C.14.04.01	SHE Insulation Verification Tests	9	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	Helium	No info available					Yes, see note	No	No	No	TBD	TBD	TBD	TBD	TBD	TBD	TBD			
GA	CTF	C.14.04.02	SHE Vibrational Fretting Wear and Sliding Wear of TRDs for Bare Tubes	9	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	Helium	No info available					Yes, see note	No	No	No	TBD	TBD	TBD	TBD	TBD	TBD	TBD			

The following DDN's are specific to a CTF																																
Vendor	Group	DDN #	(3.1) Mission Need		(3.3) Functional and Operational requirements														(3.2) Facility				(3.5) Life Cycle							rating		
					FOR-001	FOR-002	FOR-003	FOR-004	FOR-005	FOR-006	FOR-007	FOR-008	FOR-009	FOR-010	FOR-011	FOR-012	FOR-013	FOR-014	FAC-001	FAC-002	FAC-003	FAC-004	R&D	NRC Licensing	Long Lead Items	Construction	Commission	Operation	Commercial Appl.	CRL	TRL	Doc#
					P (Prim)	P (Secon)	P (Delta)	T (Prim)	T (Secon)	T (Other)	m	Q	Fluid	(Other)	(Other)	(Other)	(Other)	(Other)	HTF	HTTU	HPTU	PSMM	i	ii	iii	iv	v	vi	vii			
GA	CTF	C.14.04.03	SHE Instrumentation Attachment Test	a	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	Helium	No info available					Yes, see note	No	No	No	TBD	TBD	TBD	TBD	TBD	TBD	TBD			
GA	CTF	C.14.04.04	SHE Bare Tubes Inspection Methods and Equipment	a	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	Helium	No info available					Yes, see note	No	No	No	TBD	TBD	TBD	TBD	TBD	TBD	TBD			
GA	CTF	C.14.04.05	SHE Shroud Seal Test	a	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	Helium	No info available					Yes, see note	No	No	No	TBD	TBD	TBD	TBD	TBD	TBD	TBD			
GA	CTF	C.14.04.06	Acoustical Response of the SHE Helical Bare Tube Bundle	a	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	Helium	No info available					Yes, see note	No	No	No	TBD	TBD	TBD	TBD	TBD	TBD	TBD			
GA	CTF	C.14.04.07	SHE Inlet Flow and Temperature Distribution Test	a	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	Helium	No info available					Yes, see note	No	No	No	TBD	TBD	TBD	TBD	TBD	TBD	TBD			
GA	CTF	C.14.04.08	SHE Tube Bundle Local Heat Transfer and Flow Resistance Characteristics	a	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	Helium	No info available					Yes, see note	No	No	No	TBD	TBD	TBD	TBD	TBD	TBD	TBD			
GA	CTF	C.14.04.09	SHE Tube Helical Coil Program	a	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	Helium	No info available					Yes, see note	No	No	No	TBD	TBD	TBD	TBD	TBD	TBD	TBD			
GA	CTF	C.14.04.10	SHE Lead-in/Lead-out Expansion Loop Tube Design and Fabrication	a	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	Helium	No info available					Yes, see note	No	No	No	TBD	TBD	TBD	TBD	TBD	TBD	TBD			
GA	CTF	C.31.01	Safety Protection and Instrumentation	a	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	Helium	No info available					Yes, see note	No	No	No	TBD	TBD	TBD	TBD	TBD	TBD	TBD			
GA	CTF	C.31.01.01	Verify Helium Mass Flow Measurement Instrumentation	a	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	Helium	No info available					Yes, see note	No	No	No	TBD	TBD	TBD	TBD	TBD	TBD	TBD			
GA	CTF	C.31.01.02	Verify Conduction Cooldown Temperature Monitoring Instrumentation	a	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	Helium	No info available					Yes, see note	No	No	No	TBD	TBD	TBD	TBD	TBD	TBD	TBD			
GA	CTF	C.34.01	Nuclear Island Control and Instrumentation	a	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	Helium	No info available					Yes, see note	No	No	No	TBD	TBD	TBD	TBD	TBD	TBD	TBD			
GA	CTF	C.34.01.01	Verify Core Inlet and Outlet Helium Temperature Measurement Instrumentation	a	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	Helium	No info available					Yes, see note	No	No	No	TBD	TBD	TBD	TBD	TBD	TBD	TBD			
GA	CTF	N.42.01	SHTS Circulator (Secondary Circulator DDNs are covered by Primary Helium Circulator DDNS due to design similarity)	s	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	Helium	No info available					Yes, see note	No	No	No	TBD	TBD	TBD	TBD	TBD	TBD	TBD			
GA	CTF	N.42.02	Isolation Valves	a	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	Helium						Yes, see note	No	No	No	TBD	TBD	TBD	TBD	TBD	TBD	TBD			
GA	CTF	N.42.02.01	Effects of Primary Coolant Helium and Temperature on SHTS Piping and Valve Materials	a	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	Helium	Data are needed to assess performance of valve internal insulation, valve seat material, seal performance and structural integrity.					Yes, see note	No	No	No	TBD	TBD	TBD	TBD	TBD	TBD	TBD			
GA	CTF	N.42.02.02	High Temperature Isolation Valve Prototype Design Verification	a	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	Helium	No info available					Yes, see note	No	No	No	TBD	TBD	TBD	TBD	TBD	TBD	TBD			
GA	CTF	N.45.04	HTE Plant Supporting Equipment		TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	Helium	TBD after designed					Yes, see note	No	No	No	TBD	TBD	TBD	TBD	TBD	TBD	TBD			
GA	CTF	N.45.04.01	HTE Steam Generator/Superheater	c	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	Helium	TBD after designed					Yes, see note	No	No	No	TBD	TBD	TBD	TBD	TBD	TBD	TBD			
GA	CTF	N.45.04.02	HTE Heat Exchangers	a	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	Helium						Yes, see note	No	No	No	TBD	TBD	TBD	TBD	TBD	TBD	TBD			

The following DDN's are specific to a CTF

Vendor	Group	DDN #	(3.1) Mission Need		(3.3) Functional and Operational requirements														(3.2) Facility				(3.5) Life Cycle							rating		
					POR-001	POR-002	POR-003	POR-004	POR-005	POR-006	POR-007	POR-008	POR-009	POR-010	POR-011	POR-012	POR-013	POR-014	FAC-001	FAC-002	FAC-005	FAC-006	R&D	NRC Licensing	Long Lead Items	Construction	Commission ing	Operation	Commercial Appl.	DRL	TRL	Doc#
					P (Prim)	P (Secon)	P (Delta)	T (Prim)	T (Secon)	T (Other)	m	Q	Fluid	(Other)	(Other)	(Other)	(Other)	(Other)	HTF	HTTU	HPTU	PSMM	i	ii	iii	iv	v	vi	vii			
	CTF	Additional	Full Scale Testing/Qualification of systems and components	16	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	Helium	Complete component list TBD	N/A	N/A	N/A	N/A	No, see note	No	No	No	TBD	TBD	TBD	TBD	TBD	TBD	TBD			
	CTF	Additional	Control & Instrumentation development / qualification	8	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	Helium	Control & instrumentation development / qualification requirements					Yes, see note	No	No	No	TBD	TBD	TBD	TBD	TBD	TBD	TBD			
	CTF	Additional	CTF to be used for V&V of methods / software	11	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Helium	Specifications and requirements for CTF to be used for V&V					Yes, see note	No	No	No	TBD	TBD	TBD	TBD	TBD	TBD	TBD			
	CTF	Additional	Fluid inventory systems testing	7	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	Helium	Fluid inventory specifications TBD					Yes, see note	No	No	No	TBD	TBD	TBD	TBD	TBD	TBD	TBD			
	CTF	Additional	Quality control systems testing	12	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Helium	Quality control system requirements TBD					Possible, see note				TBD	TBD	TBD	TBD	TBD	TBD	TBD			
	CTF	Additional	Control room human factors	13	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Helium	Specify control human factor requirements					Yes, see note	No	No	No	TBD	TBD	TBD	TBD	TBD	TBD	TBD			
	CTF	Additional	Operational		N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Helium	Procedures development / qualification	Operational problems / trouble shooting				Yes, see note	No	No	No	TBD	TBD	TBD	TBD	TBD	TBD	TBD			
	CTF	Additional	Programs	14	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Helium	Maintenance and repair program / process development	Component replacement program / process development				No, see note	No	No	No	TBD	TBD	TBD	TBD	TBD	TBD	TBD			
	CTF	Additional	High temperature instrumentation (Flow control...)	8	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	Helium	Determine specific requirements for high temperature flow control				N/A	Yes, see note	No	No	No	TBD	TBD	TBD	TBD	TBD	TBD	TBD			
	CTF	White Paper	Main need from High Temp Elctrolysis (HTE) for CTF: Super heaters / Steam generators	4	N/A	8.3MPa	N/A	N/A	T_inlet 800C T_outlet 270C	FW T_inlet 220C Steam T_outlet 540C	TBD	N/A	Helium	Addressed by previous PIEOR on steam generator				N/A	Yes, see note	No	No	No	TBD	TBD	TBD	TBD	TBD	TBD	TBD			
	CTF	White Paper	Materials	15	9 Mpa	9 Mpa	< 200 kPa	T_inlet 850C T_outlet 337C	T_inlet 290C T_outlet 900C	N/A	TBD	N/A	Helium	Material List: SA508/533 Inconel 617 Haynes 230 Incoloy 800H 2-1/4 Cr-1Mo-V 9Cr-1Mo Ceramics	Material List: Creep Creep/fatigue Erosion / Corrosion High Temp material prop	Specific requirements regarding typical tests TBD. Double check with DDN			Yes, see note	No	No	No	TBD	TBD	TBD	TBD	TBD	TBD	TBD			
	CTF	White Paper	Plate IHX	1	Baseline mechanical property data, including creep-fatigue data, Long-term thermal stability, Effect of helium coolant chemistry on material degradation, Effect of 80%hydrogen-20%helium mixture on material degradation, Corrosion effects on mechanical properties.					Small test facilities << 1 MW available. Test facilities of 1 MW and 10 MW to be built.	• for development of visco-plastic model (material database to be completed) • for corrosion tests on base and coated materials in representative environment • for the development of manufacturing techniques (fusion welding, diffusion bonding, brazing, forming, etc) • for tests on representative IHX mock-ups from thermo-hydraulic and manufacturing point of view (diffusion bonding, brazing, ISR). For the component qualification, a 3 steps approach is proposed: 1) tests with small mock-ups in air 2) tests with small mock-ups in He (about 1 MW test loop). These tests should be used as a basis for providing recommendations on the type of concept to be used for the NGNP 3) final qualification on a mockup at scale 1 (at least for the channels and the plates) on a large test facility (around 10MW)																					

All DDN's				(3.3) Functional and Operational requirements														(3.2) Facility				(3.5) Life Cycle							DRL/TRL rating	
Consortium	Relevance	DDN #	(3.1) Mission Need	FOR-001 P (Prim)	FOR-002 P (Secon)	FOR-003 P (Delta)	FOR-004 T (Prim)	FOR-005 T (Secon)	FOR-006 T (Other)	FOR-007 m	FOR-008 Q	FOR-009 Fluid	FOR-010 TBD (Other)	FOR-011 TBD (Other)	FOR-012 TBD (Other)	FOR-013 TBD (Other)	FOR-014 TBD (Other)	FAC-001 HTF	FAC-002 HTTU	FAC-003 HPTU	FAC-004 PDMM	i R&D	ii NRC Licensing	iii Design/Cert.	iv Construction	v Commissioning	vi Operation	vii Commercial Appl.	DRL	TRL
		1 Nuclear Heat Supply System (NHSS)																												
		Fuel Irradiation																												
WEC	TASK/LAB	NHSS-01-01	Fuel irradiation test for normal operational conditions																			1	1						5	6
WEC	TASK/LAB	NHSS-01-02	Fuel heating tests for accident conditions																			1	1						5	6
WEC	TASK/LAB	NHSS-01-03	Fuel Graphite irradiation tests																			1	1						5	6
		Graphite																												
WEC	TASK/LAB	NHSS-02-01	Extended Properties of Irradiated Graphite at Low Temperatures																			1	1						5	6
WEC	TASK/LAB	NHSS-02-02	Extended Properties of Irradiated Graphite at High Temperatures																			1	1						5	6
		2 Heat Transport System (HTS)																												
		Intermediate Heat Exchanger - Metallic																												
WEC	TASK/LAB	HTS-01-01	Establish Reference Specifications for Alloy 617																			1	1						1	2
WEC	TASK/LAB	HTS-01-02	Thermal/Physical and Mechanical Properties of Alloy 617																			1	1						1	2
WEC	TASK/LAB	HTS-01-03	Welding and As-Welded Properties of Materials of Alloy 617for Compact Heat Exchangers																			1	1		1				1	2
WEC	TASK/LAB	HTS-01-04	Aging Effects of Alloy 617																			1	1						1	2
WEC	TASK/LAB	HTS-01-05	Environmental Effects of Impure Helium on Alloy 617																			1	1						1	2
WEC	TASK/LAB	HTS-01-06	Influence of Grain Size on Materials Properties on Alloy 617																			1							1	2
WEC	TASK/LAB	HTS-01-07	Establish Reference Specifications for Alloy 230																			1	1						1	2
WEC	TASK/LAB	HTS-01-08	Thermal/Physical and Mechanical Properties of Alloy 230																			1	1						1	2
WEC	TASK/LAB	HTS-01-09	Welding and As-Welded Properties of Materials of Alloy 230for Compact Heat Exchangers																			1	1		1				1	2
WEC	TASK/LAB	HTS-01-10	Aging Effects of Alloy 230																			1	1						1	2
WEC	TASK/LAB	HTS-01-11	Environmental Effects of Impure Helium on Alloy 230																			1	1						1	2
WEC	TASK/LAB	HTS-01-12	Influence of Grain Size on Materials Properties on Alloy 230																			1							1	2
WEC	TASK/LAB	HTS-01-13	Methods for Thermal/Fluid Modeling of Plate-Type Compact Heat Exchangers																			1							1	2
WEC	TASK/LAB	HTS-01-14	Methods for Stress/Strain Modeling of Plate-Type Compact Heat Exchangers																			1			1				1	2
WEC	TASK/LAB	HTS-01-15	Criteria for Structural Adequacy of Plate-Type Compact Heat Exchangers at Very High Temperatures																			1	1		1				1	2
WEC	TASK/LAB	HTS-01-16	Methods for Performance Modeling of Plate-Type Compact Heat Exchangers																			1		1	1	1	1		1	2
WEC	CTF	HTS-01-17	Metallic: IHX Performance Verification	9 Mpa	9MPa	< 200 kPa	T_inlet: 950C T_outlet: 337C	T_inlet: 290C T_outlet: 900C	N/A	TBD	TBD	Helium / TBD	IHX Life prediction	Controlled Impurity levels	IHX Material testing	IHX Durability Testing	IHX Performance testing	Yes, see note	No	No	No	1	1	1			1		1	2
WEC	TASK/LAB	HTS-01-18	Data Supporting Materials Code Case																			1			1		1		1	2
WEC	TASK/LAB	HTS-01-19	Data Supporting Design Code Case																			1			1		1		1	2
		Intermediate Heat Exchanger - Ceramic																												
WEC	TASK/LAB	HTS-02-01	Review Existing Technology																			1							1	3
WEC	TASK/LAB	HTS-02-02	Materials Property Database																			1							1	3
WEC	TASK/LAB	HTS-02-03	Design Methods																			1		1	1		1		1	3
WEC	CTF	HTS-02-04	Ceramic: IHX Performance Verification	9 Mpa	9MPa	< 200 kPa	T_inlet: 950C T_outlet: 337C	T_inlet: 287C T_outlet: 900C	N/A	TBD	TBD	Helium / TBD	IHX Life prediction	Controlled Impurity levels	IHX Material testing	IHX Durability Testing	IHX Performance testing	Yes, see note	No	No	No	1	1	1	1		1		1	2
WEC	TASK/LAB	HTS-02-05	Manufacturing Technology										Interface development.									1	1	1	1		1		1	3
WEC	TASK/LAB	HTS-02-06	Codes and Standards																			1	1	1	1	1	1		1	3
		SMTS Helium Mixing Chamber																												

All DDN's				(3.3) Functional and Operational requirements														(3.2) Facility				(3.5) Life Cycle							DRL/TRL rating	
Consortium	Relevance	DDN #	(3.1) Mission Need	F OR-001 P (Prim)	F OR-002 P (Secon)	F OR-003 P (Delta)	F OR-004 T (Prim)	F OR-005 T (Secon)	F OR-006 T (Other)	F OR-007 m	F OR-008 Q	F OR-009 Fluid	F OR-010 TBD (Other)	F OR-011 TBD (Other)	F OR-012 TBD (Other)	F OR-013 TBD (Other)	F OR-014 TBD (Other)	F AC-001 HTF	F AC-002 HTTU	F AC-003 HPTU	F AC-004 PBMM	i R&D	ii	iii	iv Construction	v Commissioning	vi Operation	vii Commercial Appl.	DRL	TRL
WEC	CTF	HTS-03-01	Mixing Chamber Performance Test	N/A	8.5MPa	N/A	IHX A T_outlet: 900C	PCHX T_outlet: 880C (HPS in ops) T_outlet: 900C (HPS out ops)	N/A	Total HTS flow: 159.6 kg/s Flow to PCHX: 39.9 kg/s Flow to SG: 119.7 kg/s	N/A	Helium	Performance verification test on a prototype mixing chamber	Nominal operating life of the mixing chamber (equivalent to plant life)	N/A	N/A	N/A	Yes, see note	No	No	No	1	1	1			1		1	2
		High Temperature Ducts and Insulation																												
WEC	CTF	HTS-04-01	Evaluation of High Temperature Ducts and Insulation Systems	9.0 Mpa	9.4 Mpa	N/A	Reactor T_outlet 950°C	IHX T_outlet 900°C	N/A	TBD	N/A	Helium	Nominal operating life of the hot duct and other high temperature piping systems equivalent to plant life	N/A	N/A	N/A	N/A	Yes, see note	Yes, see note	No	No	1	1	1	1		1		3	6
		3 Hydrogen Production System (HPS)																												
		Basic Data																												
WEC	TASK/LAB	HPS-01-01	Confirm Thermodynamic Data for the HyS Process																			1							1	2
WEC	TASK/LAB	HPS-01-02	Gather Reaction Kinetics Data																			1							1	2
WEC	TASK/LAB	HPS-01-03	Analyze Data and Improve simulation																			1							1	2
		Supplementary Materials																												
WEC	TASK/LAB	HPS-02-01	Develop Gasket Materials and Design	TBD			TBD															1	1		1		1		1	2
WEC	TASK/LAB	HPS-02-02	Develop Seal Materials and Design																			1	1		1		1		1	2
WEC	TASK/LAB	HPS-02-03	Develop Welding Materials																			1	1		1		1		1	2
WEC	TASK/LAB	HPS-02-04	Develop Cladding and Coating Materials																			1	1		1		1		1	2
WEC	TASK/LAB	HPS-02-05	Develop Piping Materials and Design Methods																			1	1		1		1		1	2
		Feed Purification																												
WEC	TASK/LAB	HPS-03-01	Determine Decomposer Tolerance for Impurities																			1							1	1
WEC	TASK/LAB	HPS-03-02	Determine Electrolyzer Tolerance for Impurities																			1							1	1
WEC	TASK/LAB	HPS-03-03	Test Sulfuric Acid Decomposition Methods																			1					1		1	1
WEC	TASK/LAB	HPS-03-04	Test Feed Water Purification Methods																			1					1		1	1
		Decomposer																												
WEC	TASK/LAB	HPS-04-01	Develop a Commercial Sulfuric Acid Decomposition Catalyst																			1					1		1	2
WEC	TASK/LAB	HPS-04-02	Test Silicon Carbide and other Ceramic Material in Decomposition Service																			1			1		1		2	4
WEC	TASK/LAB	HPS-04-03	Test Alloy 230 and Alloy 617 in a High Temperature Sulfuric Acid, Sulfur Dioxide and Oxygen Atmosphere																			1			1		1		2	3
WEC	TASK/LAB	HPS-04-04	Develop a Method to Bond Alloy 230 or Alloy 617 or Similar Materials to Silicon Carbide and other Ceramics																			1			1		1		2	3
WEC	TASK/LAB	HPS-04-05	Develop Materials to Seal the Joints between Ceramic Decomposer Elements and the Metallic Tubesheet or Vessel																			1			1	1	1		2	3
WEC	TASK/LAB	HPS-04-06	Test a Pilot-scale Decomposer																			1							2	2
WEC	TASK/LAB	HPS-04-07	Data Supporting Design Code Case																			1			1	1	1		2	2
		Sulfuric Acid Concentrator																												
WEC	TASK/LAB	HPS-05-01	Measure the Height Equivalent to a Theoretical Plate (HETP) for the Concentrator																			1					1			
		SO2 Absorbers																												
WEC	TASK/LAB	HPS-06-01	Measure the Height Equivalent to a Theoretical Plate (HETP) for the SO2 Absorbers																			1					1		1	4
		Electrolyzers																												
WEC	TASK/LAB	HPS-07-01	Optimize Catalyst Loading in the Electrodes																			1			1		1		1	4
WEC	TASK/LAB	HPS-07-02	Develop a Cell Membrane																			1					1		1	4
WEC	TASK/LAB	HPS-07-03	Develop a Cell Configuration and Materials																			1					1		1	4
WEC	TASK/LAB	HPS-07-04	Build and Test a Prototype Cell																			1					1		1	4
WEC	TASK/LAB	HPS-07-05	Build and Test a Pilot-scale Cell																			1					1		1	4

All DDN's				(3.3) Functional and Operational requirements														(3.2) Facility				(3.5) Life Cycle							DRL/TRL rating	
Consortium	Relevance	DDN #	(3.1) Mission Need	FOR-001	FOR-002	FOR-003	FOR-004	FOR-005	FOR-006	FOR-007	FOR-008	FOR-009	FOR-010	FOR-011	FOR-012	FOR-013	FOR-014	FAC-001	FAC-002	FAC-003	FAC-004	R&D	NRC Licensing	Component tests	Construction	Commissioning	Operation	Commercial Appl.	DRL	TRL
				P (Prim)	P (Secon)	P (Delta)	T (Prim)	T (Secon)	T (Other)	m	Q	Fluid	TBD (Other)	TBD (Other)	TBD (Other)	TBD (Other)	TBD (Other)	HTF	HTTU	HPTU	PDMM	i	ii	iii	iv	v	vi	vii		
WEC	TASK/LAB	HPS-07-06	Build and Test a Stack of Cells in a Pilot Plant																			1					1		1	4
		Product Purification																												
WEC	TASK/LAB	HPS-08-01	Identify Product Impurities																			1								
WEC	TASK/LAB	HPS-08-02	Test Product Purification Methods																			1					1			
		Instrumentation and Controls																												
WEC	TASK/LAB	HPS-09-01	Test Sensors in the Pilot Plant																			1					1			
WEC	TASK/LAB	HPS-09-02	Develop valves for High-Temperature Acid Service																			1					1			
WEC	TASK/LAB	HPS-09-03	Test Valves in the Pilot Plant																			1		1			1			
		4 Power Conversion System (PCS)																												
		Steam Generator																												
WEC	TASK/LAB	SG-01-01	Secondary side Corrosion Characteristics 800H & 2-1/4Cr-1Mo and Weldments																			1			1		1		2	6
WEC	TASK/LAB	SG-01-02	Helium Environment Effects on 2-1/4 Cr-1Mo																			1					1		2	6
WEC	TASK/LAB	SG-01-03	Helium Environment Effects on 800H																			1					1		2	6
WEC	CTF	SG-01-04	Acoustic Response of Helical Bundle	N/A	0.2 MPa	N/A	N/A	T_inlet: 900C T_outlet: 270C	FW T_inlet: 220C Steam T_outlet: 540C	TBD	N/A	Helium	The design service life is 60 equivalent full-power years.	N/A	N/A	N/A	Predict the excitation frequency for a given tube array.	Yes, see note	No	No	No	1			1				2	6
WEC	TASK/LAB	SG-01-05	Large Helical Coil Fabrication Methods																			1			1				2	6
WEC	TASK/LAB	SG-01-06	Inlet Flow Distribution																			1			1				2	6
WEC	CTF	SG-01-07	Insulation Verification Test	N/A	0.2MPa	N/A	N/A	T_inlet: 900C T_outlet: 270C	N/A	TBD	N/A	Helium	Thermal and mechanical performance of the insulation located in the active flow region (i.e., helium inlet plenum and outer shroud) of the steam generator needs to be verified.	Thermal cycling of fibrous insulation	Effects of mechanical and acoustic vibrations	Effects of flow and thermal gradients	Thermal conductivity at 0.2 Mpa.	Yes, see note	No	No	No	1			1				2	6
WEC	CTF	SG-01-08	Fretting & Sliding Wear Protection Tests	N/A	0.2MPa	N/A	N/A	T_inlet: 900C T_outlet: 270C	FW T_inlet: 220C Steam T_outlet: 540C	TBD	N/A	Helium	demonstrate that the existing TBD design	Thermal cycling might be a requirement	N/A	N/A	N/A	Yes, see note	No	No	No	1			1				2	6
WEC	TASK/LAB	SG-01-09	Tube Wear Protection Device Testing																			1			1				2	6
WEC	CTF	SG-01-10	Shroud Seal Test	N/A	0.2MPa	N/A	N/A	T_inlet: 900C T_outlet: 270C	FW T_inlet: 220C Steam T_outlet: 540C	N/A	N/A	Helium	Test of two types of seals designs to validate design features.	Measure leak rates	Measure Pressure diff	Seating load measure	N/A	Yes, see note	No	No	No	1			1				2	6
WEC	CTF	SG-01-11	Lead-In/Lead-out/Transition/Expansion Loop Mockups	N/A	0.2MPa	N/A	N/A	T_inlet: 900C T_outlet: 270C	FW T_inlet: 220C Steam T_outlet: 540C	TBD	N/A	Helium	Thermal movement characteristics	N/A	N/A	N/A	N/A	Yes, see note	No	No	No	1							2	6
WEC	CTF	SG-01-12	Flow Induced Vibration Testing of Helical Bundle	N/A	0.2MPa	N/A	N/A	T_inlet: 900C T_outlet: 270C	FW T_inlet: 220C Steam T_outlet: 540C	TBD	N/A	Helium	Flow-induced vibration characteristics of the steam generator helical tube bundle, lead-out tubes and transition tubes.	N/A	N/A	N/A	N/A	Yes, see note	No	No	No	1			1				2	6
WEC	CTF	SG-01-13	Orifice Qualification Test	N/A	N/A	N/A	FW inlet temperature of nominally 220°C	N/A	N/A	TBD	N/A	Water	Erosion / Corrosion resistance test for orifice	Orifice pressured rop performance validation	N/A	N/A	N/A	Yes, see note	No	No	No	1							2	6
WEC	CTF	SG-01-14	Instrumentation Attachment Test	N/A	0.2MPa	N/A	N/A	T_inlet: 900C T_outlet: 270C	FW T_inlet: 220C Steam T_outlet: 540C	N/A	N/A	Helium	N/A	N/A	N/A	N/A	N/A	Yes, see note	No	No	No	1			1		1		2	6
WEC	TASK/LAB	SG-01-15	Bi-Metallic Weld Structural Integrity																			1			1				2	6

All DDN's

Consortium	Relevance	DDN #	(3.1) Mission Need
WDC	CTF	SG-01-16	Helical Bundle and Transition Region Heat Transfer Test
WDC	TASK/LAB	SG-01-17	Tubing Inspection Methods and Equipment
WDC	TASK/LAB	SG-01-XX	Review and re-assemble existing SG development data.
		AREVA DDNs summary	
		Materials	
			Metallics
			Vessel materials (high temperature steel)
ARE	TASK/LAB	AREVA-001	- Testing and codification of modified 9Cr-1Mo
			Reactor internals
ARE	TASK/LAB	AREVA-002	- Testing and codification of candidate core barrel materials
			IHX
ARE	TASK/LAB	AREVA-003	- Testing and codification of Inconel 617 and/or Haynes 230
			Ceramics
ARE	TASK/LAB	AREVA-004	Reactor internals
ARE	TASK/LAB	AREVA-005	Testing and codification of materials
ARE	TASK/LAB	AREVA-006	Controls rod sheaths
ARE	TASK/LAB	AREVA-007	Testing and codification of Carbon-Carbon composites
			Graphite (initial)
ARE	TASK/LAB	AREVA-008	Qualification at low dose, limited temperature
			Graphite (subsequent)
ARE	TASK/LAB	AREVA-009	Qualification at high dose, high temperature
			Core internal structure
ARE	TASK/LAB	AREVA-010	Qualification at high dose, high temperature
		Computer Codes and Methods	
			Code development
ARE	TASK/LAB	AREVA-011	- Improvement/development of neutronics codes (e.g., MCNP, MONTEBURNS, NEPHTYS)
ARE	TASK/LAB	AREVA-012	- Improvement/development of thermal/hydraulics/pneumatics codes
ARE	TASK/LAB	AREVA-013	- Improvement/development of other codes
			Fuel performance models and codes
ARE	TASK/LAB	AREVA-014	- Develop fuel performance models based
			Code qualification of existing codes
ARE	TASK/LAB	AREVA-015	- ATLAS
ARE	TASK/LAB	AREVA-016	- MCNP
ARE	TASK/LAB	AREVA-017	- MONTEBURNS
ARE	TASK/LAB	AREVA-018	- NEPHTYS
ARE	TASK/LAB	AREVA-019	- MANTA
ARE	TASK/LAB	AREVA-020	- RELAP
ARE	TASK/LAB	AREVA-021	- CABERNET
ARE	TASK/LAB	AREVA-022	- STAR-CD
		Other DDNs/R&D needs: dual test loop to test the following components	
ARE	CTF	AREVA-023	- Circulators
ARE	CTF	AREVA-024	- Tube type IHX

(3.3) Functional and Operational requirements; (3.2) Facility; (3.5) Life Cycle; DRL/TRL rating

DDN #	F-CR-001 P (Prim)	F-CR-002 P (Secon)	F-CR-003 P (Delta)	F-CR-004 T (Prim)	F-CR-005 T (Secon)	F-CR-006 T (Other)	F-CR-007 m	F-CR-008 Q	F-CR-009 Fluid	F-CR-010 TBD (Other)	F-CR-011 TBD (Other)	F-CR-012 TBD (Other)	F-CR-013 TBD (Other)	F-CR-014 TBD (Other)	F-AC-001 HTF	F-AC-002 HTTU	F-AC-003 HPTU	F-AC-004 PGMM	i R&D	ii RFC, Licensing, Long lead items	iii	iv Construction	v Commissioning	vi Operation	vii Commercial Appl.	DRL	TRL
SG-01-16	N/A	9.2MPa	N/A	N/A	T_inlet: 900C T_outlet: 270C	FW T_inlet: 230C Steam T_outlet: 540C	TBD	TBD	Helium	Heat transfer coefficients on the outside of tubes in the transition region from cross flow in a helical tube bundle to axial flow along parallel straight tubes.	Heat transfer coefficient circumferential variation around the outside of a tube at the entrance region of a helical tube bundle.	Average heat transfer coefficients on the outside of tubes for the entrance region of a helical tube bundle.	Tube bundle friction factors for tube bundles with variation from a square pitch to a staggered pitch.	N/A	Yes, see note	No	No	No	1							2	6
SG-01-17																										2	6
AREVA-023	9 Mpa	9 Mpa	~200 kPa	T_inlet: 900C T_outlet: 337C	T_inlet: 290C T_outlet: 900C	N/A	TBD	N/A	Helium	Determine specific requirements for circulator	N/A	N/A	N/A	N/A	Yes, see note	No	No	No								2	6
AREVA-024	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	Helium	Areva specifications / requirements TBD	N/A	N/A	N/A	N/A												1	2

All DDN's				(3.3) Functional and Operational requirements														(3.2) Facility				(3.5) Life Cycle							DRL/TRL rating	
Consortium	Relevance	DDN #	(3.1) Mission Need	F-CR-001	F-CR-002	F-CR-003	F-CR-004	F-CR-005	F-CR-006	F-CR-007	F-CR-008	F-CR-009	F-CR-010	F-CR-011	F-CR-012	F-CR-013	F-CR-014	FAC-001	FAC-002	FAC-003	FAC-004	R&D	NRC Licensing	Design/Engineering	Construction	Commissioning	Operation	Commercial Appl.	DRL	TRL
				P (Prim)	P (Secon)	P (Delta)	T (Prim)	T (Secon)	T (Other)	m	Q	Fluid	TBD (Other)	TBD (Other)	TBD (Other)	TBD (Other)	TBD (Other)	HTF	HTTU	HPTU	PBMM	i	ii	iii	iv	v	vi	vii		
ARE	CTF	AREVA-025	- Plate type IHX	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	Helium	Areva specifications / requirements TBD	N/A	N/A	N/A	N/A												1	2
ARE	CTF	AREVA-026	- Isolation valves (High temperature)	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	Helium	Areva specifications / requirements TBD	N/A	N/A	N/A	N/A												2	6
		Other system/subsystem/component testing needs																												
ARE	CTF	AREVA-027	- Helium purification system	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	Helium	Areva specifications / requirements TBD	N/A	N/A	N/A	N/A												3	6
ARE	TASK/LAB	AREVA-028	- Shutdown cooling system																											
ARE	TASK/LAB	AREVA-029	- Fuel handling system																											
ARE	TASK/LAB	AREVA-030	- Neutron Control System Drive Mechanism																											
ARE	TASK/LAB	AREVA-031	- RCCS																											
ARE	TASK/LAB	AREVA-032	- Plant Control, Investment Protection, and Safety Protection																											
ARE	CTF	AREVA-033	- Hot Gas Duct	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	Helium	Areva specifications / requirements TBD	N/A	N/A	N/A	N/A												3	6
ARE	CTF	AREVA-034	- Instrumentation	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	Helium	Areva specifications / requirements TBD	N/A	N/A	N/A	N/A												1	1
		PCS																												
ARE	???	AREVA-035	- Brayton Cycle testing																											
ARE	???	AREVA-036	- Turbo-machinery testing																											
ARE	???	AREVA-037	- Generator and electrical equipment testing																											
ARE	???	AREVA-038	- Helium cycle control & ducting testing																											
ARE	???	AREVA-039	- Heat recovery steam generator testing																											
ARE	???	AREVA-040	- Steam cycle testing																											
	Not allocated	GENERAL ATOMICS Summary																												
		Fuel/Fission Products C.07.00																												
			Core graphites																											
GA	TASK/LAB	C.07.01	Fuel Fabrication																											
GA	TASK/LAB	C.07.01.01	UCO Kernel Process Development																											
GA	TASK/LAB	C.07.01.02	Fuel Particle Coating Process Development																											
GA	TASK/LAB	C.07.01.03	Fuel Compact Fabrication Process																											
GA	TASK/LAB	C.07.01.04	Quality Control Test Techniques Development																											
GA	TASK/LAB	C.07.01.05	Fuel Product Recovery Development																											
GA	TASK/LAB	N.07.01.06	Mass Production of High Quality UCO TRISO Fuel																											
GA	TASK/LAB	N.07.01.07	As-manufactured Quality of LEU UO2 (NFI extended burnup fuel)																											
GA	TASK/LAB	C.07.02	Fuel Performance																											
GA	TASK/LAB	C.07.02.01	Coating Material Property Data																											
GA	TASK/LAB	C.07.02.02	Defective Particle Performance Data																											
GA	TASK/LAB	C.07.02.03	Thermochemical Performance Data for Fuel																											
GA	TASK/LAB	C.07.02.04	Fuel Compact Thermophysical Properties																											
GA	TASK/LAB	C.07.02.05	Normal Operation Fuel Performance Validation Data																											
GA	TASK/LAB	C.07.02.06	Accident Fuel Performance Validation Data																											
GA	TASK/LAB	C.07.02.07	Fuel Proof Test Data																											
GA	TASK/LAB	N.07.02.08	Irradiation Performance of LEU UO2 (NFI extended burnup fuel)																											
GA	TASK/LAB	N.07.02.09	Accident Performance of LEU UO2 (NFI extended burnup fuel)																											
GA	TASK/LAB	C.07.03	Radionuclide Transport																											
GA	TASK/LAB	C.07.03.01	Fission Gas Release from Core Materials																											
GA	TASK/LAB	C.07.03.02	Fission Metal Effective Diffusivities in Fuel Kernels																											
GA	TASK/LAB	C.07.03.03	Fission Product Effective Diffusivities in Particle Coating																											
GA	TASK/LAB	C.07.03.04	Fission Product Diffusivities/Sorptivities in Graphite																											
GA	TASK/LAB	C.07.03.05	Tritium Permeation in Heat Exchanger Tubes																											
GA	TASK/LAB	C.07.03.06	Tritium Transport in Core Materials																											

All DDN's				(3.3) Functional and Operational requirements														(3.2) Facility				(3.5) Life Cycle							DRL/TRL rating	
Consortium	Relevance	DDN #	(3.1) Mission Need	F-CR-001 P (Prim)	F-CR-002 P (Secon)	F-CR-003 P (Delta)	F-CR-004 T (Prim)	F-CR-005 T (Secon)	F-CR-006 T (Other)	F-CR-007 m	F-CR-008 Q	F-CR-009 Fluid	F-CR-010 TBD (Other)	F-CR-011 TBD (Other)	F-CR-012 TBD (Other)	F-CR-013 TBD (Other)	F-CR-014 TBD (Other)	F-AC-001 HTF	F-AC-002 HTTU	F-AC-003 HPTU	F-AC-004 PDMM	i R&D	ii NRC Licensing	iii	iv Construction	v Commissioning	vi Operation	vii Commercial Appl.	DRL	TRL
GA	TASK/LAB	C.07.03.07	Radionuclide Deposition Characteristics of Structural Materials																											
GA	TASK/LAB	C.07.03.08	Decontamination Protocols for Turbine Alloys																											
GA	TASK/LAB	C.07.03.09	Radionuclide Reentrainment Characteristics for Dry Depressurization																											
GA	TASK/LAB	C.07.03.10	Radionuclide Removal Characteristics for Wet Depressurization																											
GA																														
GA	TASK/LAB	C.07.03.11	Characterization of the Effects of Dust on Radionuclide Transport																											
GA	TASK/LAB	C.07.03.12	Fission Product Transport in a Vented Low-Pressure Containment																											
GA	TASK/LAB	C.07.03.13	Decontamination Efficiency of Pressure Relief Train Filter																											
GA	TASK/LAB	C.07.03.14	Fission Gas Release Validation Data																											
GA	TASK/LAB	C.07.03.15	Fission Metal Release Validation Data																											
GA	TASK/LAB	C.07.03.16	Plateout Distribution Validation Data																											
GA	TASK/LAB	C.07.03.17	Radionuclide Liftoff" Validation Data "																											
GA	TASK/LAB	C.07.03.18	Radionuclide Washoff" Validation Data "																											
GA	TASK/LAB	N.07.03.19	Physical and Chemical Forms of RNs Released during Core Heatup																											
GA	TASK/LAB	N.07.03.20	RN Sorptivities of VLPC Surfaces																											
GA	TASK/LAB	N.07.03.21	Qualification of Coatings with High Iodine Sorptivity																											
GA	TASK/LAB	N.07.03.22	Validation Data for Predicting RN Transport in VLPC																											
GA	TASK/LAB	C.07.04	Core Corrosion Data																											
GA	TASK/LAB	C.07.04.01	Coated B4C Corrosion Data																											
GA	TASK/LAB	C.07.04.02	Core Matrix Materials Corrosion Data																											
GA	TASK/LAB	C.07.04.03	Core Corrosion Methods Validation Data																											
GA	TASK/LAB	N.07.05	Spent Fuel Disposal																											
GA	TASK/LAB	N.07.05.01	Long-Term Mechanical Integrity of Stressed TRISO Coatings																											
GA	TASK/LAB	N.07.05.02	PyC Coating Oxidation Rates (Air)																											
GA	TASK/LAB	N.07.05.03	SiC Coating Oxidation Rates (Air)																											
GA	TASK/LAB	N.07.05.04	Matrix Oxidation Rates (Air)																											
GA	TASK/LAB	N.07.05.05	H-451 Graphite Oxidation Rates (Air)																											
GA	TASK/LAB	N.07.05.06	Graphite Noncombustibility Demonstration																											
GA	TASK/LAB	N.07.05.07	PyC Coating Corrosion Rates (Groundwater)																											
GA	TASK/LAB	N.07.05.08	SiC Coating Corrosion Rates (Groundwater)																											
GA	TASK/LAB	N.07.05.09	Matrix Corrosion Rates (Groundwater)																											
GA	TASK/LAB	N.07.05.10	H-451 Graphite Corrosion Rates (Groundwater)																											
GA	TASK/LAB	N.07.05.11	Radionuclide Leaching Rates From UCO Kernels																											
GA	TASK/LAB	N.07.05.12	C-14 Content Of Matrix And Graphite																											
GA	TASK/LAB	N.07.05.13	Chemical Impurities In H-451 Graphite																											
GA	TASK/LAB	N.07.05.14	Radionuclide Leaching Rates From Graphite																											
		Reactor System (RC) C.11.00																												
GA	TASK/LAB	C.11.01	Neutron Control System																											
GA	TASK/LAB	C.11.01.01	Control Rod Instrumentation and Control Verification																											
GA	TASK/LAB	C.11.01.02	Qualification of Electromechanical Components of Neutron Control Assembly																											
GA	TASK/LAB	C.11.01.03	Control Rod Drive Design Verification																											
GA	TASK/LAB	C.11.01.04	Reserve Shutdown Control Equipment Design Verification																											
GA	TASK/LAB	C.11.01.05	In-Core Flux Mapping Unit (IFMU) Drive Design Verification																											
GA	TASK/LAB	C.11.01.06	In-Core Flux Mapping Unit (IFMU) Design Verification																											
GA	TASK/LAB	C.11.01.07	Neutron Control Assembly Flow and Leak Design Verification																											
GA	TASK/LAB	C.11.01.08	Guide Tubes Flow Induced Vibration Design Verification																											
GA	TASK/LAB	C.11.01.09	Demonstration of Remote Handling and Maintenance of Neutron Control Assembly																											
GA	TASK/LAB	C.11.01.10	Neutron Control Assembly Seismic Qualification																											
GA	TASK/LAB	C.11.01.11	Neutron Control Assembly Qualification Test																											
GA	TASK/LAB	C.11.02	Reactor Internals and Hot Duct																											
GA	TASK/LAB	C.11.02.01	Core Support Strength Data																											
GA	TASK/LAB	C.11.02.02	Hot Duct Integrity Verification																											

All DDN's				(3.3) Functional and Operational requirements														(3.2) Facility				(3.5) Life Cycle							DRL/TRL rating	
Consortium	Relevance	DDN #	(3.1) Mission Need	F CR-001	F CR-002	F CR-003	F CR-004	F CR-005	F CR-006	F CR-007	F CR-008	F CR-009	F CR-010	F CR-011	F CR-012	F CR-013	F CR-014	F AC-001	F AC-002	F AC-003	F AC-004	R&D	NRC Licensing Long Lead Items		Construction	Commissioning	Operation	Commercial Appl.	DRL	TRL
				P (Prim)	P (Secon)	P (Delta)	T (Prim)	T (Secon)	T (Other)	m	Q	Fluid	TBD (Other)	TBD (Other)	TBD (Other)	TBD (Other)	TBD (Other)	HTF	HTTU	HPTU	PBMM	i	ii	iii	iv	v	vi	vii		
GA	TASK/LAB	N:11.02.10	Effects of Primary He and Temperature on Metallic Reactor Internals Materials																											
GA	TASK/LAB	N:11.02.11	Irradiation Effects on Metallic Reactor Internals Materials																											
GA	TASK/LAB	N:11.02.12	Irradiation Effects on Hot Duct Metals																											
GA	TASK/LAB	N:11.02.13	Effects of Primary He and Temperature on Hot Duct Materials																											
GA	TASK/LAB	N:11.02.14	Fibrous Insulation Material Properties																											
GA	TASK/LAB	C:11.02.15	Hard Ceramic Insulation Properties Data																											
GA	TASK/LAB	N:11.02.16	Emissivity of Metallic Materials Reactor Internals (MRI)																											
GA	TASK/LAB	C:11.03	Reactor Core																											
GA	TASK/LAB	C:11.03.01	Core Column Vibration Data																											
GA	TASK/LAB	C:11.03.02	Control Rod Vibration																											
GA	TASK/LAB	C:11.03.03	Core Element Dynamic Strength Data																											
GA	TASK/LAB	C:11.03.04	Core Element Failure Mode Data																											
GA	TASK/LAB	C:11.03.05	Control Rod Shock Absorber Data																											
GA	TASK/LAB	C:11.03.06	Control Rod Structural Integrity Data																											
GA	TASK/LAB	C:11.03.11	Graphite Multiaxial Strength Data																											
GA	TASK/LAB	C:11.03.12	Graphite Fatigue Data																											
GA	TASK/LAB	C:11.03.13	Graphite Mechanical Properties Data																											
GA	TASK/LAB	C:11.03.14	Graphite Irradiation Induced Dimensional Change Data																											
GA	TASK/LAB	C:11.03.15	Graphite Irradiation Induced Creep Data																											
GA	TASK/LAB	C:11.03.16	Graphite Thermal Properties Data																											
GA	TASK/LAB	C:11.03.17	Graphite Fracture Mechanics Data																											
GA	TASK/LAB	C:11.03.18	Graphite Corrosion Data																											
GA	TASK/LAB	C:11.03.19	Graphite Corrosion Data for Methods Validation																											
GA	TASK/LAB	C:11.03.20	Graphite Destructive and Nondestructive Examination Data																											
GA	TASK/LAB	C:11.03.21	Graphite Coke Source Qualification																											
GA	TASK/LAB	C:11.03.22	Reserve Shutdown Pellet Process Development Data																											
GA	TASK/LAB	C:11.03.23	Graphite Oxidation Data for Postulated Accidents																											
GA	TASK/LAB	C:11.03.24	Properties of High Temperature Control Rod Materials																											
GA	TASK/LAB	C:11.03.31	Verification of Neutron Detectors and Cabling																											
GA	TASK/LAB	C:11.03.41	Fuel Element Channel Flow Data																											
GA	TASK/LAB	C:11.03.42	Control Rod Channel Flow Data																											
GA	TASK/LAB	C:11.03.43	Bottom Reflector/Core Support Pressure Drop and Flow Mixing Data																											
GA	TASK/LAB	C:11.03.44	Metallic Plenum Element and Top Reflector Pressure Drop and Flow Distribution																											
GA	TASK/LAB	C:11.03.45	Core Crossflow Test Data																											
GA	TASK/LAB	C:11.03.46	Core Fluctuation Test Data																											
GA	TASK/LAB	C:11.03.51	Integral Nuclear Data Measurement at Temperature for GT-MHR Physics Methods Validation																											
GA	TASK/LAB	C:11.03.52	Critical Experimental Data for GT-MHR Physics Methods Validation																											
GA	TASK/LAB	C:11.04	Reactor Service Equipment																											
GA	TASK/LAB	C:11.04.01	Reactor Equipment Service Facility Tools Design Verification																											
GA	TASK/LAB	C:11.04.02	Reserve Shutdown Vacuum Tool Design Verification																											
GA	TASK/LAB	C:11.04.03	Neutron Detector Service Equipment Design Verification																											
GA	TASK/LAB	C:11.04.04	Metallic Reactor Internals (MRI) ISI and Surveillance Equipment Design Verification																											
GA	TASK/LAB	C:11.04.05	Metallic Core Support ISI and Surveillance Equipment Design Verification																											
GA	TASK/LAB	C:11.04.06	Graphite Reactor Internals (GRI) and Core Support ISI and Surveillance Design Verification																											
		Vessel Systems (VS) C 12.00																												
GA	TASK/LAB	C:12.01	Vessels																											
GA	TASK/LAB	N:12.01.01	Irradiation Data for Reactor Vessel Materials (modified 9Cr-Mo, SA-387 Grade 91, Class 2 Plate and SA-336 Grade F91 Forging)																											
GA	TASK/LAB	N:12.01.02	Properties of Heavy Section Vessel Materials (SA-387 Grade 91, Class 2 Plate/SA-336 Grade F91 Forging) at Elevated Temperatures																											

All DDN's				(3.3) Functional and Operational requirements														(3.2) Facility				(3.5) Life Cycle							DRL/TRL rating	
Consortium	Reference	DDN #	(3.1) Mission Need	FCR-001	FCR-002	FCR-003	FCR-004	FCR-005	FCR-006	FCR-007	FCR-008	FCR-009	FCR-010	FCR-011	FCR-012	FCR-013	FCR-014	FAC-001	FAC-002	FAC-003	FAC-004	R&D	NRC Licensing	Long-lead Items	Construction	Commissioning	Operation	Commercial Appl.	DRL	TRL
				P (Prim)	P (Secon)	P (Delta)	T (Prim)	T (Secon)	T (Other)	m	O	Fluid	TBD (Other)	TBD (Other)	TBD (Other)	TBD (Other)	TBD (Other)	HTF	HTTU	HPTU	PBMM	i	ii	iii	iv	v	vi	vii		
GA	TASK/LAB	N.12.01.03	Reactor Vessel Emissivity (Modified 9Cr-1Mo, ABS-CE SA387 Grade 91, Class 2 Plate and SA-336 Grade F91 Forging)																											
GA	TASK/LAB	C.12.01.04	Helium Seal Data for Bolted Closures																											
GA	TASK/LAB	N.12.01.05	Irradiation Data for Reactor Vessel Material, (2¼ Cr – 1Mo)																											
GA	TASK/LAB	N.12.01.06	Reactor Pressure Vessel Emissivity (2¼ Cr – 1Mo)																											
		PRIMARY HEAT TRANSPORT SYSTEM (PHTS) N 13.00																												
GA	CTF	N.13.01	Primary Helium Circulator (PHC)																											
GA	TASK/LAB	N.13.01.01	Effects of Primary Coolant Helium and Temperature on Primary Heat Transport System Circulator Materials																											
GA	CTF	N.13.01.02	Circulator Magnetic and Catcher Bearings Design Verification	static and dynamic axial thrust load capacities, stiffness and damping coefficients of radial bearings for the entire operating speed range.										sensitivity of electronic control system to outside disturbances,	rotor dynamic response to externally induced unbalance loads	useful life of catcher bearings.														
GA	CTF	N.13.01.03	Circulator Prototype Design Verification	Data on the functional capability of the entire circulator system including motor/control/-circulator compatibility are required.										aerodynamic performance of the inlet, loop shutoff valve, circulator impeller and diffuser;	motor thrust bearing performance, (3) overspeed capability;	Structural integrity of rotating parts and supports	noise levels and frequencies, vibration characteristics and critical speeds, shutdown and hot restart capability including hot soak.													
GA	TASK/LAB	N.13.02	Intermediate Heat Exchanger (IHX)																											
GA	TASK/LAB	N.13.02.01	Effects of Helium and Temperature on IHX Materials																											
GA	TASK/LAB	N.13.02.02	Confirmation of PCHE Core Strength																											
GA	TASK/LAB	N.13.02.03	Confirmation of Design Evaluation Procedure																											
GA	CTF	N.13.02.04	Confirmation of PCHE Core Temperature Distribution	As applied to the IHX, it is necessary to confirm by experiment the temperature distribution accompanied by analytical evaluation																										
GA	CTF	N.13.02.05	Confirmation of IHX Thermal Hydraulic Characteristics	It is necessary to confirm by experiment the flow distribution throughout the IHX (both																										
GA	CTF	N.13.02.06	IHX Acoustic Test	Data are needed to produce frequency																										
GA	CTF	N.13.02.07	IHX Insulation Verification Tests	Physical and operational characteristics of																										
GA	CTF	N.13.02.08	IHX Seal Tests	Various sliding seals, expansion joints, and										Data are needed to																
GA	CTF	N.13.02.09	IHX Flow Induced Vibration Test	Data are needed to accurately determine the										The flowinduced																
		SHUTDOWN COOLING SYSTEM (SCS) C 14.00																												
GA	CTF	C.14.01	Shutdown Circulator										No info available																	
GA	CTF	C.14.01.01	SCS Circulator Magnetic and Catcher Bearings Design Verification										No info available																	
GA	CTF	C.14.01.02	SCS Circulator Prototype Impeller Aerodynamic and Acoustic Test Data										No info available																	
GA	CTF	C.14.01.03	SCS Circulator Prototype Test in High Pressure Test Facility (HPTF)										No info available																	
GA	CTF	C.14.01.04	Shutdown Circulator Loop Shut-off Valve (SLSV) Life Cycle Test Data										No info available																	
GA	TASK/LAB	N.14.01.05	Irradiation Effects on SCS Circulator Materials																											
GA	TASK/LAB	N.14.01.06	Effects of Primary Coolant Helium and Temperature on SCS Circulator Materials																											
GA	CTF	C.14.04	Shutdown Heat Exchanger (SHE)										No info available																	
GA	CTF	C.14.04.01	SHE Insulation Verification Tests										No info available																	
GA	CTF	C.14.04.02	SHE Vibrational Fretting Wear and Sliding Wear of TRDs for Bare Tubes										No info available																	
GA	CTF	C.14.04.03	SHE Instrumentation Attachment Test										No info available																	
GA	CTF	C.14.04.04	SHE Bare Tubes Inspection Methods and Equipment										No info available																	
GA	CTF	C.14.04.05	SHE Shroud Seal Test										No info available																	
GA	CTF	C.14.04.06	Acoustical Response of the SHE Helical Bare Tube Bundle										No info available																	
GA	CTF	C.14.04.07	SHE Inlet Flow and Temperature Distribution Test										No info available																	
GA	CTF	C.14.04.08	SHE Tube Bundle Local Heat Transfer and Flow Resistance Characteristics										No info available																	
GA	CTF	C.14.04.09	SHE Tube Helical Coil Program										No info available																	
GA	CTF	C.14.04.10	SHE Lead-in/Lead-out Expansion Loop Tube Design and Fabrication										No info available																	

All DDN's				(3.3) Functional and Operational requirements														(3.2) Facility				(3.5) Life Cycle							DRL/TRL rating	
Consortium	Relevance	DDN #	(3.1) Mission Need	FOR-001	FOR-002	FOR-003	FOR-004	FOR-005	FOR-006	FOR-007	FOR-008	FOR-009	FOR-010	FOR-011	FOR-012	FOR-013	FOR-014	FAC-001	FAC-002	FAC-003	FAC-004	i R&D	ii NRC Licensing	iii Component Testing	iv Construction	v Commissioning	vi Operation	vii Commercial Appl.	DRL	TRL
				P (Prim)	P (Secon)	P (Delta)	T (Prim)	(Secon)	T (Other)	m	Q	Fluid	TBD (Other)	TBD (Other)	TBD (Other)	TBD (Other)	TBD (Other)	HTF	HTTU	HPTU	PBMM									
GA	TASK/LAB	C.14.04.11	Irradiation Effects on Shutdown Cooling System Heat Exchanger Materials																											
GA	TASK/LAB	C.14.04.12	Effects of Primary Coolant Helium and Temperature on Shutdown Cooling System Heat Exchanger Materials																											
		REACTOR CAVITY COOLING SYSTEM (RCCS) C.16.00																												
GA	TASK/LAB	C.16.00.01	Emissivity of RCCS Panel Metal Surfaces																											
GA	TASK/LAB	C.16.00.02	Wind Tunnel Test of RCCS I/O Structure																											
GA	TASK/LAB	C.16.00.03	Integrated RCCS Performance																											
GA	TASK/LAB	C.16.00.04	RCCS Cooling Panel Heat Transfer Coefficient and Friction Factor																											
GA	TASK/LAB	C.16.00.05	Effective Conductivity of Core Blocks																											
GA	TASK/LAB	C.16.00.06	Buoyancy Induced Fluid Mixing in a High Aspect Ratio Cavity																											
		FUEL HANDLING AND STORAGE SYSTEM (FHSS) C.21.00																												
GA	TASK/LAB	C.21.01	Core Refueling																											
GA	TASK/LAB	C.21.01.01	Fuel Handling Machine/Handling Mechanism Design Verification																											
GA	TASK/LAB	C.21.01.02	Fuel Transfer Cask Component Design Verification																											
GA	TASK/LAB	C.21.01.03	Element Hoist and Grapple Assembly Robot Design Verification																											
GA	TASK/LAB	C.21.01.04	Verify Fuel Handling System Instrumentation and Control																											
GA	TASK/LAB	C.21.01.05	Integrated Fuel Handling System Test Data																											
GA	TASK/LAB	C.21.01.06	Fuel Handling Equipment Positioner Design Verification																											
GA	TASK/LAB	C.21.01.07	Fuel Handling Equipment Support Structure Design Verification																											
GA	TASK/LAB	C.21.01.08	Fuel Sealing and Inspection Equipment Design Verification																											
GA	TASK/LAB	C.21.01.09	Inflatable Seal and SN Identification Tests Design Verification																											
		REACTOR PROTECTION SYSTEM (RPS) C.31.00																												
GA	CTF	C.31.01	Safety Protection and Instrumentation										No info available																	
GA	CTF	C.31.01.01	Verify Helium Mass Flow Measurement Instrumentation										No info available																	
GA	CTF	C.31.01.02	Verify Conduction Cooldown Temperature Monitoring Instrumentation										No info available																	
		PLANT CONTROL, DATA AND INSTRUMENTATION SYSTEM (PCDIS) C.34.00																												
GA	CTF	C.34.01	Nuclear Island Control and Instrumentation										No info available																	
GA	CTF	C.34.01.01	Verify Core Inlet and Outlet Helium Temperature Measurement Instrumentation										No info available																	
GA	TASK/LAB	C.34.01.02	Verify Plateout Probe Operation																											
		POWER CONVERSION SYSTEM (PCS) N.41.00																												
		N.41.01	Turbomachine																											
GA	TASK/LAB	N.41.01.01	Service Lifetime of Uncooled Turbine Blades at 950 oC																											
GA	TASK/LAB	N.41.01.02	Verification of Blade Cooling Design																											
GA	TASK/LAB	N.41.01.03	Thermal Barrier Coatings for Turbine Blades																											
GA	TASK/LAB	N.41.02	Recuperator																											
GA	TASK/LAB	N.41.02.01	Creep Data for Candidate Recuperator Metals																											
GA	TASK/LAB	N.41.02.02	Recuperator Support System. Design Verification																											
GA	TASK/LAB	N.41.04	Ducts and Seals																											
GA	TASK/LAB	N.41.04.01	PCS Duct Design Verification & Support																											
		SECONDARY HEAT TRANSPORT SYSTEM (SHTS) N.42.00																												
GA	CTF	N.42.01	SHTS Circulator (Secondary Circulator DDNs are covered by Primary Helium Circulator DDNS due to design similarity)										No info available																	
GA	CTF	N.42.02	Isolation Valves																											

Consortium	Relevance	DDN #	(3.1) Mission Need	(3.3) Functional and Operational requirements: F-CR-001 P (Prim)	F-CR-002 P (Secon)	F-CR-003 P (Delta)	F-CR-004 T (Prim)	F-CR-005 T (Secon)	F-CR-006 T (Other)	F-CR-007 m	F-CR-008 Q	F-CR-009 Fluid	F-CR-010 TBD (Other)	F-CR-011 TBD (Other)	F-CR-012 TBD (Other)	F-CR-013 TBD (Other)	F-CR-014 TBD (Other)	(3.2) Facility: F-AC-001 HTF	F-AC-002 HTTU	F-AC-003 HPTU	F-AC-004 PDMM	(3.5) Life Cycle: R&D i	NRC Licensing ii	Design iii	Construction iv	Commissioning v	Operation vi	Commercial Appl. vii	DRL/TRL rating: DRL	TRL
All DDN's																														
GA	CTF	N.42.02.01	Effects of Primary Coolant Helium and Temperature on SHTS Piping and Valve Materials	Data are needed to assess performance of valve internal insulation, valve seat material, seal performance and structural integrity.																										
GA	CTF	N.42.02.02	High Temperature Isolation Valve Prototype Design Verification										No info available																	
		SI-BASED H2 PRODUCTION SYSTEM (SI) N.44.00																												
GA	TASK/LAB	N.44.01	Sulfuric Acid Decomposition																											
GA	TASK/LAB	N.44.01.01	Catalyst Performance																											
GA	TASK/LAB	N.44.02	Bunsen Reaction																											
GA	TASK/LAB	N.44.02.01	Bunsen Reaction Physical Chemistry																											
GA	TASK/LAB	N.44.02.02	Refined Thermodynamic Model																											
GA	TASK/LAB	N.44.03	Hydrogen Iodide Decomposition																											
GA	TASK/LAB	N.44.03.01	HI/H2 Membrane Separation																											
GA	TASK/LAB	N.44.03.02	Refined Thermodynamic Model																											
GA	TASK/LAB	N.44.03.03	Liquid HI Decomposition																											
GA	TASK/LAB	N.44.04	Materials Compatibility																											
GA	TASK/LAB	N.44.04.01	Corrosion performance																											
GA	TASK/LAB	N.44.04.02	Equipment Manufacturability																											
		HTE-BASED H2 PRODUCTION SYSTEM (HTE) N45.00																												
GA	TASK/LAB	N.45.03	SOE Modules																											
GA	TASK/LAB	N.45.03.01	SOE Pilot-Scale Module Demonstration																											
GA	TASK/LAB	N.45.03.02	SOE Engineering Scale Module Demonstration																											
GA	TASK/LAB	N.45.03.03	NGNP SOE Multi-Module Demonstration																											
GA	CTF	N.45.04	HTE Plant Supporting Equipment										TBD after designed																	
GA	CTF	N.45.04.01	HTE Steam Generator/Superheater										TBD after designed																	
GA	CTF	N.45.04.02	HTE Heat Exchangers																											
	CTF	Additional	Full Scale Testing/Qualification of systems and components	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	Helium	Complete component list TBD	N/A	N/A	N/A	N/A	No, see note	No	No	No									
	CTF	Additional	Control & Instrumentation development / qualification	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	Helium	Control & instrumentation development / qualification requirements	N/A	N/A	N/A	N/A	Yes, see note	No	No	No									
	CTF	Additional	CTF to be used for V&V of methods / software	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Helium	Specifications and requirements for CTF to be sued for V&V	N/A	N/A	N/A	N/A	Yes, see note	No	No	No									
	CTF	Additional	Fluid inventory systems testing	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	Helium	Fluid inventory specialifications TBD	N/A	N/A	N/A	N/A	Yes, see note	No	No	No									
	CTF	Additional	Quality control systems testing	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Helium	Quality control system requirements TBD	N/A	N/A	N/A	N/A	Possible, see note												
	CTF	Additional	Control room human factors	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Helium	Specify control human factor requirements	N/A	N/A	N/A	N/A	Yes, see note	No	No	No									
	CTF	Additional	Operational	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Helium	Procedures development / qualification	Operational problems / trouble shooting	N/A	N/A	N/A	Yes, see note	No	No	No									
	CTF	Additional	Programs	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	Helium	Maintenace and repair program / process development	Component replacement program / process developemnt	N/A	N/A	N/A	No, see note	No	No	No									
	CTF	Additional	High temperature instrumentation (Flow control…)	TBD	TBD	TBD	TBD	TBD	TBD	TBD	TBD	Helium	Determine specific requirements for high temepraure flow control	N/A	N/A	N/A	N/A	Yes, see note	No	No	No									
	CTF	White Paper	Main need from High Temp Elelrolysis (HTE) for CTF: Super heaters / Steam generators	N/A	0.2MPa	N/A	N/A	T_inlet: 900C T_outlet: 270C	FW T_inlet: 220D Steam T_outlet: 540D	TBD	N/A	Helium	Addressed by previous F&OR on steam generator	N/A	N/A	N/A	N/A	Yes, see note	No	No	No									

All DDN's																														
Consortium	Relevance	DDN #	(3.1) Mission Need	(3.3) Functional and Operational requirements														(3.2) Facility				(3.5) Life Cycle							DRL/TRL rating	
				F-CR-001	F-CR-002	F-CR-003	F-CR-004	F-CR-005	F-CR-006	F-CR-007	F-CR-008	F-CR-009	F-CR-010	F-CR-011	F-CR-012	F-CR-013	F-CR-014	F-AC-001	F-AC-002	F-AC-003	F-AC-004	R&D	NRC Licensing		Construction	Commissioning	Operation	Commercial Appl.	DRL	TRL
				P (Prim)	P (Secon)	P (Delta)	T (Prim)	T (Secon)	T (Other)	m	Q	Fluid	TBD (Other)	TBD (Other)	TBD (Other)	TBD (Other)	TBD (Other)	HTF	HTTU	HPTU	PBMM	i	ii	iii	iv	v	vi	vii		
	CTF	White Paper	Materials	9 Mpa	9 Mpa	< 200 kPa	T_inlet: 950C T_outlet: 337C	T_inlet: 290C T_outlet: 900C	N/A	TBD	N/A	Helium	Material List: SA508/533 Inconel 617 Haynes 230 Incoloy 800H 2-1/4 Cr-1Mo-V 9Cr-1Mo Ceramics	Material List: Creep Creep-fatigue Erosion / Corrosion High Temp material prop	Specific requirements regarding typical tests TBD. Double check with DDN	N/A	N/A	Yes, see note	No	No	No									
AREVA	TASK/LAB		Fuel																											
AREVA	TASK/LAB		Fabrication																											
AREVA	TASK/LAB		Laboratory scale fabrication	To test the industrial fabrication Main components at the Measurement of the key geometrical,																										
AREVA	TASK/LAB		- Coated particles																											
AREVA	TASK/LAB		- Compacts																											
AREVA	TASK/LAB		Industrial pilot line																											
AREVA	TASK/LAB		- Coated particles																											
AREVA	TASK/LAB		- Compacts																											
AREVA	TASK/LAB		Characterisation																											
AREVA	TASK/LAB		Before irradiation																											
AREVA	TASK/LAB		After irradiation																											
AREVA	TASK/LAB																													
AREVA	TASK/LAB		Fuel qualification																											
AREVA	TASK/LAB		Irradiation	- Online monitoring of fission gas releases in order to be																										
AREVA	TASK/LAB		Safety Testing	- Online monitoring of fission gas releases in order to be																										
AREVA	TASK/LAB																													
AREVA	TASK/LAB		Materials																											
AREVA	TASK/LAB		Corrosion studies																											
AREVA	TASK/LAB		In impure He atmosphere	Vessel material, high temperature metallic materials,																										
	TASK/LAB		Atmospheric pressure	High temperature (up to 1000°C), precise control of impurity																										
	TASK/LAB		Uniform corrosion																											
	TASK/LAB		Corrosion + creep																											
	TASK/LAB		Corrosion + low cycle fatigue																											
	TASK/LAB		Normal operating pressure																											
	TASK/LAB																													
AREVA	TASK/LAB		In air ingress situations	Graphite & composite oxidation																										
AREVA	TASK/LAB																													
	TASK/LAB		Tribology	Friction and wear in high temperature representative He																										
	TASK/LAB		Irradiation	Irradiation test rigs																										
	TASK/LAB		Vessel material																											
	TASK/LAB		Graphite																											
	TASK/LAB		Composites																											
			Components & Systems																											
	CTF		Plate IHX	Baseline mechanical property data, including creep-fatigue data,														- for development of visco-plastic model (material data-base to be completed)												
	CTF		1st Step : Separate effects tests	Thermo-mechanical behavior	Representative operating temperature of the IHX and representative temperature transient. Air atmosphere is acceptable	CLAIRE loop being presently upgraded in CEA Grenoble (900°C, cool-down transients of 300°C in 5 sec., and heat-up transients of 300°C in 120 sec).	Heat transfer performance	Representative fluids Representative geometry Representative temperature	- Tube geometry, He and He and He+N2, 900°C (AREVA Le Creusot) - Representative geometry, air (CLAIRETTE loop, CEA Grenoble) - Representative geometry, He, 500°C (HEFUS3 loop, ENEA Brasimone)	Homogeneity of flow distribution. Large flow, room temperature & air acceptable	Corrosion | Representative atmosphere with controlled impurities																			
	CTF		2nd Step: Validation of selected design		Detailed design finalized for a 1 MW He loop, 950°C,														He loop providing at the same time most of the											
	CTF		3rd Step : IHX qualification		Large He loop providing at the same time all the																									
	CTF		Tube IHX	Only final qualification necessary on the large He loop	Urgent to launch an R&D program: - tests to confirm fabrication feasibility (tube bending, tube welding, nozzles on hot header, ISIR and assembly, etc) - corrosion and nitriding tests on base and coated materials in representative environment - representative IHX mock-ups from thermo-hydraulic and manufacturing point of view. Test in helium and									For the component qualification, it is considered that the qualification on a mock-up at scale 1 on a large test facility will be sufficient (no need for intermediate testing on small size mock-ups), subject that manufacturing issues be addressed by dedicated actions.															
	CTF		Valves	Qualification on He loops	The qualification should be performed in 2 steps: 1) Elementary tests to characterize the fiber conditions, assembly techniques,							A hot gas isolation valve was designed in the context of the German HTR development program and tested in KVK test facilities. The corresponding						No for 10 MWth test loops												

All DDN's																														
Consortium	Relevance	DDN #	(3.1) Mission Need	(3.3) Functional and Operational requirements														(3.2) Facility				(3.5) Life Cycle							DRL/TRL rating	
				F-CR-001	F-CR-002	F-CR-003	F-CR-004	F-CR-005	F-CR-006	F-CR-007	F-CR-008	F-CR-009	F-CR-010	F-CR-011	F-CR-012	F-CR-013	F-CR-014	F-AC-001	F-AC-002	F-AC-003	F-AC-004	R&D	NRC Licensing	Long Lead Items	Construction	Commissioning	Operation	Commercial Appl.	DRL	TRL
				P (Prim)	P (Secon)	P (Delta)	T (Prim)	T (Secon)	T (Other)	m	Q	Fluid	TBD (Other)	TBD (Other)	TBD (Other)	TBD (Other)	TBD (Other)	HTF	HTTU	HPTU	PBMM	i	ii	iii	iv	v	vi	vii		
	CTF		Hot gas duct	The qualification should be performed in 3 steps:																										
	CTF		Circulator	Air tests of the impeller (at scale 0.2 to 0.4) | Loops available in manufacturer facilities	He high temperature test of magnetic and catcher bearings	In the first stages of the design, tests should cover both the metallic and ceramic design (pending the confirmation of the feasibility of the metallic design)								Integrated scale 1 test | Either dedicated loop at operating temperature (400°C) with very large He flow or during NGNP commissioning tests				No for 1 to 10 MWth test loops												
	CTF		Instrumentation	Below example of R&D which might be envisioned:																										
			Computer Code Qualification																											
			Neutronics	Critical experiment with the possibility of getting an asymptotic neutron spectrum as well as transition spectrum at the interface of the core and the graphite reflector							Feasibility of a representative critical experiment in the MASURCA zero power reactor in CEA Cadarache assessed			Isotopic analysis of fuel irradiated to very high burn-up		Undertaken by ITU (JRC Karlsruhe) for a pebble irradiated to 15%FIMA in HFR, also INL														
	CTF		Thermo-fluid dynamics	Representative mock-ups for critical areas, for instance	Mixing of cold and hot streaks in core outlet plenum	Validation of turbulent mixing but not of the thermal diffusion between hot and cold streaks	Conduction on cool-down : validation of modelling	Decay heat release through internal structures to the vessel outer wall	Radiative heat transfer in the reactor cavity and natural circulation in the RCCS	Flow in IHX headers (see IHX)																				
			Neutronics / Thermo-fluid dynamics coupling	In core flux and temperature instrumentation in NGNP																										
	CTF		System analysis	Comparison with data on gas loop transient operation	Many data exist on transient operation of gas systems in which same type of phenomena as in NGNP occur (EVO loop (Germany), HE-FUS3 (ENEA), Micro-model (South Africa), HTR-10, HTTR.																									

APPENDIX B - SOUTH AFRICAN PBMR TEST FACILITIES

1.1 HELIUM TEST FACILITY (HTF)

1.1.1 Background

The Helium Test Facility (HTF) is a facility for the development, verification and non-nuclear testing of critical prototype components of the PBMR and Support System. It provides the capability to test components and sub-assemblies in a high-temperature and high-pressure helium environment that are similar to the operating conditions expected for the PBMR demonstration plant.

The HTF will be used for testing of the following PBMR Demonstration Plant systems, sub-systems and components, also defined as Units Under Test (UUT):

- Fuel Handling and Storage System (FHSS)
- Reactivity Control System (RCS)
- Reserve Shutdown System (RSS)
- Helium Inventory Control System (HICS)
- Gas Cycle Valves (GCV)
- Instrumentation
- MPS Recuperator

The HTF is situated on the premises of NECSA, at Pelindaba, near Pretoria. The facility consists of a totally enclosed 40m high (8 levels) test tower with a 10m x 13m footprint and a 20 ton overhead crane with a passenger lift (ground - level 6). The facility is designed to accommodate 5 independent process streams, which are able to operate at up to 9MPa, 50ºC - 580ºC (1100ºC local) and up to 2kg/s. A simplified PFD of the HTF, indicating the maximum temperatures in the different lines is indicated in Figure 1.

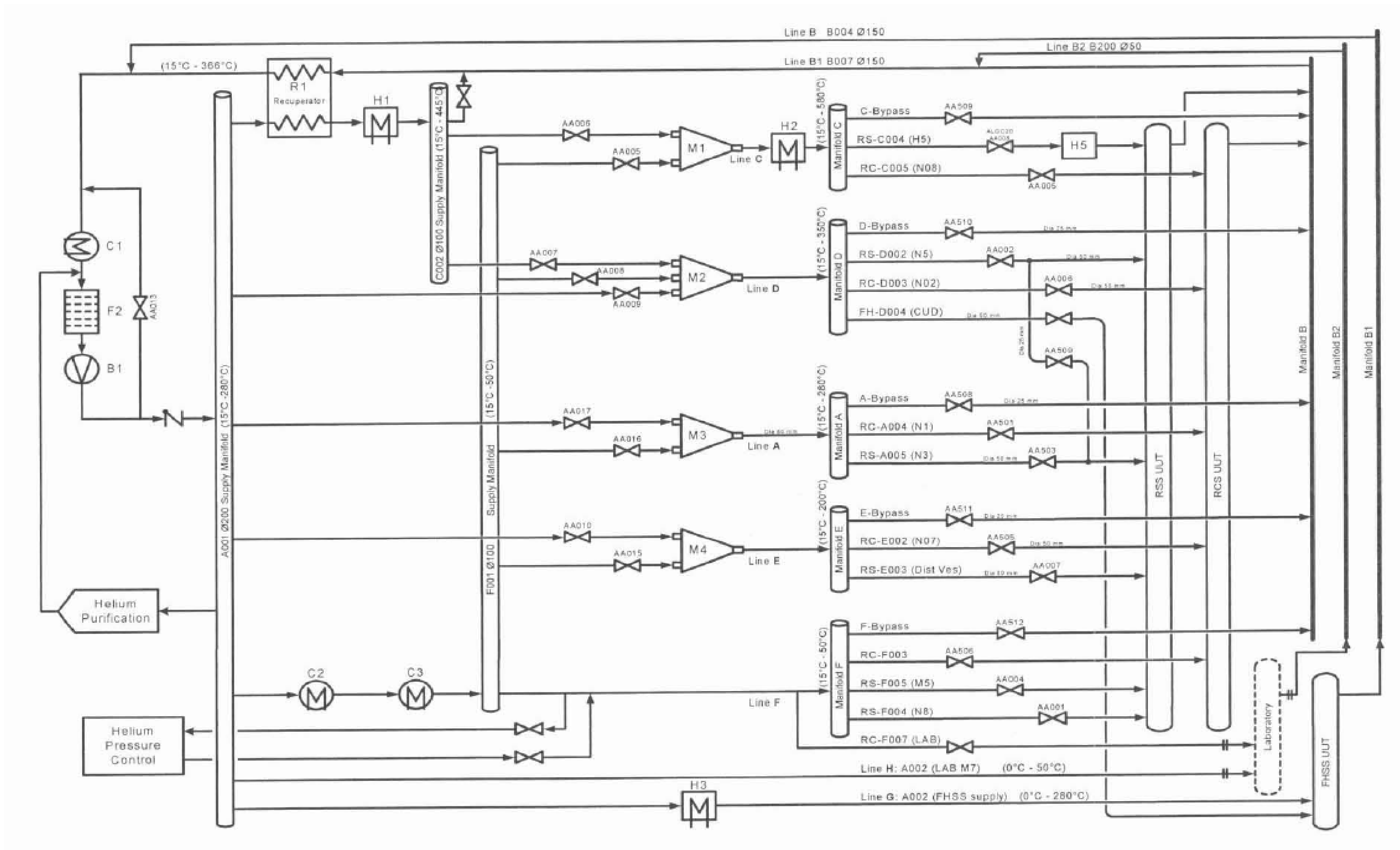


Figure 1: Simplified HTF PFD

Figure 2: Photo of HTF

1.1.2 HTF Envelope

The HTF is subjected to a list of Acceptance Test Procedures (ATPs), in order to demonstrate the required thermal-hydraulic performances as specified in the design and requirement documentation. These ATPs are summed up in Table 1, and will be conducted in three phases. These three phases are distinguished by the maximum temperature limit on the complete facility.

Table 1: Test phases

Phase	Maximum Temperature limit	Commissioned date
Phase 1	T_{max} = 300°C (Mainloop)	End 2006
Phase 2	$T_{max} \leq$ 580°C (Mainloop)	Mid 2008
Phase 3	$T_{max} \leq$ 900°C (Local in test set-up)	Mid 2009

A complete summary of the operating envelope in the different sections of the HTF is presented in Table 2. From these specifications it can be concluded that the HTF does have the potential for addressing certain of the CTF needs. This potential would however need to be assessed according to availability of the different conditions.

Table 2: HTF Thermal-fluid conditions and availability

No.	Description	Phase I	Phase II	Phase III	Manifold													Lab Availibilty		
					Pressure	C		D		A		E		F		Line G				
					[MPa]	[kg/s]	[°C]	[kg/s]	[°C]	[kg/s]	[°C]	[kg/s]	[°C]	[kg/s]	[°C]	[kg/s]	[°C]	kg/s	[°C]	Date
1	FHSS @ **1 MPa** Line D, **T = 280°C** (via FHS system)		X		1	-	-	0.051	280	-	-	-	-	-	-	-	-	0.051	280	[TBD]
2	FHSS @ **1 MPa** Line G, **T = 200 - 250°C** (via equalisation line)	X			1	-	-	-	-	-	-	-	-	-	-	0.03	250	0.03	250	[TBD]
3	FHSS @ **1 MPa** Line G, **T = 280°C** (via FHS system)		X		1	-	-	-	-	-	-	-	-	-	-	0.13	280	0.13	280	[TBD]
4	RSS @ **2.2 MPa** & **T_max ≤ 250°C**	X			2.2	0.05	250	0.05	60	0.05	60	0.15	100	0.05	50	-	-	0.05	250	[TBD]
5	RSS @ **6.5 MPa** & **T_max ≤ 300°C**	X			6.5	0.05	300	0.05	100	0.05	100	0.03	100	0.05	50	-	-	0.05	300	[TBD]
6	RSS @ **6.5 MPa** & **T_max ≤ 600°C**		X		6.5	0.05	500	0.05	100	0.05	100	0.03	100	0.05	50	-	-	0.05	500	[TBD]
7	RSS @ **9.0 MPa** & **T_max ≤ 300°C** (SAS transport)	X			9	0.05	300	0.05	280	0.05	280	0.4	150	0.05	50	-	-	0.05	300	[TBD]
8	RSS @ **9.0 Mpa** & **T_max ≤ 600°**C (SAS transport)		X		9	0.05	580	0.05	280	0.05	280	0.4	150	0.05	50	-	-	0.05	580	[TBD]
9	RSS @ **9.0 Mpa** & **T_max ≤ 900°C** (SAS transport)			X	9	0.05	750	0.05	280	0.05	280	0.4	150	0.05	50	-	-	0.05	750	[TBD]
10	RSS @ **9.0 Mpa** & T_max **≤ 600°C** (Manifold D for lower RSS vessel conditioning at **350°C**)		X		9	0.05	580	0.1	350	0	-	0	-	0.05	50	-	-	0.05	580	[TBD]
11	RSS @ **9.0 Mpa** & **T_max ≤ 900°C** (Manifold D for lower RSS vessel conditioning at **350°C**)			X	9	0.05	750	0.1	350	0	-	0	-	0.05	50	-	-	0.05	750	[TBD]
12	RCS @ **9.0 MPa** & **T_max ≤ 300°C**	X			9	0.2	300	0.06	280	0.05	280	0.05	120	0.05	50	-	-	0.2	300	[TBD]
13	RCS @ **9.0 MPa** & **T_max ≤ 600°C**		X		9	0.2	580	0.06	280	0.05	280	0.05	200	0.05	50	-	-	0.2	580	[TBD]
14	RCS @ **9.0 MPa** & **T_max ≤ 600°C**			X	9	0.05	900	0.05	280	0.05	280	0.4	150	0.05	50	-	-	0.05	900	[TBD]
15	RCS @ **9.0 MPa** & **T_max ≤ 300°C** (No manifold C flow)	X			9	0	-	0.06	280	0.05	180	0.05	120	0.05	50	-	-	0.06	280	[TBD]
16	RCS @ **9.0 MPa** & **T_max 600°C** (No manifold C flow)		X		9	0	-	0.06	350	0.05	180	0.05	120	0.05	50	-	-	0.06	350	[TBD]
17	RCS @ **9.0 MPa** & **T_max ≤ 600°C** (No manifold A & E flow)		X		9	0.22	580	0.06	350	0	-	0	-	0.05	50	-	-	0.22	580	[TBD]
18	RCS @ **9.0 MPa** & **T_max ≤ 900°C** (No manifold A & E flow)			X	9	0.22	900	0.06	350	0	-	0	-	0.05	50	-	-	0.22	900	[TBD]
19	Combined RCS & RSS @ **9.0 MPa** & **T_max ≤ 300°C**	X			9	0.25	300	0.11	0.1	0.9	280	0.35	120	0.9	50	-	-	0.25	300	[TBD]
20	Combined RCS & RSS @ **9.0 MPa** & **T_max ≤ 600°C**		X		9	0.25	580	0.11	280	0.9	280	0.35	120	0.1	50	-	-	0.25	580	[TBD]
21	FHSS @ **9.0 MPa**, **T=280°C** (via equalisation line)	X			9	-	-	-	-	-	-	-	-	-	-	0.6	280	-	0	-
22	FHSS @ **9.0 MPa**, **T=280°C** (via FHS system)		X		9	-	-	-	-	-	-	-	-	-	-	0.58	280	-	0	-
	Maximum Conditions				9	0.25	900	0.11	350	0.9	280	0.4	200	0.9	50	0.6	280			

Notes
1 Temperature measured at manifold C
2 Temperature at nozzle of RSS test set-up vessel (N6)
3 Manifold D used for conditioning of RSS vessel bottom
4 Temperature at nozzle of RSS test set-up vessel (N8)
5 Temperature at nozzle of RSC test set-up vessel (N8)
6 Temperature at nozzle of RSS (N6) and RCS (N8) test set-up vessels
7 Temperature within boring (to be achived with heater H1, H2 and H5 or internal RSS heating)
8 Boring temperature above 580 to be achieved with H6

1.1.3 Proposed Modification to HTF

The HTF currently has an empty laboratory with development potential. This laboratory is intended to be a versatile facility for testing of PBMR components in a high pressure high-temperature helium environment. The provided conditions in the laboratory are determined from the main loop capabilities. The conditions that could be available from the main loop consist of three lines (A, C and F) as indicated in Figure 3. The same laboratory could also be utilized for a complete separate CTF loop, which uses the existing auxiliaries (HICBS & HPS) as well as added benefits from existing know-how. A typical arrangement of these two loops is indicated in Figure 3.

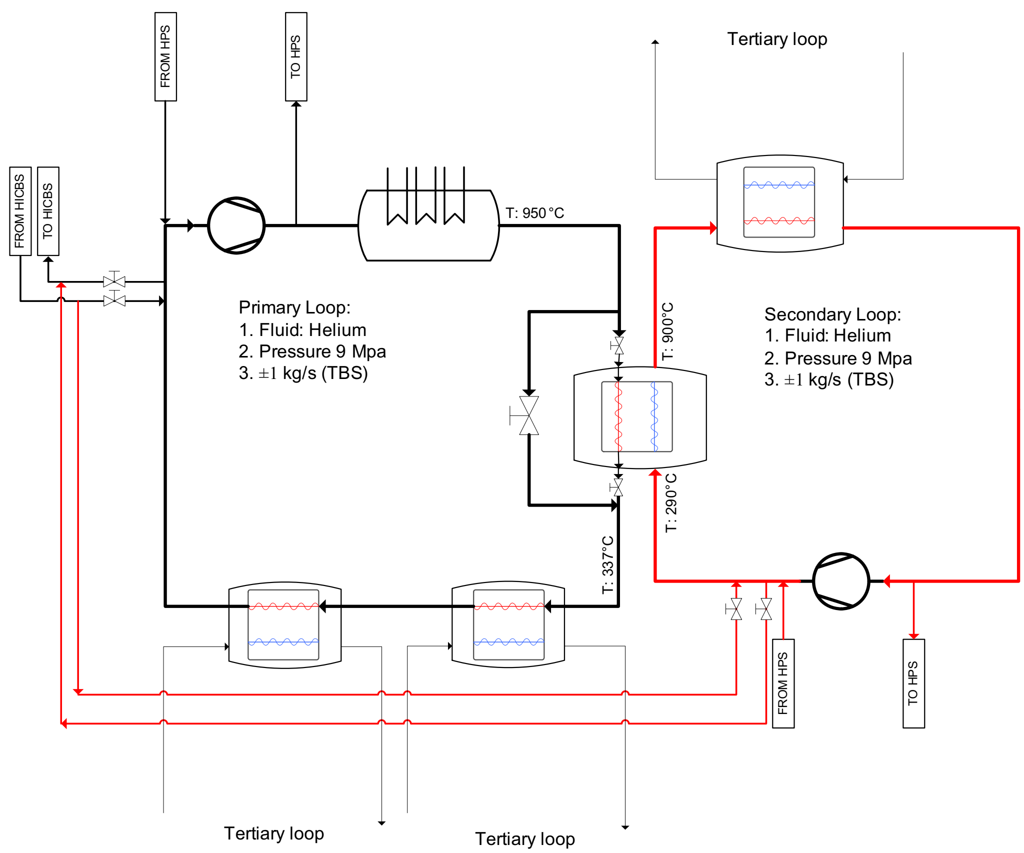


Figure 3: Proposed HTF lab configuration

The auxiliaries (HICBS & HPS) would be available for a new CTF loop. The proposed loop will consist of a blower with ±1 kg/s capability at 9 MPa. A similar blower is currently used by the HTF and can be ordered from HOWDEN. The loop will be able to test a number of the DDNs under the requirement achievable with this blower capacity.

1.1.4 HTF Summary

Although Figure 1 shows the HTF as being available, this must not be misunderstood as being available for the CTF testing. This merely indicates availability for PBMR DPP testing. The HTF was purpose-built to address specific needs for the PBMR Demonstration Power Plant (DPP), as can be seen from the design and complex PFD of the HTF. The plant, as it is functioning currently, could not be used as the CTF and modifications/extensions of the existing facility would be needed.

The HTF infrastructure, human capital and knowledge make this a very attractive facility to use for component testing. The support systems like the HICBS & HPS are already built and functional. The time schedule, however, indicates that it will not be feasible as an option for component testing due to the primary commitments of the facility to the DPP. A timeframe of FY12 is indicated by the HTF team as a possibility, making it too late for the CTF time schedule requirements.

1.2 PEBBLE BED MICRO MODEL (PBMM)

1.2.1 Background

The purpose of the Pebble Bed Micro Model (PBMM) was to demonstrate the concept and controllability of the PBMR three-shaft recuperated closed Brayton Cycle. The PBMM was also utilized to demonstrate the Flownex computer code's ability to accurately predict the dynamic behavior of the system.

The first phase of the PBMM project was to prove the feasibility of a three-shaft recuperative Brayton cycle. The next phase in the PBMM project was to gather experimental data for the verification and validation (V&V) of Flownex. During this phase, all instrumentation was calibrated to traceable standards to ensure reliable experimental data.

The Pebble Bed Micro Model (PBMM) is a fully functional model of the earlier three-shaft Power Conversion Unit (PCU) of the Pebble Bed Modular Reactor (PBMR), a predecessor of that currently under development in South Africa. Flownex was used extensively in the design of the PBMM and the prediction of its performance.

The PBMM is based on the Brayton power cycle (as used in aircraft engines) but with the following distinguishing features:

- It uses nitrogen as the working fluid.
- The gas moves around in a closed circuit, which implies that no nitrogen is consumed in the power generation process – it merely acts as an energy carrier.
- The PBMM uses single stage centrifugal compressors and turbines. It makes use of three separate shafts, one for the high-pressure (HP) compressor/turbine pair, one for the low pressure (LP) compressor/turbine pair and one for the power turbine (PT) and generator. This allows the HP and LP compressor/turbine pairs to run at high speeds thereby reducing the size and therefore also the cost of the machines.
- It makes use of a recuperator to recover heat that would otherwise have been rejected to atmosphere. The recovered heat is transferred elsewhere in the system thereby reducing the heat required from the heat source and ultimately increasing the thermal efficiency of the plant.
- The generator is emulated by a load compressor connected to a power dissipation loop consisting of a flow control valve and a heat exchanger. Variations in load are effected by increasing or decreasing the pressure level in the load rejection loop.

Figure 4 : Solid model of PBMM

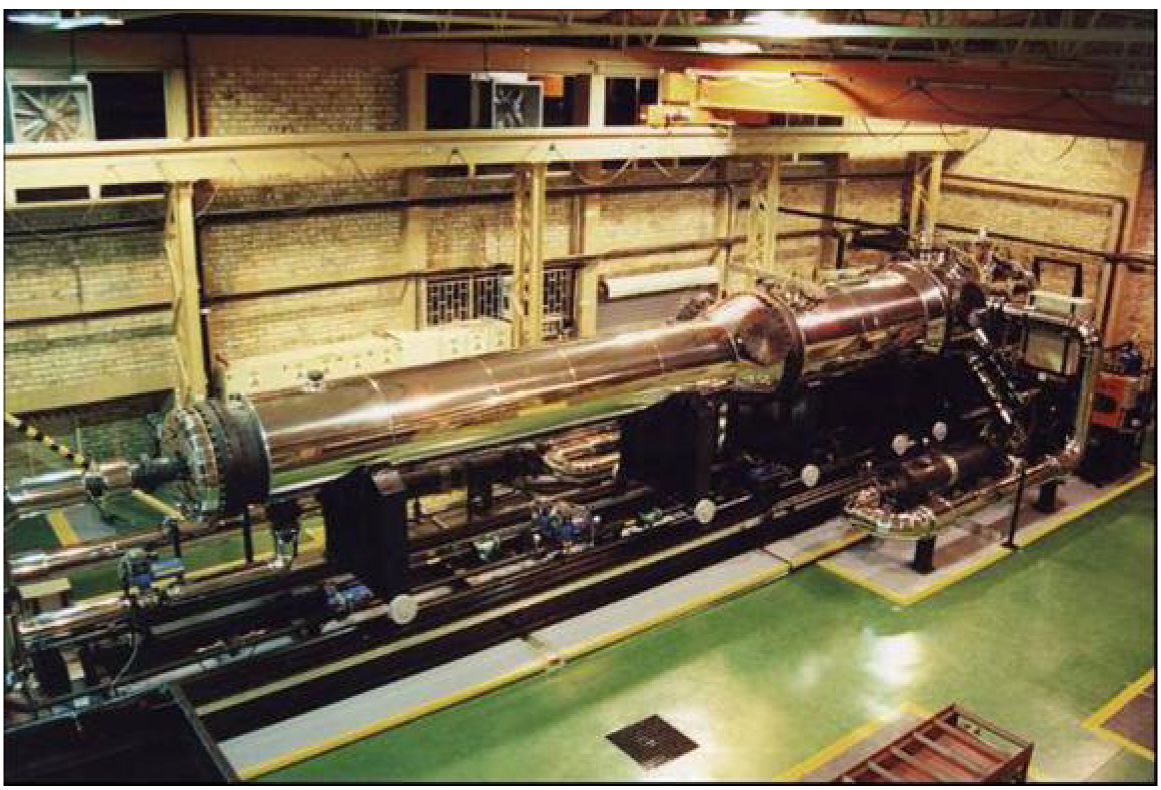


Figure 5 : Photo of PBMM

1.2.2 PBMM Envelope

Table 3 : PBMM Envelope

Variable	Unit	Min	Max
System Pressure	MPa (abs)	0	0.9
System Mass Flow Rate	kg/s	0	2
System Heater Power	kW	0	350
Heater Temperature	C	0	700
Fluid			Nitrogen

1.2.3 Proposed Modifications to PBMM

Extensive modifications are needed to change the current facility for use as a component test facility or laboratory. The major changes will include a blower, pipe work, new control systems and instrumentation. The use of Helium in the facility has to be further investigated as sealing of the vessel will be of concern.

1.2.4 PBMM Summary

The PBMM successfully completed all the tests specified, and the facility is still fully operational and immediately available. Localized temperatures of 700 degree C at a pressure of 0.9 MPa at a maximum flow rate of 2 kg/s can be achieved. The system was design with Nitrogen as the working fluid. The PBMM is not an ASME accredited facility and extensive changes/modification are needed to address the DDN requirements. The PBMM is not well suited for addressing the CTF mission needs.

1.3 HEAT TRANSFER TEST FACILITY (HTTF)

The Heat Transfer Test Facility (HTTF) consists of two clearly distinguishable test units, namely the High Temperature Test Unit (HTTU) and the High Pressure Test Unit (HPTU). The purpose of the facility is twofold namely:

- To validate the correlations that are currently used to model the relevant heat transfer and fluid flow phenomena required for the integrated simulation of the pebble bed core, via a comprehensive set of separate effects tests.
- To generate results that may be used to validate the different simulation methodologies applied in the integrated models that represent the entire pebble bed core, via a comprehensive set of integrated effects tests.

1.3.1 High Temperature Test Unit (HTTU)

The HTTU is an integrated effects test facility that represents a section of the pebble bed reactor. The HTTU pebble annulus is the same width and geometrically similar to the actual PBMR and it will be used to measure the heat transfer characteristics of the pebble bed as a whole. Some of the tests that will be conducted with the HTTU will be used to validate correlations currently employed by PBMR for the determination of the pebble-to-pebble effective conductivity, pebble-to-reflector conductivity and temperature profiles through the core for different gas flow rates. These tests include steady-state and transient experiments with nitrogen and helium under different conditions. The high temperature pebble bed core or test section forms the heart of the HTTU plant. The test section contains about 28,000 graphite spheres of similar size to those of the PBMR fuel spheres.

1.3.1.1 Background

The HTTU will contribute to both of the objectives listed above since it will be used for the following:

- Steady-state separate effects tests under near-vacuum conditions to validate the correlations used for the pebble-to-pebble effective conductivity, as well as the pebble-to-reflector effective conductivity.
- Steady-state integrated effects tests under natural convection conditions at elevated temperatures to determine the temperature profiles through the core.
- Steady-state integrated effects tests under forced convection isothermal conditions to determine the velocity profiles through the core for different flow rates.
- Steady-state integrated effects tests under forced convection conditions at elevated temperatures to determine the temperature profiles and pressure drops through the core for different flow rates.
- Transient integrated effects tests under near-vacuum conditions at elevated temperatures in order to determine the temperature profiles and the thermal energy storage characteristics of the core.

- Transient integrated effects tests under natural convection conditions at elevated temperatures in order to determine the temperature profiles and the thermal energy storage characteristics of the core.

- Transient integrated effects tests under forced convection conditions at elevated temperatures in order to determine the temperature profiles and the thermal energy storage characteristics of the core for different flow rates.

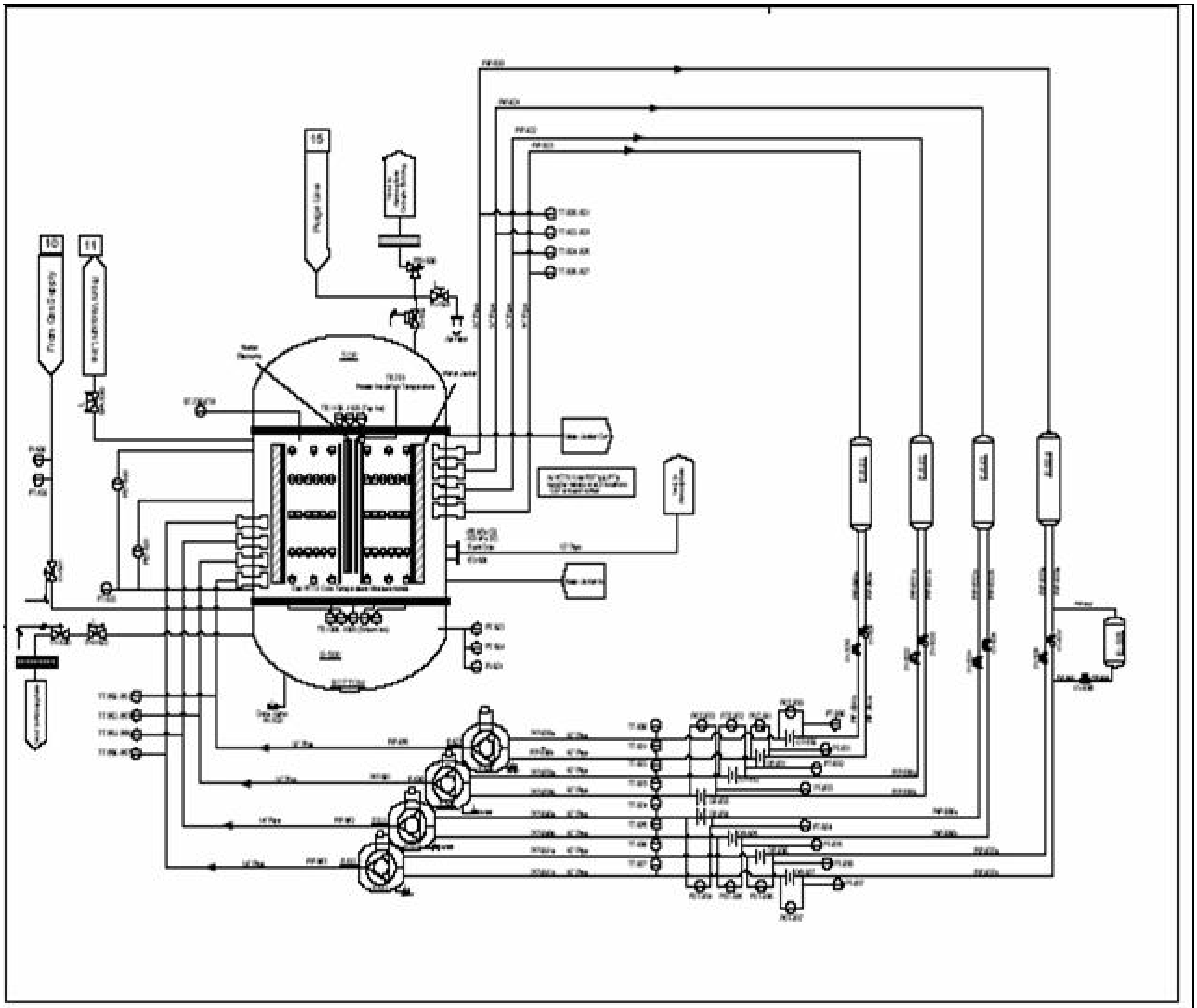


Figure 6 : High Temperature Test Unit (HTTU) process flow diagram (PFD)

Figure 7: View of the HTTU near the end of construction

Figure 8 : View of the HTTU after construction (one of four blower vessels in the foreground)

The HTTU plant consists of one main vessel section with an adjoining gas pipe network that can be configured to obtain different test results. These configurations are the Vacuum/Natural Convection-, Forced Convection- and Velocity profile measurement configuration. Figure 9 below illustrates two of the three configurations.

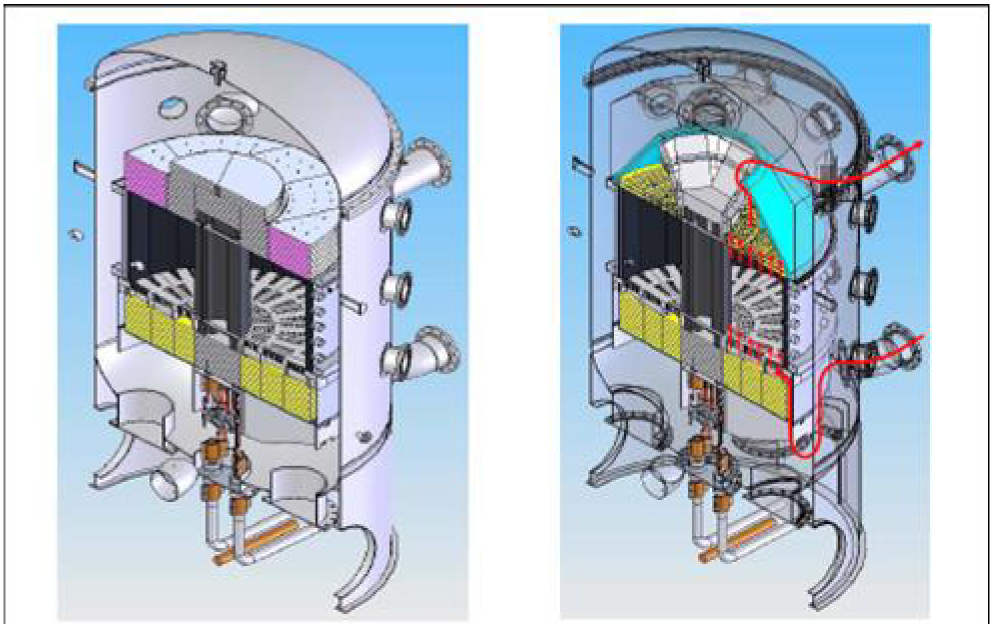


Figure 9: The HTTU in Vacuum/Natural Convection configuration (Left) and Forced Flow configuration (Right).

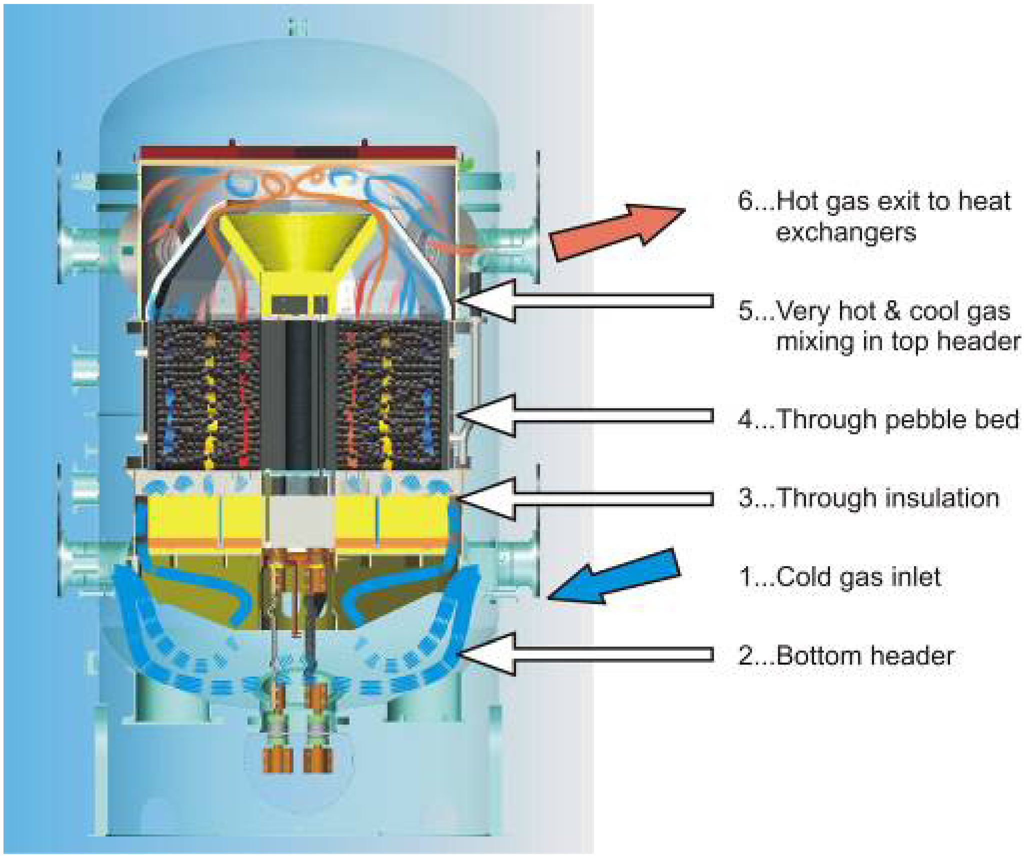


Figure 10: Gas flow path during the Forced Flow configuration

1.3.1.2 HTTU Steady-State Tests

Steady-State Tests Natural Convection High Temperature

Experiment 1: Nitrogen at 1200°C

This experiment will be a steady-state integrated effects test with Nitrogen under natural convection conditions at elevated temperatures.

The test pressure will be 100kPa with the inner wall temperature maintained at 1200°C. The inlet water temperature of the water jacket will be maintained at 25°C and the outlet 35°C. The top and bottom boundaries will be insulated.

Experiment 2: Helium at 1200°C

This experiment will be a steady-state integrated effects test with Helium under natural convection conditions at elevated temperatures.

The test pressure will be 100kPa with the inner wall temperature maintained at 1200°C. The inlet water temperature of the water jacket will be maintained at 25°C and the outlet 35°C. The top and bottom boundaries will be insulated.

Steady-State Tests Forced Convection Isothermal

Experiment 3: Nitrogen 0.5 kg/s isothermal

This experiment will be a steady-state integrated effects test with Nitrogen forced convection isothermal conditions to determine the velocity profile through the core.

The gas pressure at the inlet of the core will be maintained at 100kPa and the inlet temperature at 40°C. The flow rate will be 0.5 kg/s.

Experiment 4: Nitrogen 1 kg/s isothermal

This experiment will be a steady-state integrated effects test with Nitrogen forced convection isothermal conditions to determine the velocity profile through the core.

The gas pressure at the inlet of the core will be maintained at 100kPa and the inlet temperature at 40°C. The flow rate will be 1 kg/s.

Experiment 5: Nitrogen 2 kg/s isothermal

This experiment will be a steady-state integrated effects test with Nitrogen forced convection isothermal conditions to determine the velocity profile through the core.

The gas pressure at the inlet of the core will be maintained at 100kPa and the inlet temperature at 40°C. The flow rate will be 2 kg/s.

Experiment 6: Nitrogen 3 kg/s isothermal

This experiment will be a steady-state integrated effects test with Nitrogen forced convection isothermal conditions to determine the velocity profile through the core.

The gas pressure at the inlet of the core will be maintained at 100kPa and the inlet temperature at 40°C. The flow rate will be 3 kg/s.

Experiment 7: Nitrogen 4 kg/s isothermal

This experiment will be a steady-state integrated effects test with Nitrogen forced convection isothermal conditions to determine the velocity profile through the core.

The gas pressure at the inlet of the core will be maintained at 100kPa and the inlet temperature at 40°C. The flow rate will be 4 kg/s.

Steady-State Tests Forced Convection High Temperature

Experiment 8: Nitrogen 0.5 kg/s at 1200°C

This experiment will be a steady-state effects test with Nitrogen under forced convection conditions at elevated temperatures to determine the temperature profile and pressure drop through the core.

The gas pressure at the inlet of the core will be maintained at 100kPa and the inlet temperature at 40°C. The flow rate will be 0.5 kg/s. The inner wall temperature will be maintained at 1200°C. The inlet water temperature of the water jacket will be maintained at 25°C and the outlet temperature at 35°C.

Experiment 9: Nitrogen 1kg/s at 1200°C

This experiment will be a steady-state effects test with Nitrogen under forced convection conditions at elevated temperatures to determine the temperature profile and pressure drop through the core.

The gas pressure at the inlet of the core will be maintained at 100kPa and the inlet temperature at 40°C. The flow rate will be1 kg/s. The inner wall temperature will be maintained at 1200°C. The inlet water temperature of the water jacket will be maintained at 25°C and the outlet temperature at 35°C.

Experiment 10: Nitrogen 2 kg/s at 1200°C

This experiment will be a steady-state effects test with Nitrogen under forced convection conditions at elevated temperatures to determine the temperature profile and pressure drop through the core.

The gas pressure at the inlet of the core will be maintained at 100kPa and the inlet temperature at 40°C. The flow rate will be 2 kg/s. The inner wall temperature will be maintained at 1200°C. The inlet water temperature of the water jacket will be maintained at 25°C and the outlet temperature at 35°C.

Experiment 11: Nitrogen 3 kg/s at 1200°C

This experiment will be a steady-state effects test with Nitrogen under forced convection conditions at elevated temperatures to determine the temperature profile and pressure drop through the core.

The gas pressure at the inlet of the core will be maintained at 100kPa and the inlet temperature at 40°C. The flow rate will be 3 kg/s. The inner wall temperature will be maintained at 1200°C. The inlet water temperature of the water jacket will be maintained at 25°C and the outlet temperature at 35°C.

Experiment 12: Nitrogen 4 kg/s at 1200°C

This experiment will be a steady-state effects test with Nitrogen under forced convection conditions at elevated temperatures to determine the temperature profile and pressure drop through the core.

The gas pressure at the inlet of the core will be maintained at 100kPa and the inlet temperature at 40°C. The flow rate will be 4 kg/s. The inner wall temperature will be maintained at 1200°C. The inlet water temperature of the water jacket will be maintained at 25°C and the outlet temperature at 35°C.

1.3.1.3 HTTU Envelope

The following table indicates the test plans for the HTTU for the next two years. The current planning indicates that the tests specified for the HTTU will be completed by the end of 2009.

Table 4: HTTU Experimental Test Plan

Experiment	Pressure [kPa (abs)]	Mass Flow Rate [kg/s]	Temperature [°C]	Fluid [ ]	Completion date
Steady-state test - near vacuum - high temperature	10	0	1600	Nitrogen	Nov '09
Steady-state test – natural convection - high temperature	100	0	1200	Nitrogen	Nov '09
Steady-state Test – Forced convection – isothermal	100	0.5	40	Nitrogen	Nov '09
Steady-state Test – Forced Convection – high temperature	100	0.5	1200	Nitrogen	Nov '09
Transient Test – near vacuum – high temperature	10	0	1200 to 1600	Nitrogen	Nov '09
Transient test – natural convection – high temperature	100	0	1000 to 1600	Helium	Nov '09
Transient test – forced convection – high temperature	100	0.5	1200	Nitrogen	Nov '09

Table 5 : HTTU Envelope

Variable	Unit	Min	Max
System Pressure	kPa (abs)	10	100
System Mass Flow Rate - Nitrogen	kg/s	0	0.5
System Heater Power	kW	0	500
Heater Temperature	ºC	0	1600
Heat Exchanger Power	kW	0	157
Fluid		Helium & Nitrogen	

1.3.1.4 Proposed Modifications to HTTU

The HTTU has both helium and nitrogen inventory systems, but no control and purification of these systems. High temperatures can be reached but extensive modifications are needed to address the requirement for component testing. The HTTU can for example be used as a specialized laboratory for material testing but the current test schedule makes this only possible in 2010.

1.3.1.5 HTTU Summary

The HTTU is fully commissioned and operational. The proposed test schedule indicates that the plant will be available in 2010 for other work. The HTTU heater consists of a graphite core structure and has been designed to deliver 1600ºC helium and nitrogen that can be used as a fluid within the main heater chamber. The system can be operated under 10 kPa (abs) vacuum conditioning. A forced flow of 0.5 kg/s can be reached at a core temperature of 1200ºC. The HTTU is not an ASME accredited facility, but was designed to ASME specifications.

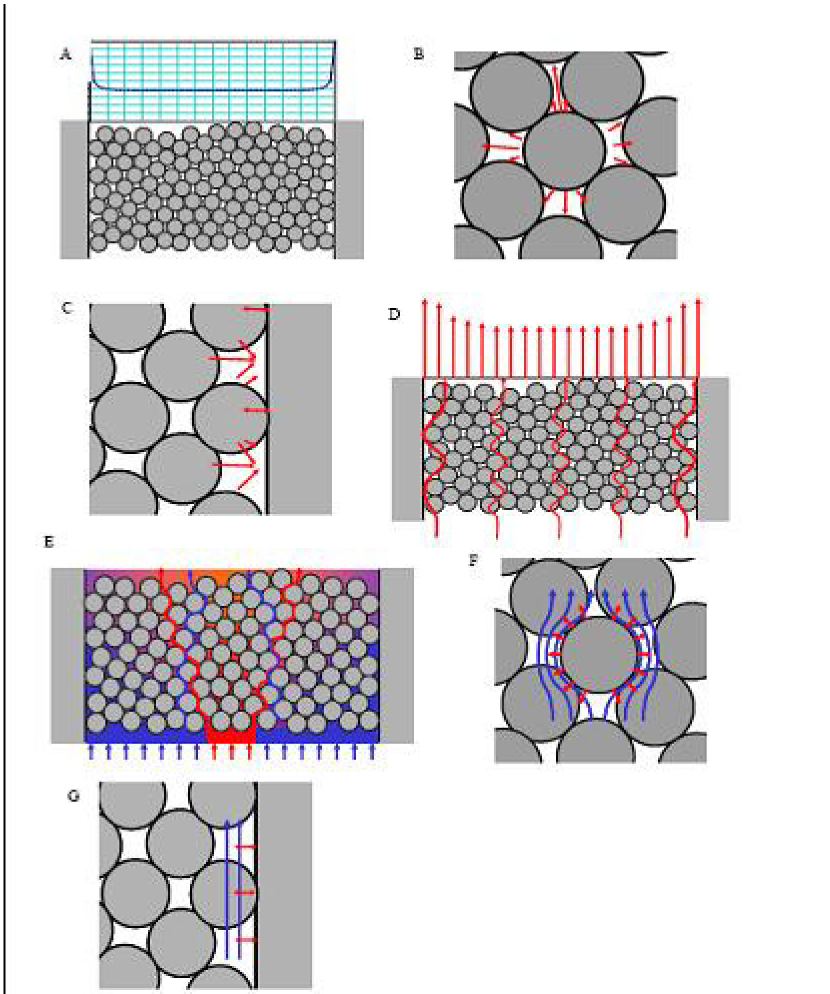
1.3.2 High Pressure Test Unit (HPTU)

The HPTU operates at a system pressure of 50 bar and a temperature of 75°C, using nitrogen as the working fluid. As mentioned earlier, the HPTU consists of a number of test sections, each evaluating different parameters and reactor phenomena.

The aim of the HPTU is to validate the correlations that are used for different heat transfer and fluid flow phenomena through comprehensive Separate Effects Tests (SET), and to validate the different simulation methodologies used in the integrated models through comprehensive Integrated Effects Tests (IET). It should be noted that the HPTU is not an exact scale model of the actual reactor core or any other reactor structures. It is merely an assortment of representative sections of a pebble bed core, suitable for conducting SET and IET.

Construction on the HPTU started in September 2005 and operation commenced a year later, in September 2006.

Due to the shape, distribution and material properties of the pebbles, various thermal fluid phenomena exist inside the reactor. The HPTU attempts to validate correlations that are used in the modeling of the following phenomena:



The thermal-fluid phenomena that the HPTU attempts to validate: A) Average porosity distribution, B) Pebble-to-pebble effective conductivity, C) Pebble-to-reflector effective conductivity, D) Velocity distribution, E) Fluid effective conductivity (braiding effect), F) Pebble-to-fluid convective heat transfer and G) Reflector-to-fluid convective heat transfer.

Figure 11: The thermal-fluid phenomena that the HPTU attempts to validate: A) Average porosity distribution, B) Pebble-to-pebble effective conductivity, C) Pebble-to-reflector effective conductivity, D) Velocity distribution, E) Fluid effective conductivity (braiding effect), F) Pebble-to-fluid convective heat transfer and G) Reflector-to-fluid convective heat transfer

1.3.2.1 Background

The HPTU will contribute to both of the objectives listed above since it will be used for the following:

- Steady-state separate effects tests to validate the correlations used for the pebble-to-fluid heat transfer coefficient at different porosities.
- Steady-state separate effects tests to validate the correlations used for the reflector surface-to-fluid heat transfer coefficient.
- Steady-state separate effects tests to determine the total pressure drop through a homogeneous packed bed at different porosities.
- Steady-state separate effects tests to determine the effective fluid heat conduction due to turbulent mixing at different porosities.
- Steady-state integrated effects tests to determine the total pressure drop through an annular packed bed.
- Steady-state integrated effects tests to determine the effective fluid heat conduction due to turbulent mixing in an annular packed bed.
- Steady-state integrated effects tests to determine the velocity profile at the outlet of the annular packed bed.
- Steady-state integrated effects tests to determine the total pressure drop through a cylindrical packed bed.
- Steady-state integrated effects tests to determine the effective fluid heat conduction due to turbulent mixing in a cylindrical packed bed.
- Steady-state integrated effects tests to determine the velocity profile at the outlet of the cylindrical packed bed.

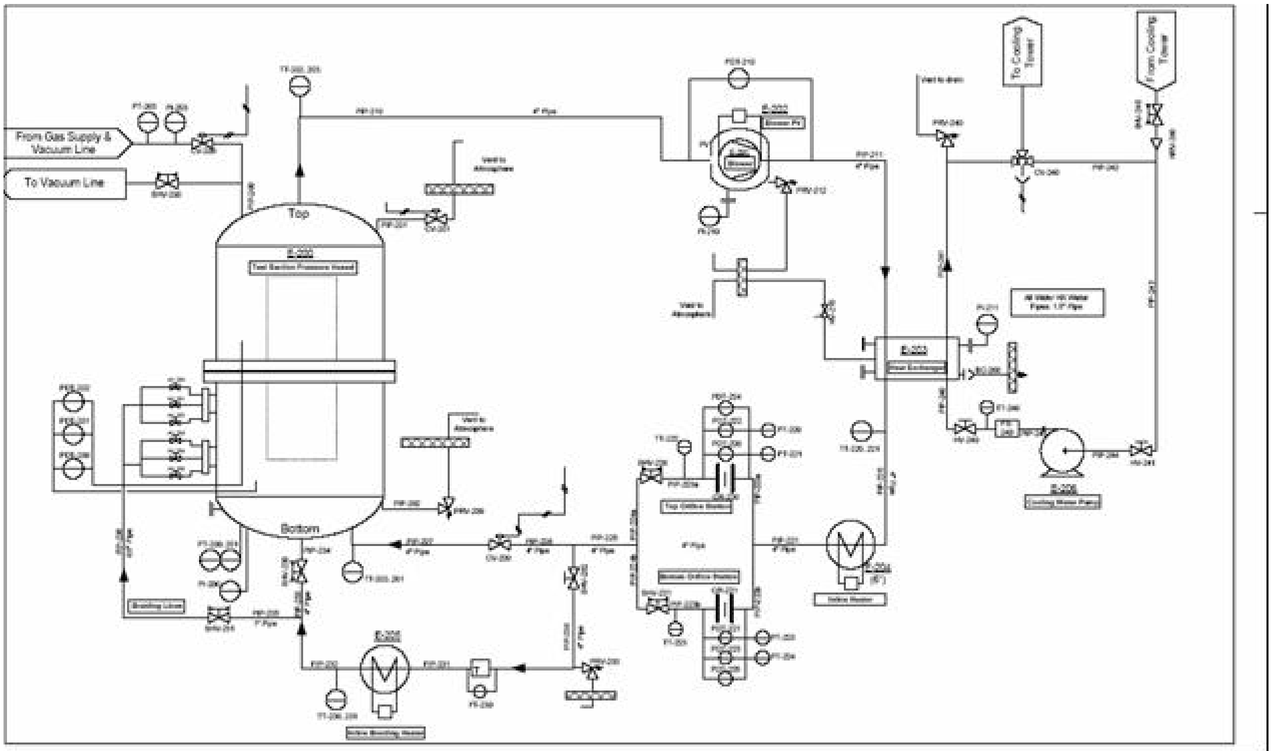


Figure 12 : HPTU PFD

Figure 13 : Photo of HPTU

1.3.2.2 HPTU Tests

Pressure Drop Test Section (PDTS)

The PDTS will be used to evaluate steady-state separate effects tests to validate the correlations used for the pressure drop at different porosities. There will be 3 different PDTSs to provide for the 3 different porosities required. The geometry of the PDTS has a square cross section with the basic dimensions of 300mm x 300mm x 720mm. This test section will consist of spheres with a diameter of 28.575mm. The pressure drop will be measured by means of an array of differential pressure transducers on the outside of the pressure vessel. The pressure drop will then be determined by means of measurements positioned at the inlet and outlet of the packed bed.

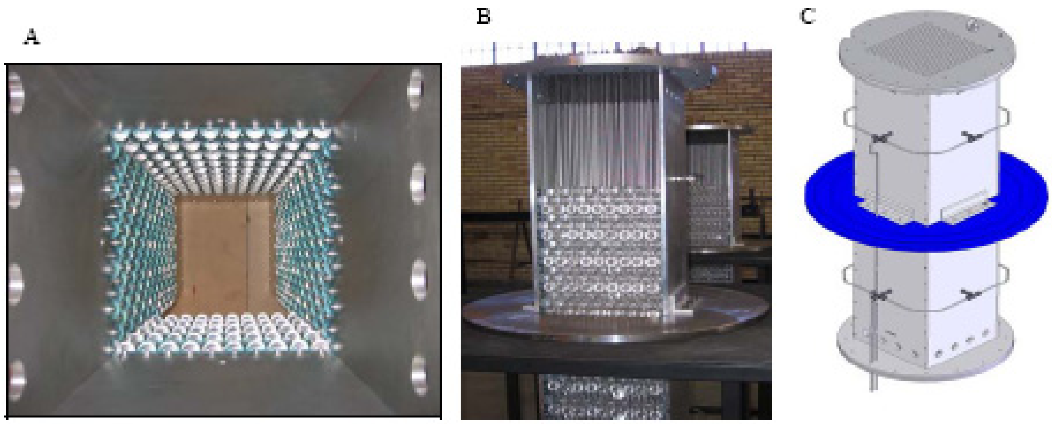


Figure 14: A) A closer look at the pebble bed, which will be used for pressure drop measurements. B) A detail look inside the test section, showing the pebbles, C) Indication of the PDTS layout.

Convection Coefficient Test Section (CCTS)

The CCTS will be used to investigate steady-state separate effects to validate the correlations used for the pebble-to-fluid heat transfer coefficient at different porosities. There will be three different CCTS inserts to provide for three different porosities. The CCTSs have a square cross sectional area of 300mm x 300mm and are 720mm long. The length of the porous bed region varies and is dictated by the different porosities.

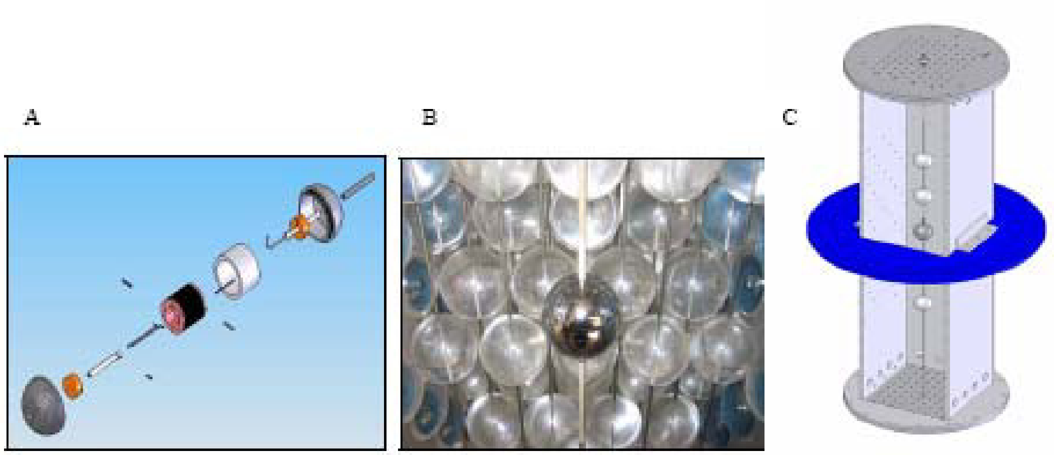


Figure 15: A) An illustration of the poisoning of the Ball Heater inside pebble bed. B) An exploded view of the Ball Heater and thermocouple, C) Indication of the CCTS layout.

Near Wall Test Section (NWTS)

The NWTS will be used to evaluate steady-state separate effects tests to validate the correlations used for the wall-to-fluid heat transfer coefficient at an average (not homogeneous) porosity. There will be one NWTS to provide for the one porosity required. The NWTS has a rectangular cross section of 300mm x 112 mm and it is 720 mm long. There will only be two rows of spheres to simulate the two walls of the packed bed. The geometry presents a bilaterally symmetric control volume with average porosity of 0.45 in the near wall region. This test section consists of 60 mm diameter spheres. The measurement requirements of the NWTS consist only of the surface temperature of the heated strip. All sides of the rectangular heated strip are isolated, except for the heated surface.

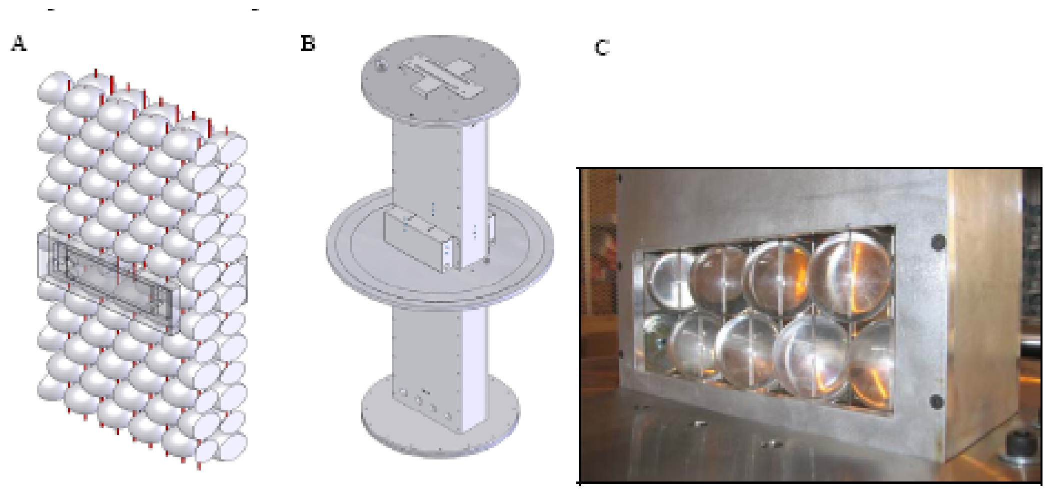


Figure 16: A) Indication of the NWTS layout, B) An indication of the location of heated strip, C) A closer view of the heated strip.

Braiding Effect Test Section (BETS)

The BETS will be used to investigate steady-state separate effects tests to validate the correlation used for the braiding effect at different porosities. There will be 3 different BETS inserts to provide the 3 different porosities. The BETS has a square cross section of 300 mm x 300 mm and is 720 mm long. This section will consist of spheres with diameters of 28.575 mm.

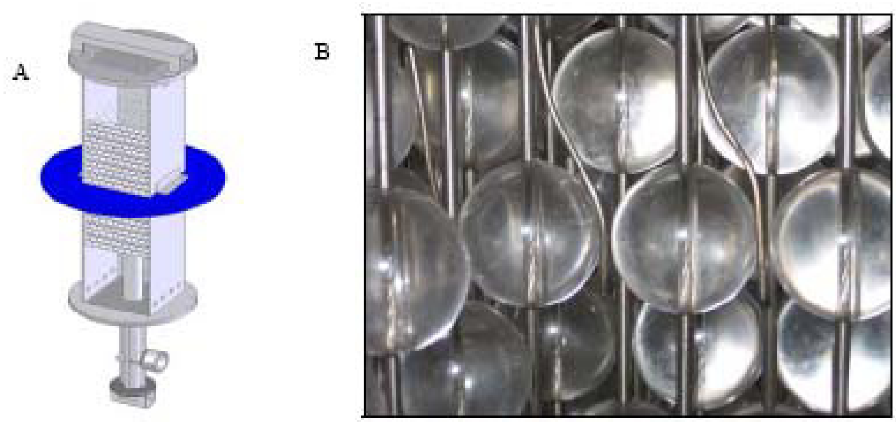


Figure 17: A) Indication of the BETS layout, B) A closer view of the test section, indicating the pebbles

The BETS will be used to measure the temperature distribution in the radial direction at two different axial positions, which will result from the diffusion of the hot gas that is injected into the test section at a specific point.

Small Annular and Small Cylindrical Packed Beds (SAPB and SCPB)

The SAPB and SCPB test sections will be used to evaluate certain integrated effects on a complete scaled model of the PBMR core. The geometry of the SAPB represents a radially scaled model of the PBMR core with a length of 30 sphere diameter, while the SCPB has the same outer diameter as the SAPB but with no central column. Both the SAPB and SCPB will make use of 6 mm diameter spheres. The total number of spheres needed is determined by the SCPB and amounts to approximately 110,000. The measurements that will be taken consist of the temperature and velocity profile at the exit of the test section as well as the pressure drop over the test section.

Figure 18: A) Indication of the BETS layout, B) A closer view of the test section, indicating the pebbles

1.3.2.3 HPTU Envelope

Table 6 : HPTU Envelope

Variable	Unit	Min	Max	Completion date
System Pressure	kPa	100	5000	Jan '08
System Mass Flow Rate	kg/s	0.01117	2.888	Jan '08
Braiding Mass Flow Rate	kg/s	0.001532	0.12480	Jan '08
System Heater Power	kW	0.03491	9.668	Jan '08
Braiding Heater Power	kW	0.127	5.481	Jan '08
Heat Exchanger Power	kW	0.04507	0.04507	Jan '08

1.3.2.4 Proposed Modifications to HPTU

Extensive modifications (localized heating and cooling) are required to reach high temperatures (T>900 ºC) and that at only 50 bar.

1.3.2.5 HPTU Summary

The HPTU is fully operational and at the end of its testing phase. The test for the PBMR will be completed at the end of Jan 2008. The plant was designed to function at a pressure of 5 MPa (50 Bar) at a temperature of 35 ºC. A maximum mass flow rate of 2.8 kg/s can be reached with the orbital blowers. The HPTU is not an ASME accredited facility, but was designed according to it. It will not be feasible to use this facility for component testing.

APPENDIX C - LITERATURE STUDY ON OTHER FACILITIES

1. INTRODUCTION

A hydrogen economy is proposed to solve the ill effects of using hydrocarbon fuels in transportation, and other so-called, stationary end-use applications where the carbon is released to the atmosphere. Some references propose a closed synthetic hydrocarbon-CO_2 cycle instead of the hydrogen-water cycle to eliminate difficulties related to the production, transport and use of hydrogen [Bossel 2003].

In the current hydrocarbon economy, the transportation of people and goods (so-called *mobile applications*) is fueled primarily by petroleum, refined into gasoline and diesel, and natural gas. However, the burning of these hydrocarbon fuels causes the emission of greenhouse gases and other pollutants. Furthermore, the supply of hydrocarbon resources in the world is limited, and the demand for hydrocarbon fuels is increasing, particularly in China, India and other developing countries.

2. NGNP PROJECT

Since 2005 South Africa has been actively involved with the pre-conceptual design of the DOE funded Next Generation Nuclear Power Plant (NGNP) Project. This project is considered to form part of the GENERATION IV initiative aimed at identifying a reactor system for producing electricity and hydrogen, which excelled at meeting the GENERATION IV goals related to safety, sustainability, proliferation resistance, physical security, and economics.

3. COMPONENT TEST FACILITY

All methods of hydrogen production, apart from the photolytic methods of synthesis, can in principle be coupled to a nuclear reactor to provide electricity and process heat. Conventional light-water reactors (LWR) can be employed for example, to deliver electricity for the low temperature electrolysis process; electricity and hydrogen production are separated effectively and could even be deployed at different locations. Different reactor types with higher coolant outlet temperatures would allow the direct utilization of the hot medium which transfers heat to a chemical process. In such cases, the H_2 production site must be in close proximity of the nuclear site. Mutual utilization of the basic reactor design for electricity and process heat generation was a fundamental requirement in the former German HTGR industrial development programs. This applied specifically to the past projects on direct gas turbine cycles (HHT), steam cycles (THTR-300, HTR-500) and the various nuclear process heat projects, PNP (Prototype nuclear process heat) and NFE (Nuclear long distance energy).

A fundamental difference between the electricity and the process heat market is the power size distribution of the energy supply system. Large plants have been favoured for dedicated electricity generation, whereas the non-electric energy market favours small and medium-sized Combined Heat and Power (CHP) plants due to the limited size of heat distribution networks and due to very high availability requirements requiring redundant, modular power supply systems. Different CHP applications clearly indicate that the power size of a 200-300 MWt modular design would well fit the needs of industrial heat consumers whereas the 600 MWt GT-MHR already represents an upper limit. A modular arrangement (2-6 units) will be necessary for redundancy, reliability and reserve capacity, which again requires a smaller power size per module. However, smaller power size allows for simplicity and robustness by higher safety margins even at higher operational temperatures if necessary at all.

Nuclear reactor and hydrogen plant will be physically separated from each other by employing an intermediate heat exchanger (IHX) between the primary helium circuit of the reactor and the steam reformer/steam generator system. All applications with IHX require helium outlet temperatures from the reactor to be 900°C or higher to realize a compact IHX component with a larger temperature difference across the IHX. The design of a plant with 850°C coolant outlet temperature and IHX is also feasible, but at the expense of a much larger heat transfer surface.

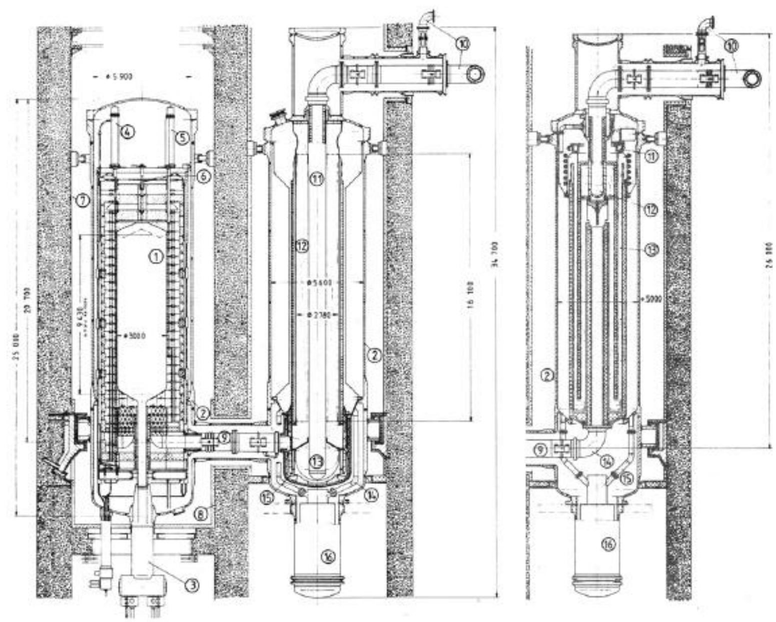
As part of the ongoing NGNP work MTECH is tasked to perform a first order cost estimation of a component loop test facility. Based on the specifications provided by INEL of the various participants the loop facility at hand is conceptually designed for purposes of the costing. Due to past experience of especially the Germans in the field of high temperature reactor technology it is deemed sensible to summarize the component and loop test facilities operated in Germany. Facilities of note constructed and operated elsewhere are also listed in what follows.

4. LIST OF COMPONENT AND LOOP TEST FACILITIES

4.1 DEVELOPMENT AND TESTING OF AN IHX IN GERMANY

In Germany the concept was investigated of a combination of the HTR-Modul with an IHX. In Figure 1 the layout is represented of the German reference design for a process heat HTR-Modul in a side by side arrangement of nuclear reactor and IHX vessel for each modular unit. The thermal power rating of the nuclear reactor and the IHX are 170 MW. The power limit is determined by the requirement of inherent decay heat removal capability in a depressurized loss of forced cooling (DLOFC) event. If larger thermal powers were needed, an annular core would be required. The limit in that case is caused by the dimensions and type of reactor pressure vessel. Details of the IHX with helical tube bundle are shown in Figure 2.

The employment of an IHX was also suggested within the PNP project with regard to the steam gasification of hard coal, for which the main characteristic data are also given in the table for comparison.



(a) (b) (c)

Figure 1: Arrangement of HTR-Module (a) with Helix-IHX (b) or U-tube-IHX (c) [IA 1983]

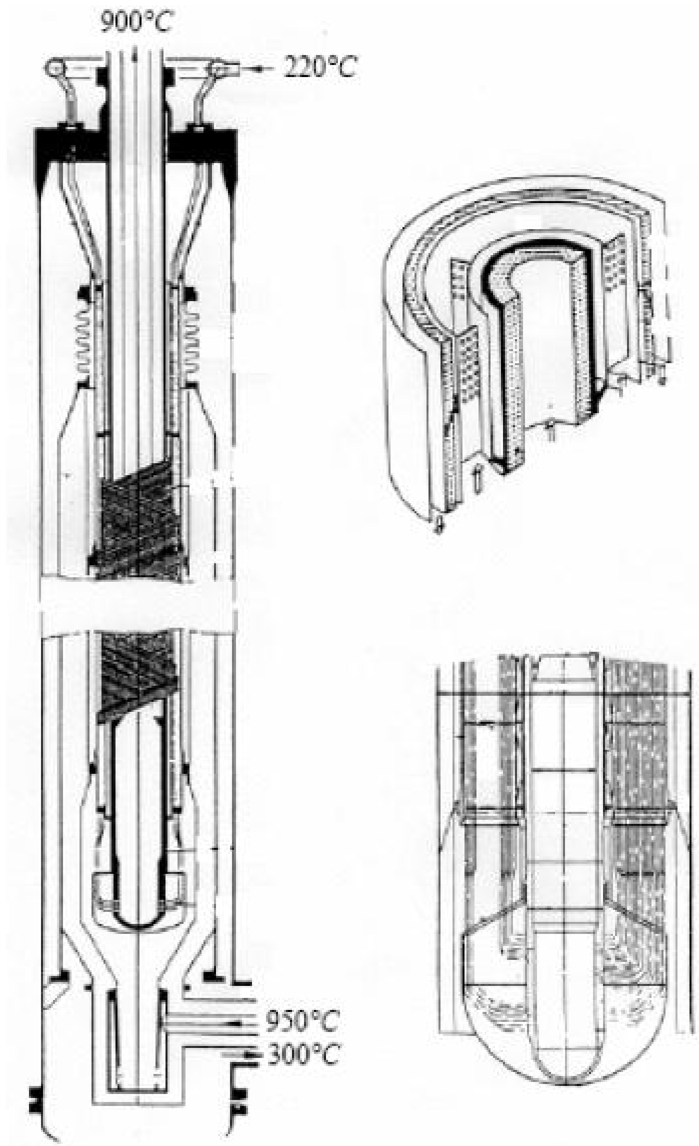


Figure 2: Intermediate heat exchanger for nuclear applications [Kugeler 2005] - helical tube bundle (left), details of hot gas collector tube and support structures (right).

The Helical coil IHX (see Figure 2) consists of a bundle of helical tubes arranged around a central return gas duct for the hot secondary helium. The support system for the tubes consists of support cylinders with star-shaped, welded-on support plates designed to carry the weight of the bundle. A segmental design of the support structure limits the relative axial expansion caused by the operation temperature. In the upper cold area, the mechanical loads are carried by the vessel cover. This ensures access to the secondary system for in-service inspection and repairs without the necessity to open the primary circuit.

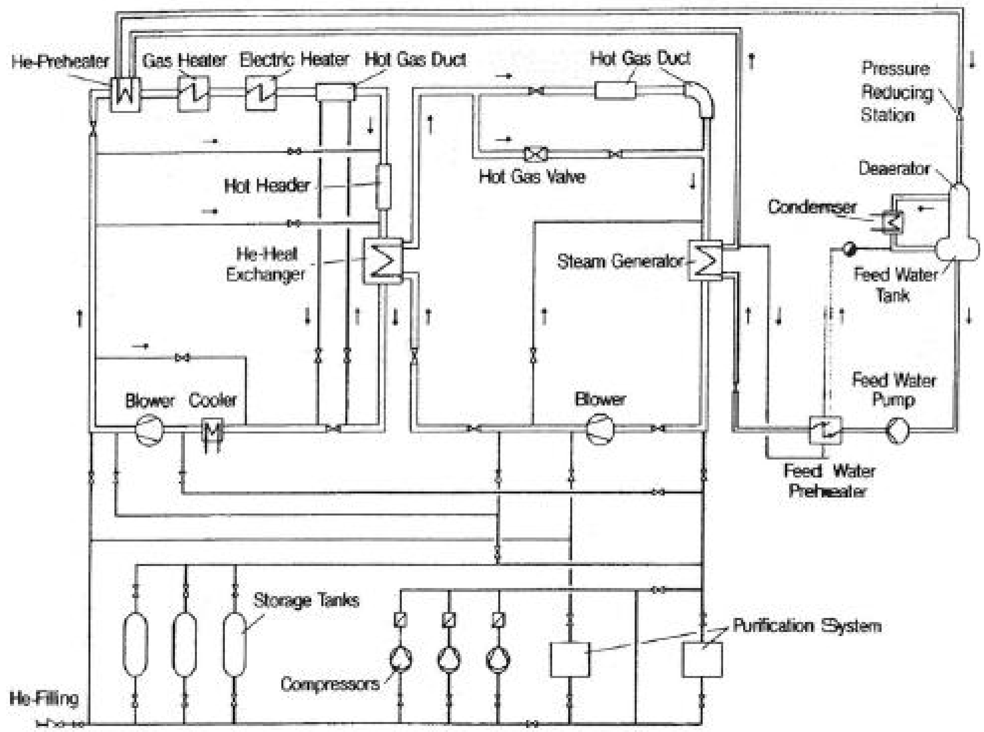


Figure 3: Flow sheet of 10 MW KVK facility for testing nuclear process heat components

A facility for large component testing (KVK) was constructed and successfully operated by INTERATOM as part of the PNP project [Harth 1990]. In a heating system consisting of a heater with steam, a natural gas burner, and an electrical heater with a total thermal power of 10 MW, helium was heated up to 950°C at 4.0 MPa (Figure 3 and Figure 4). This plant also allowed for testing of the hot gas ducts with large diameter, of a steam generator, valves for hot helium and other components like hot headers or auxiliary plants, such as gas purification.

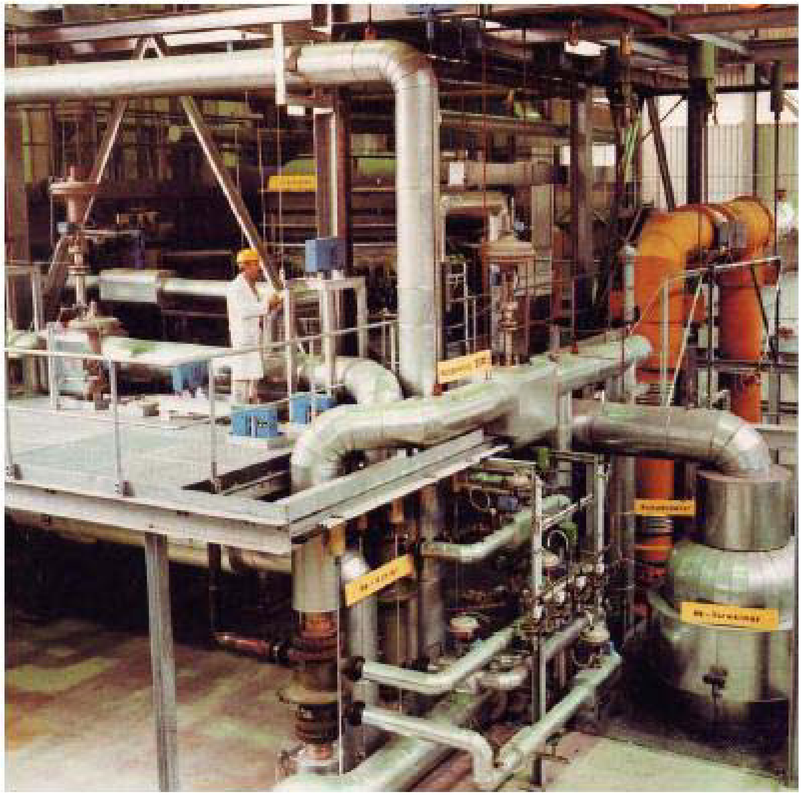


Figure 4: 10 MW KVK facility for testing nuclear process heat components.

Two IHX components were constructed and tested in the KVK loop, one with a helical tube bundle and another one with U-tubes. In Figure 5 the schematics are shown of both components. In Figure 6 and Figure 7 the IHX components are depicted still under construction.

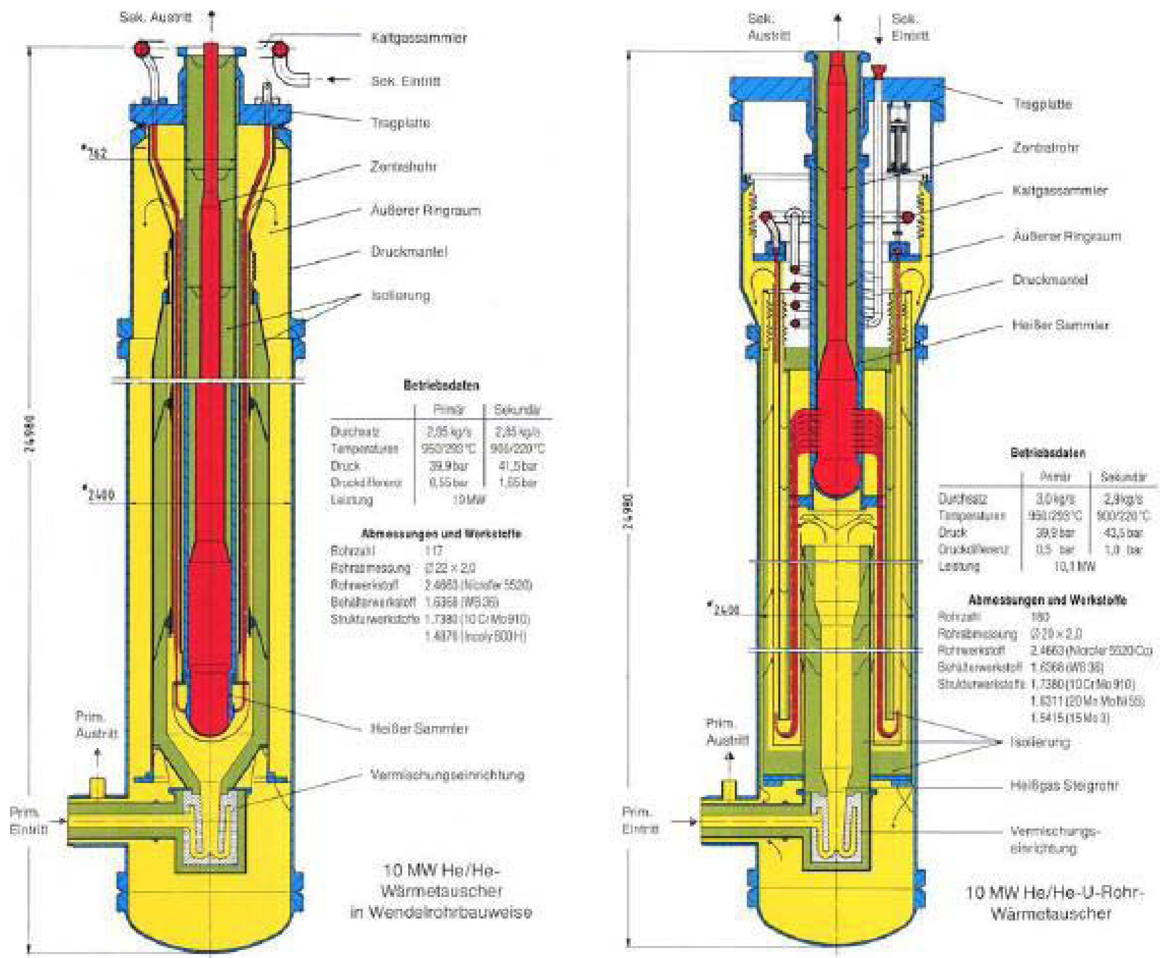


Figure 5: Two IHX components tested in KVK - Helical tube bundle by Steinmüller company (left), U-tube bundle by Balcke-Dürr company (right)

Figure 6: IHX component with helical tube bundle tested in KVK (Steinmüller)

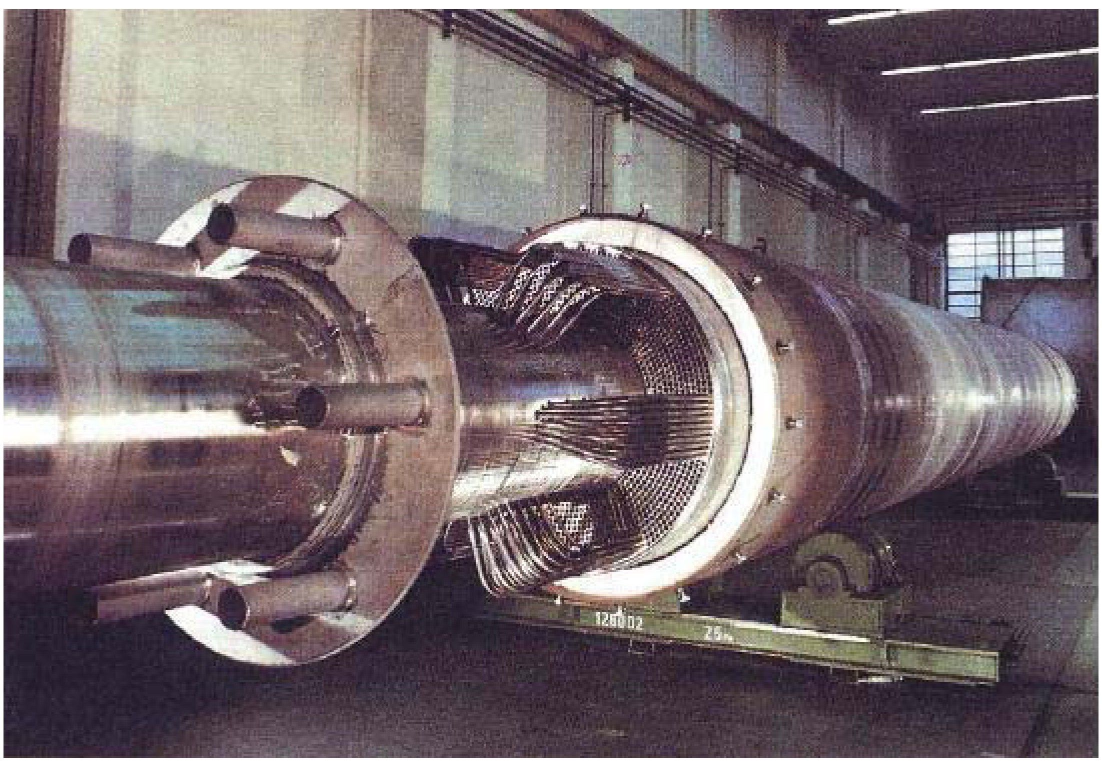


Figure 7: INX Component with U-tube bundle tested in KVK (Balcke-Dűrr)

4.2 TESTING OF THE JAPANESE IHX IN THE HTTR

The IHX used in the HTTR is a vertical, helically coiled counter flow type heat exchanger as shown in Figure 8. The primary helium enters the IHX through the inner pipe of the primary concentric hot gas duct attached to the bottom of the IHX. It flows upwards outside the tubes transferring the nuclear heat of 10 MW 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 hot header.

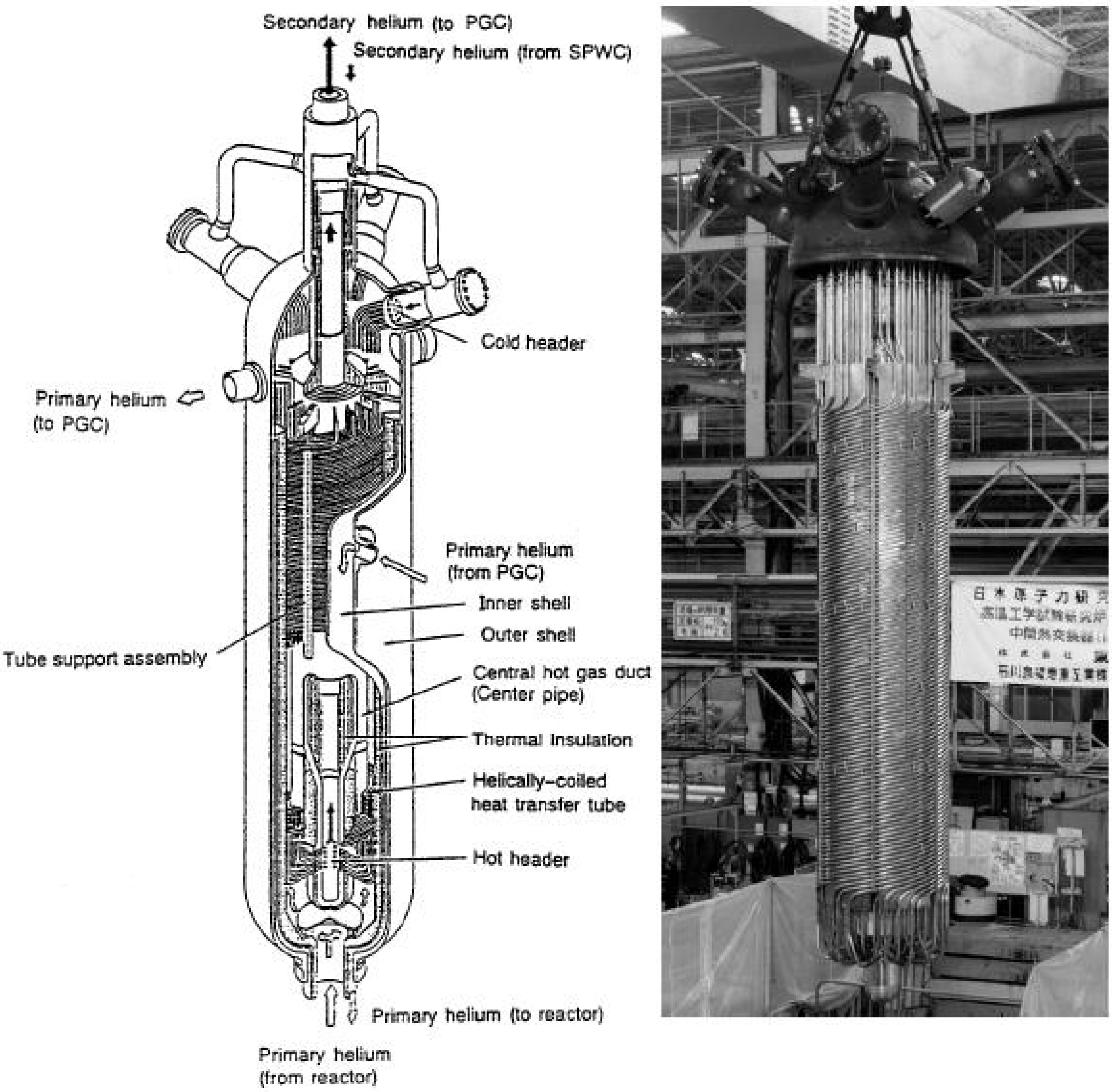


Figure 8: Schematic and photograph of the He-He intermediate heat exchanger in the HTTR.

A double-walled shell with a thermal insulation attached on the inside surface of the inner shell provides reliable separation of heat resisting and pressure retaining functions. Cold helium flowing through the annulus brings uniform temperature distribution throughout the outer shell, which has a pressure-retaining function.

Insulation inside and outside the central hot gas pipe keeps the heat transfer low to obtain a high efficiency.

4.3 IHX DESIGN CONCEPT FOR THE US H2-MHR

In the United States, the reference design for a next generation HTGR is the 600 MWt Modular Helium Reactor (MHR). For the purpose of hydrogen generation, the concept of an H2-MHR has been developed which is to be coupled to a H2 production technology based on either S-I thermo-chemical cycle or high temperature electrolysis. The intermediate heat exchanger for this facility is based on a design of so-called "Printed Circuit Heat Exchangers", PCHE, developed by the Heatric company (see Figure 9) [NERI 2003, HEATRIC].

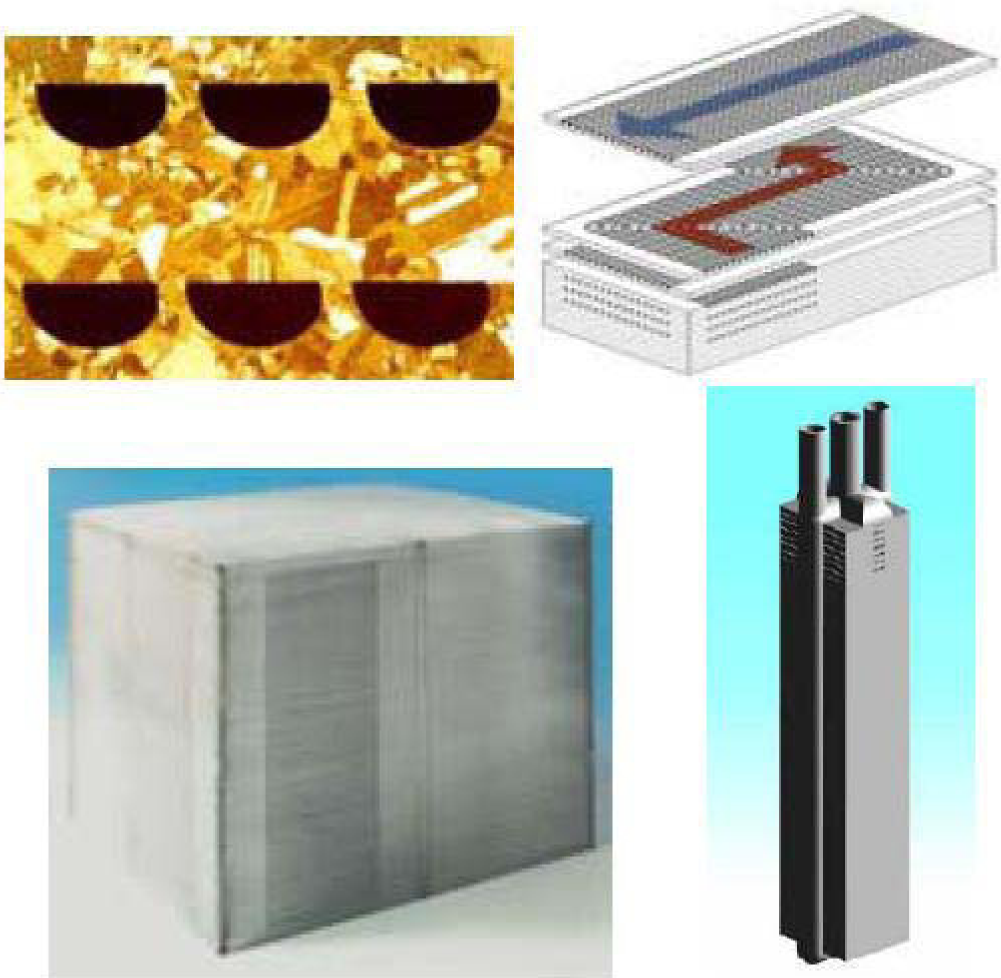


Figure 9: Printed Circuit Heat Exchanger, PCHE (source: HEATRIC) A heat exchanger module is composed of metal plate layers containing alternately coolant channels for the primary and for the secondary fluid flowing (e.g.) counter to each other (top right).

The flow channels with a semi-circular profile (top left) are chemically etched into the plates using a technique similar to that for printing electrical circuits. This manufacturing technique makes complex streams possible. The metal plates are stacked (top right) and then diffusion-bonded, where the metal surfaces are pressed together promoting a grain growth between the plates, thus becoming a solid all-metal core (bottom left). PCHE designs have been developed which are highly compact, highly robust (bottom right) and which have high thermal efficiencies, allowing pressures of 50 MPa and temperatures of 900°C.

4.4 GERMAN CONCEPTS OF HELIUM-HEATED STEAM REFORMING

In comparison to a conventional steam reformer, the employment of a nuclear steam reformer requires certain changes, since operational conditions of a nuclear reactor are not that flexible as a fossil-fueled furnace. Also safety requirements are much more stringent than for a fossil-fuelled system. It is therefore desired to achieve highest effectiveness in utilizing the nuclear process heat in the whole production process system. A large H2 production rate is achieved, if the process feed gas rate and the conversion rate are high. The feed gas rate depends on the amount of heat input into process gas and the temperature of process gas. The conversion rate depends on temperature and pressure of the process gas.

A principle flow sheet of an HTGR with steam reformer, where all heat for the reforming process, the steam production, gas purification, and gas compression can be gained from the helium circuit, is shown in Figure 10. The stages of gas purification include the shift conversion, CO_2 scrubber, H_2 separation, and a methanation reaction to remove traces of carbon oxides from the process gas. The typical temperature profiles along a splitting tube are shown in Figure 11.

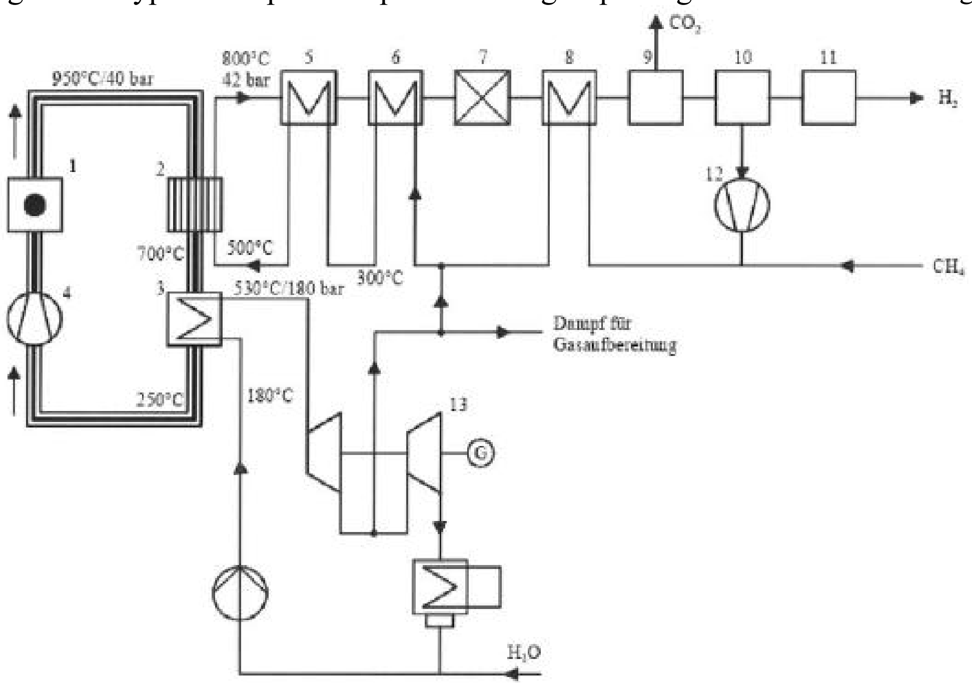


Figure 10: Principal flow sheet of HTGR with SR [Kugeler 2005] Legend: 1 - HTGR, 2 - steam reformer, 3 - steam generator, 4 - He blower, 5 - preheater gas, 6 - preheater gas, 7 - shift conversion, 8 - CH4 preheater, 9 - CO2 washer, 10 - H2/CH4 separation, 11 - me

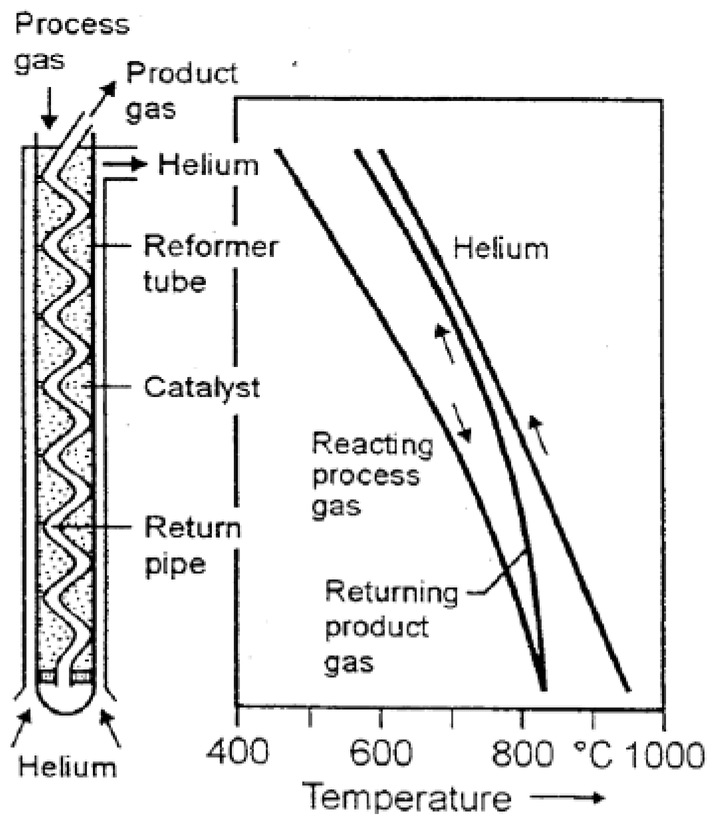


Figure 11: T-diagram for use of heat in HTGR with SR [Kugeler 2005].

Nuclear steam reforming of methane was the subject of extensive R&D activities in Germany in the 1970-1980s. Within the NFE (Nuclear Long-Distance Energy Transportation) project, large test facilities were constructed and successfully operated at FZJ to study the steam reforming process and also the reverse process of methanation under nuclear conditions.

Steam reforming was investigated in the EVA single splitting tube test facility, later in EVA-II [Verfondern 2007] representing bundles of reformer tubes. The latter used an electrical heater with a power of 10 MW to heat up helium gas to a temperature of 950°C at 4.0 MPa (see Figure 12, top). In the connected steam reformer, the heat between 950°C and 650°C was used to run the steam reforming process. In the connected steam generator (helical tubes, power 4 MW), the helium heat was used up to 350°C.

Via a helium circulator, the cold helium was routed back to the electrical heater. The circuit was operated under nuclear conditions at a lower power level, but with a full-scale SR component. Also the process gas handling system was the same as in a nuclear plant.

In a methanation plant, ADAM, the product gas was reconverted to methane and steam, thus completing a closed cycle without any CO2 emissions (see Figure 12, bottom). With regard to the power input of 10 MWe, the heat release rate achieved in the ADAM plant was 5.3 MWt. The so-called ADAM & EVA [Verfondern 2007] system represents a long-distance chemical heat transportation system based on hydrogen as the energy carrier.

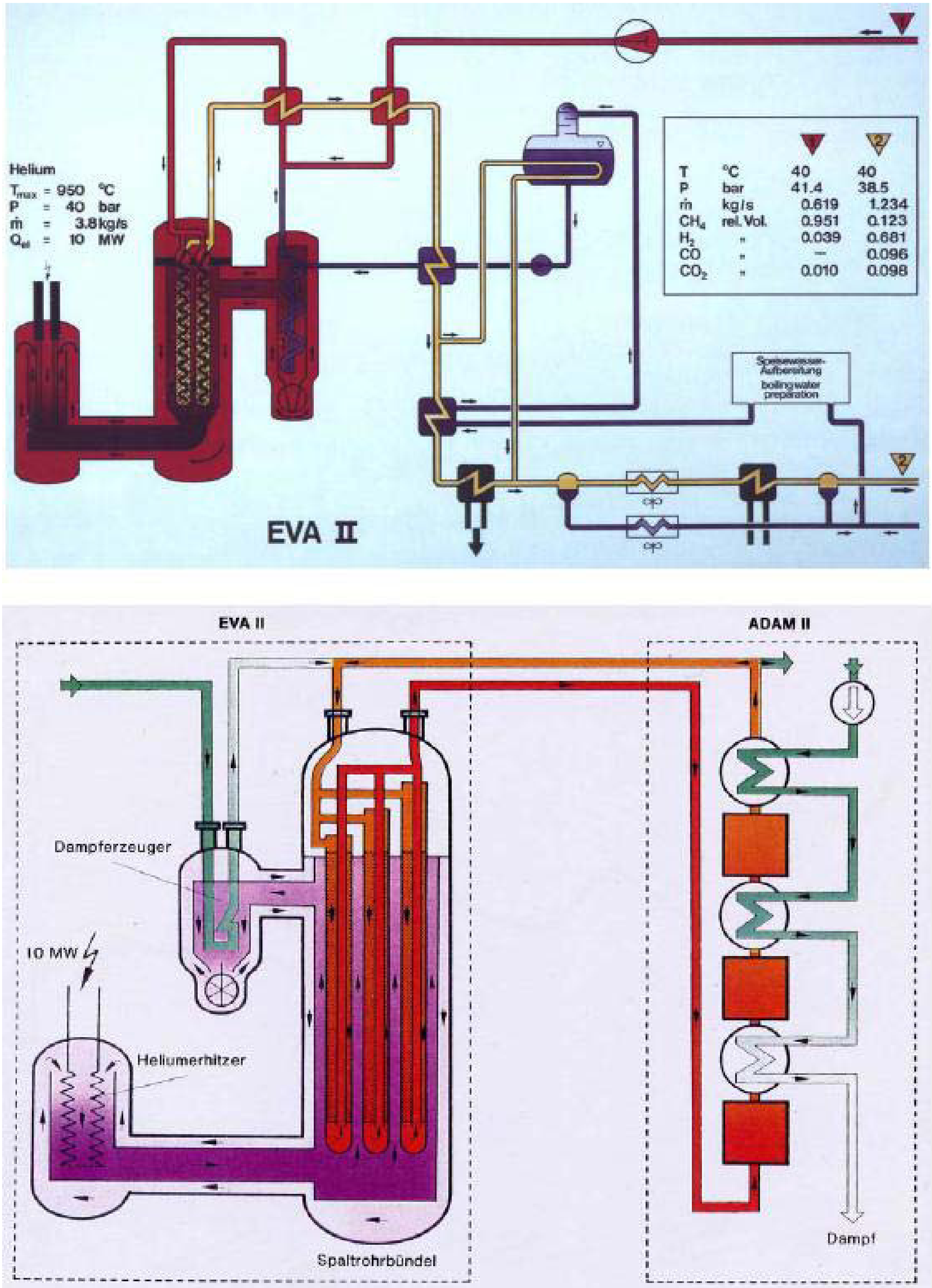
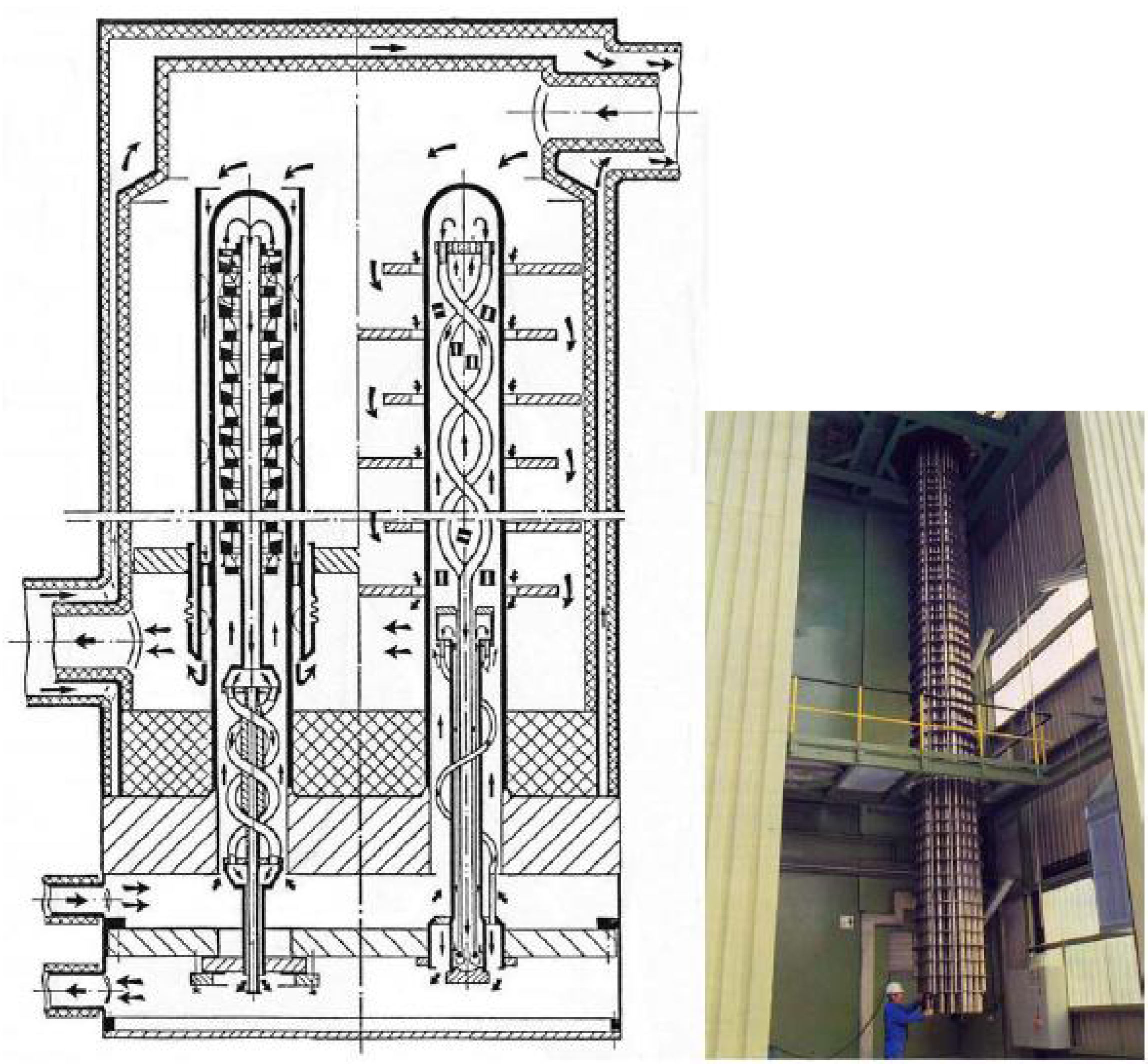


Figure 12: Flow sheet of steam reforming test facility EVA-II (top) and of combined test facilities EVA-II and ADAM-II (bottom) (source: FZJ).

Two reformer bundles have been tested in the EVA-II facility: a bundle with guiding tubes (annulus design) for each reformer tube (5 MW, 18 tubes) and a bundle with baffle structures (disks and doughnuts) on the helium side (6 MW, 30 tubes). The tubes and catalytic system were 1:1 scale compared to components planned for nuclear applications. Also the loads imposed on the supporting structures were characteristic to the nuclear case. Both have operated without any difficulties for more than 6000 h.

Figure 13 shows the component with guiding tubes tested in EVA-II. Both designs of a steam reformer bundle are shown in Figure 14. The specific data of reformer tubes investigated were very similar to the respective design for nuclear applications.



(a) (b)

Figure 13: Steam reformer bundles tested in EVA-II (source: FZJ). (a) Schematic of annulus (left), baffle design (right). (b) Photo of baffle design steam reformer bundle.

Figure 14: Steam reformer bundle of baffle design (top) and annulus design (bottom)

4.5 EVO AND HHV

Oberhausen II [IAEA 1984], operated by the German utility EVO (Energie Versorgung Oberhausen AG), is a 50 MW(e) direct-cycle Helium turbine plant (Figure 15). The power source is a gas burner rather than a nuclear reactor core, but the power conversion system resembles those of the GFR (Gas-cooled Fast Reactor) and other high-temperature reactor concepts. *Oberhausen II* was operated for more than 25 000 hours between 1974 and 1988. Design specifications, drawings and experimental data have been obtained through the European HTR-E project, offering a unique opportunity to validate codes on a large-scale Brayton cycle. Available measurements of temperature, pressure and mass flow rate throughout the circuit have allowed a very comprehensive thermohydraulic description of the plant, in steady-state conditions for design data and operating data as well as during transients.

The HHV has an electrically-driven turbo machinery consisting of a 2-stage turbine and an 8-stage compressor on a single-shaft arrangement with a synchronous rotational speed of 3,000 rpm. Figure 16 shows a picture of the HHV turbine. The compressor requires 90 MW power, the turbine power produces about 46 MW, and the electric motor supplies 45 MW. The mass flow rate is about 200 kg/s.

During the initial operation, oil ingress and excessive helium leakage occurred. After the problems were corrected, the HHV [IAEA 1984] test plant was successfully operated for about 1,100 hours, and the measured results showed that the helium gas turbine had a higher efficiency than the design value. They found that creep and fatigue crack growth at high temperature with impurities such as carbon in the helium coolant comprises the main mechanism limiting the lifetime of the turbine blades and disks. Also, it was estimated that the lifetimes of uncooled turbine components are around 50,000-60,000 hours and that the maximum temperature with uncooled metallic blades and disks is 850°C.

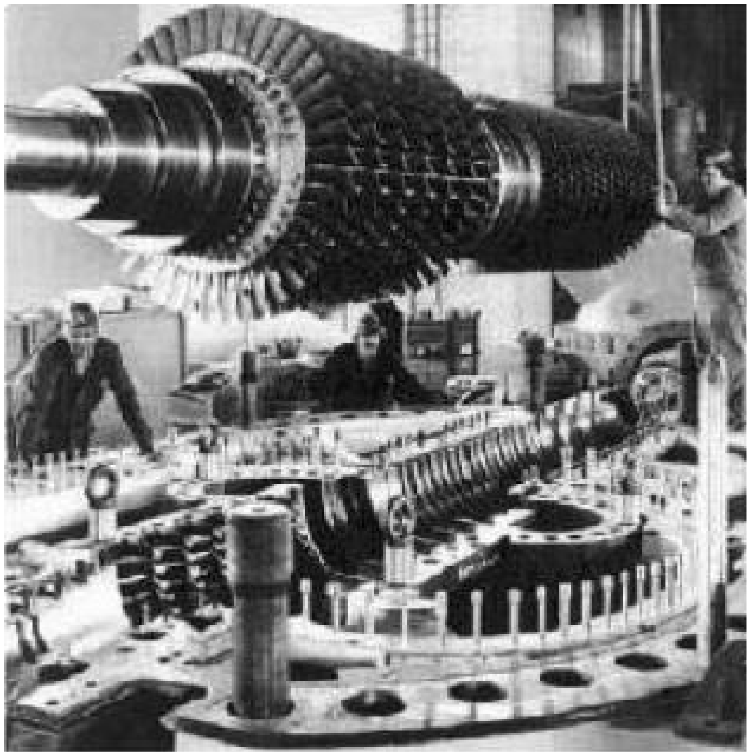


Figure 15: High-pressure Turbine Rotor from EVO in Germany.

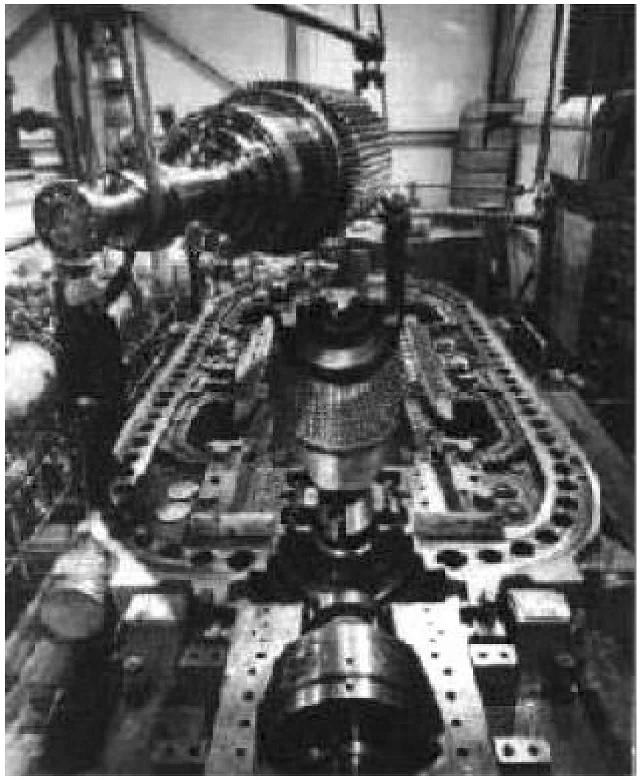


Figure 16: Rotor from HHV in Germany

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APPENDIX D CONCEPT 1 DETAILS

1.1 TEST CONFIGURATIONS

In order to provide a recommendation with regards to facility enveloping sizes, a number of different test configurations were imposed on Concept 1. These test configurations are summarized in Table 1, and were each evaluated in terms of energy balances. A complete summary of these energy balances, together with general considerations per test configuration can be found in at the end of this appendix. The “TEST#” column in Table 1 corresponds with the “DOCUMENT NUMBER” on the energy balance sheet.

Table 1: Summary of Test Configurations in Concept 1 as Dictated by the DDNs

Test #	Main Test Configuration	Sub Test	TDL #
IHX-W_1	**IHX Performance verification tests:** WEC Core A • Test core size of 1.34 MW • Prescribed mass flow • Defined inlet and outlet temperatures	Steady state	TDL 1
IHX-W_2	**IHX Performance verification tests:** WEC Core B • Test core size of 2 MW • Prescribed mass flow • Defined inlet and outlet temperatures	Steady state	TDL 1
IHX-W_3	**IHX Performance verification tests:** WEC Core A • No heat transfer to secondary loop • Primary side to accommodate high temperature in recuperator • Resulting in large duty recuperator	Loss of secondary side pressure & flow	TDL 1
IHX-W_4	**IHX Performance verification tests:** WEC Core B • No heat transfer to secondary loop • Primary side to accommodate high temperature in recuperator • Resulting in large duty recuperator	Loss of secondary side pressure & flow	TDL 1
IHX-G_1	**IHX Performance verification tests:** GA (Maximum test core size) • Determining possible test core size (small) from known conditions • Mass flow (same as for WEC) • Test core temperatures from PCDR • Resulting test core: 2.14 MW • Test core size to evaluated for feasibility • Large duty on recuperator	Steady state	TDL 1
IHX-G_2	**IHX Performance verification tests:** GA (Maximum qualification core size) • Determining possible qualification core size (large) from known conditions	Steady state	CQL

Test #	Main Test Configuration	Sub Test	TDL #
	• Mass flow (High value per TDL) • Qualification core temperatures from PCDR • Resulting qualification core: ~10 MW • Qualification core size to evaluated for feasibility		
IHX-A_1	**IHX Performance verification tests:** AREVA (Maximum test core size) • Determining possible test core size (small) from known conditions. • Secondary side to be tested with He-N_2. Calculation based on He only. • Mass flow (same as for WEC) • Test core temperatures from PCDR • Resulting test core: ~2.45 MW • Test core size to be evaluated for feasibility	Steady state	TDL 2
IHX-A_2	**IHX Performance verification tests:** AREVA (Maximum qualification core size) • Use all three TDL mass flow & duty capabilities • Three TDLs determine maximum representative core size which can be tested • Resulting test core: ~11 MW • Maximum required Recuperator size: : ~7.8 MW	Steady state	CQL
MIX-W_1	**Mixing chamber performance verification:** WEC • Prescribed Mixing Chamber test temperatures • Prescribed mass flow Minimum heater flow rate	Steady state	TDL 1
DIV-W_1	**High temperature ducts & insulation performance verification test:** WEC (small scale) • Prescribed test temperature: 950°C • Determine maximum heater outlet temperature • TDL to accommodate high temperature in recuperator	Steady state	TDL 3
DIV-W_2	**High temperature ducts & insulation performance verification test:** WEC (large scale) • Use all three TDL mass flow & duty capabilities • Three TDLs determine maximum representative mass flow and duty available Maximum return header temperature	Steady state	CQL
SG-W_1	**Steam generator performance verification test:** WEC	Steady state	CQL

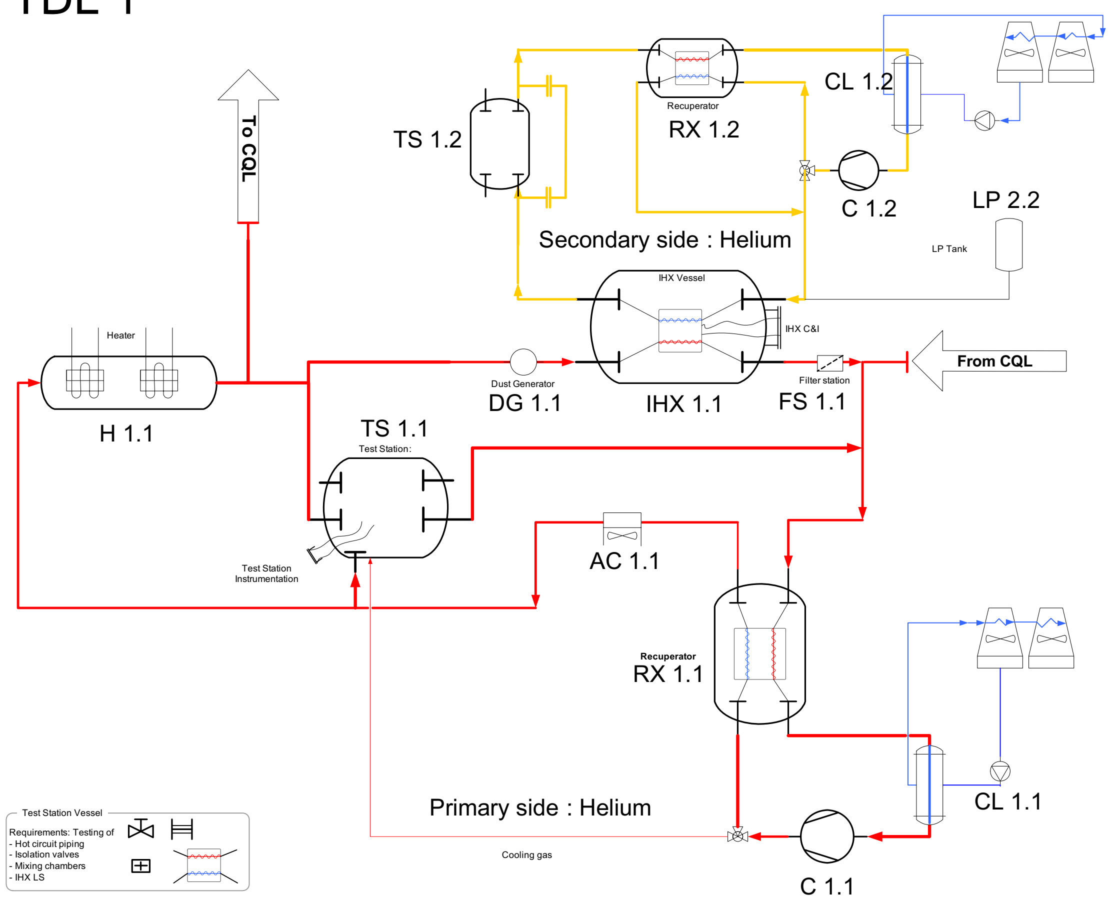
Test #	Main Test Configuration	Sub Test	TDL #
CIR-W	**Circulator performance:** WEC • Circulator requirements from WEC • Determine maximum flow rate in loop • Determine pipe size & flow velocity	Steady state	Circulator loop
CIR-G	**Circulator performance:** GA • Circulator requirements from GA • Determine maximum temperature in loop • Determine maximum cooler temperature • Determine minimum operating envelope for mass flow and heat duty of cooler • Determine loop materials & insulation requirements	Steady state	Circulator loop
CIR-A	**Circulator performance:** AREVA • Circulator requirements from WEC • Determine maximum flow rate in loop • Determine pipe size & flow velocity	Steady state	Circulator loop

The enveloping values for each TDL will be presented in the following sections from these test configurations and the energy balances.

1.2 TECHNOLOGY DEVELOPMENT LOOP 1

This loop consists of both a primary and a secondary loop, and its main sizing requirements are based on the IHX test core requirements as from the Westinghouse consortium. Both the primary and secondary loops are sized with only helium. In addition to IHX testing, this small loop also provides for testing of various components in dedicated fully instrumented test vessels in both the primary and secondary loop for temperatures up to 950°C. It is also envisaged that TDL1 will provide connection flanges for future testing of varying secondary loop contents such as liquid salt configurations for hydrogen production. This capability is provided in the form of extra connection points to the primary circuit test vessel. Additional capabilities of this loop also include testing of mixing chambers, by means of additional piping to the test station vessel in the primary circuit.

TDL 1



1.2.1 Technology Development Loop 1 – Primary Side

The primary side of TDL 1 consists of a heat source (H1.1), connected in such a way to either provide the hot helium to a test station vessel (TS1.1) or the dedicated IHX testing vessels. It is anticipated that the line to the IHX test vessel (IHX1.1) will have some kind of dust generator (DG1.1) for performance testing under controlled impurities levels followed by a filtration unit (FS1.1) after the IHX. From here on the hot helium is recuperated (RX1.1) in order to provide a more energy efficient configuration. At the outlet of the recuperator, the gas is cooled (CL1.1) by an appropriate cooler (depending in the temperature) to a conservative low temperature at the circulator (C1.1) inlet. The recuperator outlet is again connected to the heater inlet, while an additional line to the test station vessel is provided for mixing chamber testing. The secondary side is connected via the IHX test core inside the IHX testing vessel. Figure 1 illustrates this layout while the enveloping values are displayed in Table 2.

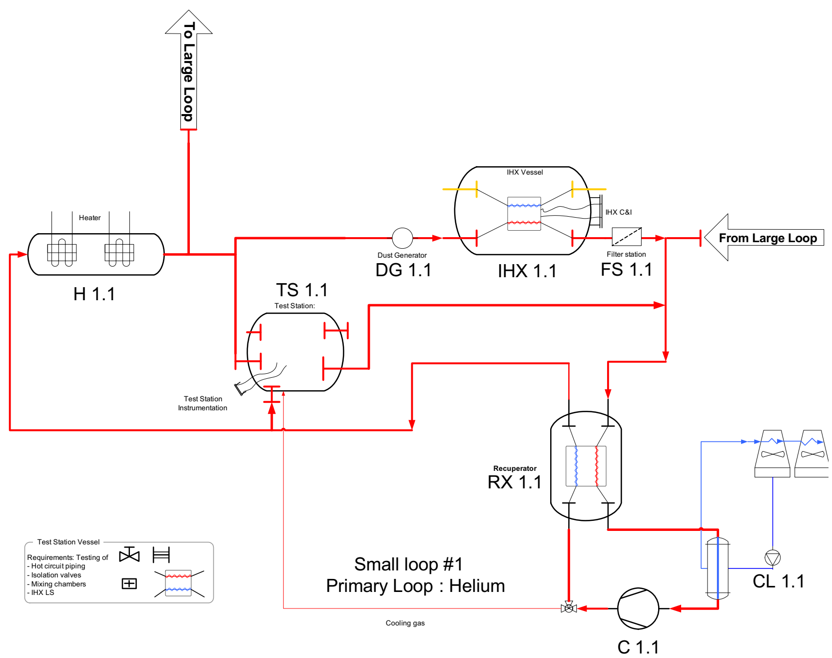


Figure 1: Technology Development Loop 1: Primary Side

Table 2: Enveloping Values of the Primary Side of Technology Development Loop 1

TDL 1 – Primary side							
No.	**Components**	**Power [MW]**	**Mass flow rate [kg/s] - MAX**	**T_in [°C]**	**T_out [°C]**	**Pressure**	**Fluid**
C 1.1	Circulator (ΔP: 500 kPa @ 5 MPa)	0.2 [max]	2	80 [min]	-	5 – 9 MPa	Pure Helium
RX 1.1	Recuperator (Hot side)	6.3 [max]	1.75	950 [max]	260 [max]		
RX 1.1	Recuperator (Cold side)		1.75	~ 85 [max]	776 [max]		
H 1.1	Heater	4.0	1.75	776 [max]	950 [max]		
TS 1.1	Vessel - Test Station	N/A	1.75	950 [min]	950 [max]		
DG 1.1	Dust Generator	N/A	1.15	760	950		
IHX 1.1	Heat exchanger Vessel (primary)	N/A	1.15	950 [max]	950 [max]		
CL 1.1	Cooler	1.6	1.75	260 [max]	80 [nom]		
FS 1.1	Filtration station	N/A	1.15	950 [max]			
PD 1.1	Pipe & Ducting	N/A	1.75	950 [max]			

1.2.2 Technology Development Loop 1 – Secondary Side

The secondary side of TDL 1 is connected to the primary side by means of the IHX test core and is also sized for helium alone. This loop is also envisaged to have a test station vessel for possible expansion while the rest of the loop is very similar to the primary side. The only difference is a mixing valve at the circulator (C1.2) outlet for controlling the IHX inlet temperature. Figure 2 illustrates the layout while the enveloping values are presented thereafter in Table 3.

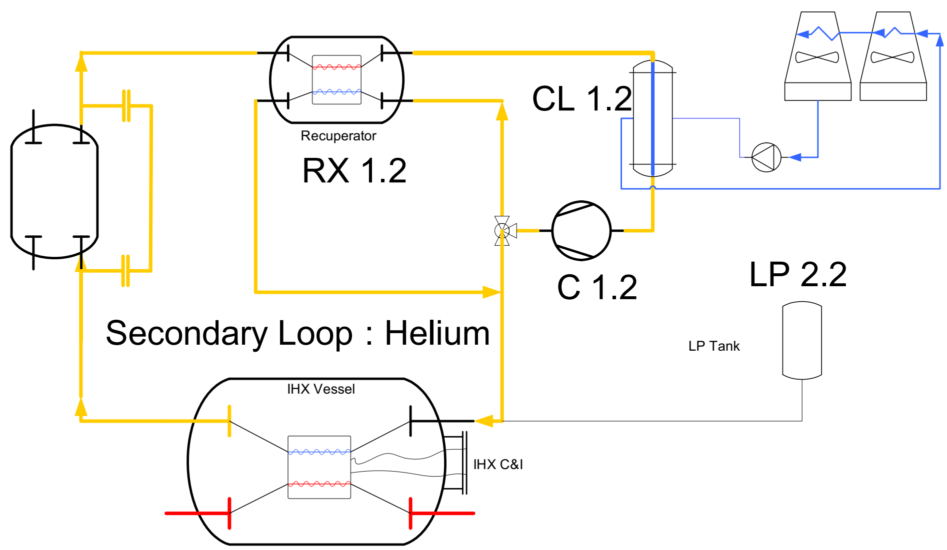


Figure 2: Technology Development Loop 1: Secondary Side

Table 3: Enveloping Values of the Secondary Side of Technology Development Loop 1

<table>
<tr><th colspan="8">TDL 1 – Secondary side</th></tr>
<tr><th>No.</th><th>Components</th><th>Power [MW]</th><th>Mass flow rate [kg/s] - MAX</th><th>T_in [°C]</th><th>T_out [°C]</th><th>Pressure</th><th>Fluid</th></tr>
<tr><td>C 1.2</td><td>Circulator (ΔP: 500 kPa @ 5 MPa)</td><td>0.2 [max]</td><td>2</td><td>80 [min]</td><td>-</td><td rowspan="6">5 – 9 MPa</td><td rowspan="6">Pure Helium</td></tr>
<tr><td>RX 1.2</td><td>Recuperator (Hot side)</td><td rowspan="2">3.7 [max]</td><td>1.15</td><td>900 [max]</td><td>464 [max]</td></tr>
<tr><td>RX 1.2</td><td>Recuperator (Cold side)</td><td>1.15</td><td>~ 85 [max]</td><td>756 [max]</td></tr>
<tr><td>TS 1.2</td><td>Vessel - Test Station</td><td>N/A</td><td>1.15</td><td>900 [min]</td><td>900 [max]</td></tr>
<tr><td>CL 1.2</td><td>Cooler</td><td>2.0 [max]</td><td>1.15</td><td>464 [max]</td><td>80 [nom]</td></tr>
<tr><td>PD 1.2</td><td>Pipe & Ducting</td><td>N/A</td><td>1.15</td><td colspan="2">900 [max]</td></tr>
</table>

1.3 TECHNOLOGY DEVELOPMENT LOOP 2

Technology Development Loop 2 (TDL2) has a similar configuration to that of TDL1, but differs in the fact that it does not provide a number of test station vessels. This loop is mainly proposed for investigation purposes of different fluids (such as He/N_2 mixtures) in the secondary loop, while also allowing for concurrent IHX testing by various vendors. The secondary loop is currently sized with helium, and further investigation is necessary to determine the suitability of one circulator for both helium and He-N_2 mixtures. It is however anticipated that a different circulator would be required for different fluids being tested.

1.3.1 Technology Development Loop 2 – Primary Side

The primary side of TDL 2 is similar to that of TDL 1, except that it does not have an additional test station vessel. Figure 3 illustrates the layout while the enveloping values are presented in Table 4.

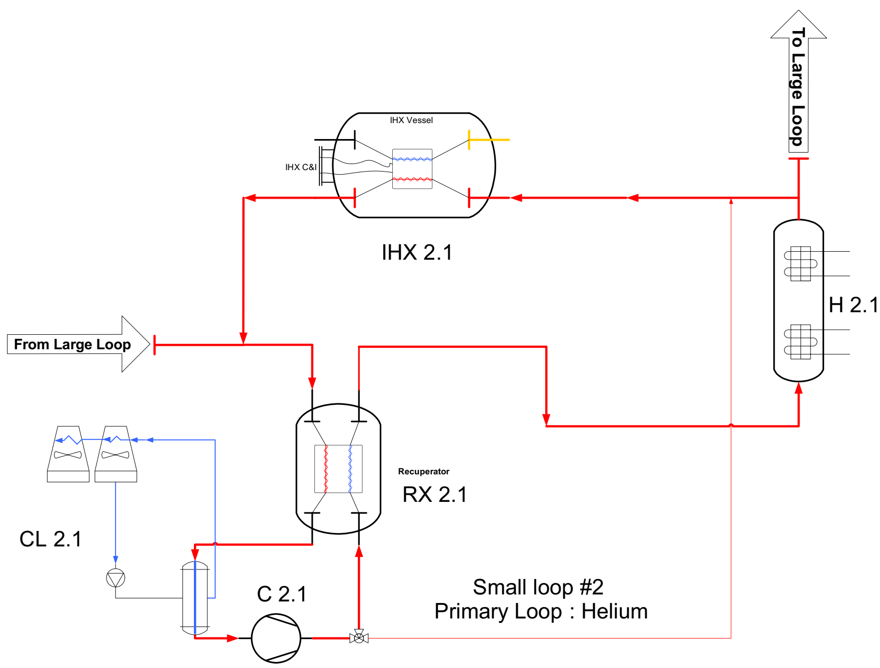


Figure 3: Technology Development Loop 2: Primary Side

Table 4: Enveloping Values of the Primary Side of Technology Development Loop 2

TDL 2 – Primary side							
No.	**Components**	**Power [MW]**	**Mass flow rate [kg/s] - MAX**	**T_in [°C]**	**T_out [°C]**	**Pressure**	**Fluid**
C 2.1	Circulator (ΔP: 500 kPa @ 5 MPa)	0.2 [max]	2	80 [min]	-	5 – 9 MPa	Pure Helium
RX 2.1	Recuperator (Hot side)	6.3 [max]	1.75	950 [max]	257 [max]		
RX 2.1	Recuperator (Cold side)		1.75	~ 85 [max]	776 [max]		
H 2.1	Heater	4.0	1.75	776 [max]	950 [max]		
IHX 2.1	Heat exchanger Vessel (primary)	N/A	1.15	900 [max]	900 [max]		
CL 2.1	Cooler	1.6	1.75	257 [max]	80 [nom]		
PD 2.1	Pipe & Ducting	N/A	1.75	900 [max]			

1.3.2 Technology Development Loop # 2 – Secondary Side

It is anticipated that the secondary side of TDL2 will be used with either helium or other fluids under testing, such as He-N_2 / CO_2 mixtures. Current sizing has been done using helium and further investigation still needs to be performed regarding the suitability of a single circulator. It is however anticipated that different circulators will be utilized with different fluids when tested. Figure 4 illustrates the process while the enveloping values are presented in Table 5.

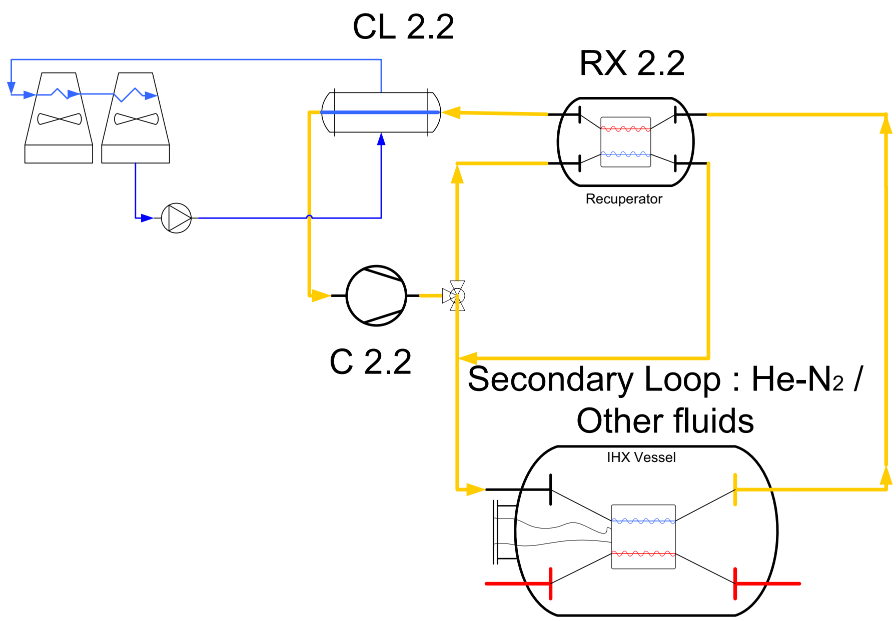


Figure 4: Technology Development Loop 2: Secondary Side

Table 5: Enveloping Values of the Secondary Side of Technology Development Loop 2

TDL 2 – Secondary side							
No.	**Components**	**Power [MW]**	**Mass flow rate [kg/s] - MAX**	**T_in [°C]**	**T_out [°C]**	**Pressure**	**Fluid**
C 2.2	Circulator (ΔP: 500 kPa @ 5 MPa)	0.2 [max]	2	80 [min]	-	5 – 9 MPa	Sizing done on Helium. Other fluids to be tested
RX 2.2	Recuperator (Hot side)	2.3 [max]	1.15	850 [max]	455 [max]		
RX 2.2	Recuperator (Cold side)		1.15	~ 85 [max]	~ 700 [max]		
CL 2.2	Cooler	2.2 [max]	1.15	455 [max]	80 [nom]		
PD 2.2	Pipe & Ducting	N/A	1.15	850 [max]			

1.4 TECHNOLOGY DEVELOPMENT LOOP 3

Technology Development Loop 3 (TDL3) again uses the basic building blocks as proposed in TDL 1, but with the sole purpose of providing a test station for non heat transfer components, such as valves, ducting, insulation etc. It also serves the purpose for providing the additional energy input when the three loops are used concurrently and connected together in a common header. Technology Development Loop 3 also addresses the need for a separate facility due to long term test requirements and the possibility of time constraint issues.

1.4.1 Technology Development Loop 3 – Primary Side

The primary loop of TDL 3 is again similar to TDL 1 expect for the fact that it does not have separate vessels for IHX and component testing. It is anticipated that this loop will be used for non-heat transfer testing while the possibility exists for future expansion of commercial testing on the secondary side.

Figure 5 Illustrates this loop with its enveloping values presented thereafter in Table 6.

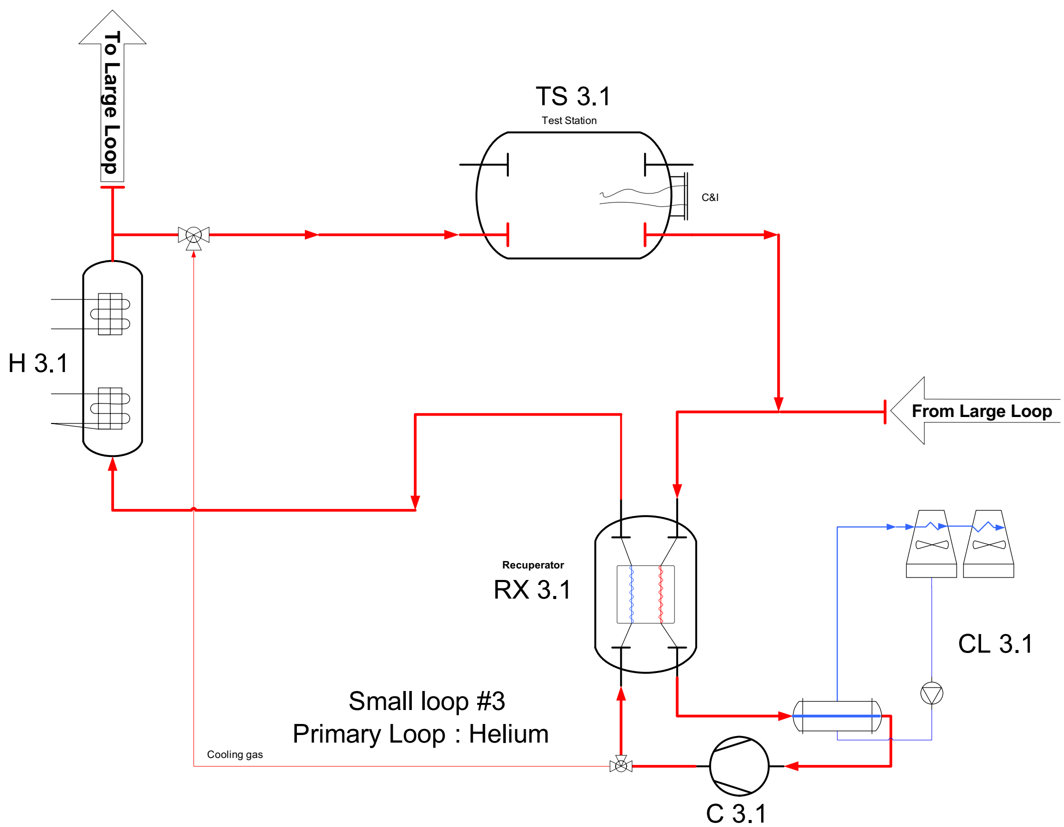


Figure 5: Technology Development Loop 3: Primary Side

Table 6: Enveloping Values of the Primary Side of Technology Development Loop 3

TDL 3 – Primary side							
No.	**Components**	**Power [MW]**	**Mass flow rate [kg/s] - MAX**	**T_in [°C]**	**T_out [°C]**	**Pressure**	**Fluid**
C 3.1	Circulator (ΔP: 500 kPa @ 5 MPa)	0.2 [max]	2	80 [min]	-	5 – 9 MPa	Pure Helium
RX 3.1	Recuperator (Hot side)	6.3 [max]	1.75	950 [max]	257 [max]		
RX 3.1	Recuperator (Cold side)		1.75	~ 85 [max]	776 [max]		
H 3.1	Heater	4.0	1.75	776 [max]	950 [max]		
TS 3.1	Vessel - Test Station	N/A	1.75	950 [min]	950 [max]		
CL 3.1	Cooler	1.6	1.75	257 [max]	80 [nom]		
PD 3.1	Pipe & Ducting	N/A	1.75	950 [max]			

1.5 COMPONENT QUALIFICATION LOOP (CQL)

A component qualification loop (CQL) is also proposed as part of Concept 1. This component qualification loop is a larger facility which is required for larger scale component qualification of up to 10 MW, as dictated by certain design data needs. It is anticipated that the primary circuit of the CQL could utilize the heating, cooling and mass flow producing capabilities of the three smaller facilities, while a dedicated secondary loop is added.

Typical tests on this facility include large scale IHX cores of up to 10 MW, duct & insulation testing and fully representative size steam generators.

1.5.1 Component Qualification Loop – Primary Side

The primary side of the CQL is shown in Figure 6, and consists of common inlet and outlet headers, steam generator testing connections (SG 4.1) as well a testing vessel for heat transfer and non heat transfer components (in IHX 4.1). A dedicated steam loop is also provided for complete representative testing of steam generator components. The primary side also incorporates a recuperator (RX 4.1) to reduce the capacity of each heater in the TDLs. A summary of the components and values for the primary side is provided in Table 7.

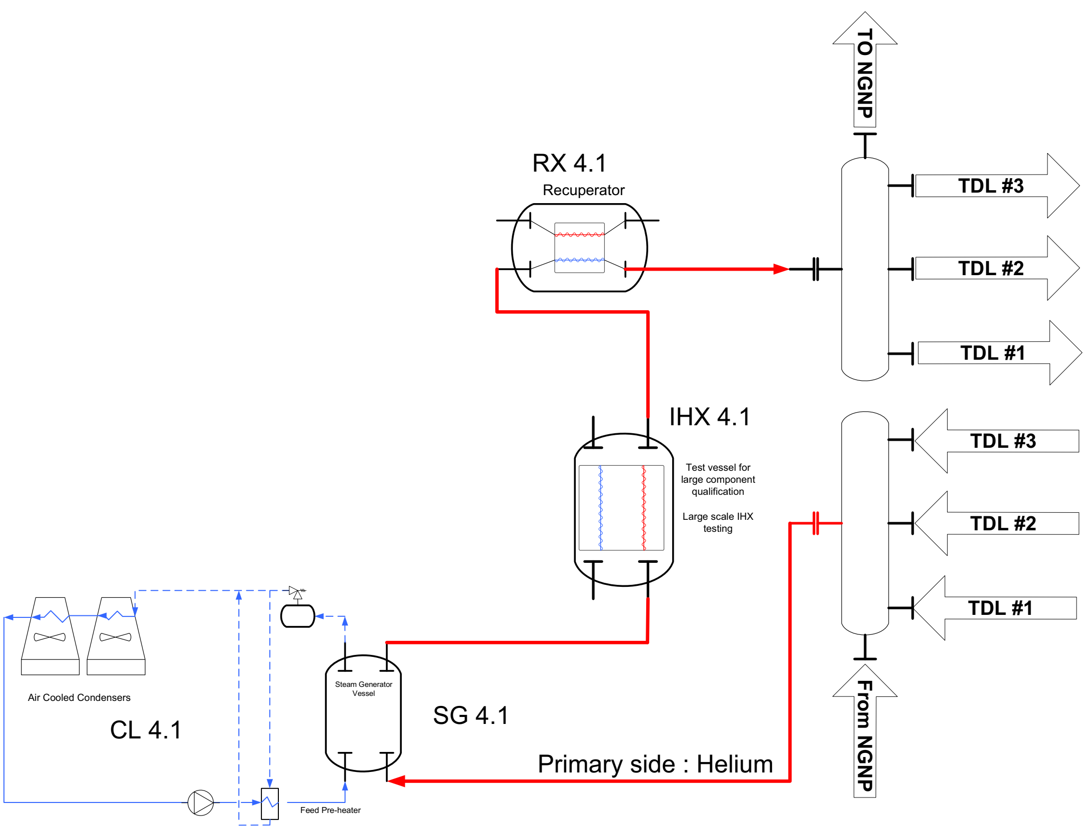


Figure 6: Large Loop: Primary Side

Table 7: Enveloping Values of the Primary Side of CQL

CQL – Primary side							
No.	Components	Power [MW]	Mass flow rate [kg/s] - MAX	T_in [°C]	T_out [°C]	Pressure	Fluid
RX 4.1	Recuperator (Hot side)	7.8 [max]	5.25	950 [max]	657 [max]	5 – 9 MPa	Helium
RX 4.1	Recuperator (Cold side)		5.25	590 [max]	858 [max]		
IHX 4.1	Heat exchanger Vessel (primary)	N/A	5.25	950 [max]	590 [max]		
SG 4.1	Steam generator (testing capability)	11.2 [max]	5.25	900 [max]	272 [nom]		
PD 4.1	Pipe & Ducting	N/A	5.25	950 [max]			

1.5.2 Component Qualification Loop – Secondary Side

The secondary side of the CQL is connected to the primary side by means of the IHX test core (in IHX 4.1) as well the recuperator (RX 4.1). The loop further consists of an additional recuperator (RX 4.2) as well as the normal cooler and circulator arrangement. Figure 7 illustrates the proposed layout with the enveloping values presented thereafter.

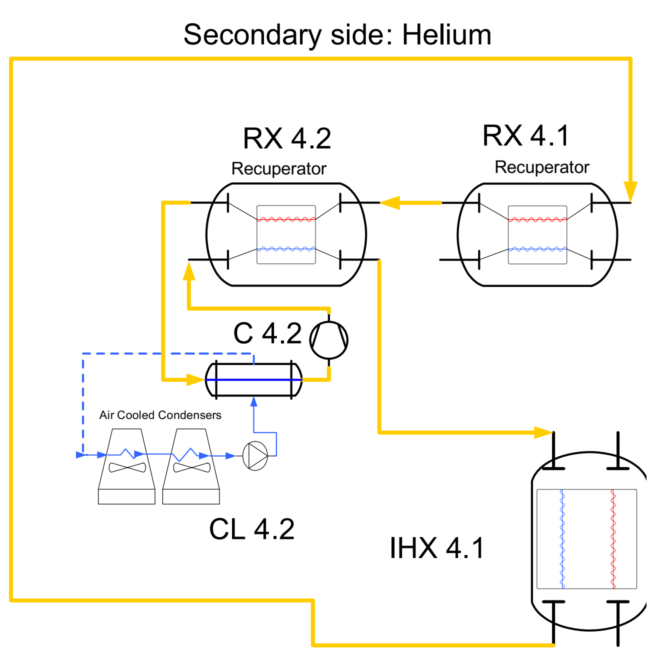


Figure 7: High Level Process Flow Diagram of the Circulator Loop Secondary Side

Table 8: Enveloping Values of the Secondary Side of CQL

CQL – Secondary side							
No.	**Components**	**Power [MW]**	**Mass flow rate [kg/s] - MAX**	**T_in [°C]**	**T_out [°C]**	**Pressure**	**Fluid**
C 4.2	Circulator (ΔP: 500 kPa @ 5 MPa)	0.6 [max]	6	80 [min]	-	5 – 9 MPa	Helium.
RX 4.2	Recuperator (Hot side)	13.1 [max]	5.25	657 [max]	184 [max]		
RX 4.2	Recuperator (Cold side)		5.25	~ 85 [max]	565 [max]		
CL 4.2	Cooler	2.8 [max]	5.25	184 [max]	80 [nom]		
PD 4.2	Pipe & Ducting	N/A	5.25	925 [max]			

1.5.3 Full Scale Circulator Loop

A full scale circulator testing loop is also proposed to address full scale testing requirements of different circulator designs. This separate loop is mainly proposed as part of the philosophy of not having 2 or more components under test in a single test configuration. A typical arrangement is shown in Figure 8, with a summary of the main components in Table 9.

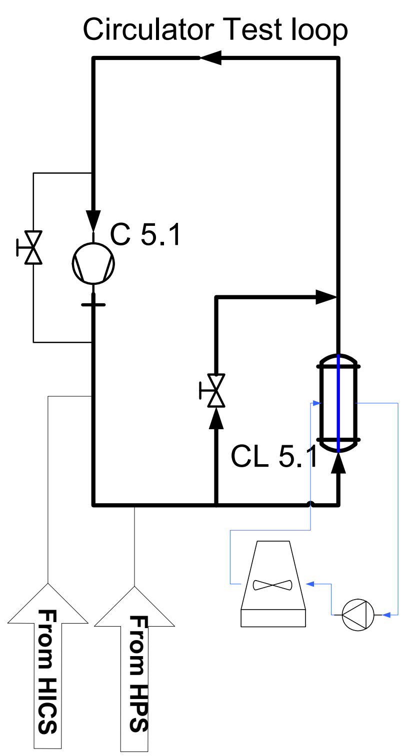


Figure 8: Circulator Test Loop

Table 9: Enveloping Values of the Circulator Test Loop

Circulator test loop – Secondary side							
No.	**Components**	**Power [MW]**	**Mass flow rate [kg/s] - MAX**	**T_in [°C]**	**T_out [°C]**	**Pressure**	**Fluid**
C 5.1	Circulator: Unit under test	12.4 MWt [max]	159.6 [max]	590 [max]	-	5 – 9 MPa	Helium.
CL 5.1	Cooler	12.4 [max]	159.6 [max]	590 [max]	272 [min]		
PD 5.1	Pipe & Ducting	N/A	159.6 [max]	590 [max]			

1.6 COMPONENT DESCRIPTIONS

This section provides a general description and recommendations for future work on the different components and sub systems of Concept 1.

1.6.1 Circulators

Circulator – TDL Primary & Secondary side

The circulator unit is used as the primary fluid mover in the process loop. The circulator should therefore be able to overcome the differential pressure demand at the required flow rate set by the individual process components, subsystems and units under test. The main requirement in terms of circulator capacity is usually driven by the units under test. Various options are available in terms of circulator type and design. However, aspects such as Helium leakage to atmosphere and contaminant into the process loop, drive the choice of design and will be discussed in the specific sections below.

- **Circulator Process Requirements**

The maximum flow rate required for the specified tests in the three TDLs is estimated at 1.75 kg/s. Provision is made for increased flow up to 2.0 kg/s which might be required for surge control by means of a bypass loop across the circulator. The required flow rate is easily obtained by a single stage high speed centrifugal design. A maximum pressure rise of 500 kPa is expected which results in a Pressure Ratio (PR) of 1.056 at an inlet pressure of 9000 kPa. The theoretical temperature rise across the compressor is calculated at 9.8°C with an inlet temperature of 80°C and isentropic efficiency of 80%. The required pumping power is calculated as approximately 200 kW.

- **Circulator Drive**

To simplify the design of the circulator system and to ensure that the facility's design integrity is one level higher than the units under test, it is recommended that the compressor uses a variable speed 2 pole electric motor and step up gearbox that is not submerged in the working fluid. This also eliminates the use of Active Magnetic Bearings (AMB) and the associated control systems. However, the circulator system should be designed in such a way to allow for later modifications in the event of a requirement for specifically testing AMB.

- **Dry Gas Seal System**

The compressor impeller is situated within the pressure boundary, with only a shaft penetration though the pressure boundary. The proposed sealing mechanism at this interface would be a dry gas seal. The dry gas seal would cause some leak to atmosphere but is assumed to be acceptable. If calculation shows that the leak is unacceptable, it is still possible to make use of the submerged type drive system.

- **Circulator Drive Lubrication**

Provision should be made to lubricate the gearbox and associated bearings in the drive system of the compressor. The details of the lubrication system will be addressed at a later stage in the design. It is of utmost importance to specify the allowable concentration of lubricant (if any) in the gas stream during the next phases of design.

- **Circulator Vessel**

The compressor is housed in its own pressure boundary assembly, with only a shaft penetration. An inlet and outlet nozzle flange is attached to the pressure boundary. The vessel design should allow for future modification of the drive system to a submerged drive system with AMB.

Circulator – CQL Secondary side

The CQL secondary side circulator would follow the same design approach as followed for the TDL circulators. However, the CQL secondary side circulator is required to circulate 5.25 kg/s through the process. Provision is made for increased flow up to 6.0 kg/s which might be required for surge control by means of a bypass loop across the circulator. The required flow rate is obtained by a single stage high speed centrifugal design. A maximum pressure rise of 500 kPa is expected which results in a Pressure Ratio (PR) of 1.056 at an inlet pressure of 9000 kPa. The theoretical temperature rise across the compressor is calculated at 9.8°C with an inlet temperature of 80°C and isentropic efficiency of 80%. The required pumping power is calculated as approximately 600 kW.

1.6.2 Heater Unit – TDL Primary Side

The heater assembly used in the three TDLs is similar in design and constitutes a number of electric resistance heaters that are installed in series. The heater configuration was determined by examining a number of different test configurations which had several requirements. Heating is done by means of electric resistance elements to ease controllability of the power level for different test configurations. The suggested heater should supply a nominal duty of approximately 4MW. The maximum flow rate through the heater is 1.75 kg/s and the maximum outlet temperature is limited to approximately 950°C. The heat loss in the piping to the test vessels and/or hot headers might require that the heater outlet temperature be raised above 1000°C. The effect of thermal losses in the hot pipes should therefore be investigated and a requirement for the maximum heat loss to atmosphere should be specified for the hot pipes.

Heating Elements

Literature suggests that a low heat flux is required to efficiently heat Helium in a high pressure environment. A typical value heat flux of 2.4 W/cm^2 is required which translates to a lower element surface temperature but requires a large equivalent heat transfer surface area. To reduce the temperature rise over the successive heater units placed in series, it is suggested that smaller independent heater units be placed in series in a single pressure vessel. The heating elements located at the inlet of the unit could typically be a lower cost heating element using sheath materials of Incoloy 800, and the heaters at the outlet of the heater unit could be a higher quality heating element such as the products manufactured by Kanthal. It is recommended that the radiation heat produced by the heating elements be utilized to heat a larger surface area which is in contact with the primary fluid. Provision should also be made to account for thermal expansion between the heating elements placed in series.

Heater Vessel

A vertical vessel is suggested with sufficient room and access openings. It is suggested that the flow be from the bottom to the top to prevent the negative effects of natural convection streams in the heater; however, from a physical layout point of view it is better to have the flow from the top to the bottom. This should be investigated to see whether it would be advantageous to orient the flow from bottom to the top. It is suggested that the vessel is passively cooled by means of internal insulation.

Care should be taken to avoid heat radiation to the pressure boundary and it is advised to install all heaters in radiation shield / boxes, either of high temperature metals or appropriate ceramics. Pressure boundaries should be designed according to standard ASME practices with surface temperatures within acceptable code limits.

Insulation

The insulation material for the heaters will ultimately be determined by the design of the heater unit internals. It is suggested that insulation blanket material be used which can easily be wrapped around the specific geometry of the heater, instead of custom engineered insulation material sections fitted to the inside of the heater. The choice of insulation will therefore be determined at a later stage.

1.6.3 Pressure Boundary

Hot Pipes – (Helium > 550°C)

The suggested method of construction of the hot pipe is a coaxial designed pipe with an exotic high temperature material flow tube liner, incorporating various insulation materials up to the larger diameter pipe pressure boundary. The use of an actively cooled pressure boundary in conjunction with insulation material should still be investigated.

The flow tube sizing was done with the lowest anticipated loop pressure, along with the maximum specified velocity. This should therefore result in lower velocities at elevated pressures. A maximum flow tube diameter of 0.2 m is calculated at a nominal flow rate of 1.75 kg/s and a flow velocity of 30 m/s at 950°C, 5 MPa. If the flow diameter is reduced to 0.16m, using the same process conditions, the flow velocity is increased to approximately 45 m/s.

The pressure boundary dimensions are to be determined once a detail calculation has been done regarding the insulation material. The pressure boundary dimensions are estimated to be approximately 0.6 – 0.8 m if the pressure boundary is not actively cooled. The pressure boundary section should make provision for instrumentation connection points which can be used to monitor the pressure and temperature levels in the hot pipe. The hot pipes should be designed to be pressure balanced across the flow tube and the possibility of isolating these two sides from each other should be investigated and could assist in the purification processes. A typical section length of 5m is foreseen. The governing philosophy for the hot pipes is to make them as short as possible, have no valves located in them, have no compensators in them but rather compensate in the cold pipes and have minimal bends except when the bends are actually used for compensating purposes.

Cold Pipes – (Helium < 350°C)

The so-called Cold Pipes are the pipes immediately before and after the Circulator units in the three TDLs. Calculations have also shown that the cold pipe temperatures will be well below 350°C. It is recommended that all the cold pipes are manufactured from a type of carbon steel, such as ASME A106 Gr B.

The use of carbon steel would reduce the total cost of the facility but the risk of corrosion of the piping in periods when the facility is open for maintenance, test setups and/or repair is increased. Tradeoff studies need to be performed in the Intermediate design phase to weigh up financial and long term life contamination issues due to rust, etc.

A maximum pipe flow diameter of 0.14 m is calculated at a nominal flow rate of 1.75 kg/s and a flow velocity of 30 m/s at 350°C, 5 MPa. If the flow diameter is reduced to 0.12m, using the same process conditions, the flow velocity is increased to approximately 40 m/s. The effect of erosion of the inner surface of the pipe should be investigated at these high flow velocities.

IHX Test Vessel – TDL Primary Side

The IHX Test Vessel is used to test various IHX functions. The design of the IHX test vessel should allow for Human Factors (HF), seeing that this test vessel will be used extensively for different IHX core setups that require adequate space for maneuverability and internal piping. The test vessel should also employ mechanisms for easy access to internal components and instrumentation without dismantling the entire vessel. It should also provide adequate internal fixture brackets, slides, rails, instrumentation channels, etc. for ease of units under test fitting and inspection. It is estimated that the vessel has an internal diameter of 3.0m and a length of 5m.

It is recommended that the vessel be oriented in a vertical manner, with a girth flange located 2m from the bottom of the vessel and the top section removable in the classic “bell” configuration. The four main inlets to the vessel are located in the “fixed/stationary” bottom section. Instrumentation and other required process equipment is also routed through this section. The top bell-section of the vessel is provided with manholes for inspection, maintenance and other tasks that do not require that the vessel top be removed. Cognizance should be taken in the design of the bell-section sealing surface and the handling of this section to prevent damage seeing that this will be an expensive item and provision should be made for adequate lay-down areas and equipment.

It is foreseen that the vessel must be insulated on the inside. This is required as a safety precaution when a Unit Under Test (UUT) fails and the vessel is exposed to the maximum heater outlet temperature.

Test Station Test Vessel – TDL Primary Side

The IHX Test Station is utilized to test various components and sub systems such as valves, hot ducting, process heat exchangers and the like. The same philosophy used for the IHX Test Vessel is employed here. It is proposed that the test Station vessel has an internal diameter of 3.0m and a length of 5m.

1.6.4 Heat Transfer Components

Recuperator Unit – TDL Primary Side

The recuperator unit in all three TDLs is used to recover the energy input of the Heater units after the UUTs. To ensure that the process loops' design integrity is one level higher than the units under test, requires that conventional type recuperators be used. Since various tests are performed at different flow rates and pressures a detailed investigation is needed to determine whether a single recuperator sized for the worst case requirement would be able to operate at a reasonable effectiveness at off design conditions.

In the event where tests are conducted and little or no heat is rejected by the test components such as valves tests and hot ducts and insulation tests, the inlet temperature of the recuperator can reach 950°C. It is recommended to use a COTS conventional type recuperator to ensure that the reliability of the loop is a level higher than that of the test components.

It should be investigated whether it would be possible to use a Helical Tubular Heat Exchanger. The tubular concept was developed and qualified in Germany for the Coal Gasification process coupled with a HTR, where the inlet temperature was 950°C and the mass flow rate approximately 3 kg/s. The operating pressure was significantly lower at 4000 kPa but this should have a negligible effect on the heat transfer capabilities.

The maximum possible heat transfer is approximately 6.3MW assuming a conservative effectiveness of 80%. The maximum required flow rate in the loop is 1.75 kg/s. A first order estimate of the size of the recuperator is approximately a diameter of 2.5m x 12m length.

Another possibility would be to use a Helical Tubular Exchanger in conjunction with a compact heat exchanger. The Helical Tubular Exchanger is used to recuperate the high temperature portion of energy whilst the compact heat exchanger exchanges the lower temperature heat. This should reduce the overall size of the recuperator section with associated savings on the required pressure vessel as well.

Recuperator Unit – TDL Secondary Side

The secondary side recuperator of the TDL loop will be a similar design to the TDL primary side recuperator. This recuperator is significantly smaller and the required duty is approximately 3.7 MW with an effectiveness (assumed) of 80%. The maximum required flow rate in the loop is 1.75 kg/s. A first order estimate of the size of the recuperator is approximately a diameter of 2.0m x 8m length. A similar approach to that of the TDL Primary Side recuperator can be followed using a Helical Tubular Exchanger in conjunction with a compact heat exchanger.

Recuperator Unit – CQL Primary Side

The primary side recuperator of the CQL loop will be a similar design to the TDL primary side recuperator. The recuperator is slightly bigger and the required duty is approximately 7.8 MW with an effectiveness (assumed) of 80%. The maximum required flow rate in the loop is 5.25 kg/s. A first order estimate of the size of the recuperator is approximately a diameter of 2.0m x 15m length. A similar approach to that of the TDL Primary Side recuperator can be followed using a Helical Tubular Exchanger in conjunction with a compact heat exchanger.

Recuperator Unit – CQL Secondary Side

The secondary side recuperator of the CQL loop will be of similar design to that of the CQL Primary Side recuperator. The recuperator is significantly bigger and the required duty is approximately 13 MW with an effectiveness (assumed) of 80%. The maximum required flow rate in the loop is 5.25 kg/s. A first order estimate of the size of the recuperator is approximately a diameter of 3.0m x 18m length. A similar approach to that of the TDL Primary Side recuperator can be followed using a Helical Tubular Exchanger in conjunction with a compact heat exchanger.

1.6.5 Heat Sink Requirements

Cooler – TDL Primary Side

The cooler is used to cool the helium prior to entering the circulator. The circulator inlet temperature is conservatively limited to 80°C. The maximum helium temperature at the inlet to the cooler (without gas bypass from the surge control valve) is approximately 260°C. The required maximum duty of the cooler at a nominal flow rate of 1.75 kg/s is 1.6 MW. It is suggested that either an air-cooler or shell-and-tube cooler be used for this application. An air cooler requires a variable speed drive to control the outlet temperature. The shell-and-tube heat exchanger performs better when sudden temperature transients are present due to the thermal inertia of cooler and coolant. If a shell-and-tube unit is used, it is recommended that a water and ethylene glycol mixture be used. The use of a mixture of water and ethylene glycol would possibly require a closed circuit cooling tower. A maximum coolant flow rate of 20 – 25 kg/s is required to keep the water temperature below 50°C at the cooler outlet. The outlet temperature of the helium can then be regulated by using a coolant bypass and circulating loop.

Cooler – TDL Secondary Side

The secondary side loop of the TDL requires that the fluid be cooled from 460°C to 80°C. The high inlet temperature requires the use of an Air-cooled Helium cooler. The required maximum duty of the cooler at a nominal flow rate of 1.15 kg/s is 2.5 MW. A first order estimate of the size of the cooler is approximately 4.0m x 4.0m x 0.5m. The cooler uses 4 axial flow fans to supply the required air flow rate of 60 kg/s.

Cooler – CQL Secondary Side

The secondary side circulator inlet temperature is also conservatively limited to 80°C. The maximum helium temperature at the inlet to the cooler (without gas bypass from the surge control valve) is approximately 185°C. The required maximum duty of the cooler at a nominal flow rate of 5.25 kg/s is 2.6 MW. A shell-and-tube cooler is recommended for this application, also with a water and ethylene glycol mixture as secondary coolant. A maximum coolant flow rate of 25 – 30 kg/s is required to keep the water temperature below 50°C at the cooler outlet.

Auxiliary Cooling System

An Auxiliary Cooling System is required for each TDL to supply cooled treated water to the helium coolers (if shell and tube coolers are used). The operation and reliability of the auxiliary cooling system is of utmost importance critical to avoid damage to the helium circulators. The auxiliary cooling system consists of the cooling tower, the water treatment and make up system, the cooling pumps and interconnecting pipe system.

- **Cooling Tower**

It is suggested that a closed circuit cooling tower be used to cool the fluid. The cooling fluid's temperature before it enters the cooling tower circuit reaches a maximum temperature of approximately 50°C. The cooling tower cools the cooling fluid down to approximately 25°C. The maximum water temperature at the inlet to the heat exchanger is approximately 30°C.

- **Cooling Pumps**

The cooling pumps required in the auxiliary cooling system should supply the coolers with approximately 20 kg/s water. A single stage centrifugal pump is suggested with a 600 kPa pressure rise at the supplied flow rate. An additional pump is suggested for redundancy.

- **Cooling System Piping**

The cooling system piping comprises the piping between the cooling tower and Helium coolers. The minimum required pipe size is a 100 mm NB.

- **Water Treatment System**

The cooling water systems are an integral part of the process. The systems require proper chemical treatment for reliable plant operation. The typical problems associated with the cooling water systems include corrosion, scale, fouling and microbiological contamination. These problems contribute to other secondary problems with heat transfer abilities of components and ultimately performance degradation of the process.

Air-cooled Condenser

The air-cooled condenser forms part of the Steam Generator Tests. The details for the condenser will only be determined once the detail of the steam generator tests has been defined. The condenser will typically have a capacity of 15MW at 5kg/s.

1.6.6 Helium Inventory and Control System

The Helium Inventory System (HICS) has the main function to supply, extract and maintain Helium inventory within the process loops. The HICS should have the ability to either fill the system from bulk Helium containers or from the storage vessels located onsite. The system should be able to pump helium from the latter at a pressure lower than the process pressure to the process.

Components of the HICS

- **Helium Storage Vessels**

The helium storage vessels are used to store the process inventory during maintenance or repair periods when the complete inventory is not to be wasted. It is suggested that the storage vessels have the capacity to store the entire inventory of the process – primary and secondary loop. The entire inventory will be stored at an estimated pressure of 14000 kPa to reduce the required storage volume. The volume of the primary side and secondary side of the loop is approximately 200 – 300 m^3. The total calculated volume of the storage tanks are 130 – 190 m^3 at 14000 kPa. The storage vessels' volume is currently limited to approximately 16 m^3. In total 10 – 12 of these vessels are required to store the entire inventory. The vessels will have an approximate diameter of 1.5m and a length of 10m. Tradeoff studies need to be performed during the Preliminary design to determine the cost implication of investing in hardware such as the Helium Storage Vessels and the cost of loss-of-inventory.

- **Inventory Transfer System**

The inventory transfer system is utilized to transfer Helium from the bulk Helium containers and the storage tanks to the primary and secondary process loops and back. The system consists of isolation and control valves as well as a positive displacement compressor unit. The compressor unit is used to transfer the fluid when the pressure of the volume to which the fluid is transferred is higher than the system from which it is pumped. The size of the compressor is determined by the maximum pressure of the storage vessels and the time required to fully transport the inventory of the process. The different modes of the inventory transfer system are illustrated in Figure 9 through Figure 13. Figure 9 shows the process flow diagram when the loop is supplied with Helium when the pressure in the loop is higher than the pressure in the storage tanks. Figure 10 shows the process flow diagram when the loop is supplied with Helium when the pressure in the loop is lower than the pressure in the storage tanks and the compressor is not needed. Figure 11 and Figure 12 show the process flow diagram when the Helium is extracted from the loop when the pressure in the loop is 1) higher than the pressure in the storage tanks and the compressor is not needed and 2) lower than the pressure in the storage tanks and the compressor is needed to increase the pressure in the storage tanks.

Figure 13 shows the process flow diagram for the conditioning of the Low Pressure Vent tank, which can be utilized when a pipe break is simulated to suddenly extract the inventory. The pressure in the LP Vent tank is reduced significantly to simulate a postulated pipe break scenario. The LP Vent tank should however be located close to the loop where the pipe break scenario is simulated to reduce the inertia effects of the gas.

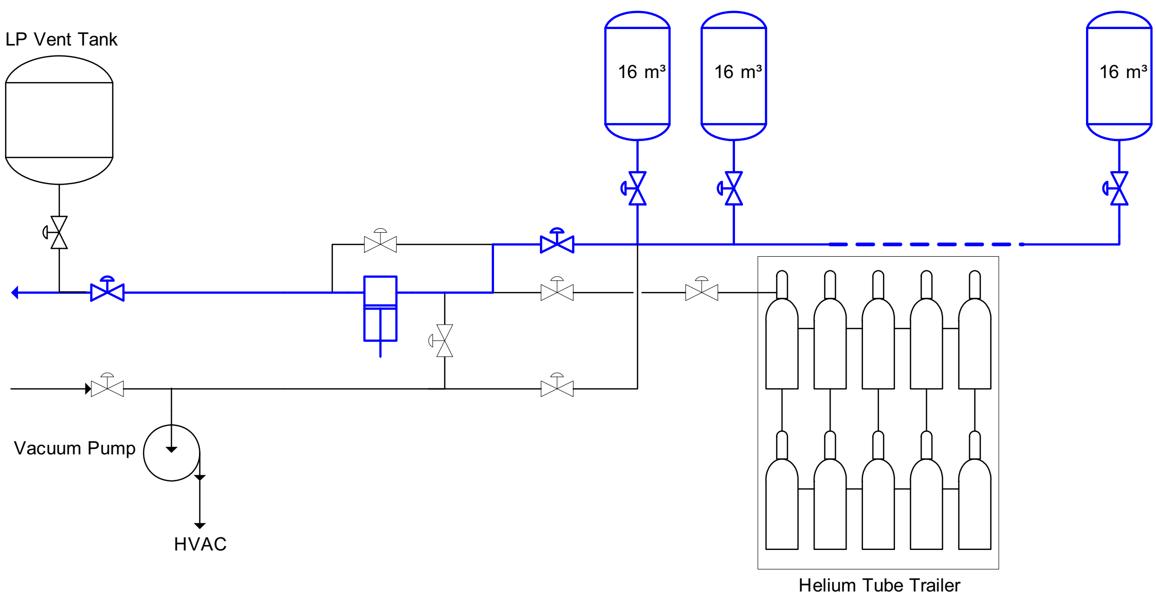


Figure 9: Helium Injection into System When the Process Pressure is Higher than the Storage Tank Pressure

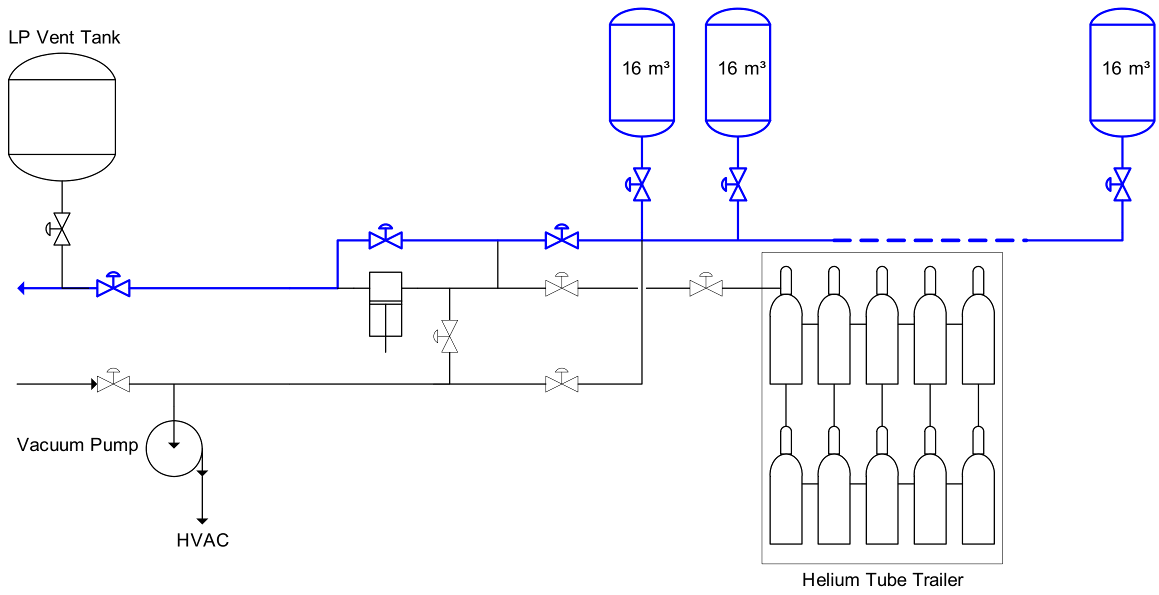


Figure 10: Helium Injection into System When the Process Pressure is Lower than the Storage Tank Pressure

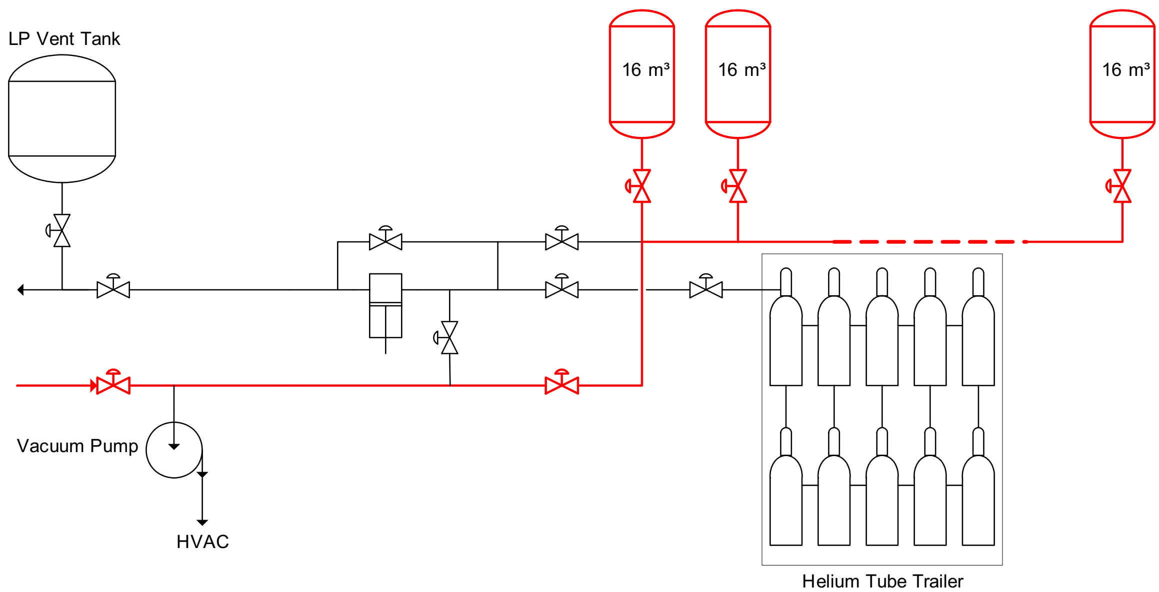


Figure 11: Helium Extraction from the System When the Process Pressure is Higher than the Storage Tank Pressure

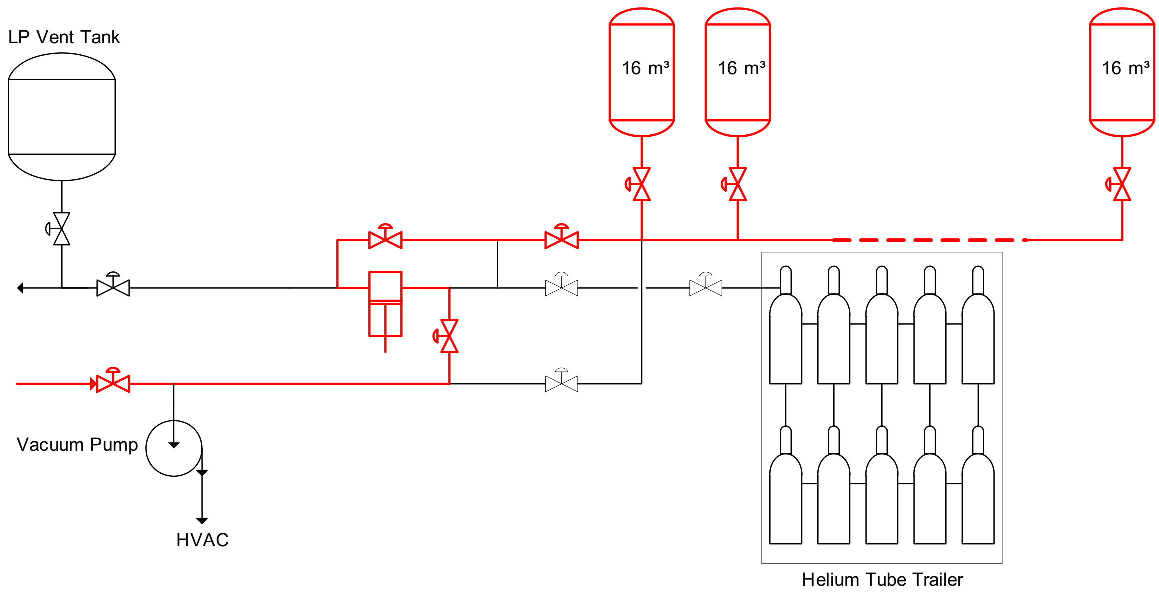


Figure 12: Helium Extraction from the System When the Process Pressure is Lower than the Storage Tank Pressure

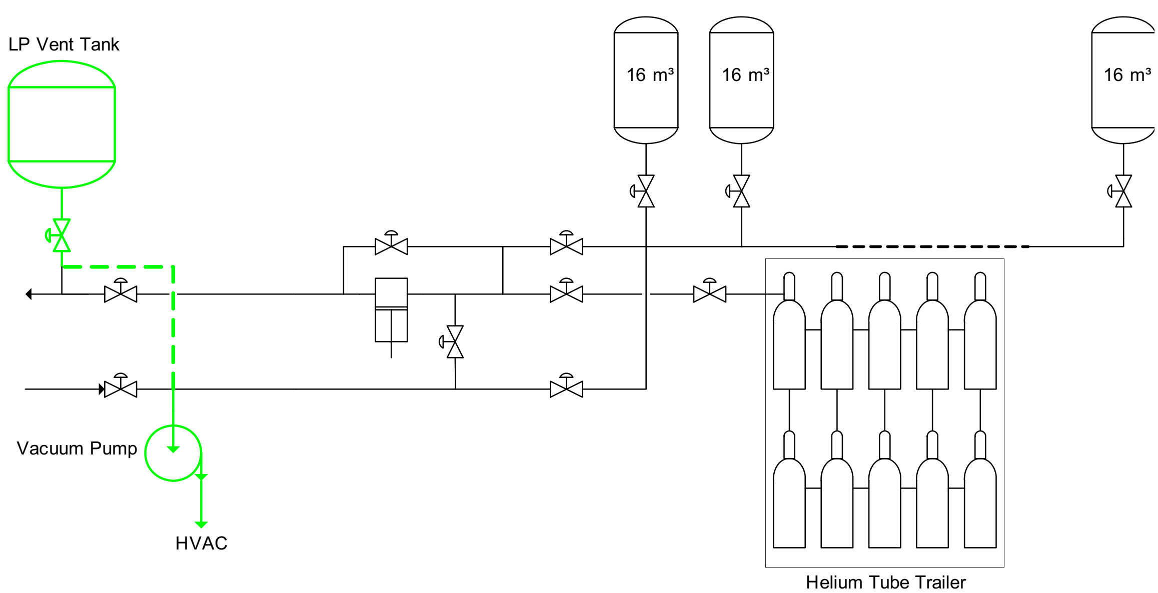


Figure 13: Conditioning of the Low Pressure Vent Tank

- **Vacuum System**

The vacuum system is used to evacuate the process loop before Helium gas is introduced into the loop. The vacuum system is also used to reduce the pressure of the low pressure vent tank that is used for specified tests.

1.6.7 Helium Purification System (HPS)

Purification Requirements

It is envisaged that the general purification requirements for the Component Test Facility would be to remove H_2 and CO from each of the primary and secondary loops to restrict the deposition of carbon on metallic surfaces, particularly ferritic steels at high temperatures (≈500°C). The moisture content in the primary loop in particular, must be removed as it will react with the dust from the dust generators to form H_2 and CO_2. Residual oxygen from air after purging will also react with the dust from the dust generators to form CO and CO_2.

Water and carbon dioxide will also be removed and be kept under the allowable limits (to be specified). It is expected that a large amount of impurities would be present after initial evacuation. It is further suggested that the dust from the dust filters be heated and purged separately to reduce the amount of moisture and oxygen present before operation.

Process Description

A Pressure Swing Adsorption (PSA) is used to remove impurities from the helium stream. A molecular sieve membrane or packed bed is used at high pressures and low temperatures to adsorb H_2O and CO_2. The packed bed or membrane becomes saturated after a period of time, and therefore needs to be regenerated. The regeneration process consists of blowing pure helium at elevated temperatures and low pressures in the reverse direction of the main process, whereby the impurities are removed from the molecular sieve. Since there will be no radioactive isotopes such as ^{14}C or ^{3}H the regeneration gas can simply be blown to the off-gas. The H_2 and CO must however first be converted for the adsorption process in the molecular sieve.

Components of the HPS

- **Dust Filters**

Since there will be dust generators, a filter or cyclone will be required to remove dust that enters the HPS. This will be necessary to ensure that the packed beds which remove impurities from the gas stream function as desired. Because of the potentially large amounts of dust generated, it is suggested that the gross amount be filtered with a cyclone or pre-filter followed by fine dust filters. The pre-filter will enhance the efficiency and operable life of the fine dust filters.

- **Copper Oxide Catalytic Converter**

The copper oxide catalytic converter oxidizes H_2 and CO so that it can be adsorbed in the molecular sieve. The CuO beds require a temperature of approximately 210°C with an oxygen supply to regenerate the bed after a period of oxidizing the CO and H_2.

- **Coolers**

After the H_2 has been oxidized to H_2O in the CuO beds, it is recuperated and cooled using the feed from the loop, after which it is further cooled using a chilled water heat exchanger. This will ensure that most of the water is condensed, and also serves as a cooling medium for the gas stream for the adsorption of the impurities in the molecular sieve.

- **Water Coalescer**

A water coalescer is installed after the coolers to remove the water from the gas stream. This is necessary since water ingress in the molecular sieve will greatly reduce the adsorption capacity.

- **Molecular Sieve**

The molecular sieve will remove the remaining H_2O and CO_2 from the helium stream. Two, type 13X molecular sieves with an effective pore size of 1nm are suggested in parallel. While one is used to adsorb the impurities, the other is regenerated. The molecular sieve sizing will depend on the amount of impurities remaining in the system after evacuation and purging.

- **Circulators**

If the HPS is to be used to remove impurities before operation a circulator will be required in parallel with a valve to pre-circulate the helium. During normal operation a control valve will be used to control the amount of flow through the HPS due to the differential pressure.

1.6.8 Control and Instrumentation

The instrumentation requirements of CTF Concept 1 will be provided in a summary of the different types and requirements as per each separate process loop, while general requirements and recommendations for the Control & Instrumentation philosophy will be presented below.

General Requirements

The following is a list of general requirements and/or recommendations for the CTF Instrumentation and Control, and is applicable to the TDLs as well as the CQL.

All instrumentation should be categorized as being part of either *plant protection*, *controllability* or *performance verification* instrumentation. A clear distinction among these should therefore prevent that performance verification instrumentation be used for controllability or equipment protection purposes and assure that Intellectual Property associated with Technology Development is protected.

These levels of categorization should then also be used to determine their robustness as well as accuracy and traceability to international standards. It is also suggested to have a dedicated Data Acquisition System (DAQ) for each of these categories, which could assist in plant operability by a single dedicated team while ensuring protection of intellectual property in the form of performance indicators.

Some of the major control items on the CTF loops include, but are not limited to the following:

- Mass flow rate control by varying the circulator drive speed with a VSD
- Circulator surge control by means of a circulator bypass loop
- Heater outlet temperature control with thyristor control on the heating elements
- Operating and position feedback on valves (typically in HICS, HPS…)
- Start-stop on all pumps, compressors, vacuum pumps.
- Helium Inventory Control
- Controllability of gas analyzer (valves, sampling pumps)

Data logging capability should at least have the following characteristics:

- The scan rate should be determined by user requirements and previous test facility experience.
- Designed in such a way to allow for easy addition of data channels
- High temperature system temperature measurements should be performed with at least 3 – 4 instruments in close vicinity, and should make use of a thermowell with a very low thermal inertia.
- All pressure measurements should use pressure averaging with at least 3 to 4 instruments
- All instrumentation penetrations should be provided through fixed sections of the appropriate vessels and provision should be made for termination of all necessary instrumentation in the inside of the vessels.

Care should be taken to install and position instrumentation (especially for performance verification) in easily accessible places, with easy replacement as a high priority.

Input and Output Channels

Table 10 gives an indication of the minimum required number of output channels. These outputs should serve as the minimum number of required measurements for Plant Protection, Plant Controllability and Performance Verification. Ultimately the entity which uses the facility to test their respective components should give an indication of what their specific needs are. Provision should also be made to have available open channels already routed to field termination points in the event of additional outputs required by the Test Entity.

Table 10: Minimum Required Number of Outputs for Concept 1

Description	T	P	ΔP	Mass flow	σ / ε	Leak Rate	Gas Analyzer	Other
TDL 1								
Primary Loop								
Heater	20	-	1	-	-	-	-	-
Piping	12	10	-	5	10	-	-	-
Test station vessel	25	-	3	-	25	5	5	5
IHX test vessel	50	-	3	-	50	5		5
Dust generator	-	-	1	-	-	-	-	-
Filtration station	-	-	1	-	-	-	-	-
Recuperator	16	-	2	-	-	-	-	-
Cooler	4	-	1	-	-	-	-	-
Circulator	8	-	2	-	-	-	-	10
Secondary Loop								
Test station vessel	25	-	3	-	25	5	5	5
Recuperator	16	-	2	-	-	-	-	-
Cooler	4	-	1	-	-	-	-	-
Circulator	8	-	2	-	-	-	-	10
TDL 2								
Primary Loop								
Heater	20	-	1	-	-	-	-	-
Piping	12	10	-	5	10	-	-	-
IHX test vessel	50	-	3	-	50	5		5
Recuperator	16	-	2	-	-	-	-	-
Cooler	4	-	1	-	-	-	-	-
Circulator	8	-	2	-	-	-	-	10
Secondary Loop								
Recuperator	16	-	2	-	-	-	-	-
Cooler	4	-	1	-	-	-	-	-
Circulator	8	-	2	-	-	-	-	10
TDL 3								
Primary Loop								
Heater	20	-	1	-	-	-	-	-
Piping	12	10	-	5	10	-	-	-
Test Station Vessel	50	-	3	-	50	5		5

Description	T	P	ΔP	Mass flow	σ / ε	Leak Rate	Gas Analyzer	Other
Recuperator	16	-	2	-	-	-	-	-
Cooler	4	-	1	-	-	-	-	-
Circulator	8	-	2	-	-	-	-	10
CQL								
Primary Loop								
Hot headers	10	2	-	-	-	-	-	-
Piping	20	5	-	3	-	-	-	-
Steam generator vessel	50	2	2	-	20	-	-	-
IHX Test Vessel	50	-	3	-	50	5	5	5
Recuperator	16	-	2	-	-	-	-	-
Cold headers	10	2	-	-	-	-	-	-
Secondary Loop								
Recuperator	16	-	2	-	-	-	-	-
Cooler	4	-	1	-	-	-	-	-
Circulator	8	-	2	-	-	-	-	10
Circulator Loop								
	20	10	5	1	-	-	-	-
HICS								
	10	10	5	2	-	-	-	10
HPS								
	10	10	5	2	-	-	-	10
TOTAL	**660**	**71**	**72**	**23**	**300**	**30**	**15**	**110**

Some general considerations regarding the different instrumentation types are summed up in the following section:

Temperature Measurement

All temperature measurements should make use of proven technology, in terms of standard thermocouples for specific ranges. Care should be taken with regards to installation and guidelines such that those from API or similar are recommended. All instruments should further be subjected to calibration from international recognized laboratories or institutions for traceability and future usage of obtained data. A summary of major aspects that need to be addressed include:

- Detailed selection of correct instruments for measurement range and application
- Calibration requirements and plan
- Installation requirements and guidelines
- Accessibility and re-calibration possibilities

Pressure Measurement

Pressure measurements should again make use of high integrity, proven instrumentation with specific attention to be given to ranges and the application of hot measurements.

Mass flow Measurement

Mass flow measurements are anticipated to be measured at the colder location of the loop, with a maximum temperature of 650°C for the mixing chamber tests. With this high temperature it is anticipated that standard pressure drop measurement installations will be used, with additional care for high temperature differential pressure measurement. A further investigation with regards to different or newly developed technology is still recommended.

Strain Measurement

Apart from the various strain measurements on the units under test, it also envisaged that the plant should have various measurements at critical locations. These should typically be high temperature strain gauges in excess of 1000°C from manufacturers such as *Strainsense* (www.strainsense.co.uk) or HPI (www.hitecprod.com).

Leak Rate Monitoring

Leak rate monitoring should be provided in at least mobile and stationary units. These different systems are needed for both leak rates monitoring on the complete plant as well dedicated installed systems where leak rates are needed to be measured on components under test. Specific means of monitoring still need to be investigated, depending on the anticipated rates and additional constraints. Typical methods include:

- Mechanical effects
- Pressure decrease
- Tracer gas measurement

1.6.9 Circulator

The circulator in this loop will be a UUT. Full scale circulator tests are required to verify their performance at design conditions. The design of the loop makes provision for a circulator up to $15MW_t$. The maximum flow rate is limited to 160 kg/s.

The following is a short write-up by one of the leading South African turbo machinery consultants and serves as motivation for employing a full scale circulator loop.

"The characteristics of helium as process gas present a very different set of constraints for the design of Turbo machinery. Firstly the sonic velocity in helium is approximately 3 times higher

than that of conventional fluids used as process fluid. Generally the tip speeds of industrial Turbo machinery is limited to velocities well below the sonic velocity i.e. Mach < 1. With Helium as operating fluid the rotating speed is no longer limited by the mechanical design. The rotating speed is governed by the maximum allowable material stress due to the centrifugal load. Secondly the specified heat capacitance of helium is approximately five times higher than air. Therefore the pressure & temperature rise that can be achieved per stage is very small.

High pressure helium Turbo machinery presents an even more challenging set of design requirements. In order to reduce the weight of the nuclear grade pressure boundary, the rotational speeds are increased to the mechanical limit of the rotating component material allowable stress limit. Even at high rotating speeds and pressure levels only moderate Reynolds numbers can be achieved. Experience has shown that the efficiency of the turbo machine as well as the performance of the individual gas path components is very dependant on the Reynolds number.

Scaled testing of Helium Turbo machinery by making use of geometrical scaling laws is difficult to achieve in practice. Ideally testing should be carried out at similar Reynolds and Mach numbers. Due to the fact that the rotational speed and pressure for the full scale model is set at high levels for the full scale design, half scale testing is not practical for the following reasons:

Doubling the operational rotational speed will require allowable stress limits well above the current state of the art material limits.

An increased density (pressure) to maintain testing similarity requires an even heavier pressure boundary, offsetting the benefit of scaled testing. Increasing the pressure also affects the pressure balancing of the rotating train.

To maintain similarity at part load presents an even bigger challenge due to the fact that the flow will not be fully turbulent.

The objectives of the full scale helium loop test are to verify the predicted compressor performance, stability of operation and reliability at both the design and the part load operations. Therefore the Helium Loop Test should confirm both the steady state and transient characteristics of the turbo compressor.

The material stress intensity due to gas path component vibration is strongly dependant on the inlet pressure. The inlet pressure should be maintained at a constant level during steady state and transient testing to make the evaluation of the test results easier. It is proposed that additional helium gas be supplied to the closed loop by means of an inventory control system, to maintain a constant pressure level at the compressor inlet. This should serve as a design criterion for the inventory control system.

Presently very limited experience exists related to surge protection of helium gas turbo compressors. Ideally the turbo compressor should be relieved from the surge condition as soon as possible. The response of the compressor bypass valve should be confirmed as an adequate surge protection system to ensure long term reliability. The suitability & reliability of surge monitoring instrumentation in a high pressure helium atmosphere should be confirmed.

In conclusion it is recommended that a full scale helium blower loop test be considered to verify various characteristics and aspects of the turbo compressor envisaged for the NGNP to ensure long term reliability."

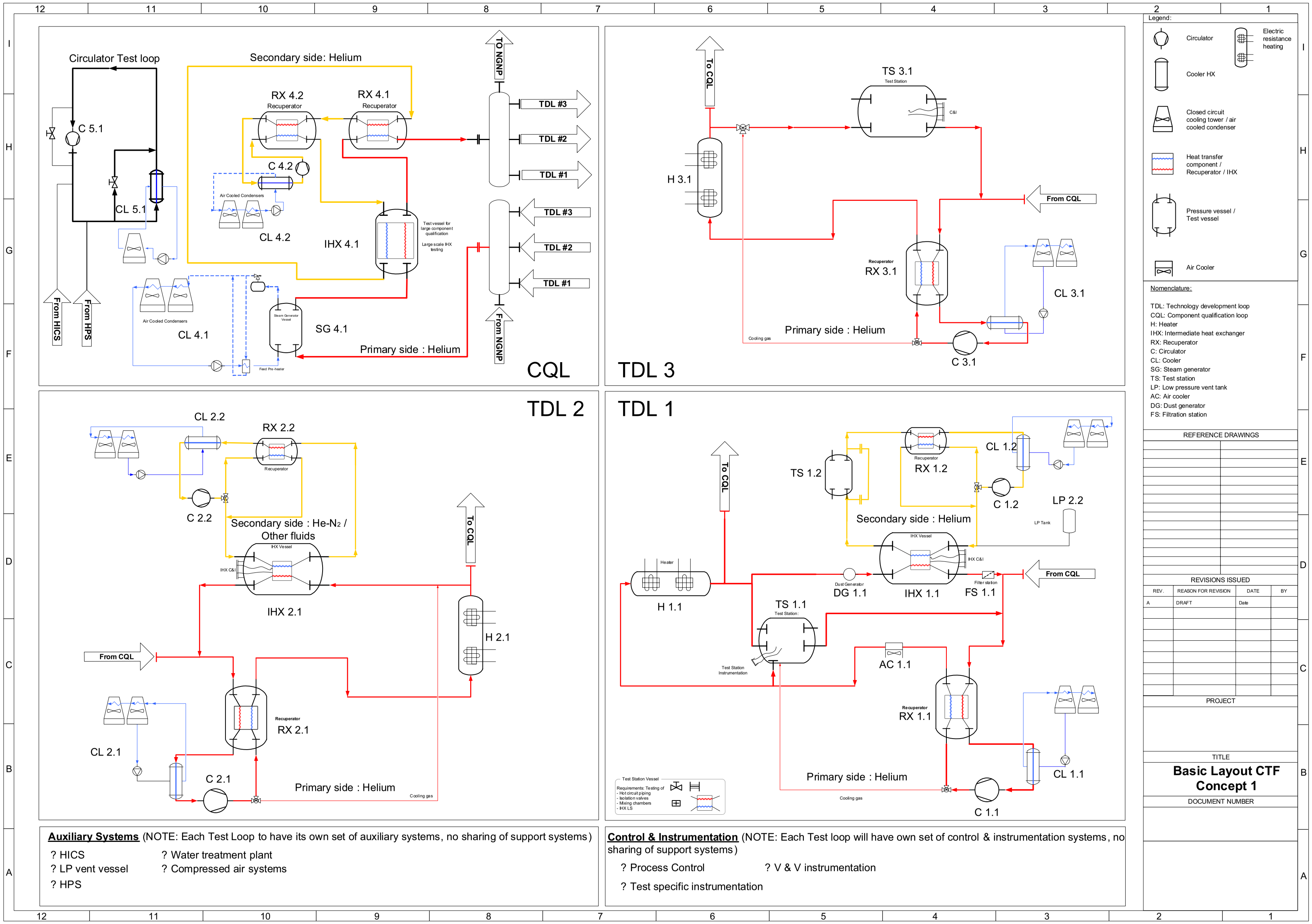
1.6.10 Piping

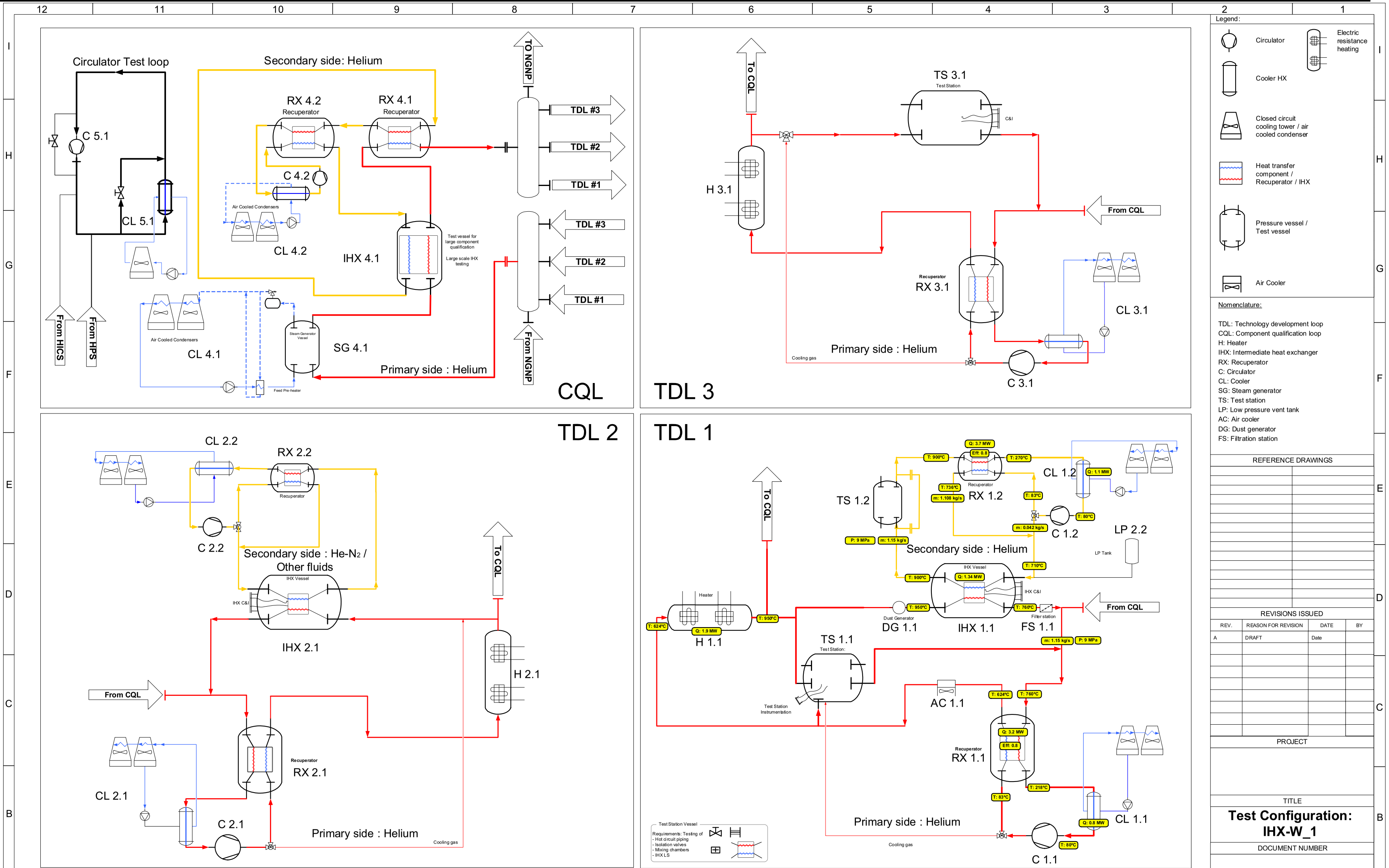
The piping in the circulator loop is required to handle a maximum temperature of 590°C. The option therefore exists for the use of a single (or multiple) stainless steel pipe(s), or a hot pipe design. To limit the maximum flow velocity in the pipe to 80 m/s, a pipe with a flow diameter of 0.7m is required at 590°C, 9 MPa.

1.6.11 Cooler

The cooler in the circulator loop should be able to extract the heat in the fluid produced by the specific circulator. Since various circulators will be tested, the cooler will be required to operate at various operating points. It should therefore be investigated whether a single unit or 2 and more in parallel is more suited to cover the entire operating range specified for the loop once more information on the circulators is available.

2.1 ENERGY BALANCES



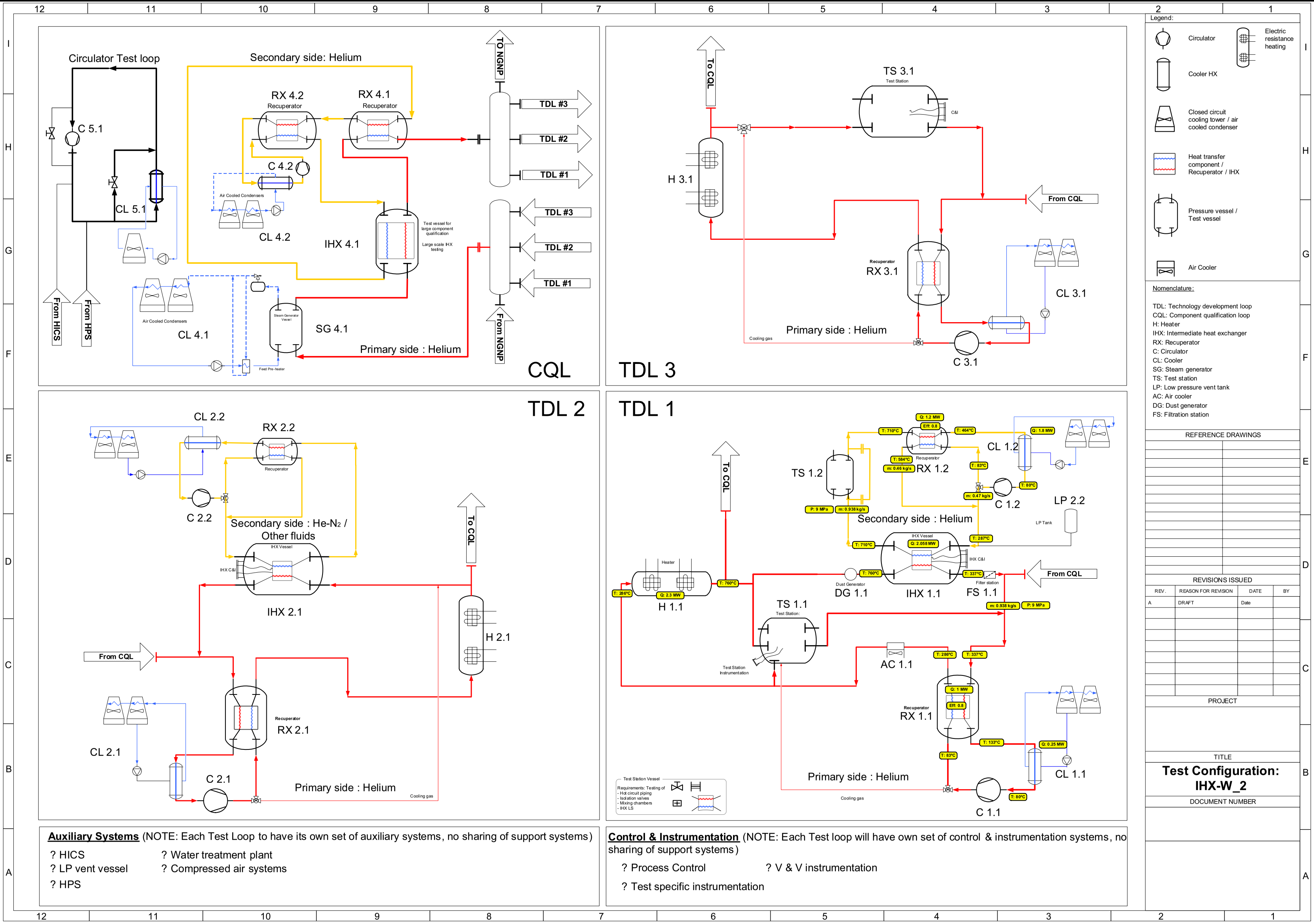


Auxiliary Systems (NOTE: Each Test Loop to have its own set of auxiliary systems, no sharing of support systems)

? HICS
? LP vent vessel
? HPS
? Water treatment plant
? Compressed air systems

Control & Instrumentation (NOTE: Each Test loop will have own set of control & instrumentation systems, no sharing of support systems)

? Process Control
? V & V instrumentation
? Test specific instrumentation


Circulator Test loop
C 5.1
CL 5.1
From HICS
From HPS
Secondary side: Helium
RX 4.2
Recuperator
RX 4.1
Recuperator
C 4.2
CL 4.2
IHX 4.1
Test vessel for large component qualification
Large scale IHX testing
CL 4.1
SG 4.1
Primary side : Helium
TO NGNP
From NGNP
TDL #3
TDL #2
TDL #1
CQL
TDL 3
To CQL
TS 3.1
Test Station
H 3.1
From CQL
Recuperator
RX 3.1
CL 3.1
Primary side : Helium
Cooling gas
C 3.1
TDL 2
CL 2.2
RX 2.2
C 2.2
Secondary side : He-N2 / Other fluids
IHX Vessel
IHX 2.1
To CQL
H 2.1
From CQL
RX 2.1
CL 2.1
C 2.1
Primary side : Helium
TDL 1
To CQL
TS 1.2
RX 1.2
CL 1.2
C 1.2
LP 2.2
LP Tank
Secondary side : Helium
Heater
H 1.1
Dust Generator
DG 1.1
IHX 1.1
Filter station
FS 1.1
From CQL
TS 1.1
Test Station
AC 1.1
Recuperator
RX 1.1
CL 1.1
Primary side : Helium
C 1.1
Legend:
Circulator
Cooler HX
Closed circuit cooling tower / air cooled condenser
Heat transfer component / Recuperator / IHX
Pressure vessel / Test vessel
Air Cooler
Electric resistance heating
Nomenclature:
TDL: Technology development loop
CQL: Component qualification loop
H: Heater
IHX: Intermediate heat exchanger
RX: Recuperator
C: Circulator
CL: Cooler
SG: Steam generator
TS: Test station
LP: Low pressure vent tank
AC: Air cooler
DG: Dust generator
FS: Filtration station
REFERENCE DRAWINGS
REVISIONS ISSUED
REV. REASON FOR REVISION DATE BY
A DRAFT Date
PROJECT
TITLE
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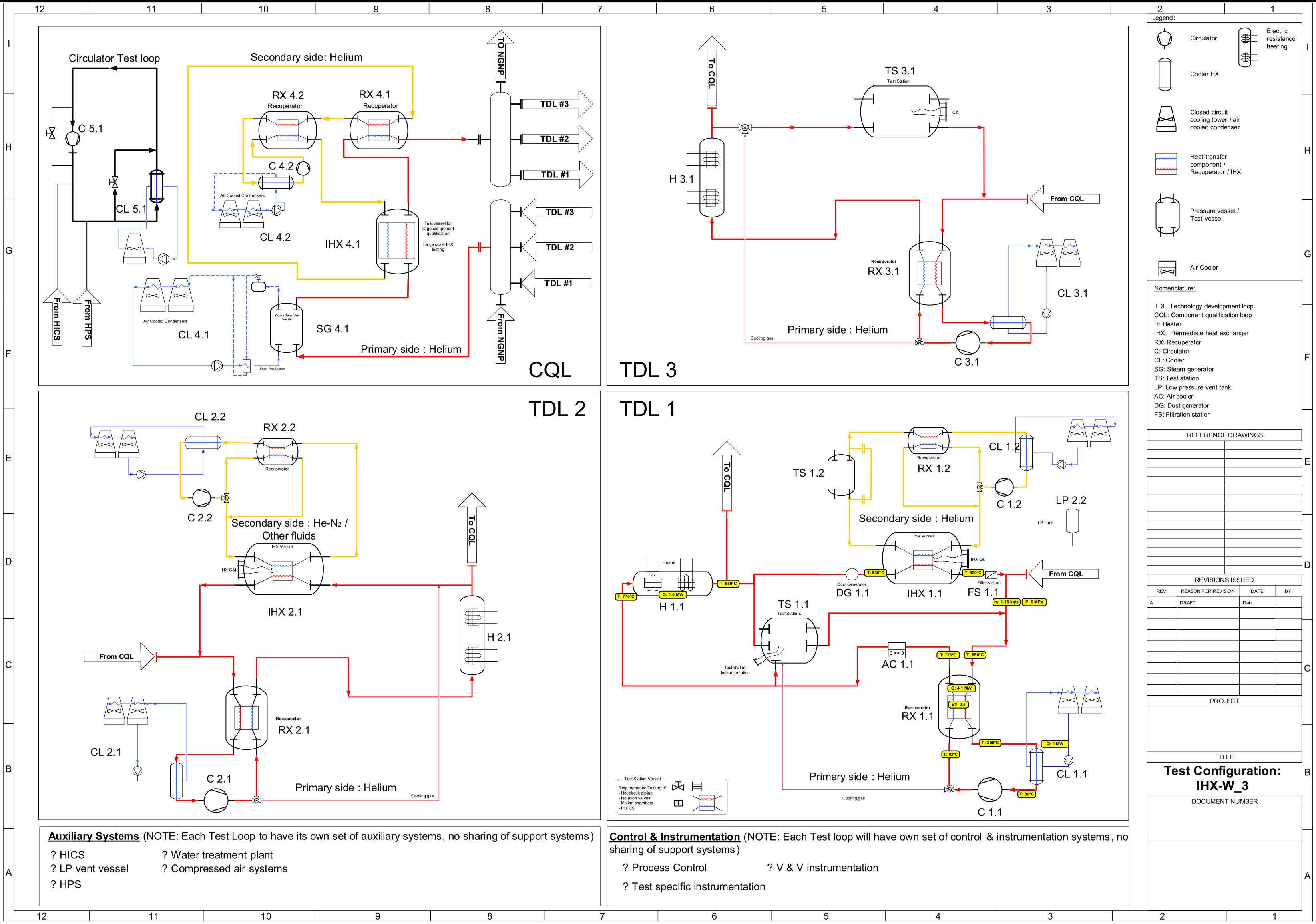
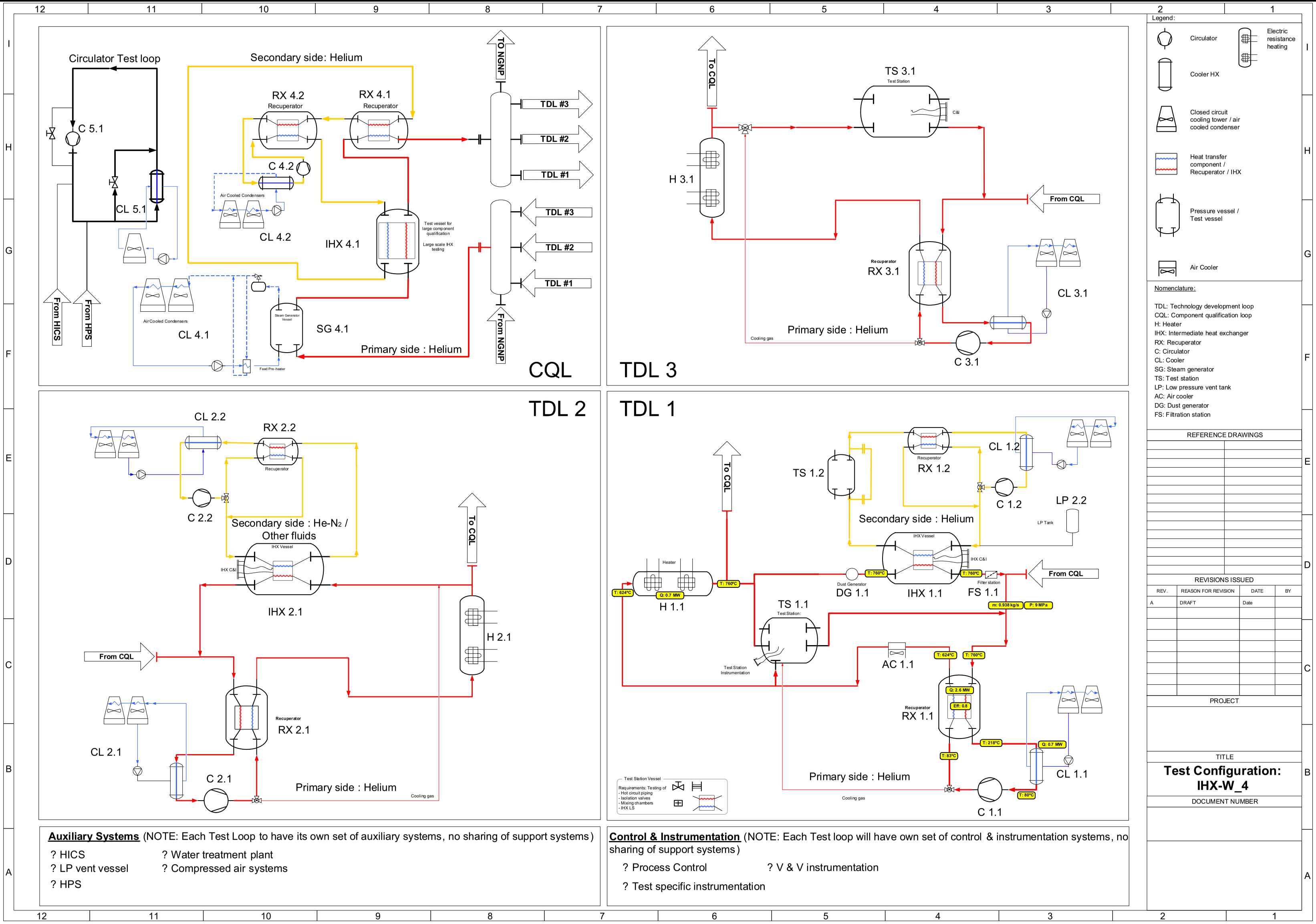
DOCUMENT NUMBER
Auxiliary Systems (NOTE: Each Test Loop to have its own set of auxiliary systems, no sharing of support systems)
? HICS
? LP vent vessel
? HPS
? Water treatment plant
? Compressed air systems
Control & Instrumentation (NOTE: Each Test loop will have own set of control & instrumentation systems, no sharing of support systems)
? Process Control
? V & V instrumentation
? Test specific instrumentation


Legend:
Circulator
Electric resistance heating
Cooler HX
Closed circuit cooling tower / air cooled condenser
Heat transfer component / Recuperator / IHX
Pressure vessel / Test vessel
Air Cooler
Nomenclature:
TDL: Technology development loop
CQL: Component qualification loop
H: Heater
IHX: Intermediate heat exchanger
RX: Recuperator
C: Circulator
CL: Cooler
SG: Steam generator
TS: Test station
LP: Low pressure vent tank
AC: Air cooler
DG: Dust generator
FS: Filtration station
REFERENCE DRAWINGS
REVISIONS ISSUED
REV. REASON FOR REVISION DATE BY
A DRAFT Date
PROJECT
TITLE
Test Configuration: IHX-W_3
DOCUMENT NUMBER
CQL
Circulator Test loop
C 5.1
CL 5.1
From HICS
From HPS
Secondary side: Helium
RX 4.2 Recuperator
RX 4.1 Recuperator
C 4.2
CL 4.2
IHX 4.1
CL 4.1
SG 4.1
Primary side : Helium
TO NGNP
From NGNP
TDL #3
TDL #2
TDL #1
TDL 3
TS 3.1
H 3.1
To CQL
From CQL
RX 3.1
CL 3.1
C 3.1
TDL 2
CL 2.2
RX 2.2
C 2.2
Secondary side : He-N2 / Other fluids
IHX 2.1
H 2.1
From CQL
To CQL
CL 2.1
RX 2.1
C 2.1
TDL 1
TS 1.2
RX 1.2
CL 1.2
C 1.2
LP 2.2
Secondary side : Helium
H 1.1
DG 1.1
IHX 1.1
FS 1.1
TS 1.1
AC 1.1
RX 1.1
CL 1.1
C 1.1
Auxiliary Systems (NOTE: Each Test Loop to have its own set of auxiliary systems, no sharing of support systems)
? HICS
? LP vent vessel
? HPS
? Water treatment plant
? Compressed air systems
Control & Instrumentation (NOTE: Each Test loop will have own set of control & instrumentation systems, no sharing of support systems)
? Process Control
? Test specific instrumentation
? V & V instrumentation


CQL
Circulator Test loop
C 5.1
CL 5.1
From HICS
From HPS
Secondary side: Helium
RX 4.2
Recuperator
RX 4.1
Recuperator
C 4.2
CL 4.2
IHX 4.1
CL 4.1
SG 4.1
Primary side : Helium
TO NGNP
From NGNP
TDL #3
TDL #2
TDL #1
TDL 3
TS 3.1
H 3.1
To CQL
From CQL
RX 3.1
CL 3.1
C 3.1
Primary side : Helium
TDL 2
CL 2.2
RX 2.2
C 2.2
Secondary side : He-N2 / Other fluids
IHX 2.1
H 2.1
To CQL
From CQL
RX 2.1
CL 2.1
C 2.1
Primary side : Helium
TDL 1
TS 1.2
RX 1.2
CL 1.2
C 1.2
LP 2.2
Secondary side : Helium
To CQL
H 1.1
DG 1.1
IHX 1.1
FS 1.1
From CQL
TS 1.1
AC 1.1
RX 1.1
CL 1.1
C 1.1
Primary side : Helium
Legend:
Circulator
Electric resistance heating
Cooler HX
Closed circuit cooling tower / air cooled condenser
Heat transfer component / Recuperator / IHX
Pressure vessel / Test vessel
Air Cooler
Nomenclature:
TDL: Technology development loop
CQL: Component qualification loop
H: Heater
IHX: Intermediate heat exchanger
RX: Recuperator
C: Circulator
CL: Cooler
SG: Steam generator
TS: Test station
LP: Low pressure vent tank
AC: Air cooler
DG: Dust generator
FS: Filtration station
REFERENCE DRAWINGS
REVISIONS ISSUED
REV. REASON FOR REVISION DATE BY
A DRAFT Date
PROJECT
TITLE
Test Configuration: IHX-W_4
DOCUMENT NUMBER
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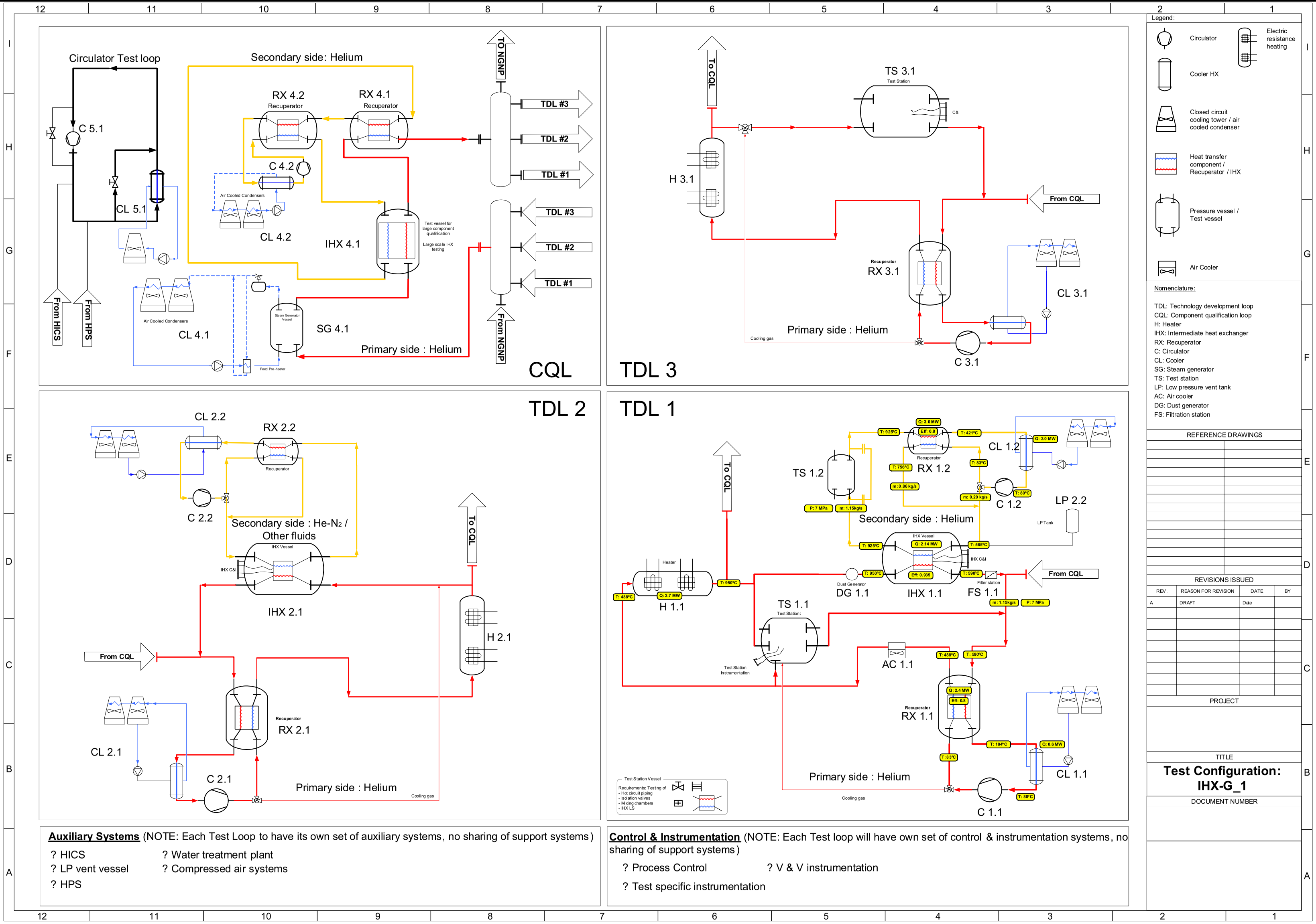
? HICS
? LP vent vessel
? HPS
? Water treatment plant
? Compressed air systems
Control & Instrumentation (NOTE: Each Test loop will have own set of control & instrumentation systems, no sharing of support systems)
? Process Control
? V & V instrumentation
? Test specific instrumentation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Circulator Test loop
Secondary side: Helium
RX 4.2
Recuperator
RX 4.1
Recuperator
C 5.1
C 4.2
CL 5.1
Air Cooled Condensers
CL 4.2
IHX 4.1
Test vessel for large component qualification
Large scale IHX testing
SG 4.1
CL 4.1
Primary side : Helium
From HICS
From HPS
TO NGNP
From NGNP
TDL #3
TDL #2
TDL #1
TDL 3
To CQL
TS 3.1
Test Station
H 3.1
From CQL
RX 3.1
Recuperator
CL 3.1
C 3.1
Primary side : Helium
Cooling gas
TDL 2
CL 2.2
RX 2.2
C 2.2
Secondary side : He-N2 / Other fluids
IHX Vessel
IHX 2.1
To CQL
H 2.1
From CQL
RX 2.1
CL 2.1
C 2.1
Primary side : Helium
TDL 1
To CQL
TS 1.2
RX 1.2
CL 1.2
C 1.2
LP 2.2
LP Tank
Secondary side : Helium
H 1.1
Heater
DG 1.1
Dust Generator
IHX 1.1
FS 1.1
Filter station
From CQL
TS 1.1
Test Station
AC 1.1
RX 1.1
Recuperator
CL 1.1
C 1.1
Primary side : Helium
Auxiliary Systems (NOTE: Each Test Loop to have its own set of auxiliary systems, no sharing of support systems)
? HICS
? LP vent vessel
? HPS
? Water treatment plant
? Compressed air systems
Control & Instrumentation (NOTE: Each Test loop will have own set of control & instrumentation systems, no sharing of support systems)
? Process Control
? V & V instrumentation
? Test specific instrumentation
Legend:
Circulator
Electric resistance heating
Cooler HX
Closed circuit cooling tower / air cooled condenser
Heat transfer component / Recuperator / IHX
Pressure vessel / Test vessel
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DG: Dust generator
FS: Filtration station
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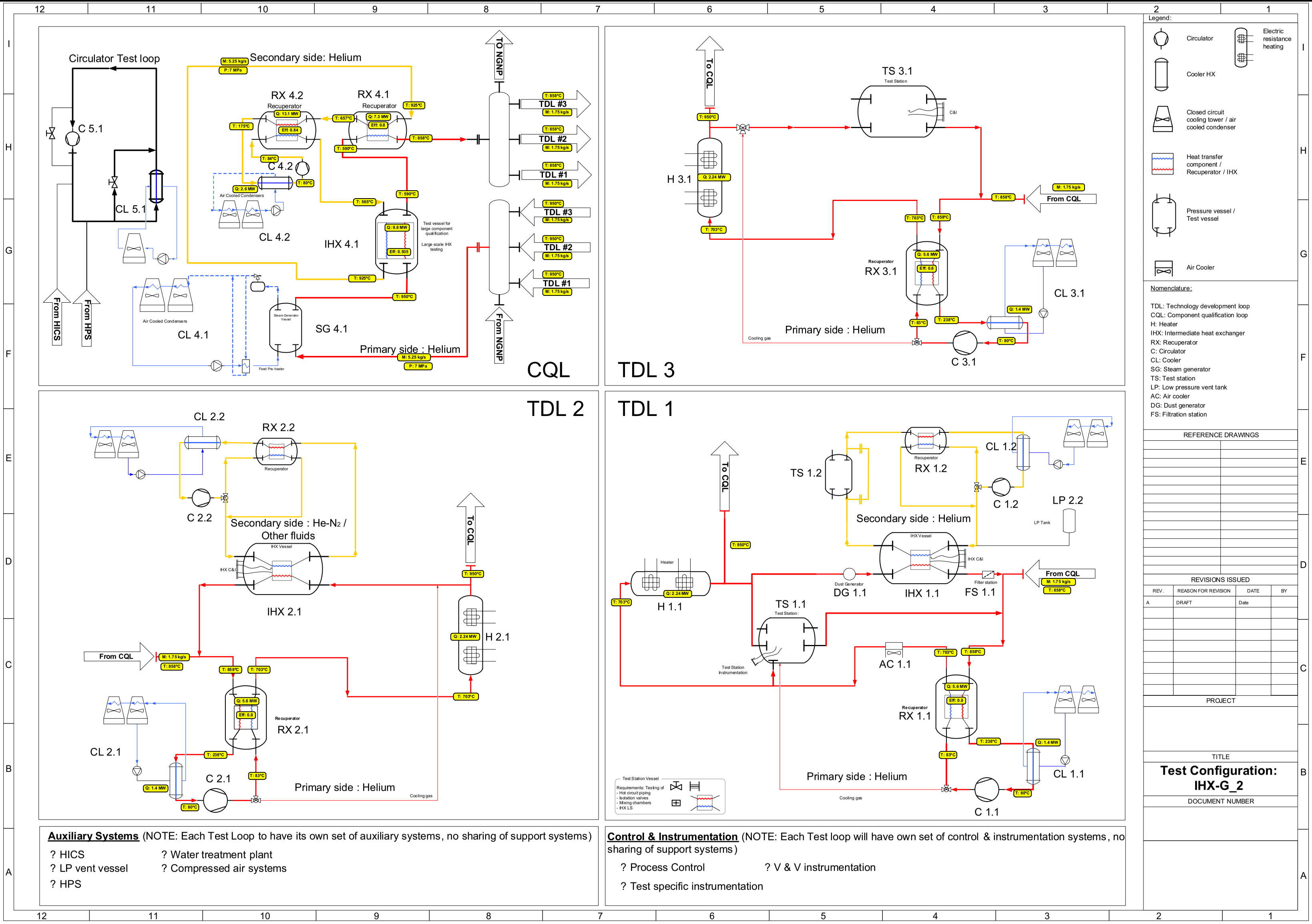
DOCUMENT NUMBER


Legend:
Circulator
Electric resistance heating
Cooler HX
Closed circuit cooling tower / air cooled condenser
Heat transfer component / Recuperator / IHX
Pressure vessel / Test vessel
Air Cooler
Nomenclature:
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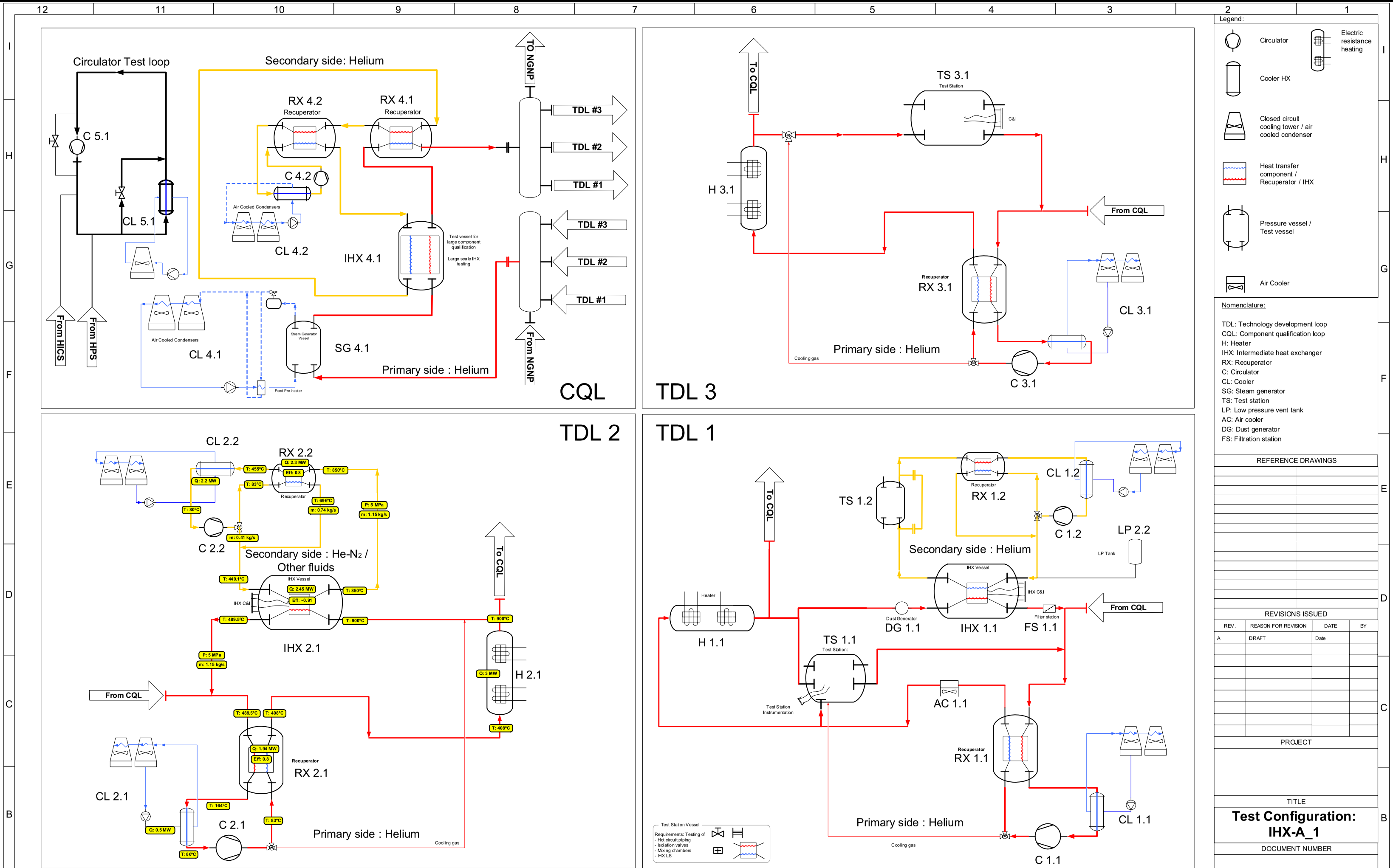
REFERENCE DRAWINGS
REVISIONS ISSUED
REV. REASON FOR REVISION DATE BY
A DRAFT Date
PROJECT
TITLE
Test Configuration:
IHX-G_2
DOCUMENT NUMBER
CQL
Circulator Test loop
C 5.1
CL 5.1
From HICS
From HPS
Secondary side: Helium
RX 4.2
RX 4.1
C 4.2
CL 4.2
IHX 4.1
CL 4.1
SG 4.1
Primary side : Helium
TO NGNP
From NGNP
TDL #1
TDL #2
TDL #3
TDL 3
To CQL
TS 3.1
H 3.1
RX 3.1
From CQL
CL 3.1
C 3.1
Primary side : Helium
TDL 2
CL 2.2
RX 2.2
C 2.2
Secondary side : He-N2 / Other fluids
IHX 2.1
To CQL
H 2.1
From CQL
CL 2.1
RX 2.1
C 2.1
Primary side : Helium
TDL 1
To CQL
TS 1.2
RX 1.2
CL 1.2
C 1.2
LP 2.2
Secondary side : Helium
From CQL
H 1.1
TS 1.1
DG 1.1
IHX 1.1
FS 1.1
AC 1.1
RX 1.1
CL 1.1
C 1.1
Primary side : Helium
Auxiliary Systems (NOTE: Each Test Loop to have its own set of auxiliary systems, no sharing of support systems)
? HICS
? LP vent vessel
? HPS
? Water treatment plant
? Compressed air systems
Control & Instrumentation (NOTE: Each Test loop will have own set of control & instrumentation systems, no sharing of support systems)
? Process Control
? V & V instrumentation
? Test specific instrumentation

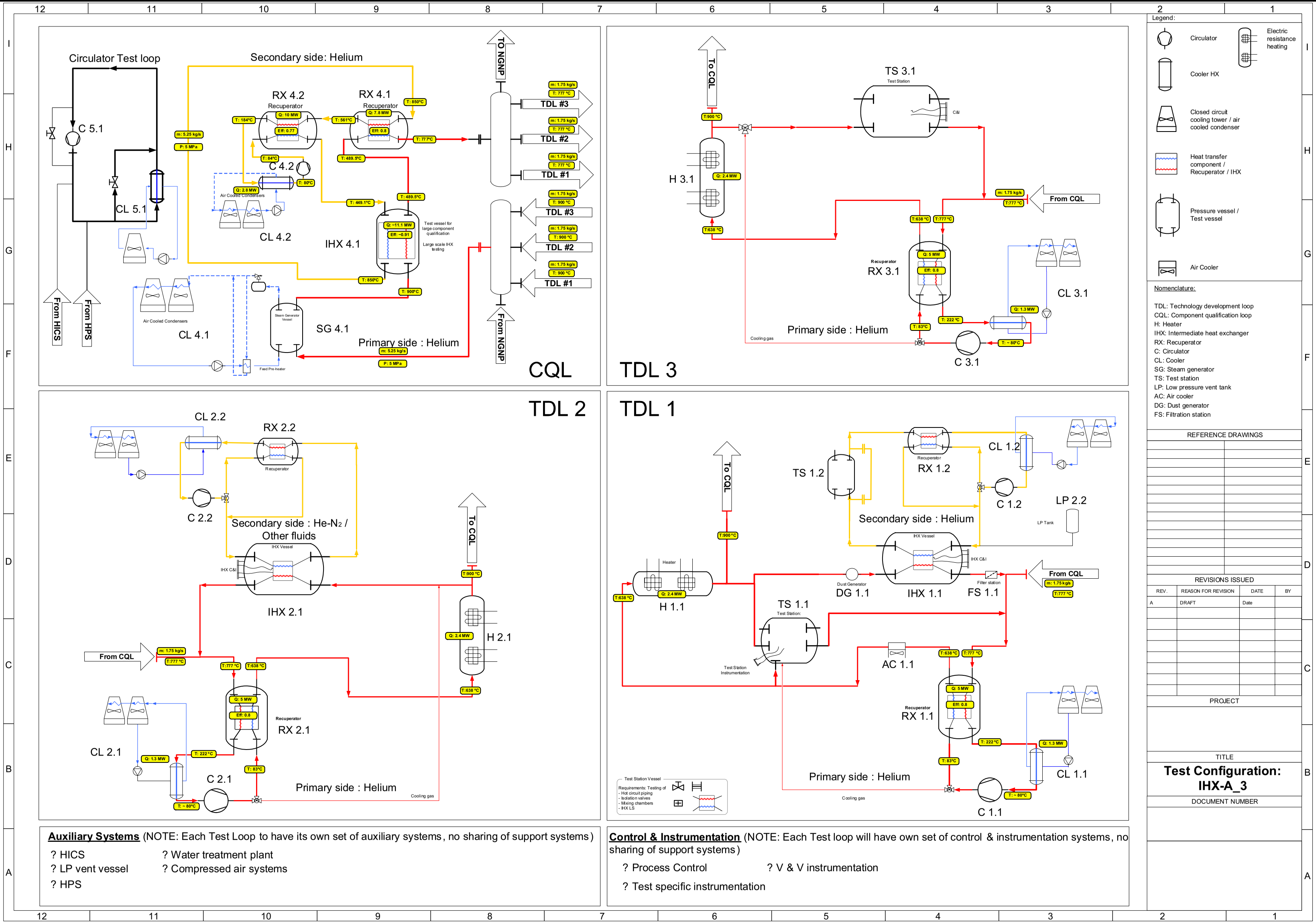


Auxiliary Systems (NOTE: Each Test Loop to have its own set of auxiliary systems, no sharing of support systems)

? HICS
? LP vent vessel
? HPS
? Water treatment plant
? Compressed air systems

Control & Instrumentation (NOTE: Each Test loop will have own set of control & instrumentation systems, no sharing of support systems)

? Process Control
? Test specific instrumentation
? V & V instrumentation


CQL
Circulator Test loop
C 5.1
CL 5.1
From HICS
From HPS
Secondary side: Helium
RX 4.2
Recuperator
RX 4.1
Recuperator
C 4.2
CL 4.2
IHX 4.1
SG 4.1
CL 4.1
Primary side : Helium
TO NGNP
From NGNP
TDL #3
TDL #2
TDL #1
TDL 3
TS 3.1
H 3.1
To CQL
From CQL
RX 3.1
CL 3.1
C 3.1
TDL 2
CL 2.2
RX 2.2
C 2.2
Secondary side : He-N2 / Other fluids
IHX 2.1
To CQL
H 2.1
From CQL
CL 2.1
RX 2.1
C 2.1
TDL 1
To CQL
TS 1.2
RX 1.2
CL 1.2
C 1.2
LP 2.2
Secondary side : Helium
H 1.1
DG 1.1
IHX 1.1
FS 1.1
From CQL
TS 1.1
AC 1.1
RX 1.1
CL 1.1
C 1.1
Legend:
Circulator
Electric resistance heating
Cooler HX
Closed circuit cooling tower / air cooled condenser
Heat transfer component / Recuperator / IHX
Pressure vessel / Test vessel
Air Cooler
Nomenclature:
TDL: Technology development loop
CQL: Component qualification loop
H: Heater
IHX: Intermediate heat exchanger
RX: Recuperator
C: Circulator
CL: Cooler
SG: Steam generator
TS: Test station
LP: Low pressure vent tank
AC: Air cooler
DG: Dust generator
FS: Filtration station
REFERENCE DRAWINGS
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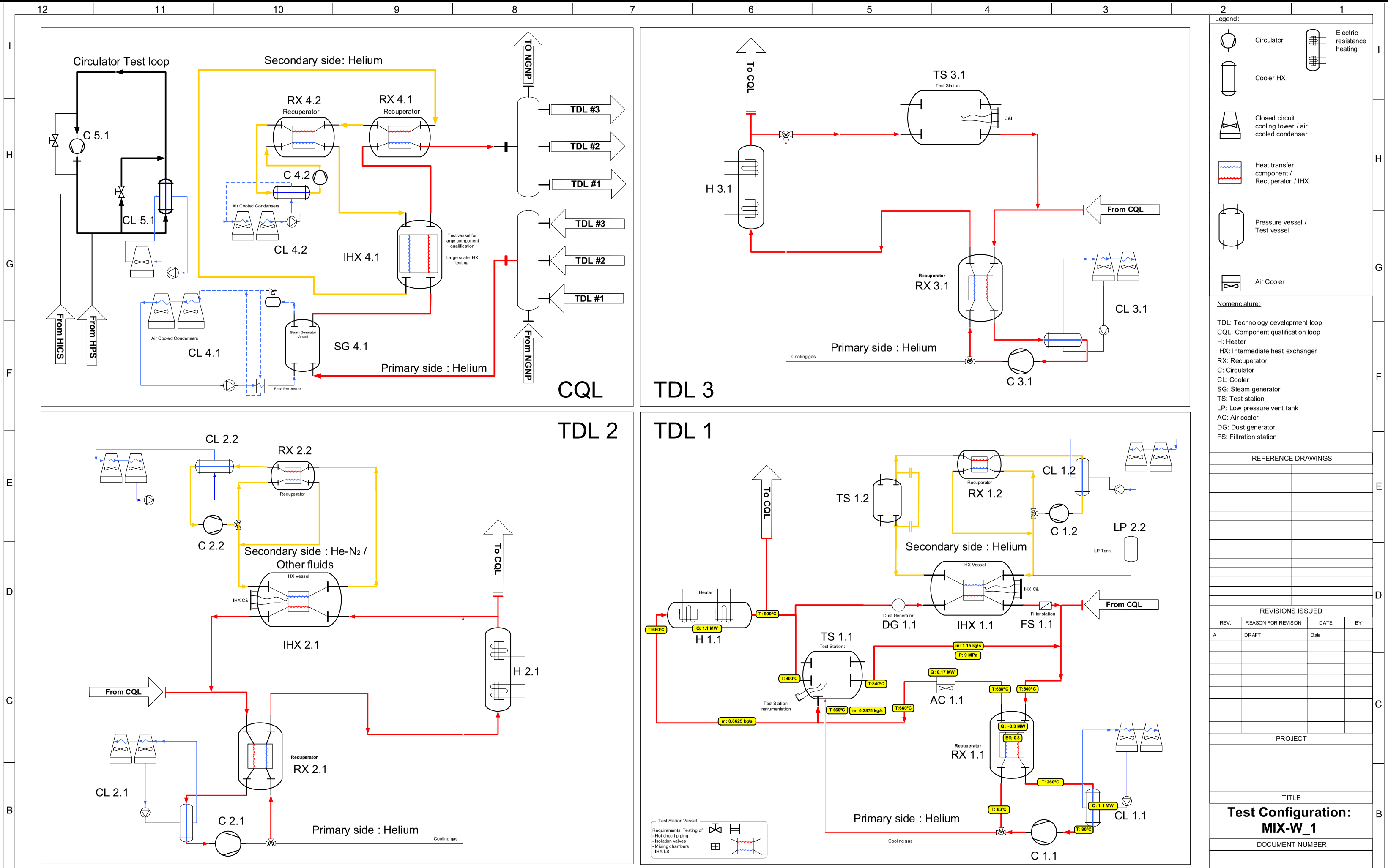
Date
PROJECT
TITLE
Test Configuration: IHX-A_3
DOCUMENT NUMBER
Auxiliary Systems (NOTE: Each Test Loop to have its own set of auxiliary systems, no sharing of support systems)
? HICS
? Water treatment plant
? LP vent vessel
? Compressed air systems
? HPS
Control & Instrumentation (NOTE: Each Test loop will have own set of control & instrumentation systems, no sharing of support systems)
? Process Control
? V & V instrumentation
? Test specific instrumentation

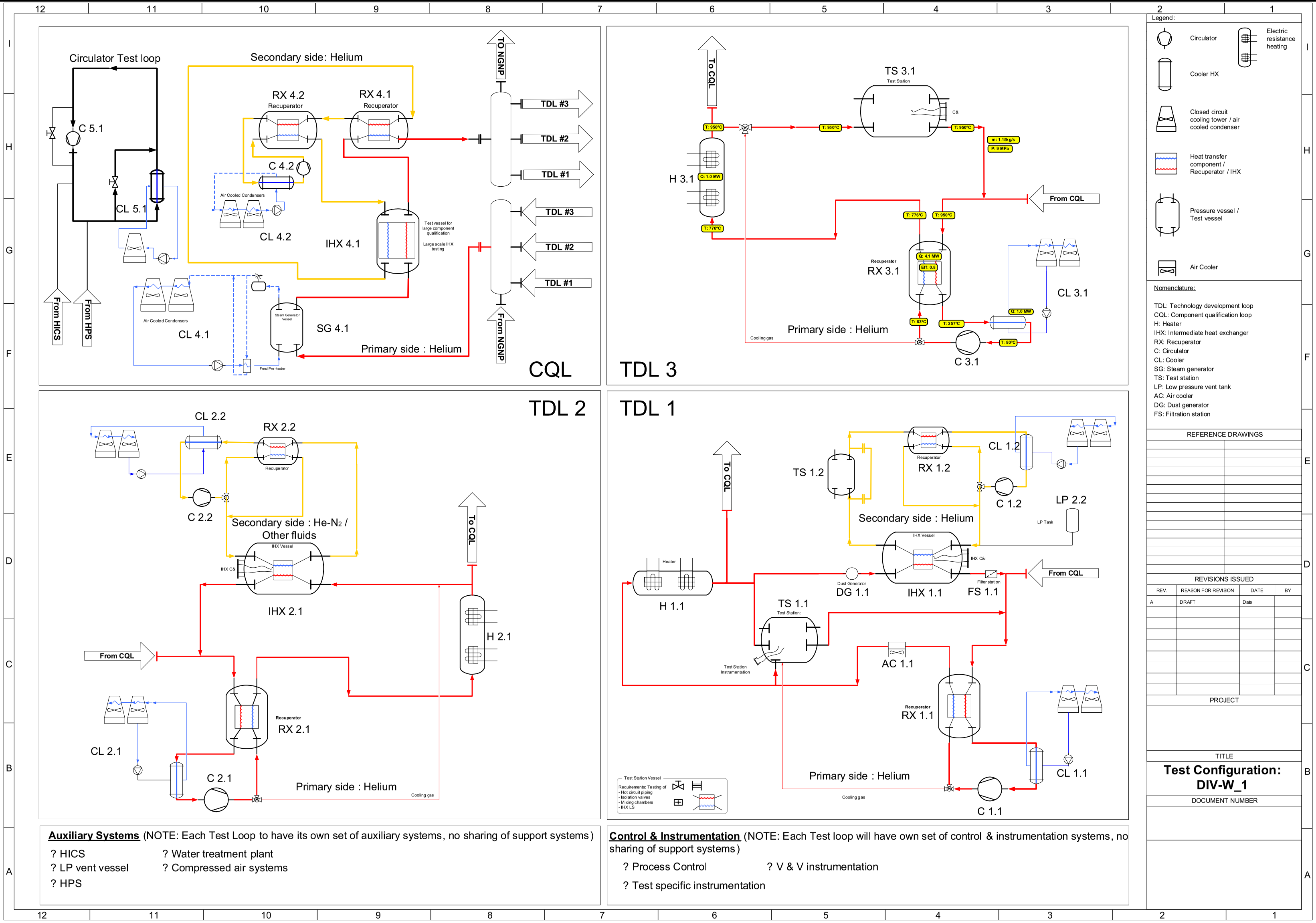


Auxiliary Systems (NOTE: Each Test Loop to have its own set of auxiliary systems, no sharing of support systems)

? HICS
? Water treatment plant
? LP vent vessel
? Compressed air systems
? HPS

Control & Instrumentation (NOTE: Each Test loop will have own set of control & instrumentation systems, no sharing of support systems)

? Process Control
? V & V instrumentation
? Test specific instrumentation


Circulator Test loop
C 5.1
CL 5.1
From HICS
From HPS
Secondary side: Helium
RX 4.2
Recuperator
RX 4.1
Recuperator
C 4.2
CL 4.2
IHX 4.1
SG 4.1
CL 4.1
Primary side : Helium
TO NGNP
From NGNP
TDL #3
TDL #2
TDL #1
CQL
TDL 3
TS 3.1
H 3.1
RX 3.1
CL 3.1
C 3.1
To CQL
From CQL
Primary side : Helium
TDL 2
CL 2.2
RX 2.2
C 2.2
Secondary side : He-N2 /
Other fluids
IHX 2.1
H 2.1
From CQL
To CQL
CL 2.1
RX 2.1
C 2.1
Primary side : Helium
TDL 1
To CQL
TS 1.2
RX 1.2
CL 1.2
C 1.2
LP 2.2
Secondary side : Helium
H 1.1
DG 1.1
IHX 1.1
FS 1.1
From CQL
TS 1.1
AC 1.1
RX 1.1
CL 1.1
C 1.1
Primary side : Helium
Auxiliary Systems (NOTE: Each Test Loop to have its own set of auxiliary systems, no sharing of support systems)
? HICS
? LP vent vessel
? HPS
? Water treatment plant
? Compressed air systems
Control & Instrumentation (NOTE: Each Test loop will have own set of control & instrumentation systems, no sharing of support systems)
? Process Control
? V & V instrumentation
? Test specific instrumentation
Legend:
Circulator
Electric resistance heating
Cooler HX
Closed circuit cooling tower / air cooled condenser
Heat transfer component / Recuperator / IHX
Pressure vessel / Test vessel
Air Cooler
Nomenclature:
TDL: Technology development loop
CQL: Component qualification loop
H: Heater
IHX: Intermediate heat exchanger
RX: Recuperator
C: Circulator
CL: Cooler
SG: Steam generator
TS: Test station
LP: Low pressure vent tank
AC: Air cooler
DG: Dust generator
FS: Filtration station
REFERENCE DRAWINGS
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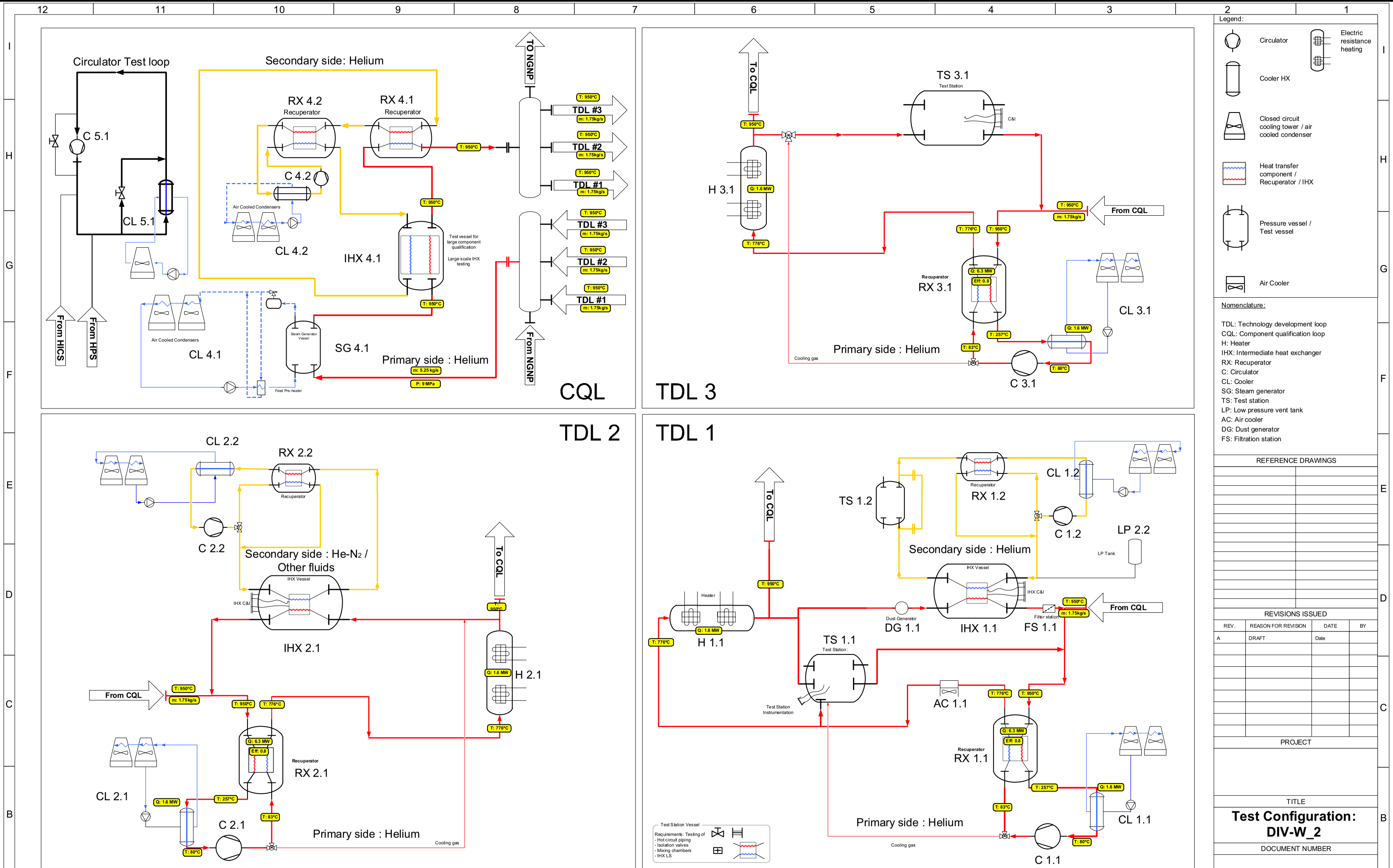
Date
PROJECT
TITLE
Test Configuration:
DIV-W_1
DOCUMENT NUMBER

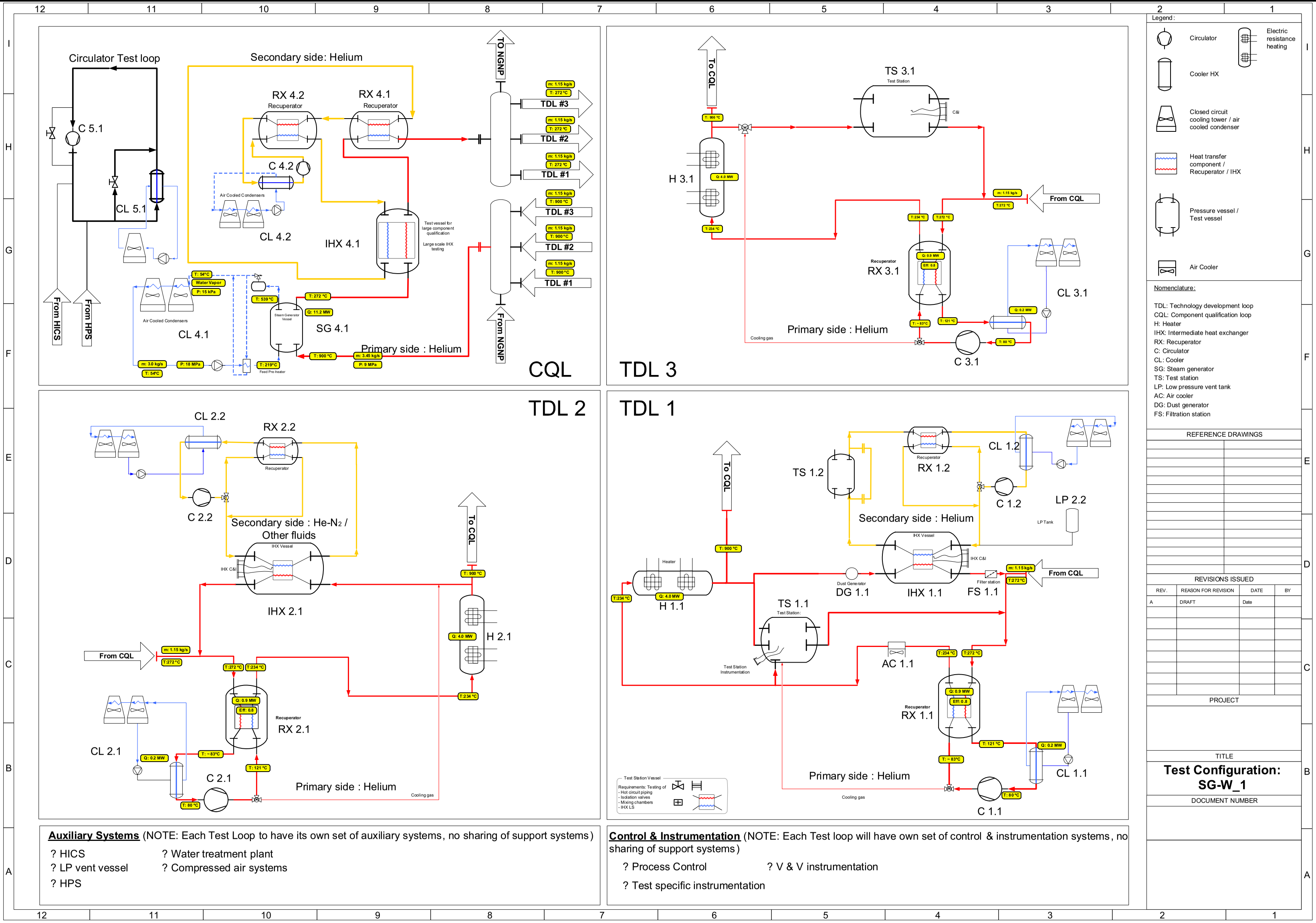


Auxiliary Systems (NOTE: Each Test Loop to have its own set of auxiliary systems, no sharing of support systems)

? HICS
? LP vent vessel
? HPS
? Water treatment plant
? Compressed air systems

Control & Instrumentation (NOTE: Each Test loop will have own set of control & instrumentation systems, no sharing of support systems)

? Process Control
? V & V instrumentation
? Test specific instrumentation


CQL
Circulator Test loop
C 5.1
CL 5.1
From HICS
From HPS
Secondary side: Helium
RX 4.2
Recuperator
RX 4.1
Recuperator
C 4.2
CL 4.2
IHX 4.1
SG 4.1
CL 4.1
Air Cooled Condensers
Primary side : Helium
TO NGNP
From NGNP
TDL #3
TDL #2
TDL #1
TDL 3
TS 3.1
Test Station
To CQL
H 3.1
From CQL
RX 3.1
CL 3.1
C 3.1
Primary side : Helium
Cooling gas
TDL 2
CL 2.2
RX 2.2
C 2.2
Secondary side : He-N2 / Other fluids
IHX 2.1
To CQL
H 2.1
From CQL
RX 2.1
CL 2.1
C 2.1
Primary side : Helium
TDL 1
TS 1.2
RX 1.2
CL 1.2
C 1.2
LP 2.2
Secondary side : Helium
To CQL
H 1.1
DG 1.1
IHX 1.1
FS 1.1
From CQL
TS 1.1
AC 1.1
RX 1.1
CL 1.1
C 1.1
Primary side : Helium
Legend:
Circulator
Electric resistance heating
Cooler HX
Closed circuit cooling tower / air cooled condenser
Heat transfer component / Recuperator / IHX
Pressure vessel / Test vessel
Air Cooler
Nomenclature:
TDL: Technology development loop
CQL: Component qualification loop
H: Heater
IHX: Intermediate heat exchanger
RX: Recuperator
C: Circulator
CL: Cooler
SG: Steam generator
TS: Test station
LP: Low pressure vent tank
AC: Air cooler
DG: Dust generator
FS: Filtration station
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BY
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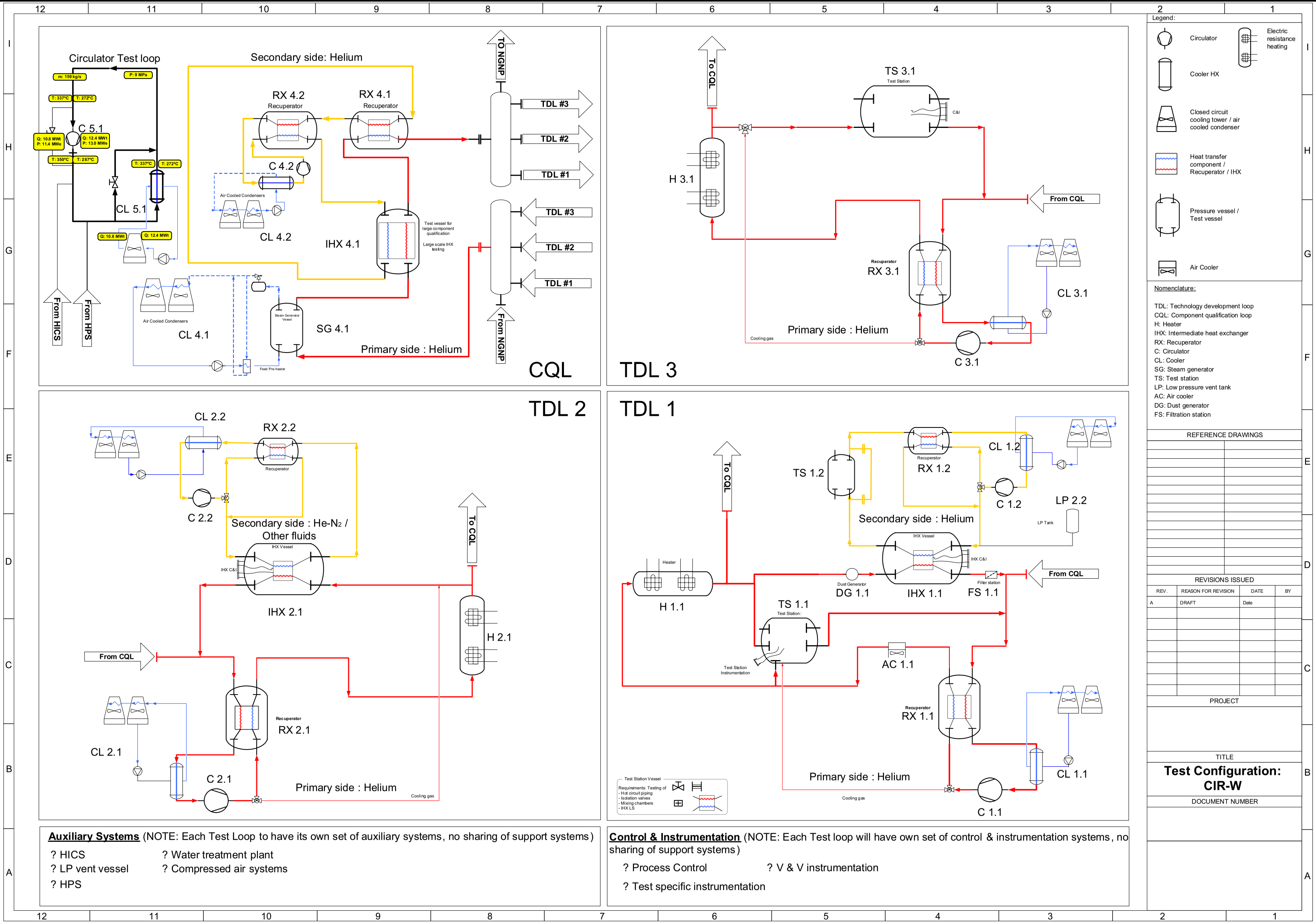
DRAFT
Date
PROJECT
TITLE
Test Configuration: SG-W_1
DOCUMENT NUMBER
Auxiliary Systems (NOTE: Each Test Loop to have its own set of auxiliary systems, no sharing of support systems)
? HICS
? LP vent vessel
? HPS
? Water treatment plant
? Compressed air systems
Control & Instrumentation (NOTE: Each Test loop will have own set of control & instrumentation systems, no sharing of support systems)
? Process Control
? V & V instrumentation
? Test specific instrumentation


Circulator Test loop
C 5.1
CL 5.1
From HICS
From HPS
Secondary side: Helium
RX 4.2
Recuperator
RX 4.1
Recuperator
C 4.2
Air Cooled Condensers
CL 4.2
IHX 4.1
Test vessel for large component qualification
Large scale IHX testing
SG 4.1
CL 4.1
Primary side : Helium
TO NGNP
TDL #3
TDL #2
TDL #1
From NGNP
CQL
TS 3.1
Test Station
H 3.1
To CQL
From CQL
Recuperator
RX 3.1
CL 3.1
Primary side : Helium
Cooling gas
C 3.1
TDL 3
TDL 2
CL 2.2
RX 2.2
Recuperator
C 2.2
Secondary side : He-N2 / Other fluids
IHX Vessel
IHX 2.1
To CQL
H 2.1
From CQL
Recuperator
RX 2.1
CL 2.1
C 2.1
Primary side : Helium
Cooling gas
TDL 1
To CQL
TS 1.2
RX 1.2
CL 1.2
C 1.2
LP 2.2
LP Tank
Secondary side : Helium
IHX Vessel
Heater
H 1.1
DG 1.1
Dust Generator
IHX 1.1
FS 1.1
Filter station
From CQL
TS 1.1
Test Station
Test Station Instrumentation
AC 1.1
Recuperator
RX 1.1
Primary side : Helium
Cooling gas
C 1.1
CL 1.1
Test Station Vessel
Legend:
Circulator
Electric resistance heating
Cooler HX
Closed circuit cooling tower / air cooled condenser
Heat transfer component / Recuperator / IHX
Pressure vessel / Test vessel
Air Cooler
Nomenclature:
TDL: Technology development loop
CQL: Component qualification loop
H: Heater
IHX: Intermediate heat exchanger
RX: Recuperator
C: Circulator
CL: Cooler
SG: Steam generator
TS: Test station
LP: Low pressure vent tank
AC: Air cooler
DG: Dust generator
FS: Filtration station
REFERENCE DRAWINGS
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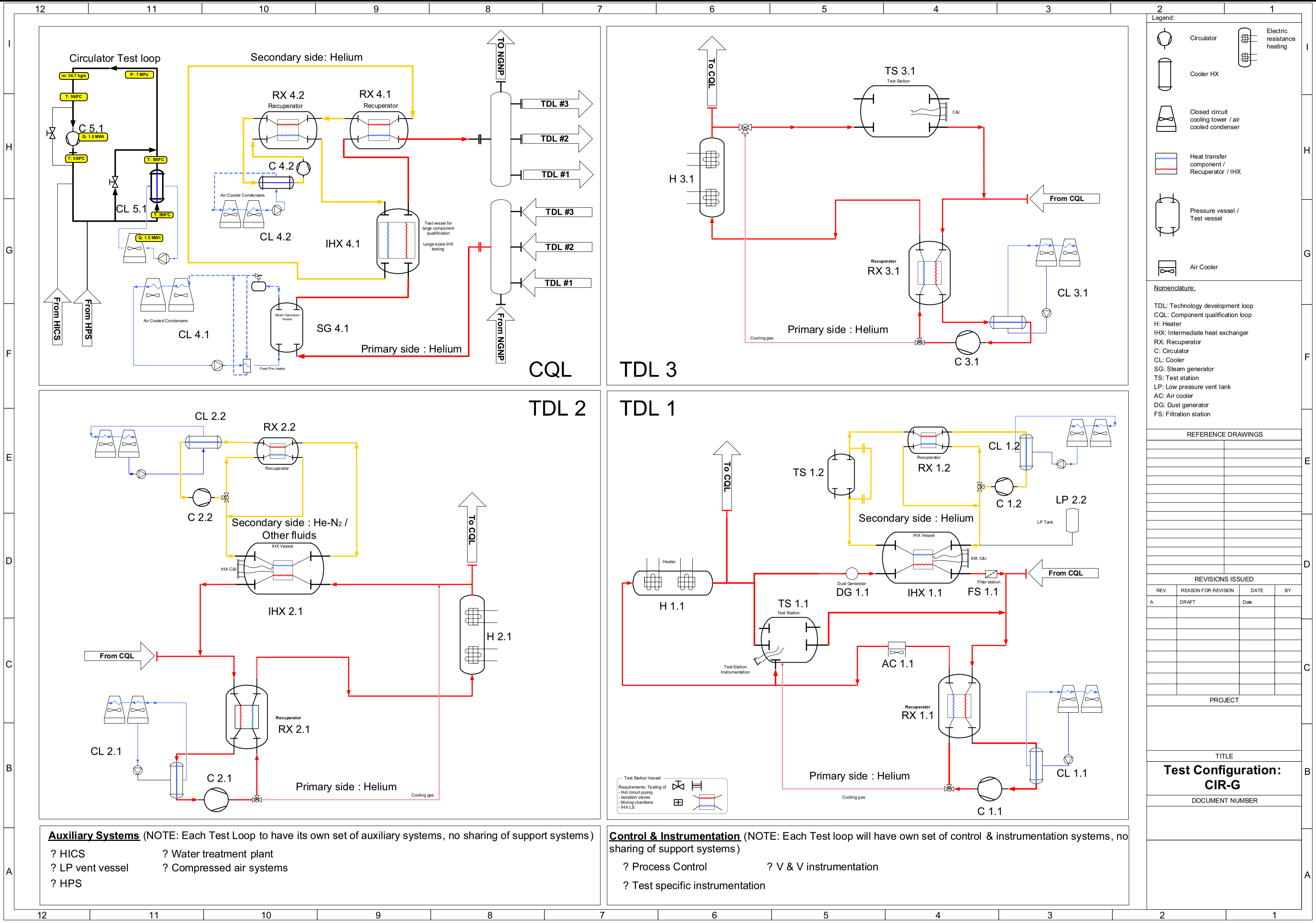
BY
A
DRAFT
Date
PROJECT
TITLE
Test Configuration: CIR-W
DOCUMENT NUMBER
Auxiliary Systems (NOTE: Each Test Loop to have its own set of auxiliary systems, no sharing of support systems)
? HICS
? LP vent vessel
? HPS
? Water treatment plant
? Compressed air systems
Control & Instrumentation (NOTE: Each Test loop will have own set of control & instrumentation systems, no sharing of support systems)
? Process Control
? Test specific instrumentation
? V & V instrumentation


Legend:
Circulator
Electric resistance heating
Cooler HX
Closed circuit cooling tower / air cooled condenser
Heat transfer component / Recuperator / IHX
Pressure vessel / Test vessel
Air Cooler
Nomenclature:
TDL: Technology development loop
CQL: Component qualification loop
H: Heater
IHX: Intermediate heat exchanger
RX: Recuperator
C: Circulator
CL: Cooler
SG: Steam generator
TS: Test station
LP: Low pressure vent tank
AC: Air cooler
DG: Dust generator
FS: Filtration station
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REVISIONS ISSUED
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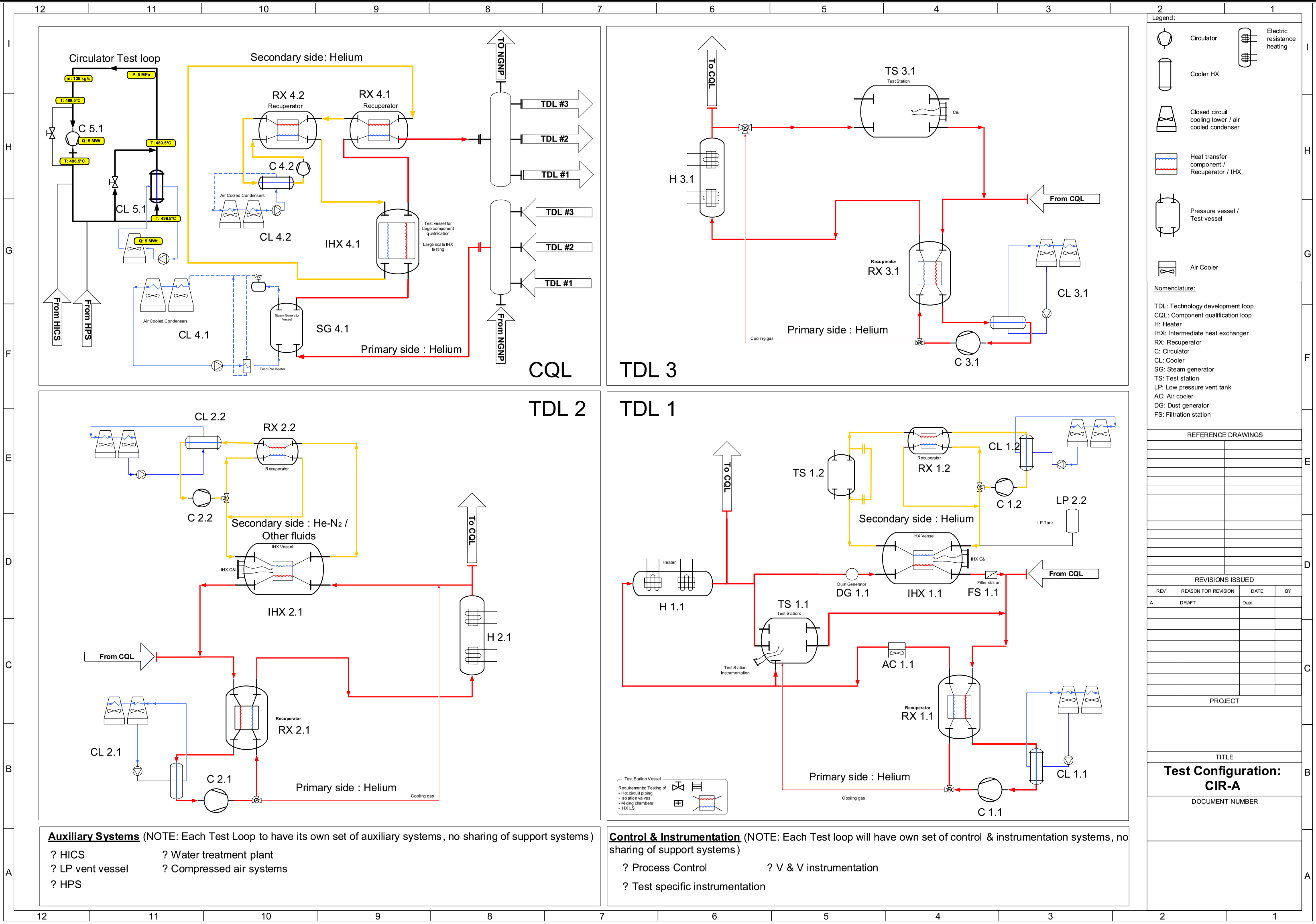
REASON FOR REVISION
DATE
BY
A
DRAFT
Date
PROJECT
TITLE
Test Configuration: CIR-G
DOCUMENT NUMBER
CQL
Circulator Test loop
Secondary side: Helium
RX 4.2
Recuperator
RX 4.1
Recuperator
C 4.2
CL 4.2
IHX 4.1
CL 5.1
C 5.1
SG 4.1
CL 4.1
Primary side : Helium
TO NGNP
From NGNP
TDL #3
TDL #2
TDL #1
From HICS
From HPS
TDL 3
TS 3.1
H 3.1
To CQL
From CQL
RX 3.1
CL 3.1
C 3.1
Primary side : Helium
TDL 2
CL 2.2
RX 2.2
C 2.2
Secondary side : He-N2 / Other fluids
IHX 2.1
H 2.1
To CQL
From CQL
RX 2.1
CL 2.1
C 2.1
Primary side : Helium
TDL 1
To CQL
TS 1.2
RX 1.2
CL 1.2
C 1.2
LP 2.2
Secondary side : Helium
H 1.1
DG 1.1
IHX 1.1
FS 1.1
From CQL
TS 1.1
AC 1.1
RX 1.1
CL 1.1
C 1.1
Primary side : Helium
Auxiliary Systems (NOTE: Each Test Loop to have its own set of auxiliary systems, no sharing of support systems)
? HICS
? LP vent vessel
? HPS
? Water treatment plant
? Compressed air systems
Control & Instrumentation (NOTE: Each Test loop will have own set of control & instrumentation systems, no sharing of support systems)
? Process Control
? V & V instrumentation
? Test specific instrumentation


CQL
Circulator Test loop
C 5.1
CL 5.1
From HICS
From HPS
Secondary side: Helium
RX 4.2
Recuperator
RX 4.1
Recuperator
C 4.2
CL 4.2
Air Cooled Condensers
IHX 4.1
SG 4.1
CL 4.1
Primary side : Helium
TO NGNP
From NGNP
TDL #3
TDL #2
TDL #1
TDL 3
To CQL
TS 3.1
Test Station
H 3.1
From CQL
Recuperator
RX 3.1
CL 3.1
C 3.1
Primary side : Helium
Cooling gas
TDL 2
CL 2.2
RX 2.2
Recuperator
C 2.2
Secondary side : He-N2 / Other fluids
IHX Vessel
IHX 2.1
To CQL
H 2.1
From CQL
CL 2.1
RX 2.1
C 2.1
Primary side : Helium
Cooling gas
TDL 1
To CQL
TS 1.2
RX 1.2
CL 1.2
C 1.2
LP 2.2
LP Tank
Secondary side : Helium
IHX Vessel
H 1.1
Heater
DG 1.1
Dust Generator
IHX 1.1
FS 1.1
Filter station
From CQL
TS 1.1
Test Station
Test Station Instrumentation
AC 1.1
Recuperator
RX 1.1
CL 1.1
C 1.1
Primary side : Helium
Cooling gas
Test Station Vessel
Legend:
Circulator
Electric resistance heating
Cooler HX
Closed circuit cooling tower / air cooled condenser
Heat transfer component / Recuperator / IHX
Pressure vessel / Test vessel
Air Cooler
Nomenclature:
TDL: Technology development loop
CQL: Component qualification loop
H: Heater
IHX: Intermediate heat exchanger
RX: Recuperator
C: Circulator
CL: Cooler
SG: Steam generator
TS: Test station
LP: Low pressure vent tank
AC: Air cooler
DG: Dust generator
FS: Filtration station
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DRAFT
Date
PROJECT
TITLE
Test Configuration: CIR-A
DOCUMENT NUMBER
Auxiliary Systems (NOTE: Each Test Loop to have its own set of auxiliary systems, no sharing of support systems)
? HICS
? LP vent vessel
? HPS
? Water treatment plant
? Compressed air systems
Control & Instrumentation (NOTE: Each Test loop will have own set of control & instrumentation systems, no sharing of support systems)
? Process Control
? V & V instrumentation
? Test specific instrumentation

APPENDIX E CONCEPT 2 DETAILS

1.1 TEST CONFIGURATIONS

In order to provide a recommendation with regards to facility envelope sizes, a number of different test configurations were imposed on Concept 2. These test configurations are summed up in Table 1, and were evaluated by means of energy balances to determine component sizing. A complete summary of these energy balances, together with general considerations per test configuration can be found in at the end of this appendix. The “TEST#” column in Table 1 corresponds with the “DOCUMENT NUMBER” on the energy balance sheet.

Table 1: Summary of Test Configurations in Concept 2 as Dictated by the DDNs

Test #	Main Test Configuration	Sub Test	Loop
IHX- 1	**IHX Performance verification tests:** WEC Core A & B	Steady state	Primary / Secondary
DIV- 1	**High temperature ducts & insulation performance verification test**)	Steady state	Secondary
SG-1	**Steam generator performance verification test:** WEC	Steady state	Steam generator testing loop
CIR-W	**Circulator performance:** WEC	Steady state	Circulator loop

The enveloping values for each loop, from these test configurations and the energy balances, will be presented in the following section.

1.1.1 Concept 2 – Primary Side

The primary loop of Concept 2 is very similar to the primary side of the TDLs of Concept 1. Helium is circulated at a maximum rate of 25 kg/s with two 650 kW circulators (C1.1 & 1.2) while the other main components include large scale electrical heaters (H 1.1), double vessel test stations (TS 1.1) as well as the IHX test station vessels (IHX 1.1 & 1.2). Figure 1 illustrates the primary loop, with the maximum component values following thereafter.

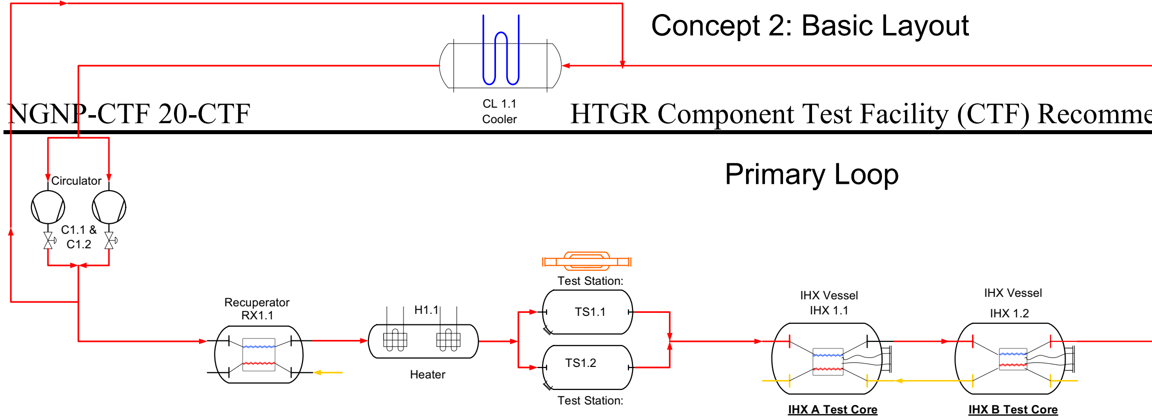


Figure 1: High Level Process Flow Diagram of Concept 2 Primary Side

Table 2: Enveloping Values of the Primary Side of Concept 2

Concept 2 – Primary side							
No.	**Components**	**Power [MW]**	**Mass flow rate [kg/s] - MAX**	**T_in [°C]**	**T_out [°C]**	**Pressure**	**Fluid**
C 1.1 & 1.2	Circulator (ΔP: 500 kPa @ 9 MPa)	1.9	25	250[max]	-	9 MPa (Calculations based only on 9 MPa)	Pure Helium
RX 1.1	Recuperator (Hot side)	68 [max]	25	925 [max]	394 [max]		
RX 1.1	Recuperator (Cold side)		25	~ 263 [max]	793 [max]		
H 1.1	Heater	23	25	793 [max]	950 [max]		
TS 1.1	Vessel - Test Station	N/A	25	950 [min]	950 [max]		
IHX 1.1	Heat exchanger Vessel (primary)	N/A	25	950 [max]	950 [max]		
CL 1.1	Cooler	19	25	396 [max]	250 [nom]		
PD 1.1	Pipe & Ducting	N/A	25	950 [max]			

1.1.2 Concept 2 – Secondary Side

The secondary side of Concept 2 is again similar to that of the TDL's of Concept 1 and is will be used during IHX testing. This loop also has two test vessels, apart from the IHX test vessels and could be used for concurrent testing of non heat transfer components. A simplified PFD of the secondary loop is illustrated in Figure 2, while the component values follow thereafter.

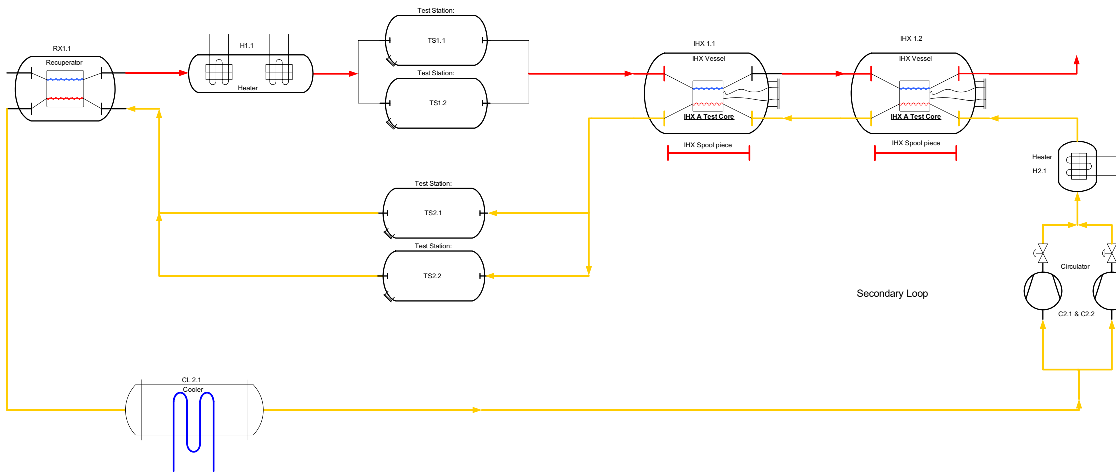


Figure 2: High Level Process Flow Diagram of Concept 2 Secondary Side

Table 3: Enveloping Values of the Secondary Side of Concept 2

Concept 2 – Secondary side							
No.	**Components**	**Power [MW]**	**Mass flow rate [kg/s] - MAX**	**T_in [°C]**	**T_out [°C]**	**Pressure**	**Fluid**
C 2.1 & 2.2	Circulator (ΔP: 500 kPa @ 9 MPa)	1.9	25	250[max]	-	9 MPa (Calculations based only on 9 MPa)	Pure Helium
H 2.1	Heater	3.1	25	263 [max]	287 [max]		
TS 2.1	Vessel - Test Station	N/A	25	950 [min]	950 [max]		
CL 2.1	Cooler	18.2	25	390 [max]	250 [nom]		

1.1.3 Concept 2 – Steam Generator Loop

The steam generator loop is a separate loop which extends the primary loop for specific steam generator testing. This separate loop will provide representative steam producing capabilities on the water side of the steam generator with the required condensing capabilities.

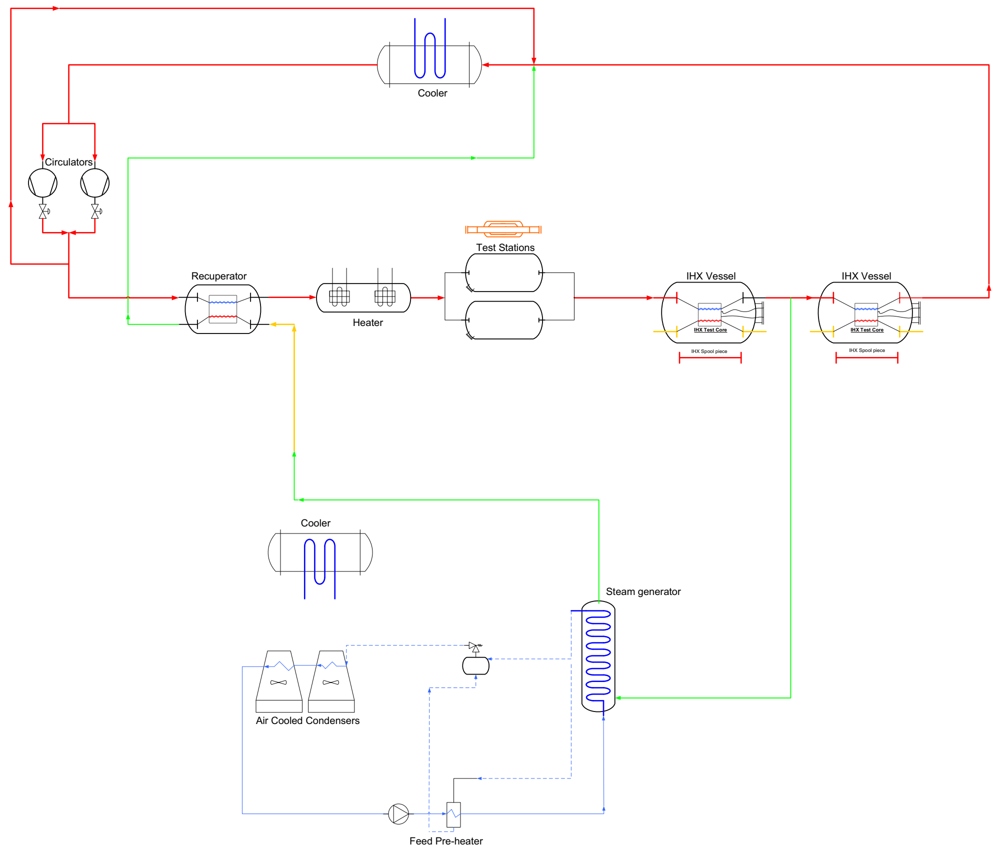


Figure 3: High Level Process Flow Diagram of Concept 2 in the Steam Generator Configuration

Table 4: Enveloping Values Maximum Steam Generator Testing Capability

Concept 2 – Secondary side							
No.	**Components**	**Power [MW]**	**Mass flow rate [kg/s] - MAX**	**T_in [°C]**	**T_out [°C]**	**Pressure**	**Fluid**
SG	Unit under test	23.2	7.15	900 [max]	272 [max]	9 MPa (Calculations based only on 9 MPa)	Pure Helium
CL 3.1	Cooler	17	6.23 (Water)	54 (vapor) [max]	54 (liquid) [nom]	18 MPa	Water

Details regarding the specific components that are proposed for each of these loops will be provided in the component descriptions.

1.1.4 Full Scale Circulator Loop

A circulator testing loop is purposed again to address full scale testing requirements of different circulator designs as in Concept 1. This separate loop is mainly proposed as part of the philosophy of not having two or more components under test in a single test configuration. A typical arrangement is shown in Figure 4, with a summary of the main components in Table 5.

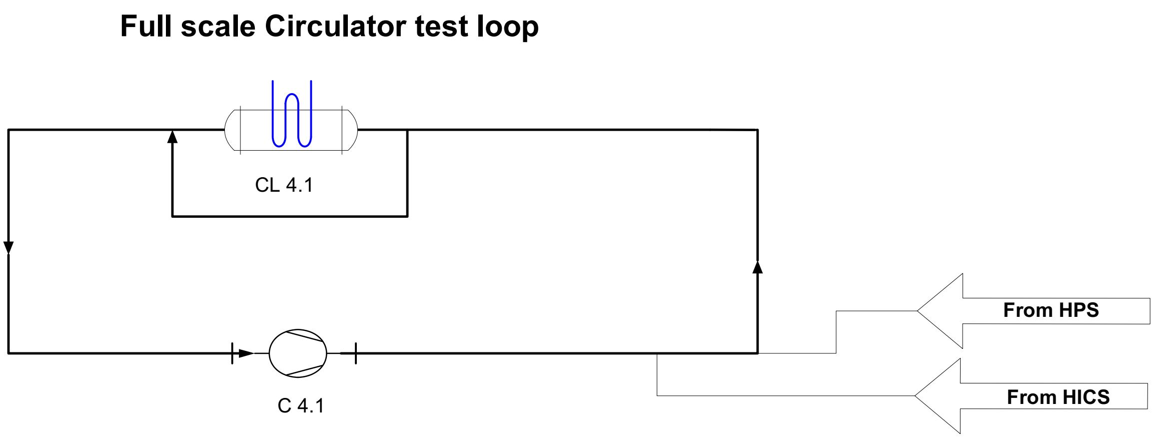


Figure 4: High Level Process Flow Diagram of the Full Scale Circulator Test Loop

Table 5: Enveloping Values of the Full Scale Circulator Test Loop

Circulator test loop							
No.	**Components**	**Power [MW]**	**Mass flow rate [kg/s] - MAX**	**T_in [°C]**	**T_out [°C]**	**Pressure**	**Fluid**
C 4.1	Circulator: Unit under test	12.4 MWt [max]	159.6 [max]	337 [max]	-	9 MPa	Helium.
CL 5.1	Cooler	12.4 [max]	159.6 [max]	350 [max]	337 [min]		
PD 5.1	Pipe & Ducting	N/A	159.6 [max]	350 [max]			

1.2 COMPONENT DESCRIPTIONS

This section provides a general description and recommendations for future work on the different components and sub systems of Concept 2.

1.2.1 Circulators

The Circulators used for Concept 2 employ the same philosophy as for the TDLs. However, the circulators for Concept 2 require research and development during design and are therefore not COTS items. For the same reason, two full flow circulators are employed, with one used for redundancy. A single stage high-speed circulator is the preferred option with an oil bearing and seal combination as in the case of the TDL circulators. The Circulator must circulate Helium at a process flow rate of 25kg/s. Allowance should be made for a bypass of at least 15% of the process flow to account for Surge Control. It is estimated that a pressure drop of 450 kPa is required, which gives a pressure ratio of 1.05 at an inlet total pressure of 9.0 MPa. It is therefore critical that the piping and associated components have a low pressure drop. If a higher pressure ratio is required, a multi-stage radial or axial circulator will be required. The estimated driver power is 1.6 MW.

The proposed circulator layout is typically a Howden submerged motor circulator with AMBs that is modified to accommodate oil bearing or dry gas seals. The approach is to utilize a highly reliable product for the test loop, but provide flexibility in introducing new developed product such as submerged motor circulators with AMBs.

1.2.2 Heater Unit

The Heater Unit for Concept 2 employs a similar philosophy as for the TDLs. The heater will however, be divided into two units which use various smaller heaters placed in series in the two pressure vessels. The heaters are also electrically powered with thyristor control. The pressure vessel is thermally insulated from the high temperature gas, as well as protected against heating element radiation. The heater unit is installed in a vertical position with the gas flowing in an upwards direction. The heater has a typical inlet temperature of 700°C and an outlet temperature of 950°C. Each heater has a flow rate of 12.5 kg/s.

Each heater vessel has an estimated size of Ø of 2.5m, a height of 8m and weighs approximately 120 metric tons.

1.2.3 Pressure Boundary

Hot Pipes (T_{Helium}>550°C)

The hot-pipes will be of a similar design and construction as those developed in Germany for the high temperature gas cooled reactor program. It also follows the PBMR approach.

The construction is made up of an inner gas guiding tube, thermally well insulated, with a gap between the actual pressure pipe and this insulated inner pipe (similar to the TDL design). This gap is thermally conditioned by forced convection of cooling gas provided by an independent circulator system.

A maximum flow tube diameter of 0.35 m is calculated at a nominal flow rate of 25 kg/s and a flow velocity of 80 m/s at 950°C, 9 MPa. The pressure boundary dimensions are to be determined once a detail calculation has been done regarding the insulation material, but is estimated at approximately 1.0 – 1.2 m with active cooling. The pressure boundary section should make provision for instrumentation connection points which can be used to monitor the pressure and temperature levels in the hot pipe. The hot pipes should be designed to be pressure balanced across the flow tube and the possibility of isolating these two sides from each other should be investigated and could assist in the purification processes. A typical section length of 5m is foreseen. As a result of the high cost of this pipe, the physical layout should be done sensitively to keep the total length of this item to a minimum. The governing philosophy for the hot pipes is to make them as short as possible, have no valves located in them, have no compensators in them but rather compensate in the cold pipes and have minimal bends except when the bends are actually used for compensating purposes.

Cold Pipes (T_{Helium}<350°C)

It is recommended that all the cold pipes are manufactured from carbon steel, such as ASME A106 Gr B.

The use of carbon steel would reduce the total cost of the facility but the risk of corrosion of the piping in periods when the facility is open for maintenance, test setups and/or repair is increased. Tradeoff studies need to be performed in the Intermediate design phase to weigh financial and long term life contamination issues due to rust, etc. A maximum pipe flow diameter of 0.25 m is calculated at a nominal flow rate of 25 kg/s and a flow velocity of 80 m/s at 350°C, 9 MPa. The effect of erosion of the inner surface of the pipe should be investigated at these very high flow velocities.

1.2.4 Valves

The layout of the process loop was carefully done to eliminate the need for valves. Valves operating in a high temperature helium environment are not readily available commercially and must be developed for the specific application. Some tests that are done in parallel might require the use of valves for helium flow control. Bellow-sealed valves (bellow on the stem) are the best option for helium applications. Rotational valve stems require a different sealing concept. Multi-stage wet oil/grease seals will successfully seal off the high pressure helium against leaks to atmosphere (10^{-5}mbar.l/ sec per stem can be achieved). The actuation can be by pneumatic or electric actuators.

1.2.5 Test Vessels

The test of specific full size components or representative size components for the NGNP required custom "designed-for" test vessels. The test loop provides space and the necessary interfaces for a few high-pressure test setups. The design of the test vessels should allow for Human Factors (HF), seeing that these vessels will be used extensively for different UUT setups that require adequate space for maneuverability and internal piping. These vessels must be thermally conditioned by a thermal conditioning system. The temperature of the vessels should preferably be low enough to eliminate any thermal insulation.

Provision is made for three test setups. Two dedicated test vessels are provided, one being vertically oriented and one horizontally oriented. The third setup allows the vendors to connect directly to the process loop via a "test spool piece". The test spool piece is a UUT and can typically be a component such as a hot pipe design, etc.

Even though one can only use a single test vessel at a time, vendors will be able to do three simultaneous setups during plant outage. The selection between different test setups can then be done by minor configuration changes without necessarily shutting down the plant.

The envisaged size of the horizontal test vessel has an inner diameter of approximately of 2.0m and a length of 15m. The vertical test vessel's inner diameter is approximately 2.0m with a height of 5m. A distance of 15m is available between the process connections to connect UUTs via a "test spool piece".

1.2.6 Heat Transfer Components

Recuperator

The recuperator unit in the loop is used to recover the energy input of the Heater units after the UUTs. To ensure that the process loops' design integrity is one level higher than the units under test, requires that conventional type recuperators be used.

In the event where tests are conducted and little or no heat is rejected by the test components such as valve tests and hot ducts and insulation tests, the inlet temperature of the recuperator can reach 900°C. It is recommended to use a COTS conventional type recuperator to ensure that the reliability of the loop is a level higher than that of the test components.

It should be investigated whether it would be possible to use a Helical Tubular Heat Exchanger. The layout will be in such a manner that the pressure retaining sections, e.g., the shell, will be at acceptable temperatures. The sections subjected to the very high temperatures will be of special alloys. The maximum possible heat transfer is approximately 68MW assuming a conservative effectiveness of 80%. The maximum required flow rate in the loop is 25 kg/s. A first order estimate of the size of the recuperator is a vessel with approximate dimensions of a diameter of 3m and a length of 20m. The shell thickness will be in the order of 140 mm, with a total weight of 260 metric tons.

Another possibility would be to use a Helical Tubular Exchanger in conjunction with a compact heat exchanger. The Helical Tubular Exchanger is used to recuperate the high temperature portion of energy whilst the compact heat exchanger exchanges the lower temperature heat. This should reduce the overall size of the recuperator section with associated savings on the required pressure vessel as well.

1.2.7 Heat Sink Requirements

Coolers

The primary loop requires that the fluid be cooled from 400°C to 250°C before entering the circulator. The high inlet temperature requires the use of an air-cooled Helium cooler. The required maximum duty of the cooler at a nominal flow rate of 25 kg/s is 19 MW. A first order estimate of the size of the cooler is approximately 10.0m x 4.0m x 0.5m. The cooler uses 10 axial flow fans to supply the required air flow rate of 150 kg/s. All the fans will be equipped with variable speed drives to control the helium outlet temperature.

1.2.8 Helium Inventory Control System

The helium inventory control system (HICS) of this loop will be similar to the TDL's of Concept 1. The loop allows for the storage of the total inventory of the main and secondary loops of the test facility. Eight vessels of a capacity 125 m^3 should be installed inside or outside of the main building. These vessels should be designed according to ASME VIII division 1 and could be manufactured from carbon steel. They have a diameter of 3 meters and a height of 18 meters. Tradeoff studies need to be performed during the Preliminary design to determine the cost implication of investing in hardware such as the Helium Storage Vessels and the cost of loss-of-inventory.

The Helium compressor has a larger flow capacity than that of the TDLs. A single stage positive displacement compressor with a pumping capacity to pump down the test loop to at least 5kPa in less than 24 hours is recommended. This compressor is also used to provide high-pressure helium for pressure control purposes. A typical membrane type compressor is preferred because of low leaking characteristics.

1.2.9 Helium Purification System

The Helium Purification System (HPS) of Concept 2 will be similar in operation to the HPS of the TDL but an order of magnitude larger. The purification take off flow rate will approximately be less than 0.5% of the process flow rate.

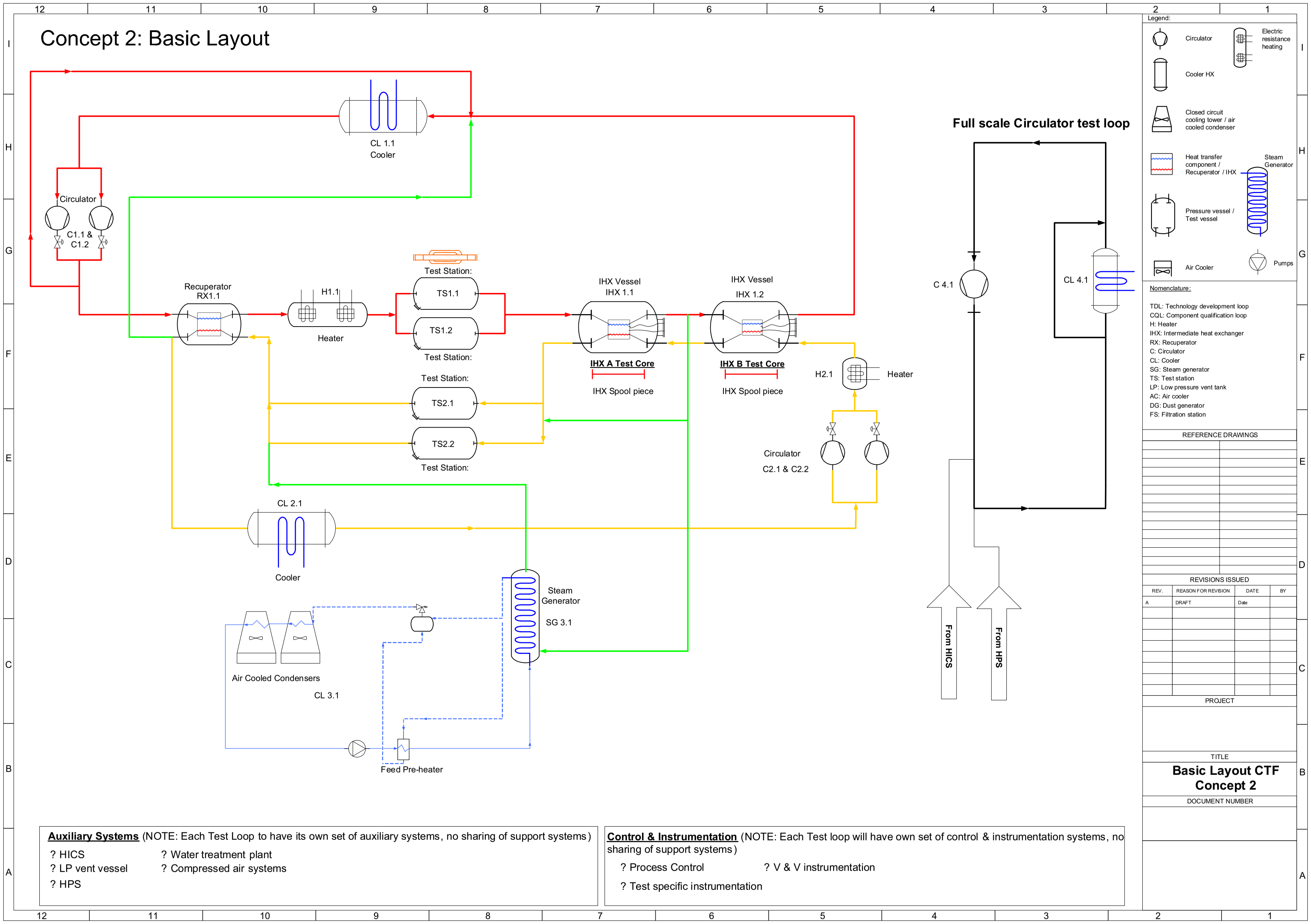
1.2.10 Control and Instrumentation

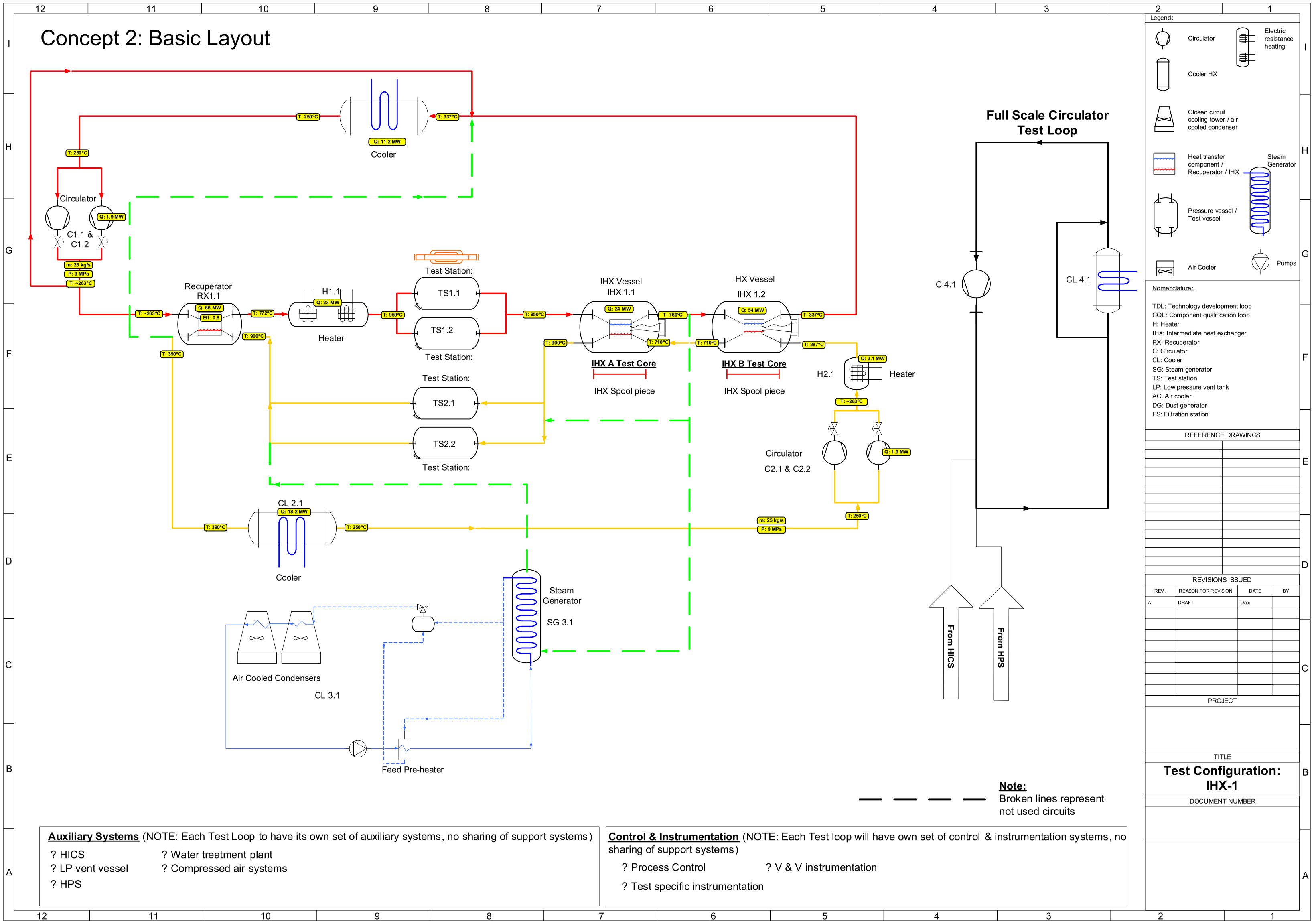
The same Control and Instrumentation (C&I) philosophy is used as in Concept 1, except that the number of I/O's will have an increased number of electrical loads.

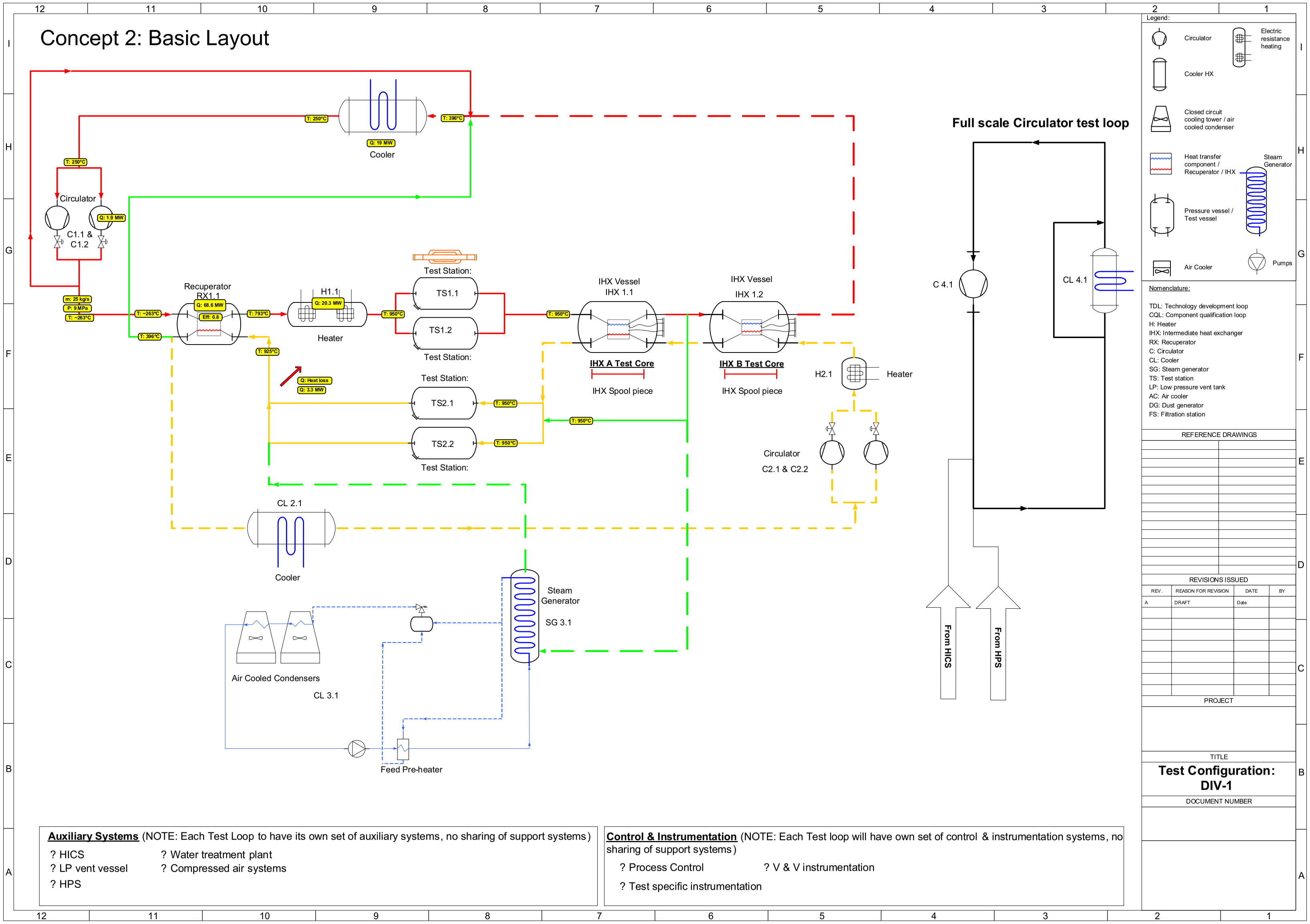
1.2.11 Circulator Test Loop

The Circulator Test loop is identical to that of Concept 1.

2.1 ENERGY BALANCES




Concept 2: Basic Layout
Cooler
Circulator
C1.1 & C1.2
Recuperator
RX1.1
H1.1
Heater
Test Station:
TS1.1
TS1.2
Test Station:
Test Station:
TS2.1
TS2.2
Test Station:
IHX Vessel
IHX 1.1
IHX A Test Core
IHX Spool piece
IHX Vessel
IHX 1.2
IHX B Test Core
IHX Spool piece
H2.1
Heater
Circulator
C2.1 & C2.2
CL 2.1
Cooler
Steam Generator
SG 3.1
Air Cooled Condensers
CL 3.1
Feed Pre-heater
Full Scale Circulator Test Loop
C 4.1
CL 4.1
From HICS
From HPS
Note:
Broken lines represent not used circuits
Auxiliary Systems (NOTE: Each Test Loop to have its own set of auxiliary systems, no sharing of support systems)
? HICS
? LP vent vessel
? HPS
? Water treatment plant
? Compressed air systems
Control & Instrumentation (NOTE: Each Test loop will have own set of control & instrumentation systems, no sharing of support systems)
? Process Control
? Test specific instrumentation
? V & V instrumentation
Legend:
Circulator
Electric resistance heating
Cooler HX
Closed circuit cooling tower / air cooled condenser
Heat transfer component / Recuperator / IHX
Steam Generator
Pressure vessel / Test vessel
Air Cooler
Pumps
Nomenclature:
TDL: Technology development loop
CQL: Component qualification loop
H: Heater
IHX: Intermediate heat exchanger
RX: Recuperator
C: Circulator
CL: Cooler
SG: Steam generator
TS: Test station
LP: Low pressure vent tank
AC: Air cooler
DG: Dust generator
FS: Filtration station
REFERENCE DRAWINGS
REVISIONS ISSUED
PROJECT
TITLE
Test Configuration:
IHX-1
DOCUMENT NUMBER



Concept 2: Basic Layout
Full scale Circulator test loop
Cooler
Circulator
C1.1 & C1.2
Recuperator RX1.1
H1.1
Heater
Test Station:
TS1.1
TS1.2
TS2.1
TS2.2
IHX Vessel IHX 1.1
IHX Vessel IHX 1.2
IHX A Test Core
IHX B Test Core
IHX Spool piece
H2.1
Circulator C2.1 & C2.2
CL 2.1
Steam Generator
SG 3.1
Air Cooled Condensers
CL 3.1
Feed Pre-heater
C 4.1
CL 4.1
From HICS
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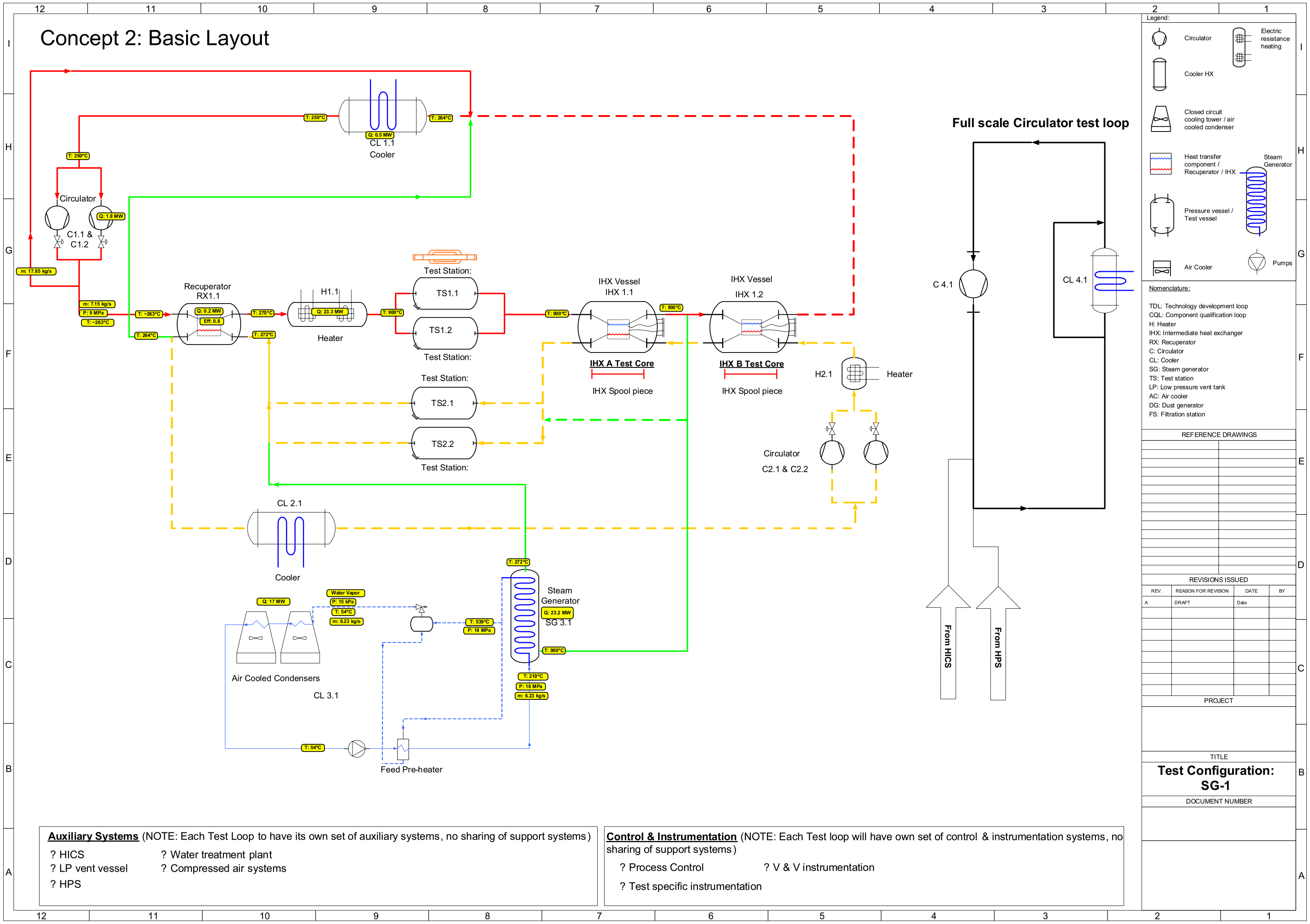
REFERENCE DRAWINGS
REVISIONS ISSUED
REV. REASON FOR REVISION DATE BY
A DRAFT Date
PROJECT
TITLE
Test Configuration: DIV-1
DOCUMENT NUMBER
Auxiliary Systems (NOTE: Each Test Loop to have its own set of auxiliary systems, no sharing of support systems)
? HICS
? LP vent vessel
? HPS
? Water treatment plant
? Compressed air systems
Control & Instrumentation (NOTE: Each Test loop will have own set of control & instrumentation systems, no sharing of support systems)
? Process Control
? Test specific instrumentation
? V & V instrumentation


Concept 2: Basic Layout
CL 1.1
Cooler
Circulator
C1.1 &
C1.2
Recuperator
RX1.1
H1.1
Heater
Test Station:
TS1.1
TS1.2
Test Station:
Test Station:
TS2.1
TS2.2
Test Station:
IHX Vessel
IHX 1.1
IHX Vessel
IHX 1.2
IHX A Test Core
IHX B Test Core
IHX Spool piece
IHX Spool piece
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Heater
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SG 3.1
Air Cooled Condensers
CL 3.1
Feed Pre-heater
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C 4.1
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FS: Filtration station
REFERENCE DRAWINGS
REVISIONS ISSUED
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DATE
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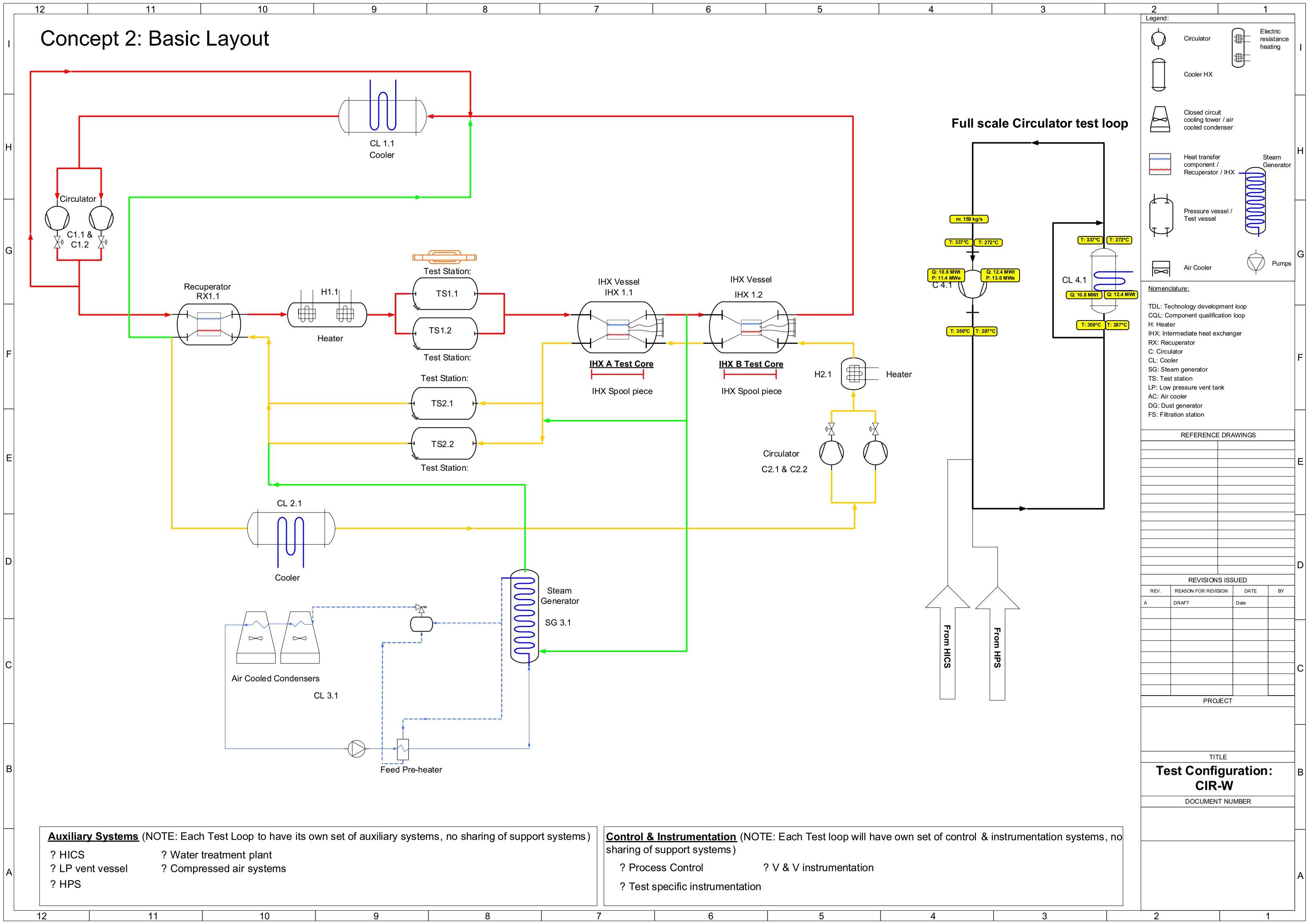
Date
PROJECT
TITLE
Test Configuration:
SG-1
DOCUMENT NUMBER
Auxiliary Systems (NOTE: Each Test Loop to have its own set of auxiliary systems, no sharing of support systems)
? HICS
? LP vent vessel
? HPS
? Water treatment plant
? Compressed air systems
Control & Instrumentation (NOTE: Each Test loop will have own set of control & instrumentation systems, no sharing of support systems)
? Process Control
? Test specific instrumentation
? V & V instrumentation


Concept 2: Basic Layout
CL 1.1
Cooler
Circulator
C1.1 & C1.2
Recuperator
RX1.1
H1.1
Heater
Test Station:
TS1.1
TS1.2
Test Station:
Test Station:
TS2.1
TS2.2
Test Station:
IHX Vessel
IHX 1.1
IHX A Test Core
IHX Spool piece
IHX Vessel
IHX 1.2
IHX B Test Core
IHX Spool piece
H2.1
Heater
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CL 3.1
Feed Pre-heater
Full scale Circulator test loop
m: 159 kg/s
C 4.1
CL 4.1
From HICS
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REFERENCE DRAWINGS
REVISIONS ISSUED
REV.
REASON FOR REVISION
DATE
BY
A
DRAFT
Date
PROJECT
TITLE
Test Configuration:
CIR-W
DOCUMENT NUMBER
Auxiliary Systems (NOTE: Each Test Loop to have its own set of auxiliary systems, no sharing of support systems)
? HICS
? LP vent vessel
? HPS
? Water treatment plant
? Compressed air systems
Control & Instrumentation (NOTE: Each Test loop will have own set of control & instrumentation systems, no sharing of support systems)
? Process Control
? Test specific instrumentation
? V & V instrumentation

APPENDIX F - DDNS TEST CONFIGURATIONS

No:	Main Test Configuration	Sub Test	Description
1.	**IHX Performance verification tests:** (*Steady-state tests to verify design, material and thermal fluid performance)*	- WEC (Core A & B)	Test core sizes and conditions defined. To be used as direct input for possible test configurations.
		- GA	No test core size defined. Typical conditions from PCDR used.
		- AREVA	Core sizes of ~1 MW and ~10 MW to be tested. Conditions extracted from PCDR
	IHX Performance verification tests: (*Transient tests to verify design, material and thermal fluid performance)*	- WEC	• Loss of secondary side pressure and flow (Adiabatic conditions). • Start-up and shut down cycles (*Not specifically addressed. Need to be investigated*)
		- GA	Non defined
		- AREVA	Heat-up and cool-down cycles (*Not specifically addressed. Need to be investigated*)
2.	**Mixing chamber performance verification**	- WEC	Representative conditions. Mock-up scale TBD.
3.	**High temperature ducts & insulation performance verification test:**	- WEC	Piping prototype need to be tested at full temperature & pressure.
		- GA	Mockup sizes to be tested in a 1 MW facility and qualification on a 10 MW facility. Conditions extracted from PCDR
4.	**Steam generator performance verification test:**	- WEC	Numerous tests to be conducted on helium and water side at representative conditions.
		- GA	Need for tests identified but detail to be determined.
5.	**Circulator performance / control tests:**	- All vendor groups	Full scale at representative conditions.

No:	Main Test Configuration	Sub Test	Description
6.	**Isolation valves**	- GA	Large scale valve tests at representative conditions
7.	**Auxiliary system testing:**	Helium purification systems	Facility should provide capability to be tested
		Helium inventory & control systems	
		Heat rejection systems	
8.	**Control & instrumentation tests:**	- All consortiums	Facility to provide capability of C&I development as well being a V&V compliant
9.	**Other HX test:**	- GA	Various shutdown heat exchanger (SHE) tests
10.	**General functions:**	[TBD]	
		[TBD]	

APPENDIX G – IHX TEST SPECIFICATION

1.1 SUMMARY OF TYPICAL COMPONENT UNDER TEST (IHX)

IHX stress and life prediction tests are based on the premise that due to the large size and cost of a full-scale IHX, finite element models will be used extensively in design and life prediction models. These tests are intended to generate steady-state and transient temperatures within the core for precisely controlled temperature, pressure, and flow inlet conditions. Most IHX designs utilize strain relief features to isolate the core from strain introduced by ducting and support structures; thus, life testing requires rigorous consideration and simulation of the IHX boundary conditions and core symmetry. An appropriate test specimen should include the full size core and realistic boundary conditions up to the point of isolation.

The Technology Development Loops (Concept 1) with its 3-meter-diameter test vessel is sized to accommodate very large IHX cores. The data gathered from these tests will be used for the development of a test specification for testing of a representative full scale IHX core in the large loop of Concept 1 or in the proposed Concept 2 vessels. Tests can be conducted up to 2MW capacity in the TDLs and up to 10MW in the large loop, allowing development work and full dimensional scale testing at full temperature and pressure, and reduced mass flow rate (25 kg/s). The imposed transient stresses may be reduced, but quantitative measurements with model validation can be employed to interpret the results.

1.1.1 Test Modes

The following table indicates the general test modes for Units Under Test (UUTs) and more specifically an IHX core.

MODE NR	DESCRIPTION	PURPOSE	OPERATIONAL STATUS	DESCRIPTION
1	Modification/Maintenance Mode	This mode is used to maintain the Test set-up or to made changes to the equipment that are tested	System is depressurised and may be open to air System Helium has to be cleaned to the correct specification and the IHX pressurised to 0.1 MPa for start-up.	IHX Test set-up is isolated from CTF primary and secondary loops.
2	Off Mode	Default mode after completion of maintenance, shutdown or failure of the Test set-up	Power is supplied, but electrical equipment in the IHX is switched off. Instrumentation is active and all events are monitored.	IHX Test set-up is isolated from CTF primary and secondary loops.
3	Standby Mode	Diagnostics performed on Test set-up to check for readiness of system	Components and support systems initialised and checked for readiness, availability and operation. System equipment and instrumentation are energised and ready for operation	Primary & Secondary loop must be in Standby Mode or Operate Mode
4	Operate Mode	This mode is when the Test set-up is operational, either with conditioning or for the execution of the tests	System is pressurised and thermally conditioned as required for the selected test	CTF primary and secondary loop is in Operate Mode and supply IHX vessel with helium at required temperature, pressure and flow rate
5	Conditioning Mode	This mode is used to condition the Test set-up to the required test mode	System is in the process of being pressurised and thermally conditioned as required for the selected test	CTF loops supply helium for the start-up/thermo-hydraulic conditioning of the IHX Test set-up
6	Experimental Modes	These modes are use for the execution of the tests	As per specific experiment	Operations supply (steady state and transients)
7	Shutdown Mode	System is shut down from Standby or Operate Mode	Components in the Test set-up is shut down in an orderly manner C&I monitor all events	RCS Test set-up can be isolated from or connected to the HTF Main loop
8	Failure Mode	Default Mode after component malfunction	Components are shut down and fault is investigated	CTF loops must be in Standby Mode or Operate Mode

MODE NR	DESCRIPTION	PURPOSE	OPERATIONAL STATUS	DESCRIPTION
			There is an opportunity for the system to recover and progress to Standby Mode Fault is identified and system progresses to Standby Mode, OR Cannot recover from fault and Shutdown is initiated	
9	Isolation mode low pressure	This mode is use to set the Test set-up to a state that it could be used as a storage vessel for helium	Test set-up is isolated from the main loop System is cooling down (if applicable) System is depressurised to the HICBS	RCS Test set-up is isolated from HTF Main loop
10	Isolation mode high pressure	Helium may be stored in test set-up	Test set-up is isolated from the primary loop System is pressurised	IHX Test set-up is isolated from CTF primary and secondary loops

1.1.2 Example of a Test Specification

1.1.2.1 Description

IHX stress and life prediction model validation tests

1.1.2.2 Purpose

Model Finite Element Analysis (FEA) validation – accurate prediction of thermal profile throughout the core and structure, assures accuracy of the FEA stress maps.

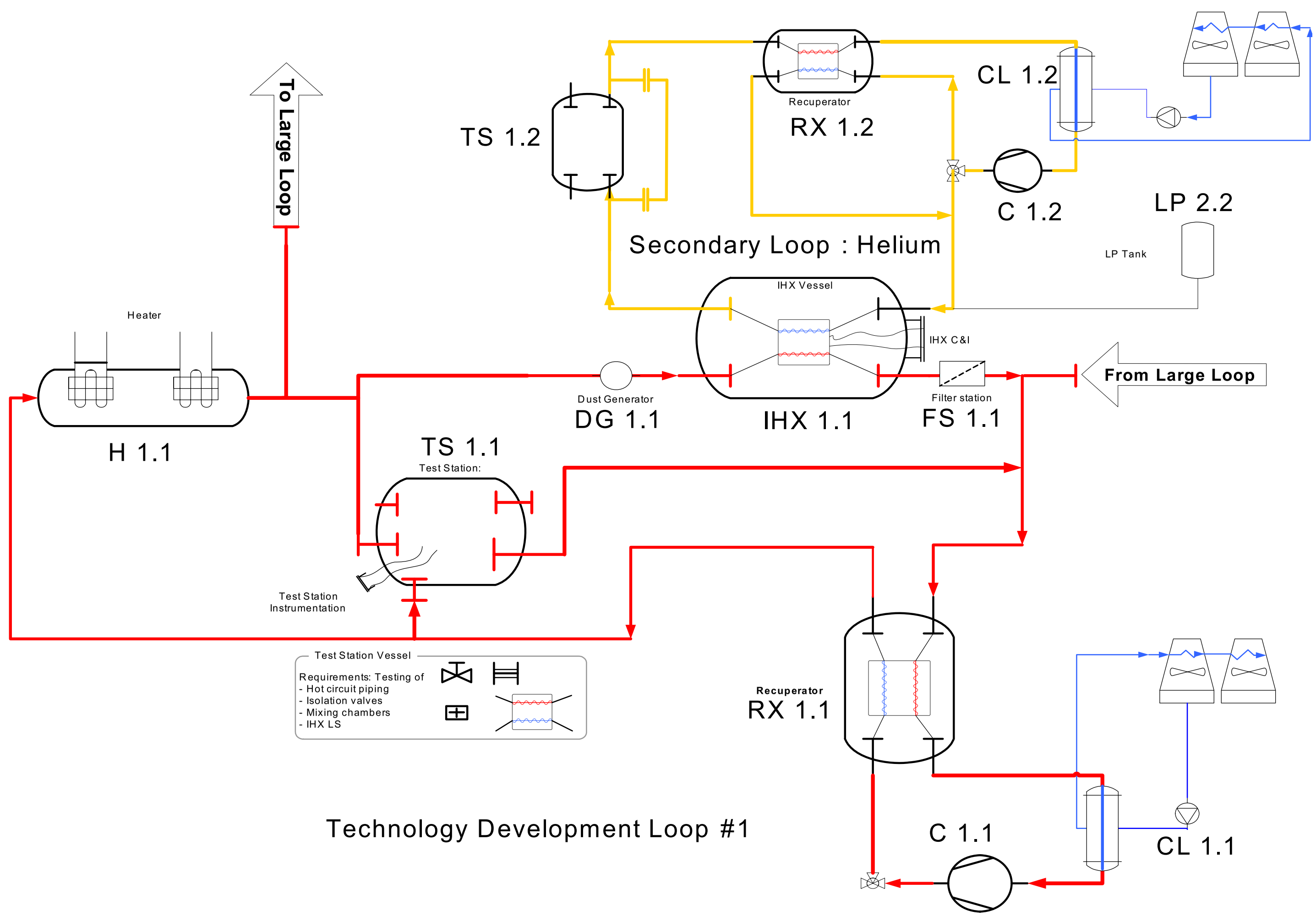
1.1.2.3 Operating Test Conditions

The table below indicates the operating test conditions for the above mentioned test.

No.	Components	Q [MW]	m [kg/s]	T_in [C]	T_out [C]	T_delta [C]	P_in [Mpa]	P_out [Mpa]	Fluid
	Primary Loop #1								
C1.1	Circulator	0.088	1.15	80	83	3	9	9	Helium
RX1.1	Recuperator (Hot)	3.4	1.15	760	218	542	9	9	Helium
RX1.1	Recuperator (Cold)	3.4	1.15	83	624	541	9	9	Helium
H1.1	Heater	1.7	1.15	624	950	326	9	9	Helium
TS1.1	Vessel - Test Station	0	1.15	950	950	0	9	9	Helium
DG1.1	Dust Generator	TBD	1.15	950	950	0	9	9	Helium
IHX1.1	Heat exchanger Vessel (primary)	1.34	1.15	950	760	190	9	9	Helium
IHX1.1	Heat exchanger Vessel (secondary)	1.34	1.15	704	900	196	9	9	Helium
CL1.1	Cooler	0.8	1.15	218	80	138	9	9	Helium
	Secondary Loop #1								
TS1.2	Vessel -Test station	0	1.15	900	900	0	9	9	Helium
RX1.2	Recuperator (Hot)	3.7	1.15	900	279	621	9	9	Helium
RX1.2	Recuperator (Cold)	3.7	1.15	83	704	621	9	9	Helium
CL1.2	Cooler	1.2	1.15	279	80	199	9	9	Helium
C1.2	Circulator	0.058	1.15	80	83	3	9	9	Helium
LP1.2	LP Vent tank	0	TBD	TBD	TBD	TBD	9	9	Helium

1.1.2.4 CTF Test Configuration

The configuration below will be the typical setup for above mentioned test.



1.1.2.5 Specific Conditions for Test

- Stable control over inlet set points for temp, pressure, and flow. Uniform inlet temperature profiles, with temperature measurement rakes to confirm pattern factors. Traceable calibration facility provides mass flow, pressure, and temperature measurements.
- The CTF control system regulates a wide range of primary and secondary side delivery temperatures as well as mass flow and pressure to simulate typical NGNP conditions.
- The high temperature gas loop provides independent control over inlet flow rates, temperature and the secondary pressure. The control system provides PID control over 5 degrees-of-freedom.
- Strain gauges to be applied to the secondary inlet side, due to the more moderate temperatures.
- Six-degree-of-freedom control system to simulate equal or faster temperature and pressure transitions than that projected for the NGNP. Data sample rates 200 channels /second
- The rig tolerates repetitive cycles of simultaneous cut of electric power to the heater and primary circulator without damage to the electric elements. The secondary loop utilizes inventory blow-down to simulate the engine spool-down.
- The CTF is equipped with primary and secondary mass flow control, primary and secondary pressure control, and primary and secondary temperature control. An interactive central control and monitor system will be programmed to automate repetitive control of these control variables. This type of testing may result in IHX failure, resulting in the breach of the IHX pressure boundary. The CTF containment boundary is designed to tolerate IHX failures, and execute appropriate safety measures.

1.1.2.6 Quality Assurance Provisions

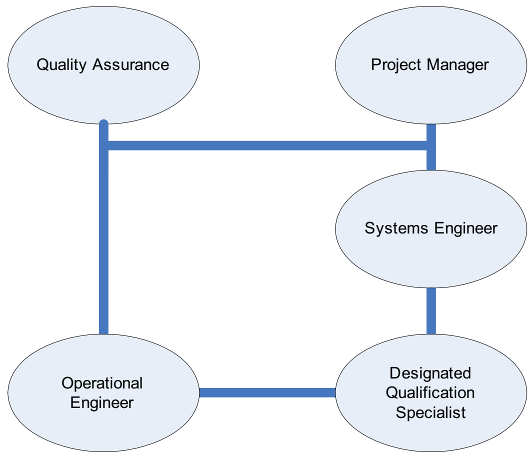
General Requirements

Quality Assurance shall be responsible to, independently, monitor all test and qualification activities. Quality Assurance shall ensure that the applicable procedures exist and that they are followed correctly during the test and qualification process and shall further verify:

- That the Test set-up conforms to the design requirement
- That all procedures have been followed during the commissioning, and operation of the test set-up.
- That all instruments have been issued with the necessary calibration certificates.
- That all procedures (according to the test instructions) have been followed during the execution of the test in the test set-up.
- The validity of all test results
- The correctness and completeness of the RSS Test report.

Test Roles and Responsibilities

The qualification board has the main responsibility for the test and qualification of systems and components in the CTF. The designated qualification specialist (DQS) will perform all test and qualification work. The following organizational structure shall be applicable for the tests performed in the test set-up.



The CTF operational engineers and the test set-up design engineers will be jointly responsible for the execution of the tests. No test will commence without the approval of these persons. A test register shall be kept at all times, and shall be signed by both parties before a test will commence.

The Designated Qualification specialist shall be responsible for:

a) The preparation of the test set-up,
b) The conditioning of the test set-up for a specific test
c) Execution of the tests
d) Recording of results
e) Preparation of test report

The CTF operational personnel shall be responsible for:

a) The preparation of the CTF primary and secondary loop for the specific test,
b) The conditioning of the CTF loops for the specific test
c) Support in conditioning of the test set-up for the specific test
d) Support in execution of the IHX tests
e) Monitoring of CTF loops and test set-up condition during the test
f) Recording of results

g) Supply of results to the Designated Qualification specialist in paper or electronic format.

Safety Requirements and Considerations

The following will be required for test personnel.

a) All test personnel must use safety clothes
b) All relevant safety regulations and special conditions must be followed.

Calibration and Measurements

All temperature sensors/gauges, pressure sensors/gauges, flow meters and height measurement equipment shall be issued with a calibration certificate. The calibration certificates shall form part of the test report.

Test Documentation and Data

All test documentation and data for each test shall be available in paper or electronic format.

Test Report

A report will be generated after completion of the tests. The test report will include the results as well as recommendations (if any) to the design.