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NGNP Component Test Facility Test Loop Pre-Conceptual Design

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BEA Contract No. 000 75310

AREVA NP Inc.

AREVA NP Inc.,

an AREVA and Siemens company

Technical Document Record

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Safety Related? ☐ YES ☒ NO

Does this document contain assumptions requiring verification? ☐ YES ☒ NO

Signature Block

Name and Title/Discipline	Signature	P/LP, R/LR, A/A-CRF	Date	Pages/Sections Prepared/Reviewed/ Approved or Comments
Farshid Shahrokhi	F. Shahrokhi	LP	12/15/08	Section 1, 2, 3, and 7 (w/ input from MHI)
Bob Zimmerman	R. Zimmerman	P	12/15/08	All except Section 1, 2, 3, 6, and 7
Matt Touna	Matt Touna	P	12-15-08	Section 6, App B&C
Jerry Wilk	[signature]	P	12-15-08	Section 8, App B&C
Surinder Gill	[signature]	P	12-15-08	Section 9, App B&C
James Bakke	[signature]	P	12-15-08	Section 6 and Appendix D
David Shelton	David Shelton	P	12-15-08	Appendix B
David Freeman	David Freeman	P	12/15/08	Appendix B
Farshid Shahrokhi	F. Shahrokhi	LR	12/15/08	All except 1, 2, 3, and 7
Bill DeCooman	W. J. DeCooman	R	12/16/08	1, 2, 3, and 7
Marty Parece	F. Shahrokhi for Marty Parece	A	12/17/08	

Note: P/LP designates Preparer (P), Lead Preparer (LP)
R/LR designates Reviewer (R), Lead Reviewer (LR)
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000	Dec 2008	All	Initial Issue
001	Dec 2008	Various	Incorporated customer comments from
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1.0 SUMMARY

The Next Generation Nuclear Plant (NGNP), as the lead demonstration plant for High Temperature Gas-cooled Reactor (HTGR) process heat technology, requires research and development, testing and qualification for critical systems, structures, and components (SSCs). Prior to commercialization of next generation HTGR technology additional plant SSCs will be designed that require R&D, testing and qualification. To meet the needs the R&D, testing and component qualification of HTGRs, a highly versatile test facility is needed. This facility is referred to as the HTGR Component Test Facility (CTF) and is to be located at and operated by the Idaho National Laboratory.

The activity reported in this document provided a pre-conceptual design for test loops. The test loops will provide representative thermal and fluidic conditions of the HTGRs as it has been identified and defined in the NGNP Technology Development Road Mapping (TDRM) and Test Planning (TP) [Reference 12.12] activity.

To proceed with this design activity an assessment of the mission needs of the facility was performed and justification for the need of such facility completed by AREVA in a previously reported activity. The recommendations made by the Mission Needs and Justification study were validated against the requirements of the TDRM activity to ensure that the proposed test loop will have the required capability.

A System Requirements Manual (SRM) [Reference 12.13] was prepared for the CTF to drive the design. The pre-conceptual design of the CTF test loops reported in this document provides for two separate and independent loops. A small versatile and highly configurable test loop has been designed to provide representative temperature and pressure conditions for early testing needs of the NGNP technology development activities. The small test loop has two sub-loops with multiple test sections provision. This loop can deliver helium at temperatures as high as 1000°C and as low as 50°C to several test sections with a controlled helium chemical composition.

The second loop designed is a large, 30 MWt, test loop that can supply high temperature helium with a large test section that can simulate full length intermediate heat exchangers and helium steam generators. This loop can also produce helium temperature, pressure, and flows to test core internal components, compact IHXs and hot gas duct assemblies.

In addition to the mechanical design of the test loops, the electrical distributions system to power the test loop heaters and the facility components were developed. The controls and control strategy for the test loops are also provided. This includes the required instrumentation, and the digital distributed control system. The data collection and storage capability of the test facility is also defined.

The safety of the test loops is the cornerstone of the design. The design is supported by a preliminary hazards analysis and ample passive and active safety features are designed into the system to protect loop operation and personnel safety.

Project risk and R&D are minimal because the final design of the small loop is available from AREVA. The large loop is a nominal scale up of a similar loop designed by MHI. Therefore, the project risk is considered nominal because of the past experience of the design teams in designing and manufacturing of similar test loops.

2.0 INTRODUCTION

This report provides the AREVA High Temperature Gas Reactor - Component Test Facility pre-conceptual design performed by the AREVA NGNP design team for the Battelle Energy Alliance (BEA), the Management & Operating Contractor of the Idaho National Laboratory (INL) as part of the Department of Energy's (DOE) NGNP Project. The scope of this pre-conceptual design effort is limited to the CTF test loop(s) design and the interface requirements. In addition, the design provides the facility electrical support system and the control and instrumentation design and layout.

The design of the CTF test loops are derived from current and past knowledge, and experience of designing high temperature helium test loops. The details of operation, configuration and design parameters of the loops are governed by the NGNP Technology Development Road Mapping and Test Planning activities.

Therefore, the mission of the NGNP CTF is to support qualification and testing of large scale NGNP components and sub-components in high temperature, high pressure, and representative helium chemistry. The test loops shall also provide for material testing condition and support thermo-fluidic design code development, and validation and verification (V&V).

The pre-conceptual design of the CTF test loops includes the following elements:

- CTF System Requirements Manual
- Loop pre-conceptual design
- The loop schematic and layout
- Provisions for test sections and the loops operating strategy
- Support system interface requirements
- Facility Electrical distribution system and one-line drawings
- Facility I&C system and data collection and storage

Based on current and past experience of the AREVA design team, two test loops were proposed in initial high-level assessment of the CTF test loop needs development. The first loop is a medium powered versatile and highly flexible test loop with several test sections that can be operated simultaneously. This loop would be necessary in the near term to provide representative high temperature and pressure test conditions for material, small scale components and sub-component testing. The second loop is a high powered loop capable of testing full-height components such as IHX in representative flow conditions. The second loop can be used for steam generator qualification, core internal flow evaluations, and provide process heat to a nearby hydrogen generation test facility.

A pre-conceptual safety and quality assessment was also conducted to identify possible hazards associated with operation of the loop. The loop design includes accident prevention and mitigation measures. These measures provide operations and life safety to limit property damage and assure personnel safety in case of an accident.

3.0 BACKGROUND AND SCOPE OF THE REPORT

DOE's NGNP Project, as authorized by the Energy Policy Act of 2005, will develop and demonstrate a first-of-a-kind very-high-temperature gas-cooled nuclear system with the capability to generate electrical power and demonstrate nuclear hydrogen production. A key activity necessary for completion of the NGNP Project is the technology development of critical first-of-a-kind high temperature heat transfer SSCs that require a high temperature test facility. This facility will support development and qualification of High Temperature Gas-cooled Reactors (HTGRs) thermal-fluidic technologies including materials, and component development, testing and qualification.

As part of the initial conceptual design studies, the AREVA design team performed a high-level mission needs and justification, and provided a high level recommendation for the CTF test loop configuration based on R&D needs identified by AREVA in the NGNP Pre-conceptual Design Studies. The results of that study were reported in References 14.7 and 14.8. As a follow up to that study, INL authorized AREVA to perform a Technology Development Road Mapping with test plan development for the NGNP reactor design utilizing indirect steam cycle Reference 12.12.

In addition, INL authorized preparation of a pre-conceptual design of the AREVA recommended Component Test Facility with capabilities that meets the test requirements identified in the TDRM activity.

The purpose of INL in authorizing the pre-conceptual design is two-fold:

- Assist INL in focusing the technical scope and priorities of research & development (R&D) activities for the NGNP.
- Provide INL a basis for subsequent development of the technical and functional specifications for the Component Test Facility.

The CTF pre-conceptual design as performed by AREVA within the authorized work scope and as reported herein are consistent with the corresponding elements of the Phase I Scope Of Work defined for the NGNP Project in the Energy Policy Act of 2005.

In support of the CTF pre-conceptual design work, AREVA assembled a team of sub-contractor companies with the key technical competencies needed to cover the full breadth and scope of the CTF project including final design, construction, and operations.

The AREVA CTF Team includes Burns & Roe, and Mitsubishi Heavy Industries (MHI), and others. The functional CTF design team organization is shown graphically in Figure 3-1.

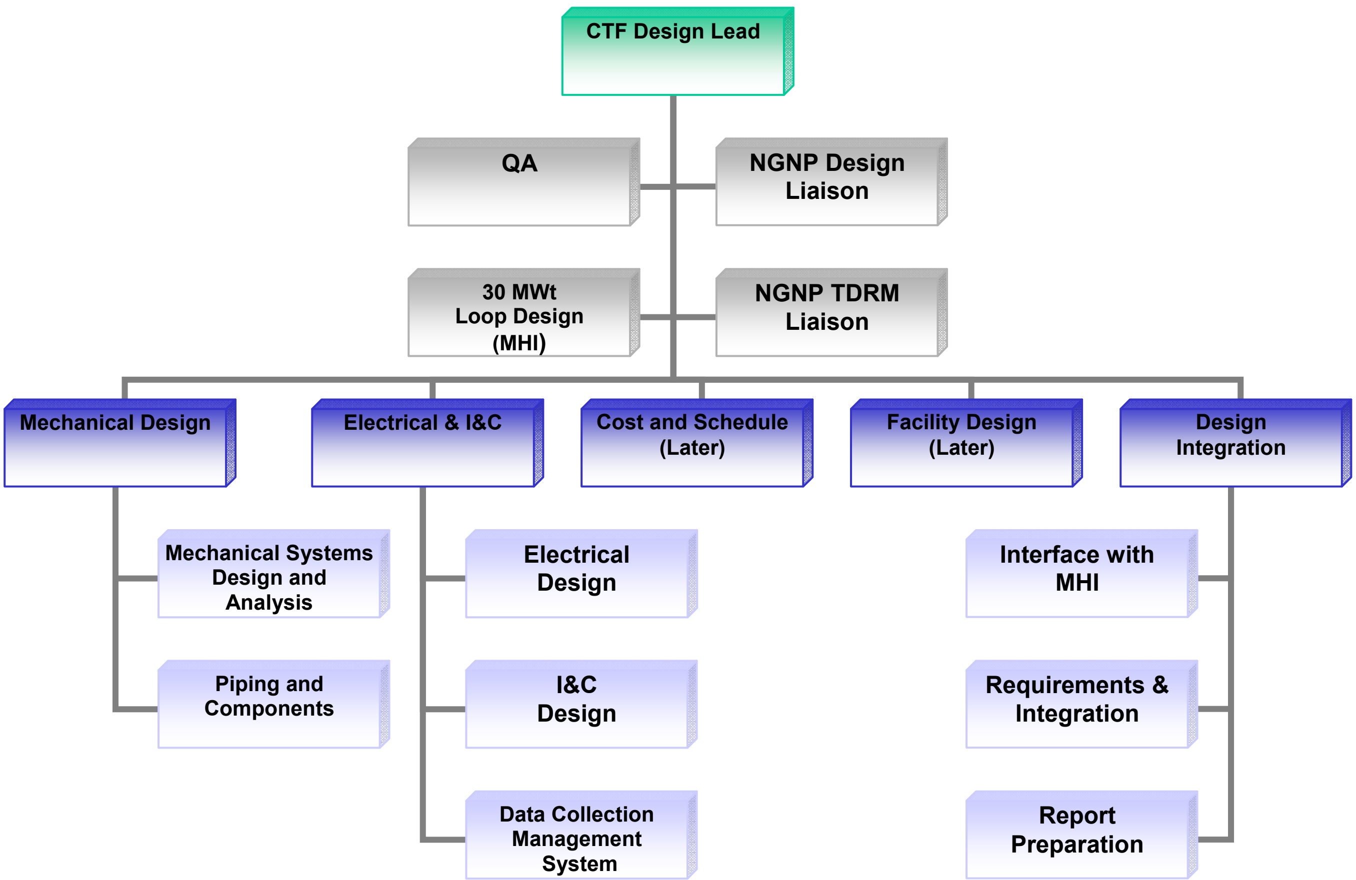


Figure 3-1: AREVA CTF Design Team organization

The Scope of Work assigned to the AREVA NGNP team consisted of the preparation of the test loops pre-conceptual design to accommodate the test configuration supporting the Test Plans for NGNP critical systems, structures and components, as well as a generic testing envelope to facilitate future testing needs. The level of design detail provided is sufficient to define the facility functional requirements, develop pre-conceptual design cost estimates, and provide input to the development of the CTF conceptual design.

The majority of the design effort under this scope is devoted to develop the large test loop design because an existing medium loop design exists that can be made available to support the development of the CTF conceptual design subject to the conditions of this Scope Of Work. Design details related to a medium test loop are provided without inclusion of intellectual property. The technical and functional requirements for performance test (e.g. flow induced vibration, materials performance, and seals leak rates) instrumentation is included in the Pre-Conceptual (test loop) Design Report (PCDR), but not the detail specifications or equipment selection. Included in the pre-conceptual test loop design is the identification of any

R&D needed for the test loop components, equipment and component handling and installation requirements, and instrumentation and control systems.

Furthermore, AREVA recognizes that data collection and data quality control are the primary deliverable from the CTF. Therefore, the pre-conceptual design effort pays extensive attention to configuration of the data collection system, fidelity and repeatability of test results.

Key work elements developed within the framework of the scope of work are:

- HTGR CTF Pre-conceptual System Requirements Manual (Appendix A, Reference 12.13)
- Development CTF Pre-conceptual Design (Chapters 6 and 7)
- Identification of R&D needs and project risks
- Loop cost estimate (Later)
- Project schedule (Later)

The design of the CTF test loops are based on the existing and past experience of the design team with high temperature helium test loops. These configurations include:

- HELITE loop – high temperature helium loop has been developed by AREVA and Commiserate á l' Énergie Atomique (CEA)
- KVK loop – developed by an AREVA German subsidiary for the German high temperature reactor component qualification and test purposes. This loop is now decommissioned and dismantled
- HENDEL loop - developed with design and manufacturing support from MHI to support the Japanese THTR component development and testing. This loop is now decommissioned and dismantled.

The NGNP CTF test loop design and configurations proposed by AREVA is based on the above technologies and experiences with further adaptation to meet the required test conditions defined by the NGNP TDRM and TP activity.

4.0 MISSION NEEDS AND JUSTIFICATION

The mission needs and justification for the CTF are summarized in INL/MIS-08-14156, High Level Requirements High Temperature Gas Reactor (HTGR) – Component Test Facility (CTF) [Reference 12.1]. The Component Test Facility is required to provide engineering scale testing and qualification of heat transfer systems and components used in the NGNP indirect steam cycle. The Energy Policy Act of 2005 authorized the development and demonstration of the NGNP, a first-of-a-kind very-high-temperature gas-cooled nuclear system with the capability to generate electrical power and demonstrate nuclear hydrogen production. Key activities necessary for completion of the Next Generation Nuclear Plant (NGNP) are the:

1. Qualification and testing of large scale components in a high-temperature, high pressure environment.
2. Design code development verification and validation collaboration.
3. Materials development and qualification.
4. Manufacturer and supplier evaluation and development.

INL/EXT-08-14150 Rev 0. High Temperature Gas-Cooled Reactor (HTGR) Component Test Facility (CTF) Technical and Functional Requirements [Reference 12.2] determined that a suitable facility does not exist for testing the NGNP heat transfer system components (e.g., IHX, valves, and hot gas duct), reactor internals, or the interface with the hydrogen generation processing plant, and that one needs to be built. The Idaho site was identified as a preliminary test location. Following the completion of an alternatives study which considers all potential sites in the DOE complex, a final test location preference will be established. This report based its recommendations on a review of the technology readiness levels and risks identified in INL/EXT-07-12967, Next Generation Nuclear Plant Pre-Conceptual Design Report [Reference 12.5]. That report included an evaluation of AREVA document 12-9051191-001, NGNP with Hydrogen Production Preconceptual Design Studies Report [Reference 12.6]

AREVA document 12-9072397-000, High Temperature Gas Reactor Component Test Facility Mission Needs and Requirements [Reference 12.7], identified the specific needs and requirements for the CTF based the technology development needs of the NGNP Conceptual Design. This document identified the need for: very short term preliminary tests for selecting materials and design options during the NGNP conceptual design phase and troubleshooting support during early NGNP operations and confirmed the need for testing NGNP heat transfer systems and components at representative temperature, pressure, fluid flow and chemical environments. The report recommended building two test loops. The first loop would be a small (1 MWt) test loop that could be used for early developmental and pilot scale tests during NGNP conceptual design and for testing the unique (not off the shelf) components of the large (30 MWt) test loop. The large test loop would be used for engineering scale testing of the larger components, such as the Intermediate Heat Exchanger (IHX) and Steam Generator (SG). This recommendation is based on experience with the HELITE, HENDEL, and KVK test loops, which demonstrated that the design risks of the large test loop components (i.e., helium gas seals, hot gas piping, instrumentation, gas circulators) are similar to those of the reactor components. The staff familiar with those test loops recommend that design concepts and equipment that was not commercially available off the shelf be tested at a small scale before finalizing their design and qualifying them for use. Technical issues associated with the small loop design can be addressed in other facilities that already exist or can be performed by the vendors. The small loop would be designed with sufficient flexibility to meet the needs for pilot scale testing of Compact IHX test modules, engineering scale tests of the NGNP primary loop instrumentation, and qualification testing of the NGNP helium purification system. The large loop would have the capability for testing engineering scale testing of the compact and tubular intermediate heat exchangers, would have the secondary and tertiary heat transfer circuits required for testing the SG, and would be capable of providing high temperature helium for demonstrating hydrogen production or other industrial processes.

The NGNP Component Test Facility Conceptual Configuration, Cost, and Schedule Estimate; AREVA document 12-9076931-000 [Reference 12.8] confirmed that a CTF built at the INL test site could meet the NGNP mission needs and identified site infrastructure requirements. INL/EXT-08-14052, Site Selection Study for the High Temperature Gas-Cooled Reactor (HTGR) Component Test Facility (CTF) [Reference 12.9] identified the preferred location on the site and the available utility services.

The overall objectives of this phase of the project include:

- Prepare pre-conceptual design of the CTF to provide Helium environmental and chemistry conditions at high temperature, pressure and flow conditions defined in the NGNP Technology Development Road Maps (TDRMs) and associated Test Plans (TPs) [Reference 12.12].
- Design the CTF test loops and define strategies for construction and commissioning for these loops that satisfy the TDRM and TP requirements and support the integrated test schedule.
- Design the CTF test loops for long term usage by the HTGR community for commercialization of advanced technology.

The NGNP indirect steam cycle uses an intermediate heat exchanger to separate the primary heat transfer loop from the secondary heat transfer loop which heats the steam generator. The primary coolant will be helium. Helium, helium-nitrogen, and other gas mixtures (i.e., helium and argon) are under consideration for the secondary heat transfer loop. Ongoing NGNP conceptual design studies are evaluating other configurations, including but not limited to, the direct steam cycle. The NGNP Technology Development Road Maps and Test Plans identify 17 critical systems, structures, and components that require additional testing before demonstrating hydrogen production using process heat from the reactor. The test plans identified recommended test locations. The CTF is recommended as the test facility if no existing test facility could provide the required test conditions. The TDRM test plans identified the CTF for the following component tests:

Compact IHX - pilot scale demonstrations (~40 plates)
Primary Loop Instrumentation
Reactor Vessel Internals (heat transfer tests)
Neutron Control System (assembly and guide rods)
Helical Tube Intermediate Heat Exchanger
Primary Hot Gas Duct
High Temperature Isolation Valve
Compact Intermediate Heat Exchanger (IHX) - engineering scale demonstration
Steam Generator

The TDRMs will be revised in step with changes to the NGNP Conceptual Design. The CTF facility and test loops are designed with flexibility to accommodate configuration changes for testing alternative gas-cooled reactor heat transfer configurations (i.e., indirect and direct steam cycles, process heat) and heat transfer fluids (i.e.,He, He:Air, and He:Ar). The large loop can be used for testing reactor internals phenomena and demonstration of the hydrogen production process heat application.

The initial use of this facility will be in support of the R&D for completion of the Next Generation Nuclear Plant (NGNP). This facility will also be used for qualification of systems and components that require testing with high temperature helium, such as the helium purification system. Future use of this test facility will be 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.

Justification

The Next Generation Nuclear Plant (NGNP) project involves research, development, design, construction, and operation of a prototype nuclear plant intended for both high-efficiency electricity production and high-temperature industrial applications, such as hydrogen production. The NGNP project requires the capability for R&D, testing and development of critical systems, structure, and components used for heat transfer and transport. The Component Test Facility (CTF) is required to provide that capability. A two loop test facility with one large loop and one small loop provides significant advantages. The large (30 MWt) test loop provides for engineering scale testing and qualification of heat transfer system components. The small (1 MWt) test loop provides for early testing of components and design options that require special development tests before finalizing their design and qualifying them for operation in the larger loop. The small loop will require fewer resources to operate. The large loop can be used for testing reactor internals phenomena and demonstration of the hydrogen production process heat application.

This CTF capability is required as a risk reduction measure for HTGR electric production and for process heat applications such as hydrogen generation. Testing is required to address design data needs and establish the technology readiness levels and design readiness levels during NGNP conceptual and detailed design. The loop has the capability for a wide variety of transient and endurance testing that will be needed for licensing. This capability is also required for demonstrating nuclear process heat technology. The 1 MWt test loop is designed for testing prismatic and pebble bed NGNP reactor heat transfer components, based on the 2007 PCDRs. The 30 MWt test loop is designed for testing prismatic reactor SSCs. This facility is required if the NGNP goals and schedule in the Energy Policy Act of 2005 are to be met.

5.0 FUNCTIONAL AND OPERATIONAL REQUIREMENTS

The US Department of Energy (DOE), through the Next Generation Nuclear Plant (NGNP) project, is developing a High Temperature Gas-cooled Reactor (HTGR) to be used as a heat source for a variety of process heat applications (e.g. hydrogen production, coal to liquids, tar sands oil recovery, electricity production, etc.). Currently, this HTGR is envisioned as providing a reactor outlet temperature of 900 ºC and will be operational by 2021. In order to meet these ambitious goals, a Component Test Facility (CTF) will be built at the Idaho National Laboratory (INL). The CTF will be a critical program component to demonstrate NGNP technologies and design readiness through testing, piloting, and prototyping. INL/EXT-08-04150, *Technical and Functional Requirements* [Reference 12.2] outlines the top level requirements for the CTF.

AREVA has developed initial Technology Development Road Maps (TDRMs) and associate initial Test Plans (TPs) [Reference 12.12] for critical Plant, Area, Systems, Structures and Components (PASSCs) of the NGNP indirect steam cycle configuration. The TDRM document identifies where R&D is required, the functional and operating requirements for each test, and the recommended test location. The TDRMs focused on those PASSC's that are currently in its baseline design for an HTGR with a 900ºC outlet temperature operating on an indirect steam cycle; NGNP Conceptual Design Studies Baseline Document for Indirect Steam Cycle Configuration [Reference 12.17].

The depth and the breadth of each TDRM have been developed to a sufficient level of detail to allow initiation of the pre-conceptual design development of the CTF test loops. The road maps are also expected to drive the needed actions to down-select the configuration and design of the NGNP. Future refinements to the TDRMs and TPs will be necessary to address the specifics of the component maturation process without causing major modifications or obsolescence of CTF.

The test plans identify the requirement for two test loops; a 1MWt (small) and a 30 MWt (large) test loop. The small test loop would be used for testing NGNP primary loop Instrumentation and the compact intermediate heat exchanger mock-up. The large loop would be capable of engineering scale testing the compact intermediate heat exchanger, helical tube intermediate heat exchanger, primary hot gas duct, high temperature isolation valve, and steam generator. The two loops need to be capable of independent operation to maximize facility utilization and support the project schedule.

Section 5.1 identifies the project functional requirements. Section 5.2 identifies the technical and functional requirements identified in the Technology Development Road Mapping Report. The CTF System Requirements and Engineering Design Requirements are documented Appendix A.

5.1 Functional and Operating Requirements

The following design requirements are derived from *Technical and Functional Requirements [*Reference 12.1], Section 3, Requirements and Basis. The section number is identified in brackets (INL section number) for traceability to the source document. This section does not include requirements for design activities (i.e., define Systems, Structures, and Major Components, Boundaries and Interfaces) or documentation that were included in Reference 12.1.

- Enable and Equip CTF Program Testing and Qualification Function (INL 3.1.3)
- The CTF shall provide the flexibility to test a range of component designs, configurations, operating conditions, materials, and heat transport fluids. The heat transport fluids provided by the CTF helium purification system should have controlled levels of impurities. Mockup or scaled representative equipment components testing capability shall provide representative environments with operating conditions comparable to anticipated NGNP condition including large scale testing.
- NGNP Primary Heat Transport Capability functions include (INL 3.1.3.1):
    - The number and scale of test stations support the NGNP schedule and component development test plans.
    - Capable of tests at various scales, up to full scale, simulating the fluidic conditions (pressure, temperature, temperature transients and mass flow rates) of NGNP.
    - There must be helium inventory and chemistry controls to provide the expected environmental test conditions.
    - An interface to allow testing of the IHX between the NGNP Primary and Secondary heat transfer loop.
    - Component, material and instrumentation to verify NGNP design and fabrication methods and predict component life.
    - Seals testing at various interfaces as well as leak rate data collection recorded with process parameter data.
    - Flow induced vibration testing and data collection of frequency spectra and sound pressure levels.
- NGNP Secondary Heat Transport Capability functions (INL 3.1.3.2).

  The functions will be the same as the Primary Heat Transport Capability functions except that the SSC interfaces will be different. In both cases they will be based on the NGNP component development test plans.
- Enable tertiary/process heat applications component tests with consideration of test scales, types, and scenarios; components; HT gas environment; and impurity controls (INL 3.1.3.3).

  The tertiary/process heat applications shall be designed to support the range and scale of tests identified in Reference [ii], Technology Development Road Mapping Report. The test capability will include the steam generator for process steam, isolation valves, auxiliary systems, controls and instrumentation, and one test station capable of accepting H2 production processes or components.

- Enable coolant and heat transfer fluid testing (INL 3.1.3.7)
- Enable direct-cycle power conversion component testing (INL 3.1.3.8)
- Enable materials testing capability (INL 3.1.3.20)
- Enable in service inspection and testing (INL 3.1.3.21)
- Provide component/process/system control loop philosophy, evaluation, and analysis capability (INL 3.1.4.4)

  Summarize functional and physical requirements for each SSC in the small and large test loops [maximum temperature, heating/cooling rate, design flow rate, design leak rate, safety systems, He supply & purification system, test section interfaces with critical SSC]. The design will include traceability to these requirements.

- Safety (INL 3.3.10)
  - o Comply with safety regulations (INL 3.3.10.1)
  - o Provide facility features for test safety (INL 3.3.10.2)
  - o Note: This scope of work does not include the safety, but does include identification of hazards, failure mode and effects analysis, and preventive and mitigating features related to test loops.

5.2 NGNP Testing Technical and Functional Requirements

The following design requirements are derived from *Technical and Functional Requirements* [Reference 12.1], Section 3, Requirements and Basis. The section number is identified in brackets (INL section number) for traceability to the source document. This section does not include requirements for design activities (i.e., define Systems, Structures, and Major Components, Boundaries and Interfaces) or documentation that were included in Reference 12.1.

- Enable and Equip CTF Program Testing and Qualification Function (INL 3.1.3)
- The CTF shall provide the flexibility to test a range of component designs, configurations, operating conditions, materials, and heat transport fluids. The heat transport fluids provided by the CTF helium purification system should have controlled levels of impurities. Mockup or scaled representative equipment components testing capability shall provide representative environments with operating conditions comparable to anticipated NGNP condition including large scale testing.
- NGNP Primary Heat Transport Capability functions include (INL 3.1.3.1):
  - o The number and scale of test stations support the NGNP schedule and component development test plans.
  - o Capable of tests at various scales, up to full scale, simulating the fluidic conditions (pressure, temperature, temperature transients and mass flow rates) of NGNP.

  - There must be helium inventory and chemistry controls to provide the expected environmental test conditions.
  - An interface to allow testing of the IHX between the NGNP Primary and Secondary heat transfer loop.
  - Component, material and instrumentation to verify NGNP design and fabrication methods and predict component life.
  - Seals testing at various interfaces as well as leak rate data collection recorded with process parameter data.
  - Flow induced vibration testing and data collection of frequency spectra and sound pressure levels.
- NGNP Secondary Heat Transport Capability functions (INL 3.1.3.2).
  The functions will be the same as the Primary Heat Transport Capability functions except that the SSC interfaces will be different. In both cases they will be based on the NGNP component development test plans.
- Enable tertiary/process heat applications component tests with consideration of test scales, types, and scenarios; components; HT gas environment; and impurity controls (INL 3.1.3.3).
  The tertiary/process heat applications shall be designed to support the range and scale of tests identified in Reference [ii], Technology Development Road Mapping Report. The test capability will include the steam generator for process steam, isolation valves, auxiliary systems, controls and instrumentation, and one test station capable of accepting H2 production processes or components.
- Enable coolant and heat transfer fluid testing (INL 3.1.3.7)
- Enable direct-cycle power conversion component testing (INL 3.1.3.8)
- Enable materials testing capability (INL 3.1.3.20)
- Enable in service inspection and testing (INL 3.1.3.21)
- Provide component/process/system control loop philosophy, evaluation, and analysis capability (INL 3.1.4.4)
  Summarize functional and physical requirements for each SSC in the small and large test loops [maximum temperature, heating/cooling rate, design flow rate, design leak rate, safety systems, He supply & purification system, test section interfaces with critical SSC]. The design will include traceability to these requirements.
- Safety (INL 3.3.10)
  - Comply with safety regulations (INL 3.3.10.1)
  - Provide facility features for test safety (INL 3.3.10.2)
  - Note: This scope of work does not include the safety, but does include identification of hazards, failure mode and effects analysis, and preventive and mitigating features related to test loops.

5.2.1 1 MWt Test Loop Operating Conditions

The 1 MWt Test Loop is required to deliver helium to a test section at the conditions required for the test. The test modules and test sections are not part of the loop design.

Compact intermediate heat exchanger (Reference 12.12, Appendix L)

Primary loop:	900 °C inlet, 5 MPa, 0.5 Kg/s Design for 500 °C IHX outlet Capability for testing impurities and dust
Secondary loop:	475 °C inlet, 5.5 MPa, 0.5 Kg/s Design for 875 °C IHX outlet

Primary loop instrumentation (Reference 12.12, Appendix N)

High temperature thermocouple	<1100 °C, 6 MPa
Low temperature thermocouple	< 600 °C, 6 MPa
Other instruments	100 – 300 °C, 7 MPa

5.2.2 30 MWt Test Loop Operating Conditions

The 30 MWt Test Loop is required to deliver helium to a test section at the conditions required for the test. The 30 MWt Test Loop shall be designed for 1000 °C. The test sections will be designed to provide supplemental heating to reach temperatures above 1000 °C. The test modules and test sections are not part of the loop design.

Reactor vessel internals (Reference 12.12, Appendix B)

Conduction cool down test	
Normal conditions	500 °C
Depressurization accident	1700 °C
Core barrel emissivity Test	500 – 800 °C
Fuel and reflector block conduction	1200 °C
Gap friction loss coefficients	500 °C, flows TBD
Fuel block coolant channel frictional loss coefficients	500 °C, flows TBD

Neutron control system (Reference 12.12, Appendix D)

Control rod assembly	Temperature TBD Estimated at <1300 °C for pressurized conduction cool down

	5 m high x 20 cm diameter
Control rod guide tubes	Temperature TBD Estimated at <1300 °C for pressurized 5 m high x 20 cm diameter
Qualification tests	20 m high x 20 cm diameter

Helical tube intermediate heat exchanger (Reference 12.12, Appendix H)

Primary loop:	900 °C inlet, 5 MPa, 1.4 - 14 Kg/s Design for 500 °C IHX outlet Capability for testing impurities and dust
Secondary loop:	415 °C inlet, 5.5 MPa, 0.5 Kg/s Design for 825 °C IHX outlet

Primary hot gas duct (Reference 12.12, Appendix I)

Start-up	100 °C inlet and outlet, 0.1 MPa, 0.1 Kg/s
Normal	900 °C inlet, 500 °C outlet, 5.0 MPa, 14 Kg/s Depressurization transients

Note: hot streak effects are planned as analytical tests. Special effects testing may be recommended based on those results.

High temperature isolation valve (Reference 12.12, Appendix K)

Secondary loop side of the Intermediate Heat Exchanger
875 °C, 5.5 MPa, 1.0 – 10 Kg/s
Depressurization transients

Compact intermediate heat exchanger (Reference 12.12, Appendix L)

Primary loop:	900 °C inlet, 5 MPa, 14 Kg/s Design for 500 °C IHX outlet Capability for testing impurities and dust
Secondary loop:	475 °C inlet, TBD MPa, TBD Kg/s Design for 875 °C IHX outlet

Steam generator (Reference 12.12, Appendix M)

Secondary loop:	(helium to steam generator primary side), 825 °C, 5.5 MPa, 13.8 Kg/s Design for 405 °C steam generator outlet
Tertiary loop:	(steam generator secondary side) 282 °C inlet, 566 °C outlet, 17 MPa, 11.6 Kg/s

5.3 Bounding Functional and Operating Requirements

The test loops shall be designed to the following conditions. These conditions bound anticipated NGNP transient conditions and postulated off normal conditions.

	1 MWt Loop	**30 MWt Loop**
Temperature (°C)	100 to 1000 (primary side) 475 to 875 (secondary side)	100 to 1000 (primary side) 415 to 950 (secondary side)
Pressure (MPa)	0.1 - 8	0.1 – 8
Flow (Kg/s)	0.05 to 0.5 (primary side) 0.05 to 0.5 (secondary side)	1 – 14
Power (MWt)	1 to 1.5	30
Temperature Transients	High Temperature Test Section: from 850 °C to 480 °C in 100 s (~220 °C/min), then 480 °C to 200 °C in 15 min (~19 °C/min), or 850 °C to 380 °C in 5 min 30 s	[±200 °C/min]
Pressure Transient	+0.9 Mpa/min and -0.38 MPa/min in	Later

	1 MWt Loop	30 MWt Loop
	80 sec	
Flow Transients	+0.07 kg/s/s and -0.04 kg/s/s	Later

The details of the conditions that drive the design of the CTF can be found in Appendix A. The test modules and test sections are not included in the scope of this design activity.

6.0 CTF SMALL LOOP DESIGN

6.1 Design Description

The applications of the 1 MWt test loop are discussed in Section 2.0 and the functional and operational requirements are discussed in Section 5.0. This section discusses the design features of the 1 MWt test loop that allow it to meet the aforementioned requirements.

The 1 MWt test loop design consists of a primary loop and a secondary loop each configured as "Figure 8". The interface between the two loops is an Intermediate Heat Exchanger (IHX) test mock-up (See P&IDs in Appendix B, B.4). Each loop is a closed loop and the fluids in each loop do not mix. This design allows for the flexibility of using a different fluid and establishing a different flow rate, process fluid chemistry, and process pressure in the secondary side of the IHX test mock-up. The design discussed in this section will utilize helium in both the primary and secondary loops. This design also allows for testing to be conducted in the secondary loop thus utilizing the energy transferred by the IHX test mock-up rather than rejecting this energy to a cooling water system. The design of the test loop also allows for different test loop configurations that provide the flexibility of performing testing in the primary loop with the secondary loop not in operation. See Section 6.1.4 for a discussion of the available test loop configurations.

The primary loop will also have connections for a future tertiary loop. The primary and tertiary loop would be connected by a heat exchanger which will transfer heat to the tertiary loop. The tertiary loop could be used for testing the helium purification and IHX with representative helium chemistry, including gas impurities and dust. The tertiary loop could also be used for testing hydrogen production processes. The design of the tertiary loop is not included here, however, the components will be similar to the secondary loop with special consideration to allow loop cleanup following dust testing.

6.1.1 Primary Loop

The primary loop consists of a hot leg and cold leg which are connected by a recuperator Heat Exchanger (HX). The recuperator HX enables cold leg operation in a temperature range of 50°C to 200°C. This allows the components in the cold leg to operate in a lower temperature environment which reduces degradation and simplifies the design of the components. The use of a recuperator to cool the helium that enters the cold leg is more efficient than rejecting the heat to a cooling water system.

The hot leg contains two electric heaters which are used for obtaining the required helium gas temperature for testing. Using a recuperator to preheat the helium entering the heaters helps reduce the size of the heaters and the energy economy of the system. Testing in the hot leg is conducted in the high temperature, medium temperature and IHX test sections. The high temperature test section is designed to accommodate a maximum temperature of 1000°C and the medium temperature test section is designed to accommodate a maximum temperature of 500°C. The hot leg also contains a high temperature HX that is utilized when the IHX test section is not in use. This provides the flexibility of performing tests in the primary loop when the IHX test mock-up is not connected. See Section 6.1.4 for a discussion of test loop configurations.

The cold leg contains a low temperature HX to further reduce the temperature to the circulator. The cold leg interfaces with the Helium Storage and Supply System and the Helium Purification System. The cold leg also contains a pipe connection to the hot leg at the inlet of the medium temperature test section. This line contains temperature control valve TCV-1 that maintains the proper inlet temperature for the medium temperature test section when the IHX test section is in use. When the IHX test section is not in use this temperature control line is isolated by removal of spool piece SP-14. See Section 6.1.4 for a discussion of test loop configurations. There are also pipe connections to each test section that are used to create the temperature transients for testing. See Section 6.1.3 for a discussion of the test section.

6.1.2 Secondary Loop

The secondary loop is very similar to the primary loop in that it consists of a hot leg and cold leg which are connected by a recuperator HX.

Unlike the primary loop the secondary loop does not contain heaters in the hot leg. The IHX test section provides the energy to obtain the required helium gas temperatures for testing. Therefore, the secondary loop can only be utilized if the IHX test section is in use. In addition, a medium temperature HX between the recuperator and the IHX test section is used to control the IHX secondary side inlet temperature. Testing in the hot leg is conducted in the high temperature and medium temperature test sections.

The cold leg for the secondary loop is identical to the primary loop's cold leg. The only exception is the absence of a pipe connection to the hot leg for temperature control of the inlet temperature to the medium test section. The high temperature HX in the hot leg is used to control temperature for the medium temperature test section.

6.1.3 Test Sections

The test sections will be designed to provide a means for producing the required temperature, flow and pressure transients for the test mock-ups (See drawing in Appendix B, section B.1.5). The temperature transients will be produced using a piping connection to the cold leg with a temperature control valve (TCV) installed. The temperature controller for the TCV will create the required temperature transient by modulating the injection of helium from the cold leg. The pressure transients will be produced using a piping connection to the vent tanks in the Helium Storage System. A pressure control valve (PCV) installed in the connection line will create the required pressure transient by modulating the discharge flow to the vent tanks. To prevent pressure transients from affecting the entire test loop the test mock-up will be isolated before operating the PCV. The flow transients will be produced using a bypass line with a flow control valve (FCV) installed. The bypass line will also be used when the test mock-up is isolated for pressure transient testing.

6.1.4 Test Loop Configurations

The 1 MWt test loop is designed to allow for three different configurations; (1) Single Test Loop, (2) Single Test Loop – IHX and (3) Primary/Secondary Test Loop. This provides the flexibility to perform testing in the primary loop without relying on the operation of the secondary loop. Arrays of spool pieces are used to configure the test loop for the desired operation. Spool pieces were chosen instead of valves due to the high temperature of the helium in the hot leg. Specialty valves would need to be chosen that could operate in a high temperature helium environment. The initial cost and maintenance costs of these valves would be relatively high. Changing the configuration of the test loop is not envisioned to be a frequent activity, so the labor in removing and installing relatively small spool pieces would be acceptable. The spool piece flange connections would use a spring energized metal gasket or a seal weld could be utilized. However, the spool pieces could be easily replaced with valves in the future if so desired.

6.1.4.1 Single Test Loop

The single test loop configuration accommodates testing in the high temperature and medium temperature test sections (See drawing in Appendix B section B.1.1). The IHX test section and the secondary loop are not used in this configuration. The heaters control temperature to the high temperature test. The high temperature HX controls the temperature to the medium temperature test section. Temperature control is accomplished by temperature control valve TCV-2 which modulates cooling water flow to the high temperature HX (See P&IDs in Appendix B, B.4).

6.1.4.2 Single Test Loop – IHX Configuration

The single test loop – IHX configuration accommodates testing in the IHX and medium temperature test section (See drawing in Appendix B section B.1.2). The secondary loop is not used in this configuration. Therefore, the secondary side of the IHX test mock-up must contain the same fluid, flow rate and process pressure as the primary side of the IHX. The heaters control temperature to the primary side of the IHX test section. The high temperature HX controls the temperature to the secondary side of the IHX test section. Temperature control is accomplished by temperature control valve TCV-2 which modulates cooling water flow to the high temperature HX. A temperature control valve (TCV-1) is used to control temperature to the medium temperature test section by modulating flow from the cold leg into the hot leg (See P&IDs in Appendix B, B.4).

6.1.4.3 Primary / Secondary Test Loop Configuration

The primary/secondary test loop configuration accommodates testing in the IHX and medium temperature test sections (See drawings in Appendix B, sections B.1.3 & B.1.4). As was discussed earlier, this allows for the flexibility of using a different fluid and establishing a different flow rate and process pressure in the secondary side of the IHX test mock-up. Each test loop has an independent helium purification system for controlling the fluid chemistry in each loop. This allows for testing the IHX at representative environmental conditions (pressure, temperature, and chemistry).

In the primary loop, the heaters control temperature to the primary side of the IHX test section. A temperature control valve (TCV-1) is used to control temperature to the medium temperature test section by modulating flow from the cold leg into the hot leg (See P&IDs in Appendix B, B.4).

In the secondary loop, the medium temperature HX is used to control temperature to the secondary side of the IHX test section. The high temperature HX controls the temperature to the medium temperature test section. Temperature control is accomplished by temperature control valve TCV-4 which modulates cooling water flow to the high temperature HX (See P&IDs in Appendix B, B.4).

6.1.5 Heat Balance

A preliminary heat balance calculation was performed for the three different test loop configurations discussed above (See Appendix D). The results are documented on the process block flow diagrams in Appendix B, B.7. Assumptions were made for heat exchanger efficiencies, piping heat loss and test section heat loss. The following table documents the maximum calculated capacities from all three configurations. More detailed heat balance calculations must be conducted before design capacities are chosen for the components.

Configuration	Component	Tin (°C)	Tout (°C)	Flow (kg/s)	Capacity (kW)
1	First Stage Heater	403	850	0.4	928.3
1	Second Stage Heater	850	1007	0.4	326.1
3 Secondary	Recuperator hot side	479	100	0.38	-747.8
3 Secondary	Recuperator cold side	150	495	0.38	680.7
1	High Temp HX	986	507	0.4	-994.8
3 Secondary	Medium Temp HX	488	475	0.38	-25.6
2	Low Temp HX	200	50	0.4	-311.5

6.2 System Specification

The functional requirements for the primary and secondary test loops are given below.

6.2.1 Primary loop:

- A high-temperature test section with a maximum of 1000°C
- A medium-temperature test section with a maximum of 500°C
- Fluid: Helium gas
- Flow Range: 0.1 to 0.4 kg/s
- Operating Pressure: 4 to 8 MPa

6.2.2 Secondary loop:

- A high-temperature test section with a maximum of 850°C
- A medium-temperature test section with a maximum of 500°C
- Fluid: Helium gas
- Flow rate: 0.1 to 0.4 kg/s
- Operating Pressure: 4 to 8 MPa

6.2.3 Transients

- Temperature transients:
  850°C to 480°C in 100 seconds (- 220°C/min)
  480°C to 200°C in 15 min (- 19 °C/min)
  850°C to 380°C in 5 min 30 seconds (- 85°C/min)
- Pressure transients
  + 0.9 MPa/min
  18 MPa/min maximum
- Flow transients
  + 0.07 Kg/s/s
  – 0.04 Kg/s/s

6.3 Piping and Component Layout

6.3.1 Piping

The layout of the piping and piping supports will accommodate thermal expansion while avoiding potentially damaging strain at interfaces with major components. The high energy components and piping will be housed in a bunker area for personnel protection.

6.3.1.1 High Temperature Piping

The high temperature piping (>500°C) located in the hot legs will have a size of DN 500 and have external and internal insulation installed. The internal insulation will be ceramic fiber and be protected by a metal liner. The smooth metal liner also reduces flow friction losses. The piping will be made from carbon steel (SA-515 Grade 70). The metal liner will be made from Incoloy 800H.

6.3.1.2 Low Temperature Piping

The low temperature piping (<500°C) size will be DN 100 and have external insulation installed protected with a metal sheeting. The piping will be made of stainless steel Type 316.

6.3.2 Layout

It is envisioned that the test loop would be located inside a facility that contains all the support utilities required for operation of the test loop. This includes the support systems discussed in Section 6.4.2. The high energy test loop components will be located inside a bunkered area for personnel safety. See layout drawing in Appendix B, B.5.

6.4 Components and Subsystems Description

6.4.1 Components

The test loop will be comprised of the following major components, for which the design data is listed in Appendix C.

- First Stage Electric Heater
- Second Stage Electric Heater
- Recuperator Heat Exchangers
- High Temperature Heat Exchangers
- Medium Temperature Heat Exchanger
- Low Temperature Heat Exchangers
- Circulators
- Control, Isolation, Check and Relief Valves

6.4.1.1 Electric Heaters

The primary loop contains two heaters. The First Stage heater raises the helium temperature to 850°C. The Second Stage heater raises the helium temperature to 1000°C. Each heater will have heater elements contained inside a pressure vessel which shall be made of carbon steel (SA-516 Grade 70) and internally insulated with ceramic fiber thermal insulation. For the First Stage heater the internal insulation metal liner and pipe heaters will be made from Incoloy 800H. For the Second Stage heater the internal insulation metal liner will be made from Hastelloy X and the pipe heaters will be made of graphite.

6.4.1.2 Recuperator, Medium & High Temperature Heat Exchangers

Both compact and tubular heat exchangers were considered for the recuperator, medium temperature and high temperature heat exchanger applications. The tubular heat exchanger using the helical coil concept was chosen.

The tubular heat exchangers are related to conventional shell and tube heat exchangers. They commonly use a helical coil tube bundle with the cold fluid flowing in the tubes and the hot fluid flowing over the bundle in a counterflow arrangement. Tubular heat exchangers are relatively robust and they have been demonstrated at high temperature.

For applications at temperatures lower than 650°C standard stainless steels have been proven compatible with the pressure and temperature conditions involved. For applications in the range of 650–950°C, use of nickel-base alloys is required. Two potential candidate materials are Inconel 617 and Haynes 230. These heat exchangers are readily available from select vendors.

6.4.1.3 Low Temperature Heat Exchangers

Both compact and tubular heat exchangers were considered for the low temperature heat exchanger applications. The tubular heat exchanger using the U-tube concept was chosen. The low temperature heat exchanger is a conventional application that can be procured from various vendors.

6.4.1.4 Circulators

The design configuration selection for the circulator was a centrifugal flow impeller, submerged electric motor, magnetic bearings, and vertical orientation.

The circulator drives chosen were submerged induction motors using solid state inverters to control the variable motor speed. This technology was demonstrated in the AGR, AVR and THTR reactor prototypes and is considered established technology. The major advantage of the submerged motor was that it eliminated the need for drive shaft penetrations in the primary coolant boundary.

The motor compartment is cooled by a water/helium heat exchanger; a fan within the compartment ensures fluid circulation for an efficient heat transfer. Also helium injection into the cavity allows maintaining a slightly higher pressure into the compartment and can be used for cavity cooling at motor standby if required. It could also be considered as a redundant cooling system in case of water/helium heat exchange cooling circuit failure.

The gas circulator is supported by radial and axial electro-magnetic bearings (EMB). Mechanical catcher bearings are set to support the machine in case of EMB failure.

There is no material issue concerning the gas circulators. AREVA has conducted ongoing studies of compressor technology for high temperature reactor designs over the past 20 years. That experience formed the basis for the NGNP conceptual design studies and recommendations made for testing and qualification of the NGNP circulators. Outside the NGNP program, AREVA has evaluated the feasibility of circulators over a range of sizes. Both internal AREVA experts and external vendors indicate that circulators of up to 5 MW are clearly feasible and could be supplied readily.

6.4.1.5 Valves

Valves are used in the test loop for various functions; control, over pressure protection and isolation. See valve list in Appendix C, C.2. Various types of valves are utilized for these functions; ball, globe, spring-relief and spring-check valves. The control valves are air operated globe valves used to modulate flow and pressure. The relief valves are pressure actuated, spring close and are used for overpressure protection in the cold and hot legs. The isolation valves are manually operated ball valves and are used for isolating the cold legs and isolating the test sections.

The valves installed in the cold legs are low temperature valves and are considered conventional valves. The valves in the hot legs are high temperature valves and are readily available from select vendors.

6.4.2 Support Systems (Not considered as part of test loops)

6.4.2.1 Helium Purification System

The Helium Purification System will maintain the required helium chemistry by removing impurities such as Hydrogen, Carbon Monoxide, Carbon Dioxide and Methane and injecting wanted impurities. The helium from the storage tanks is first processed by this system to adjust the chemistry, and then used to fill the test loop. During test loop operation a portion of the helium flow is continuously extracted and processed to maintain helium chemistry. The design of the Helium Purification System is beyond the scope of this report. A typical purification loop is shown in Appendix B, B.1.6. However, the components used for injecting impurities to control chemistry are not shown in the typical figure.

6.4.2.2 Helium Storage and Supply System

The Helium Storage and Supply System stores helium and controls helium test loop pressure. The design of the Helium Storage and Supply System is beyond the scope of this report. A typical Helium Storage and Supply System is shown in Appendix B, B.1.7.

6.4.2.3 Cooling Water System

The cooling water system will provide cooling water to the low, medium and high temperature heat exchangers in the test loop. It will also provide cooling water to the test sections for use by the test apparatus. The cooling water system will consist of a low and high pressure loop. The high pressure loop is pressurized to avoid local boiling in the high and medium temperature heat exchangers in the test loop. The low pressure loop circulates cooling water to low temperature heat exchangers in the test loop and the high pressure cooling loop heat exchanger. The design of the cooling water system is beyond the scope of this report. A typical cooling water system is shown in Appendix B, B.1.8.

6.4.2.4 Compressed Air System

The compressed air system will provide instrument air to the control valves in the test loop. The design of the compressed air system is beyond the scope of this report. A typical compressed air system is shown in Appendix B, B.1.9.

6.5 Control and Instrumentation

The test loop will utilize temperature, pressure and flow instruments to monitor and control the required parameters. See instrument list in Appendix C, C.3.

6.5.1 Temperature Control

Temperature Control Valves will be used to modulate cooling water flow to the high, medium and low temperature heat exchangers. Each TCV will control its associated heat exchanger outlet helium temperature.

The temperature transients in the test sections and the inlet temperature to the medium temperature test section will each be controlled by an associated TCV that modulates cold helium injection from the cold leg into the hot leg.

The outlet helium temperature from the electric heaters will be controlled by modulating electrical power to the heater elements.

6.5.2 Pressure Control

The Pressure Control Valves that interface with the Helium Supply and Storage system maintain the inlet helium pressure to the circulators. This ensures that normal helium leakage from the test loop is replenished.

The pressure transients in the test sections will be controlled by a PCV. The PCV will modulate the discharge of helium from the test section to the vent tanks in the Helium Supply and Storage system.

6.5.3 Flow Control

The test loop main helium flow is controlled by modulating the rotational speed of the circulator. The rotational speed is modulated by modulating the frequency to the electric motor.

The flow rate transients in the test sections will be controlled by each individual Flow Control Valve.

7.0 CTF LARGE LOOP DESIGN

The pre-conceptual design of the CTF 30 MWt test loop includes (a) the major systems supporting the loop, (b) schematic and equipment layouts of each heat transfer loop and sections of major CTF test loop SSCs and possibility of each test station with interfaces to critical NGNP SSCs, (c) block flow diagrams, (d) P&IDs, (e) energy and material balance, (f) data sheets for each major system. Also included are the summarized internal thermal mechanical calculations for the loop start-up, normal operations, and shut-down.

The 30 MWt test loop has the following systems identified by the corresponding NGNP heat transfer loop. Note that an IHX transfers heat between the NGNP primary heat transfer loop and the secondary heat transfer loop. The IHX is tested when both heat transfer loops are in operation.

Major components of the CTF 30 MWt test loop are:

- Primary Loop
  - Electric Heater 1 (EH1A & EH1B)
  - Electric Heater 2 (EH2A & EH2B)
  - Water Cooler 1 (WC1)
  - Water Cooler 2 WC2
  - Intermediate Heat Exchanger (IHX)
  - Primary Helium Circulator (PHC)
  - Mixing Tanks (MT)
  - Primary Helium Piping (High Temperature Piping (Hot Gas Duct), Low Temperature piping)
  - Safety, Control and Stop Valves
- Secondary Loop
  - Steam Generator (SG)
  - Secondary Helium Circulator (SHC)
  - Mixing Tanks (MT)
  - Secondary Helium Piping (High Temperature Piping (Hot Gas Duct), Low Temperature piping)
  - Safety, Control and Stop Valves
- Tertiary Loop
  - Feed Water Pump
  - High Pressure Feed Water Heater
  - Low Pressure Feed Water Heater
  - Deaerator
  - Condenser
  - Condensate Water Tank

  - Condensate Water Pump
  - Sub-cooler
  - Demineralizer
  - Steam-Water Separator
  - Recirculation Pump
  - Steam, Feed Water and Other Piping
  - Safety Relief, Control and Stop Valves

7.1 Design Description

The 30 MWt test loop is designed to allow for performance tests of major components for HTGRs including the intermediate heat exchanger, steam generators and double hot gas ducts.

The main systems of 30 MWt test loop includes a primary helium system, a secondary helium system and a tertiary system. It has connection flanges, which will allow the loop to be extended and optional equipment to be tested including the heat transfer and flow distribution in the HTGR core, performance of the heat exchangers in the heat utilization systems, direct cycle turbines, and support of industrial process heat applications.

7.1.1 System Functions

The main loop circulates helium at the pressure, temperature and flow rate as required in order to ensure that the following components are duly qualified.

- Intermediate Heat Exchanger, shell and tube, printed circuit design, and 1000°C IHX
- Mixing Tanks
- High temperature ducting and insulation
- Steam Generator
- Isolation Valves
- Auxiliary Systems
- Other components of NGNP Loop Systems as necessary
- Instrumentation
- Other heat exchangers and coolers

Connection flanges for future test equipment to be added in future are provided to ensure that the following components can be tested for thermal-hydraulic characteristics and performance.

- Direct-cycle power conversion component
- Reactor vessel and core structure
- Hydrogen production process interface (NHI)
- Process heat to industrial users

7.1.2 Requirements

The CTF will be designed for an operational life of 40 years. Major performance requirements for the primary and secondary helium systems as listed in the System Requirements Manual [Reference 12.13 – See Appendix A] are as follows.

- Primary Helium System (PHS):
  - Temperature up to 1000°C
  - Gas helium
  - Flow Rate 10kg/s
  - Thermal Power 30 MWt
  - Pressure 4-7MPa
  - Temperature Transients +/-200°C /min

- Secondary Helium System (SHS):
  - Temperature up to 950°C
  - Gas helium or other gas, mixture of gas
  - Flow Rate 10kg/s
  - Pressure 3.5-7.5MPa

7.1.3 System Design Requirements

The specifications of main loop design are defined as follows, based on the functions described in section 7.1.1 and loop requirements discussed in section 7.1.2. The specifications dictate the system capacity and equipment sizing.

- Primary loop:
  - Temperature 1000°C at outlet temperature of electric heater
  - Gas helium
  - Flow Rate 10kg/s
  - Thermal Power 30 MWt
  - Pressure 7MPa
  - Temperature Transients +/-200°C /min

- Secondary loop:
  - Temperature 950°C at outlet temperature of IHX
  - Gas helium
  - Flow Rate 10kg/s
  - Pressure 7.5MPa at outlet pressure of Secondary Gas Circulator

7.1.4 System Configuration

The main loop consists of primary and secondary helium systems and a tertiary system. Figure 7-1 shows the system configuration of the main loop.

(1) Primary Helium System (PHS):

The Primary Helium System includes the Electric Heater 1, Electric Heater 2, intermediate heat exchanger, primary helium circulator, mixing tanks, primary helium piping (high temperature single pipes and conventional single pipes), and safety relief, control and stop valves.

The electric heaters can heat up the helium to 1000°C. They are separated into two stages; EH1 and EH2, and each one is divided into two components (i.e. EH1A and EH1B) because of its materials of heater and limit of dimension. The EH1 heats up the helium to approximately 700°C, while the EH2 covers the remaining range of heating to 1000°C. The emergency electric heater cooler and helium circulator are connected with the electric heaters to cool them after loss of power.

The water cooler is operated with two stages. The first stage, WC2, removes heat in the cooling system, which is pressurized to prevent cooling water from boiling. The second stage, WC1, contains a bypass line to correct the total heat removal throughout the entire water cooler system.

The PHS has a mixing tank at the mixing section to modify the mixing ratio of cold helium and hot helium. The mixing tank allows mixed helium temperature to vary at a rate of +/- 200°C /min for thermal transient tests. Another mixing tank is also available in the PHS to a provide connection with the outlet line to and the return line from the Primary Helium Purification System (PHPS).

The PHS has test equipment in place to accommodate the double hot gas duct, isolation valve, and IHX tests.

Connection flanges are available for additional test facilities, which will accommodate thermal-hydraulic and performance tests for direct-cycle power convention components, NHI process, reactor vessel and core structure, and industrial process heat applications.

The following subsystems are connected to the Primary Helium System.

- Primary Helium Purification System for removing impurities from the primary helium
- Helium Storage and Supply System for supplying the primary helium and control its pressure
- Pressurized Cooling Water System for cooling the heated helium
- Cooling Water System for cooling the heated helium

- Helium Sampling System for analyzing impurities from the primary loop helium
- Compressed Air Supply System for supplying the instrumentation air

(2) Secondary Helium System

The Secondary Helium System consists of the steam generator, secondary helium circulator, piping (high temperature piping and conventional single piping), mixing tank, and safety, control and stop valves.

Another mixing tank is set up to provide a connection to the outlet line and the return line from the Secondary Helium Purification System.

Pipe lines and connection flanges are set up to use the WC1 and WC2 as an alternative heat removing resources to the steam generator that is not available for heat removal when performing 1000°C IHX test.

The following subsystems are connected to the Secondary Helium System.

- Secondary Helium Purification System for removing impurities from the primary helium
- Helium Storage and Supply System for supplying secondary helium and controlling its pressure
- Helium Sampling System for analyzing impurities from the secondary helium
- Compressed Air Supply System for supplying instrumentation air

(3) Tertiary System (TS)

The Tertiary System consists of the feed water pump, high pressure feed water heater, condenser, condensate water tank, condensate water pump, subcooler, demineralizer, low-pressure condensate water heater, deaerator, steam-water separator and recirculation pump as well as steam, feed water and other piping, and safety, control and stop valves.

The following subsystems are connected to the tertiary system.

- Cooling Water System for cooling steam at the condenser and condensate water at the subcooler
- Chemical Supply System for controlling feed water pH
- Purified Water Production System for providing pure water
- Compressed Air Supply System for supplying instrumentation air

7.1.5 Description of the system

The main loop transfers the helium heated in EH1 and EH2, which have a combined capacity for 30 MWt, to the IHX. Then it transfers the heat to the secondary helium loop. The secondary loop helium goes into the steam generator to produce steam. The steam is then cooled in the tertiary system into condensate water, and purified, pumped, heated and returned to the SG as the feedwater.

The primary helium system has the WC1 and WC2 with a combined cooling capacity for 30 MWt, which provides adequate heat removal capacity for helium heated in EH1 and EH2 when the steam generator is out-of-service.

The tests involving the main loop include four categories.

- IHX, SG Operation
  - Simulation test for NGNP power conversion system (PCS)
  - Tests for the components included in the PCS
    - IHX (Shell and Tube Type, Printed Circuit Type)
    - SG
    - Auxiliary System
    - Components of NGNP Loop System
    - Instrumentation

- 1000°C IHX Test
  - 1000°C IHX Test

- DHD Test
  - DHD Test
  - Isolation Valve test
  - Other heat exchanger test (ex. Cooler)

- Tests to be planned in the future
  - Direct-cycle power conversion component test
  - Reactor vessel and core structure test
  - NHI tests
  - Industrial process heat transfer tests

The system configuration and specific system designs are defined so as to allow these tests. The design considerations include;

(1) Control of primary and secondary helium flow rate

The PHC and SHC are operated on a constant rotation speed. The bypass lines and control valves are set in the PHC and SHC, as shown in Figure 7-3 to allow the primary and secondary helium flow rate to vary for different test conditions.

(2) Control of helium temperature at the outlet of the EH1 and EH2

EH1 covers the process where helium is heated to approximately 700°C, while the EH2 covers the process of helium heating to 1000°C. As the electric heater outlet temperature varies depending on the test conditions, the helium temperature at the outlet of the EH1 and EH2 is controlled by heater power control system so as to achieve the specified level, as shown in Figure 7-2.

(3) Correction of heat removal capacity by the water cooler

The water cooler includes WC1 and WC2, which have heat removal capacities for 5MWt and 25 MWt, respectively. WC1 has a bypass line and control valve, which controls the flow rate at the WC1 to correct the total heat removal throughout the entire water cooler system, Figure 7-4.

(4) Temperature Transient Tests

The design enables the IHX to provide temperature transients ranging over +/- 200°C /min. The electric heaters cannot realize such a large helium temperature change in one minute. Temperature transients are accomplished by changing the mixing ratio of hot and cold helium.

Specifically, a mixing tank is set up at the EH2 outlet. A helium line with a control valve is placed between the mixing tank and EH 1 inlet to bypass EH1 and EH2, which directly inject cold helium to the mixing tank from PHC. This design allows the mixing tank to blend the cold helium with the helium heated through EH1 and EH2.

The bypass line control valve can initiate a temperature transient of +200°C /min, as shown in Figure 7-5. Specifically, the valve is initially set to deliver a mixed helium flow at 800°C by blending the helium flow at 428°C coming from the bypass line with another helium flow at 1000°C from EH2. The valve is gradually closed to reduce the 428°C helium flow, resulting in increased temperature of helium at the mixing tank outlet. The actuator allows the change in valve closing rate to adjust the increasing helium temperature rate.

Figure 7-6 shows how a temperature transient of -200°C /min is operated. The low primary helium flow through the bypass line to the mixing tank is initially set at 0 (control valve closed) while 1000°C heated helium alone is allowed to flow into the mixing tank. Then, the bypass line control valve is gradually opened to deliver 428°C helium into the

MT, resulting in temperature reduction of mixed helium at MT outlet. The valve actuator again allows the change in valve opening rate to adjust for a temperature decreasing rate.

(5) Common use of WC1 and WC2 for Primary and Secondary Helium System

The operational temperature limit for the SG is 825°C, which is the secondary helium temperature at the IHX outlet. This is a PCS operational limit. When the IHX is operated under 1000°C, the secondary helium temperature, which is measured at 925°C at the IHX outlet, is above the PCS operational limit. The secondary helium temperature is reduced via WC1 and WC2 instead of the SG. The line connecting the primary and secondary systems is set up so that the WC1 and WC2 can reduce the Secondary Helium System temperature, as shown in Figure 7-7.

(6) Primary Helium Pressure Control

The primary helium pressure is maintained at a specified level by adjusting the helium supply and discharge from the Primary Helium Purification System and Helium Storage and Supply System, as shown in Figure 7-8.

(7) Secondary Helium Pressure Control

The secondary helium pressure is controlled to maintain a differential pressure between the primary and secondary helium systems at 0.5 MPa.

As shown in Figure 7-9, the differential pressure between the primary helium pressure at the IHX outlet and the secondary helium pressure at the IHX inlet, can be maintained by adjusting the helium supply or discharge from the Secondary Helium Purification System and Helium Storage and Supply System.

(8) Connection with the helium purification systems

Mixing tanks (MTs) are installed upstream to the PHC and SHC and connected to the Primary and Secondary Helium Purification Systems. The setting precludes any effect on the main helium flow rate.

(9) Emergency Electric Heater Cooling

EH1 and EH2 should be cooled to prevent the electric heater components from over heating after loss of power accident because of the large latent heat capacity of heater elements.

The emergency EH cooler, helium circulator, piping and valves are set up between EH1 inlet and EH2 outlet and the emergency EH helium circulator is connected to emergency power supply bus.

7.1.6 Operations

(1) IHX,SG Operation

The IHX and SG can be used to test the NGNP power conversion system. Their test operation modes and heat balance is shown in Figure 7-10. In the primary helium system, the primary helium is transferred from the PHC to the EH1 and EH2 and is heated to 900°C. The IHX provides heat transfer and cools the primary helium to 490°C. The helium is returned to the PHC and allowed to circulate within the primary helium system.

In the Secondary Helium System the secondary helium is transferred from the SHC to the IHX to be heated at 825°C. In the steam generator, the secondary helium cooled down to 405°C and returns to the SHC.

In the tertiary system, the feedwater is pressurized by the feedwater pump to 17.2 MPa and heated to 282°C by the high pressure feed water heater before it is transferred to the SG. The steam evaporating region of the SG generates steam at 566°C. Once it goes out of the SG, the steam pressure and temperature are reduced to 3.7MPa and 362°C, respectively. The depressurized and cooled steam is transferred to the reheating region of SG for heating to 538°C. Exiting the SG, the reheated steam is cooled again and depressurized before it is condensed in the condenser and transferred to the condensate tank. The condensate water is pumped into the subcooler and then the demineralizer. The purified condensate water is heated in the low pressure condensed water heater, deaerated in the deaerator and returned to the feedwater pump.

(2) Double Hot Duct (DHD) Operation

The system configuration and heat mass balance of the operation test is shown in Figure 7-11. The helium discharged from the PHC flows through the outer pipe to cool the inner pipe in the DHD. Helium is then discharged from the outer line and transferred to the EH1 and EH2 and heated to 1000°C. The heated helium is then allowed to go through the DHD inner pipe. The WC1 and WC2 cool the helium to 422°C. The cooled helium returns to the PHC and circulates through Primary Helium System.

The DHD is replaceable to an isolation valve to test the valve for durability under the 1000°C helium condition.

(3) 1000°C IHX Operation

The system configuration and heat mass balance of the operation test is shown in Figure 7-12. The operation involves exclusively the Secondary Helium System. The Primary Helium System and SG are not involved. Instead of the SG, the WC1 and WC2 are used as cooler in the Secondary Helium System. The DHD is removed and a high temperature single line is installed to directly connect the IHX secondary outlet and the WC2 inlet.

In the Primary Helium System the primary helium flows from the PHC to the EH1 and EH2, where the helium is heated to 1000°C before it is transferred to the IHX. The IHX provides heat transfer to cool the primary helium to 422°C. The helium is returned to the PHC and allowed to circulate in the Primary Helium System. In the Secondary Helium System the helium is transferred from the SHC to the IHX and heated to 925°C. The helium is then cooled to 335°C in the WC2 and WC1. The Helium is returned to the SHC and allowed to circulate in the Secondary Helium System.

(4) Tests to be planned in future

Future tests include those which will involve test equipment for the direct cycle power conversion components, NHI process, reactor vessel and core structure, and industrial process heat applications. These components will be attached to the connection flange on the Primary Helium System for testing. These tests may also be supported by the PHC, EH1 and EH2, and WC1 and WC2, which provide helium circulation, heating and cooling, respectively.

The test methods and other details including structures of the specimens, and their possible connections with those equipments would be developed.

7.1.7 Process and Instrumentation Diagram

The P&ID of main helium loop is shown in Figure 7-1. Instruments for components such as helium circulator, electric heater, DHD, IHX and SG should be developed and inserted in the P&ID.

Figure 7-1: Process Flow Diagram of the Main Loop

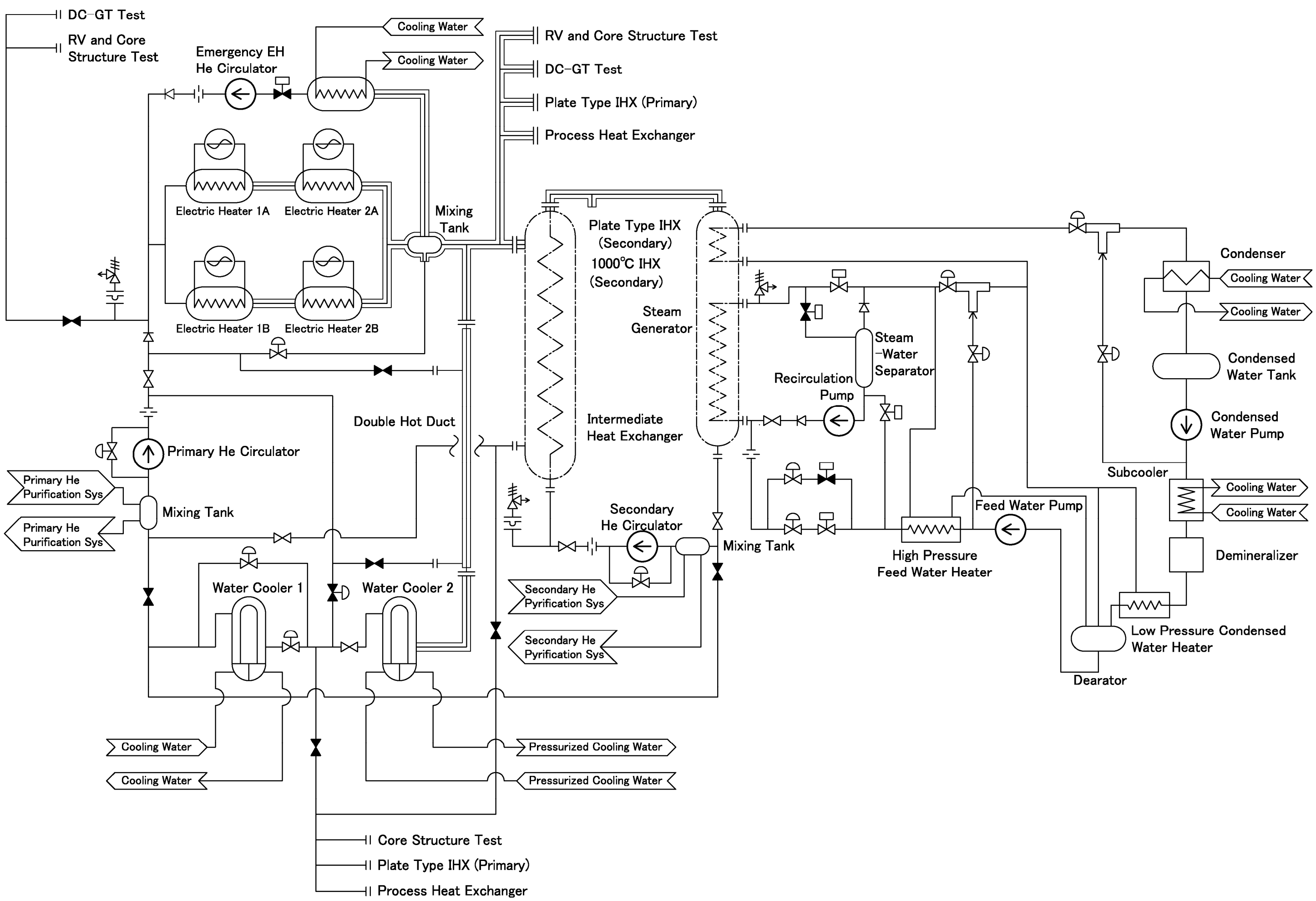


Figure 7-2: EH1 & EH2 Outlet He Temperature Control

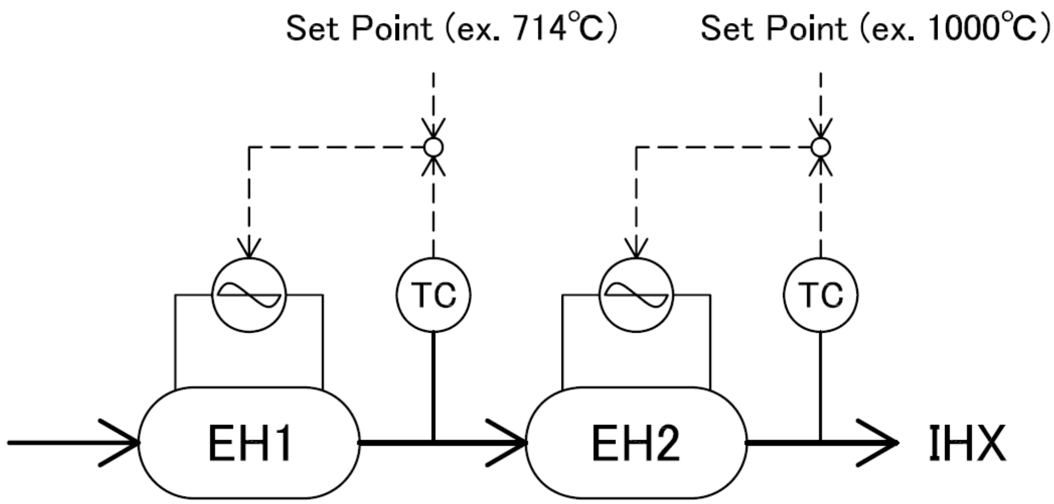


Figure 7-3: PHC Helium Flow Control

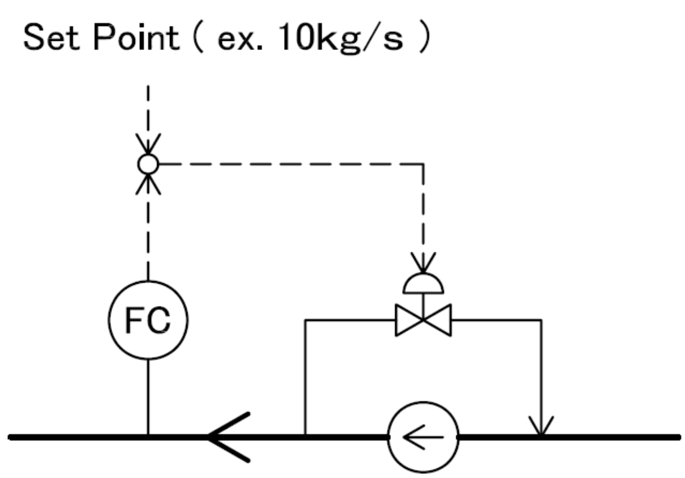


Figure 7-4: Correction of Cooling Capacity

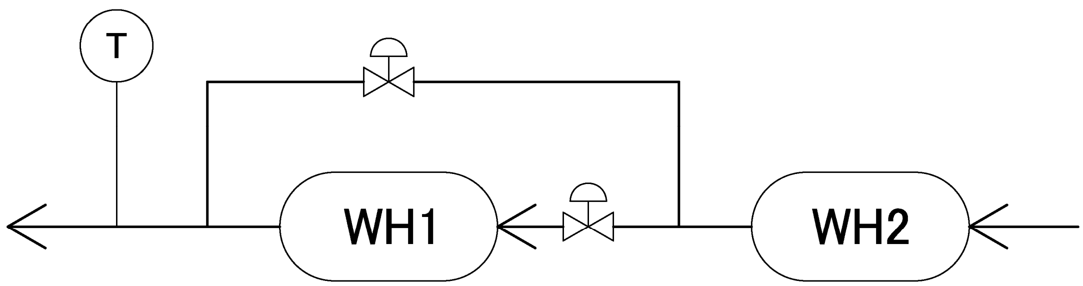


Figure 7-5: +200°C /min Temperature Transient Test

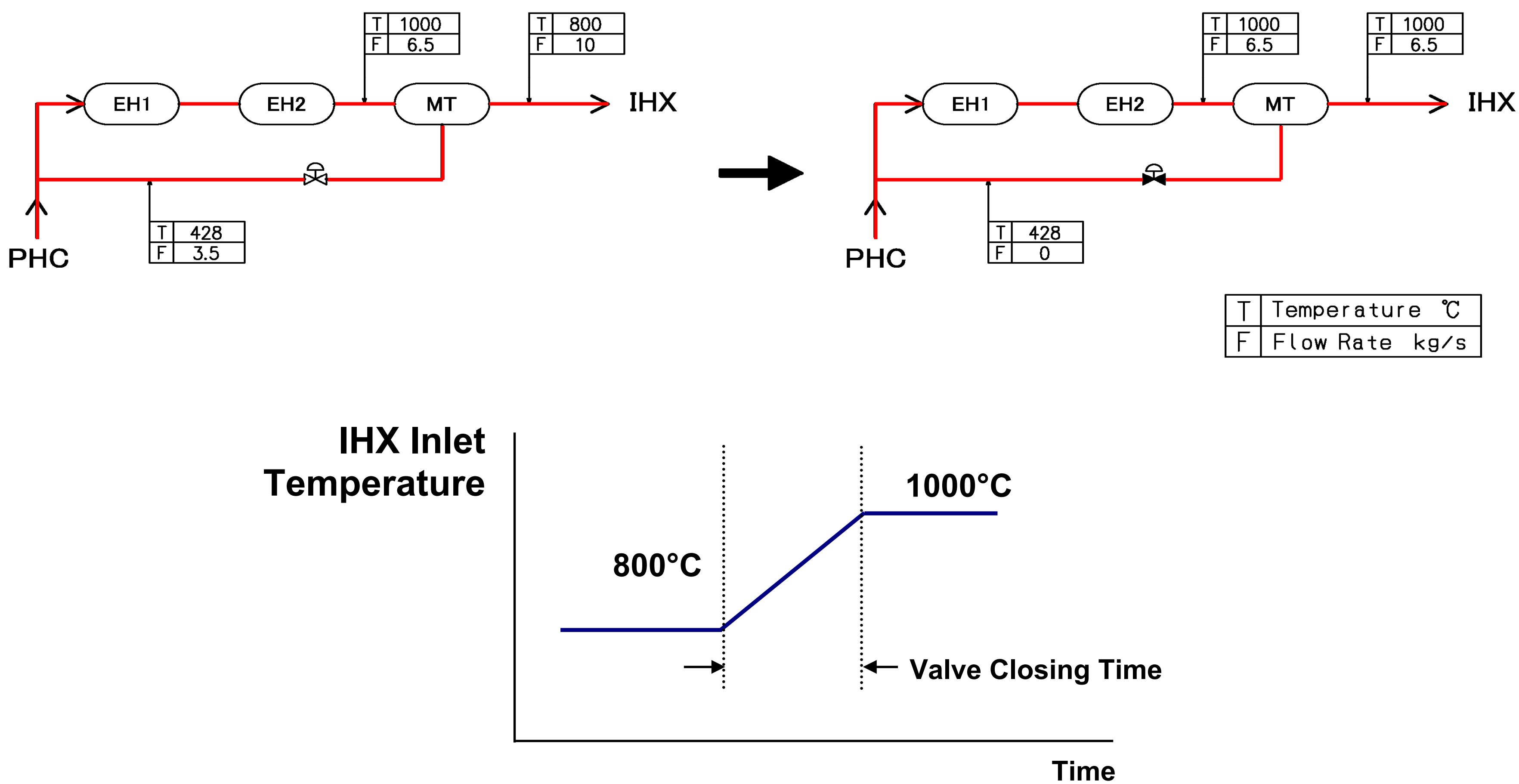


Figure 7-6: -200°C /min Temperature Transient Test

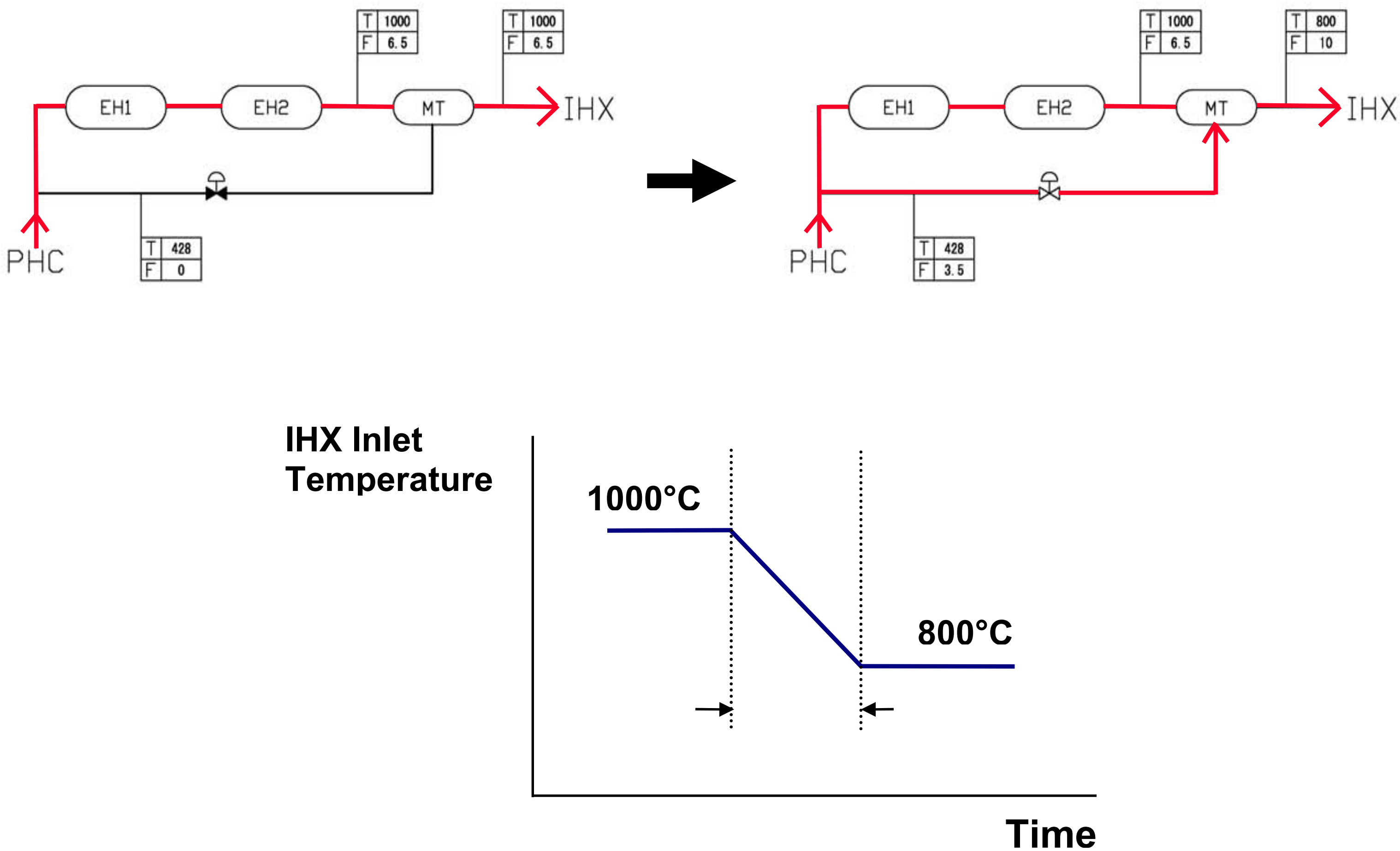


Figure 7-7: Common Use of WC1 and WC2 for Primary and Secondary Helium

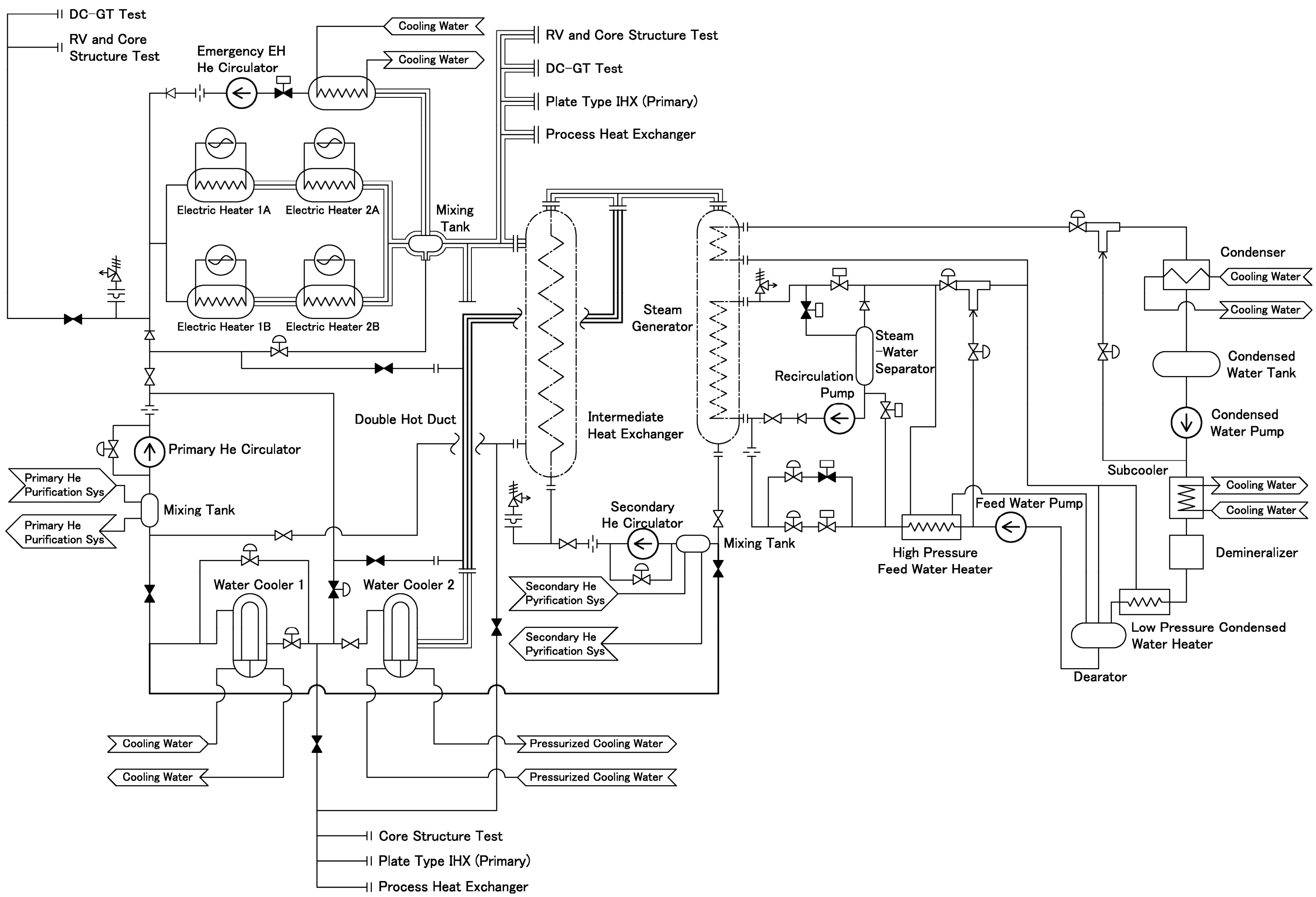


Figure 7-8: Primary Helium Pressure Control

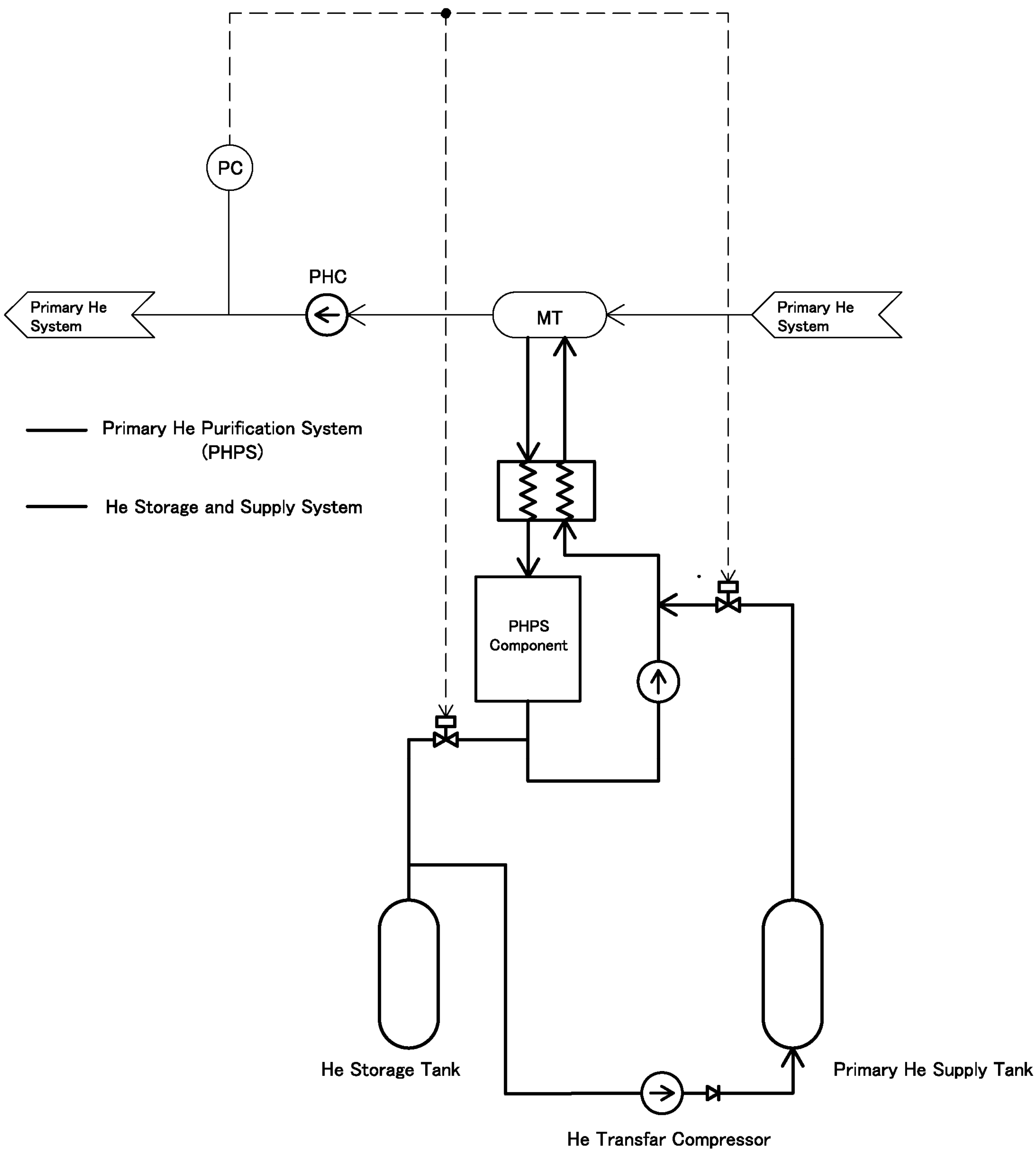


Figure 7-9: Secondary Helium Pressure Control

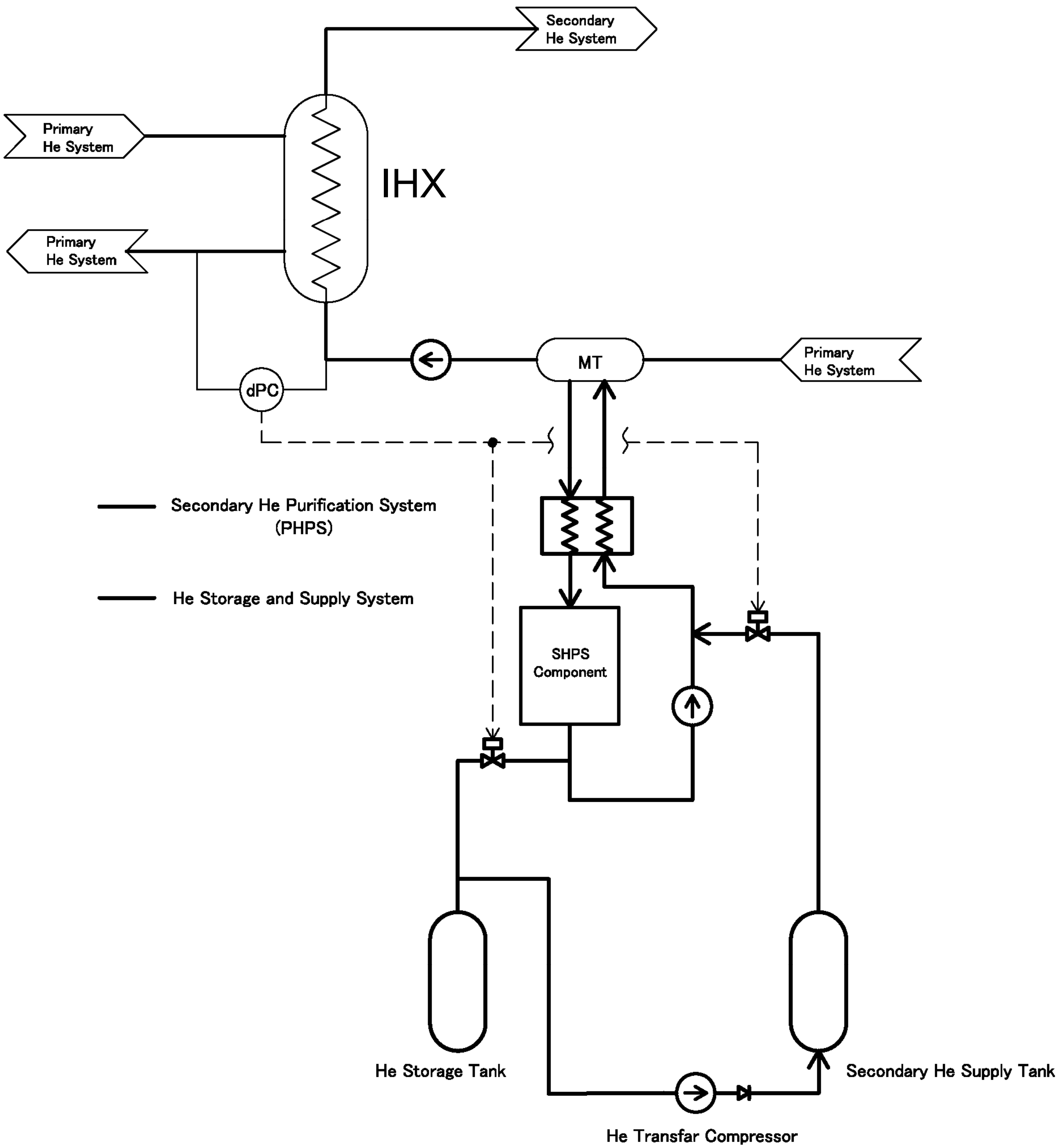


Figure 7-10: Heat and Mass Balance of 30 MWt Test Loop (IHX and SG Operation)

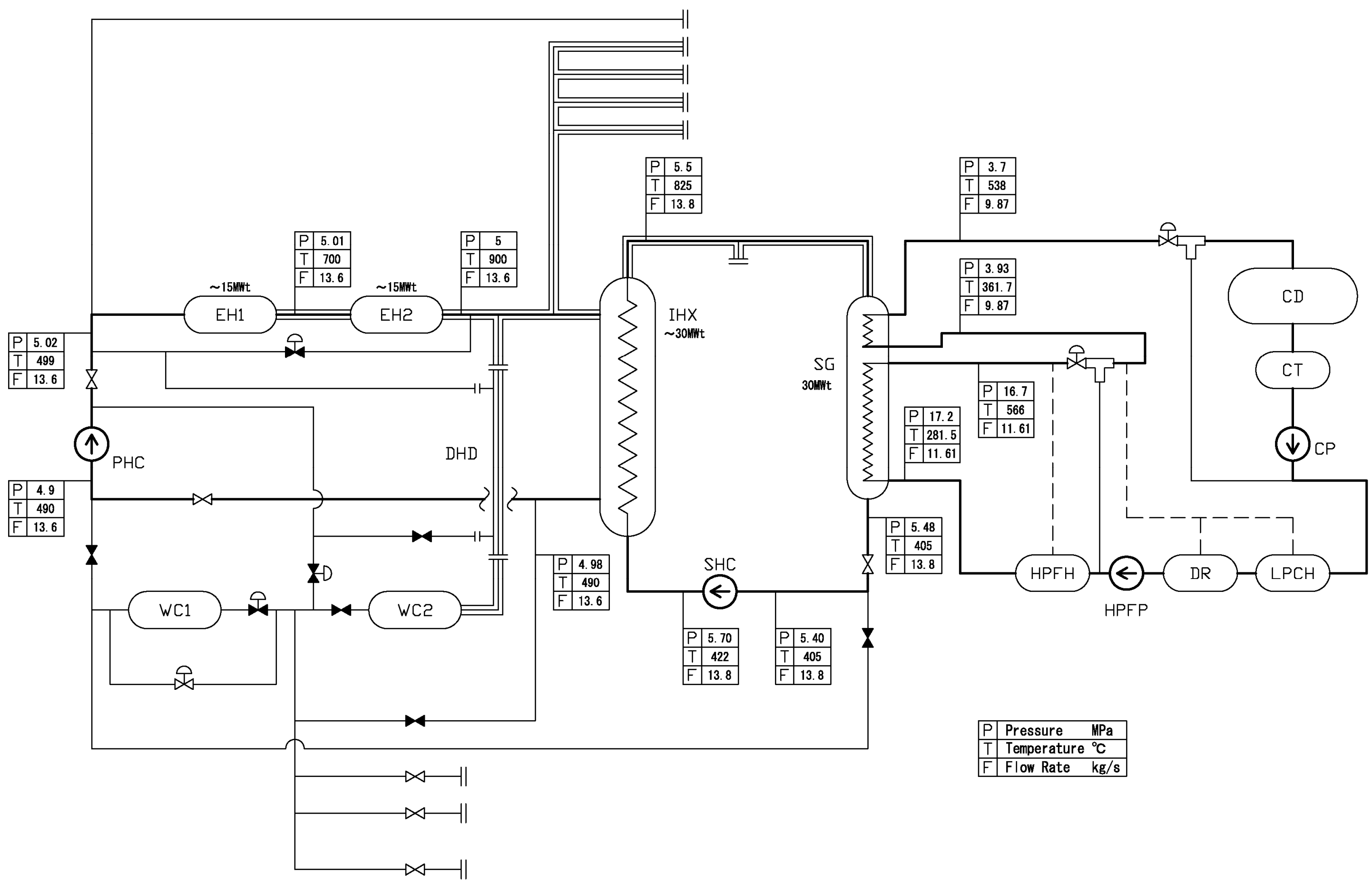


Figure 7-11: Heat and Mass Balance of 30 MWt Test Loop (DHD Operation)

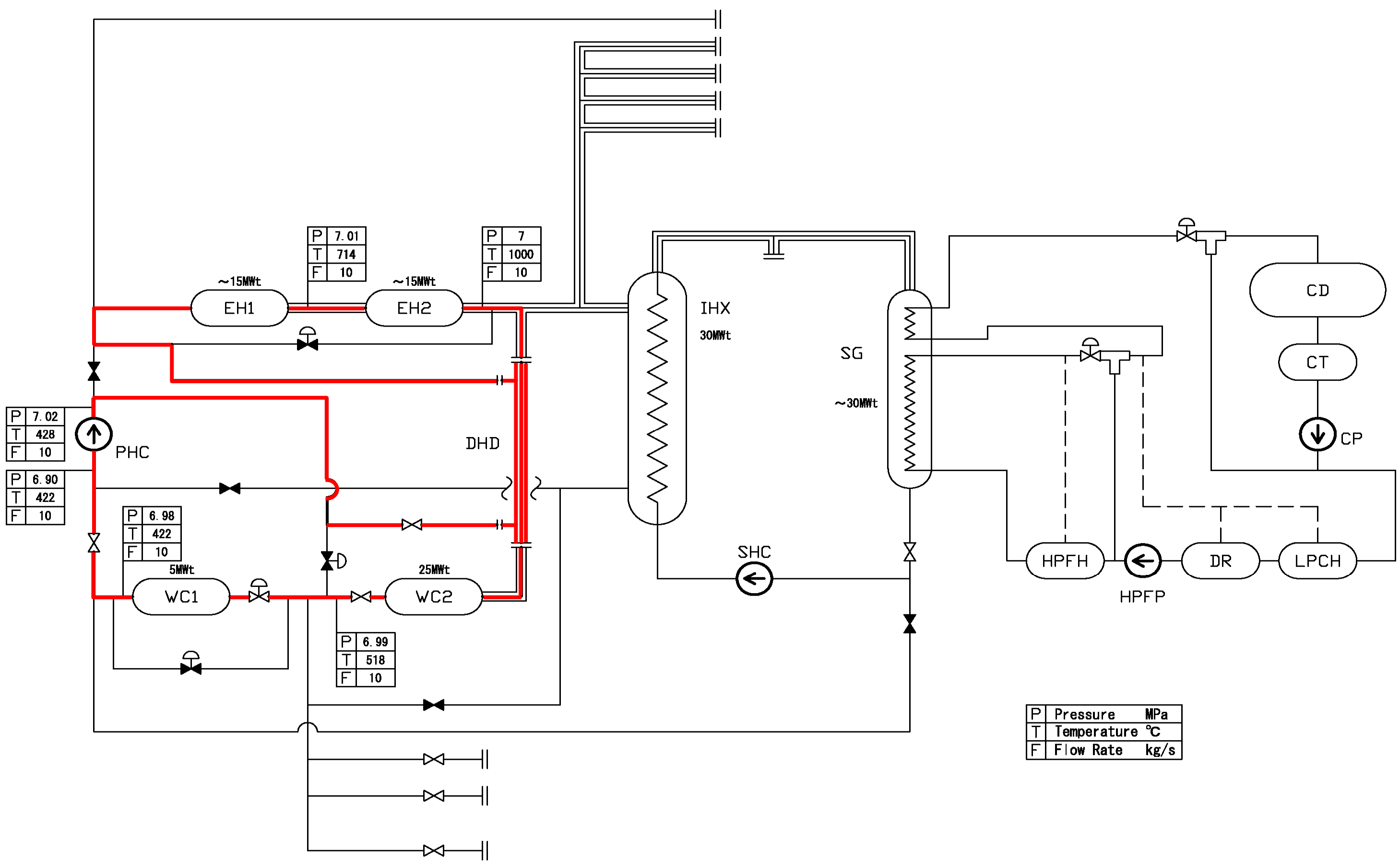


Figure 7-12: Heat and Mass Balance of 30 MWt Test Loop (1000°C IHX-SG Operation)

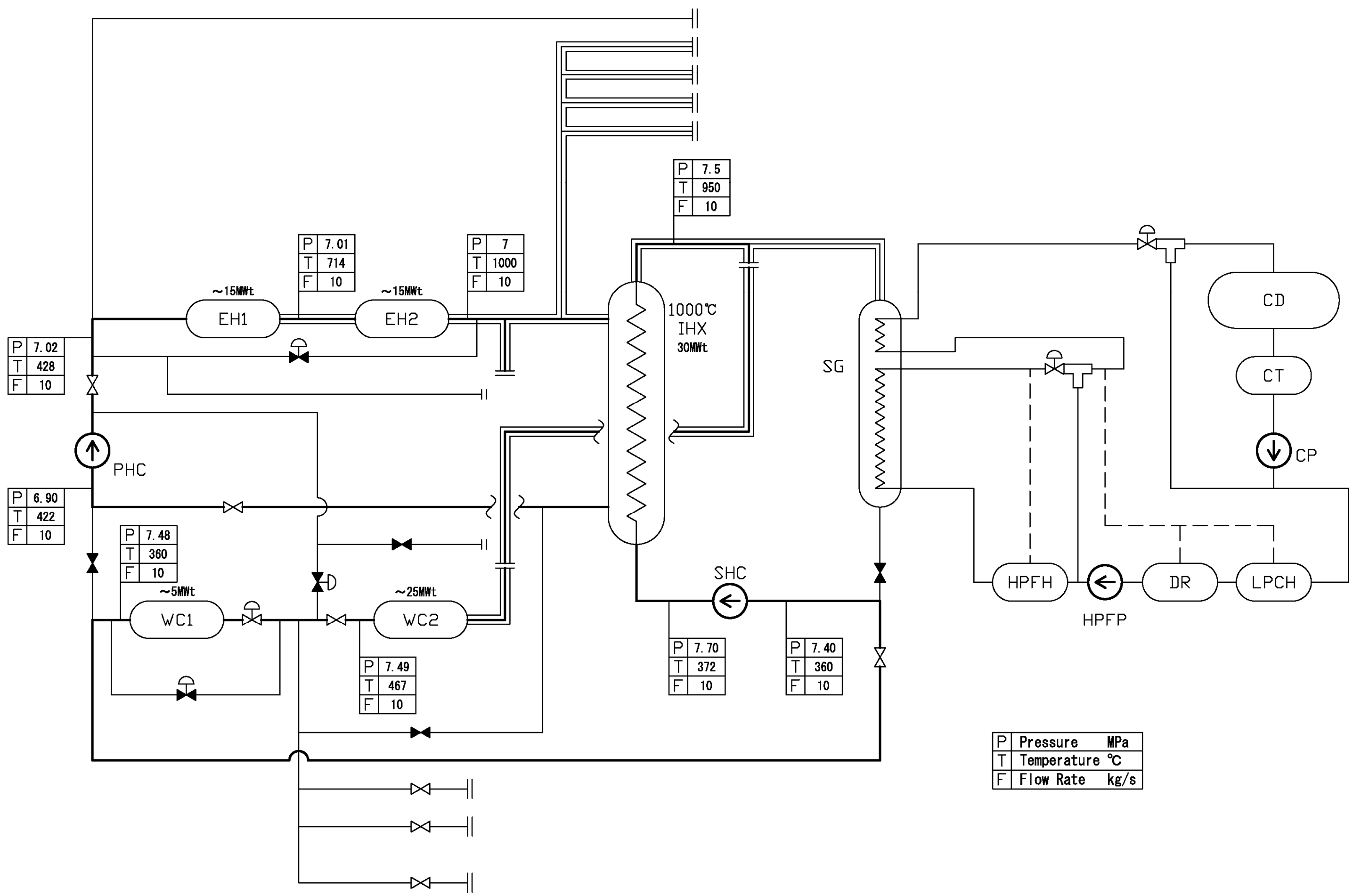
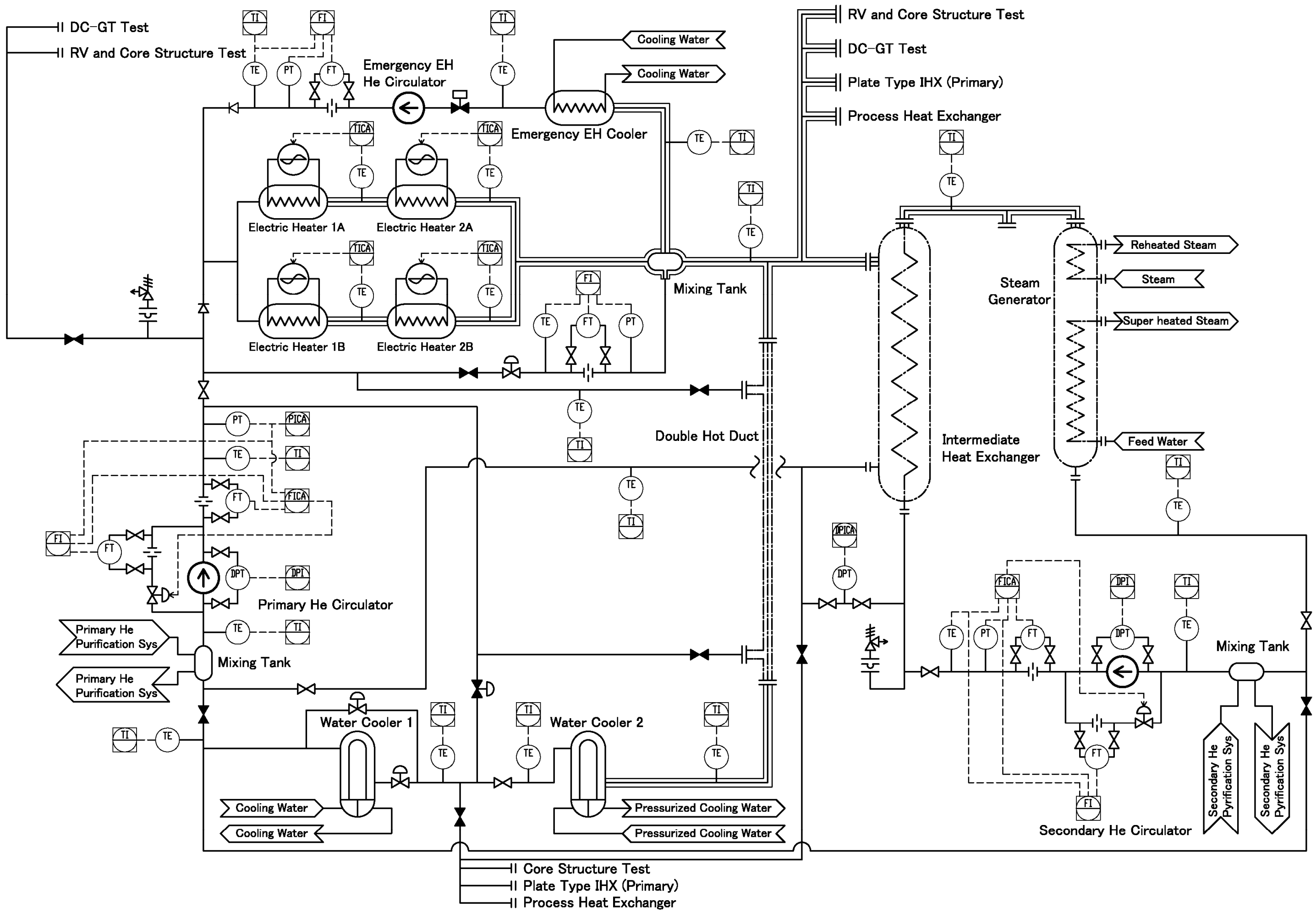


Figure 7-13: P&ID of 30 MWt Main Helium Loop



7.2 System Specification

The system specifications are selected from the inclusive parameters of heat mass balance shown in Figure 7-10 to Figure 7-12.

7.2.1 Primary Helium System

(1) System

o Design Pressure (MPa)	8.4
o Design Temperature (ºC) (Hot Leg / Cold Leg)	030/530

Operating Condition at 1000 °C IHX Operation

o Pressure (MPa)	7
o Temperature (ºC) (Hot Leg / Cold Leg)	1000/422
o Flow Rate (kg/s)	10

Operating Condition 2 at IHX SG Operation

o Pressure (MPa)	5
o Temperature (ºC)	900/490
o (Hot Leg / Cold Leg)	
o Flow Rate (kg/s)	13.6

(2) Components

- Electric Heater 1 A/B

o Design Temperature (ºC)	745
o Design Pressure (MPa)	8.4
o Inlet Operating Temperature (ºC)	428
o Outlet Operating Temperature (ºC)	714
o Inlet Operating Pressure (MPa)	7.02
o Fluid	Helium
o Flow Rate (kg/s)	5
o Heating Capacity (MWt)	7.5

- Electric Heater 2 A/B

o Design Temperature (ºC)	1030
o Design Pressure (MPa)	8.4
o Inlet Operating Temperature (ºC)	714
o Outlet Operating Temperature (ºC)	1000
o Inlet Operating Pressure (MPa)	7.01
o Fluid	Helium

- Flow Rate (kg/s) 5
- Heating Capacity (MWt) 7.5

* Water Cooler 1
  - Design Temperature (ºC) 550
  - Design Pressure (MPa) 9
  - Fluid
    - Tube Side Water
    - Shell Side Helium
  - Operating Temperature
    - Helium Inlet/ Outlet (ºC) 467/360
    - Water Inlet/ Outlet (ºC) 30/50
  - Operating Pressure
    - Helium Inlet/ Outlet (MPa) 49/7.48
    - Water Inlet/ Outlet (MPa) 0.2/0.1
  - He Flow Rate (kg/s) 10
  - Water Flow Rate (kg/s) 60
  - Cooling Capacity (MWt) 5

* Water Cooler 2
  - Design Temperature (ºC) 1030
  - Design Pressure (MPa) 9
  - Fluid
    - Tube Side Water
    - Shell Side Helium
  - Operating Temperature
    - Helium Inlet/ Outlet (ºC) 950/467
    - Pressurized Water Inlet/ Outlet (ºC) 150 /100
  - Operating Pressure
    - Helium Inlet/ Outlet (MPa) 7.5/7.49
    - Pressurized Water Inlet/ Outlet (MPa) 7.0/7.1
  - Helium Flow Rate (kg/s) 10
  - Pressurized Water Flow Rate (kg/s) 118
  - Cooling Capacity (MW) 25

* Primary Helium Circulator
  - Design Temperature (ºC) 530
  - Design Pressure (MPa) 8.4
  - Fluid Helium
  - Inlet Operating Temperature (ºC) 490
  - Inlet Operating Pressure (MPa) 4.9
  - Compression Ratio *1.044
  - Flow Rate (kg/s) 13.6

$$\text{* Compression Ratio}=\frac{4.9+[0.12+0.06(\because \text{CorePressureDrop})]\times 1.2}{4.9}=1.044$$

7.2.2 Secondary Helium System

(1) System

- o Design Pressure (MPa) 9
- o Design Temperature (ºC) (Hot Leg / Cold Leg) 980/450
- o Operating Condition 1 (1000 ºC IHX Operation)
  - Pressure (MPa) 7.5
  - Temperature (ºC) (Hot Leg / Cold Leg) 950/360
  - Flow Rate (kg/s) 10
- o Operating Condition 2 (IHX SG Operation)
  - Pressure (MPa) 5.5
  - Temperature (ºC) (Hot Leg / Cold Leg) 825/405
  - Flow Rate (kg/s) 13.8

(2) Components

- Secondary Helium Circulator
  - o Design Temperature (ºC) 450
  - o Design Pressure (MPa) 9
  - o Fluid Helium
  - o Inlet Operating Temperature (ºC) 405
  - o Inlet Operating Pressure (MPa) 5.4
  - o Compression Ratio 1.067**
  - o Flow Rate (kg/s) 13.8

$$\text{** Compression Ratio}=\frac{5.4+0.3\times 1.2}{5.4}=1.067$$

7.2.3 Piping

Piping Specifications are shown in Table 7-1 and Table 7-2.

Table 7-1: Specification of Hot leg Helium Piping

	Piping	Design Condition		Operating Condition		Flow Rate (kg/s)
		Pressure (MPa)	Temperature (ºC)	Pressure (MPa)	Temperature (ºC)	
1	EH1 to EH2	8.4	750	7.01/5.01	714/700	10/13.6
2	EH2 to IHX	8.4	1030	7.0/5.0	1000/900	10/13.6
3	IHX to SG	9	980	7.5/5.5	950/825	10/13.8
4	DHD to WC2	9	1030	7.5	1000	10

Operating Condition: 1000 ºC IHX Operation/IHX, SG Operation

Table 7-2: Specification of Cold leg Helium Piping

	Piping	Design Condition		Operating Condition		Flow Rate (kg/s)
		Pressure (MPa)	Temperature (ºC)	Pressure (MPa)	Temperature (ºC)	
1	Primary	8.4	530	7.02/5.02	428/499	10/13.6
2	Secondary	9	450	7.7/5.7	372/422	10/13.6

Operating Condition: 1000 ºC IHX Operation/IHX, SG Operation

7.3 Piping and Component Layout

(1) Layout Design Policy
The component layout was designed by following layout policies.

- The facility layout shall be acceptable in terms of economical viability, safety, operability and maintainability.
- The components which constitute the boundary to hot helium are grouped within partitioned rooms to limit the consequences of hot helium leak.
- The instrumentation and electric equipment which are sensitive to temperature are located within air-conditioned rooms. The rooms are located closely to each other to reduce the cable length.
- Monorail lines shall be located in the center of the buildings to provide transportation routes for the equipment, which are brought into and out of the buildings when construction or maintenance operations are engaged.
- Components shall be essentially installed on the floor. They shall not be tiered.
- Any components which are likely to work in the outdoor environment are installed outdoors to reduce the size of the associated building.

(2) Design Description
A description of the component layout shown in Figure 7-14 to Figure 7-16 is provided below.

- The Primary and Secondary Helium Systems (between 5th and 10th passages, and between the passages A and C.)

  Since the IHX and SG are lengthy in shape and the height of the ceilings above them is different from those for the other compartments, the components are installed at the perimeter of the relevant buildings. The walls are reinforced concrete to provide sufficient strength to support a high-rise structure. The heavy components are mounted on stand-alone pedestals to avoid inducing loads on building walls and ceilings. An access hatch is fitted in the ceiling to allow an outdoor crane to lift equipment into or out of the building.

  Some Primary Helium System components are located near the IHX, including two water coolers (WC1 and WC2), four electric heaters (EH1A, EH1B, EH2A and EH2B), primary helium circulator, two mixing tanks and a double hot gas duct, in order to make the piping layout as compact as possible. In addition, the component layout addresses the concerns about the thermal expansion of hot gas piping.

The secondary helium circulator and the mixing tank, which constitute the Secondary Helium System, are located in the vicinity of the SG. The steam-water separator is located above the SG, which must be installed at a higher elevation.

- Tertiary System (between 3rd and 5th passages, and between the passages B and C.)

  The Tertiary System is located in the vicinity of the Secondary Helium System to make the piping layout as compact as possible. The layout also addresses the concerns about the thermal expansion of hot gas piping. The deaerator is located at a high elevation to provide an NPSH for the feedwater pump.

- Primary and Secondary Helium Purification System and Helium Sampling System (between the 10th and 12th passages, and between the passages A and C)

  The Primary and Secondary Helium Purification Systems are in the vicinity of their own helium system to extract helium gas from the corresponding main loops. The recovery heater, cooler and recovery circulation pump as well as the vacuum pump, which are shared by the Primary and Secondary Helium Purification Systems, are located on the primary system side.

  The Helium Sampling System is located in the immediate and unoccupied vicinity of the Secondary Helium Purification System to extract helium from the Primary and Secondary Helium System.

- The Helium Storage and Supply System and Nitrogen Supply System (between the 3rd and 5th passages and between the passages A and B)

  The Helium Storage and Supply System and Nitrogen Supply System are located outdoors to avoid oxygen starvation induced by gas leakage and to improve convenience in receiving supply from tank trucks

- Pressurized Water Cooling System and Compressed Air Supply System (between the 4th and 7th passages and between the passages D and E)

  The pressurized water cooling system, which supplies coolant (water) to the WC 2, is located in its vicinity. In addition the distance between the cooling system and the nitrogen gas cylinder is minimized. The Compressed Air Supply System is located in the vicinity both to the Primary and Secondary Helium Systems, and Tertiary System because those systems largely are supplied instrumentation air for air-operated valves.

  The pipes providing those water and gas supply systems and the receiving ones are laid under the floor. This provides an unobstructed path in the building for the monorail line, which is running in between the building columns. It is impractical to position the pipes above the floors.

- Cooling Water System, Purified Water Production System, Waste Water Treatment System and Chemical Supply System (between the 3rd and 7th passages and between the passages F and G)

  The Cooling Water System is located outdoors because it involves a cooling tower. The Water Treatment Systems and Chemical Supply System are also located outdoors near the Cooling Water System.

- Power Control Systems for the electrical heaters (between the 8th and 12th passages and between the passages D and F)

  The Power Control Systems for EH1A, 1B and EH2A and 2B are located in the vicinity of the Primary Helium System where these heaters are installed. The cables for the heaters will be laid under the floor through a dedicated cable pit because the monorail line running between the passages C and D makes it impractical to position the cables above the floor.

Figure 7-14: Equipment Layout - Plan View (1FL-2FL)

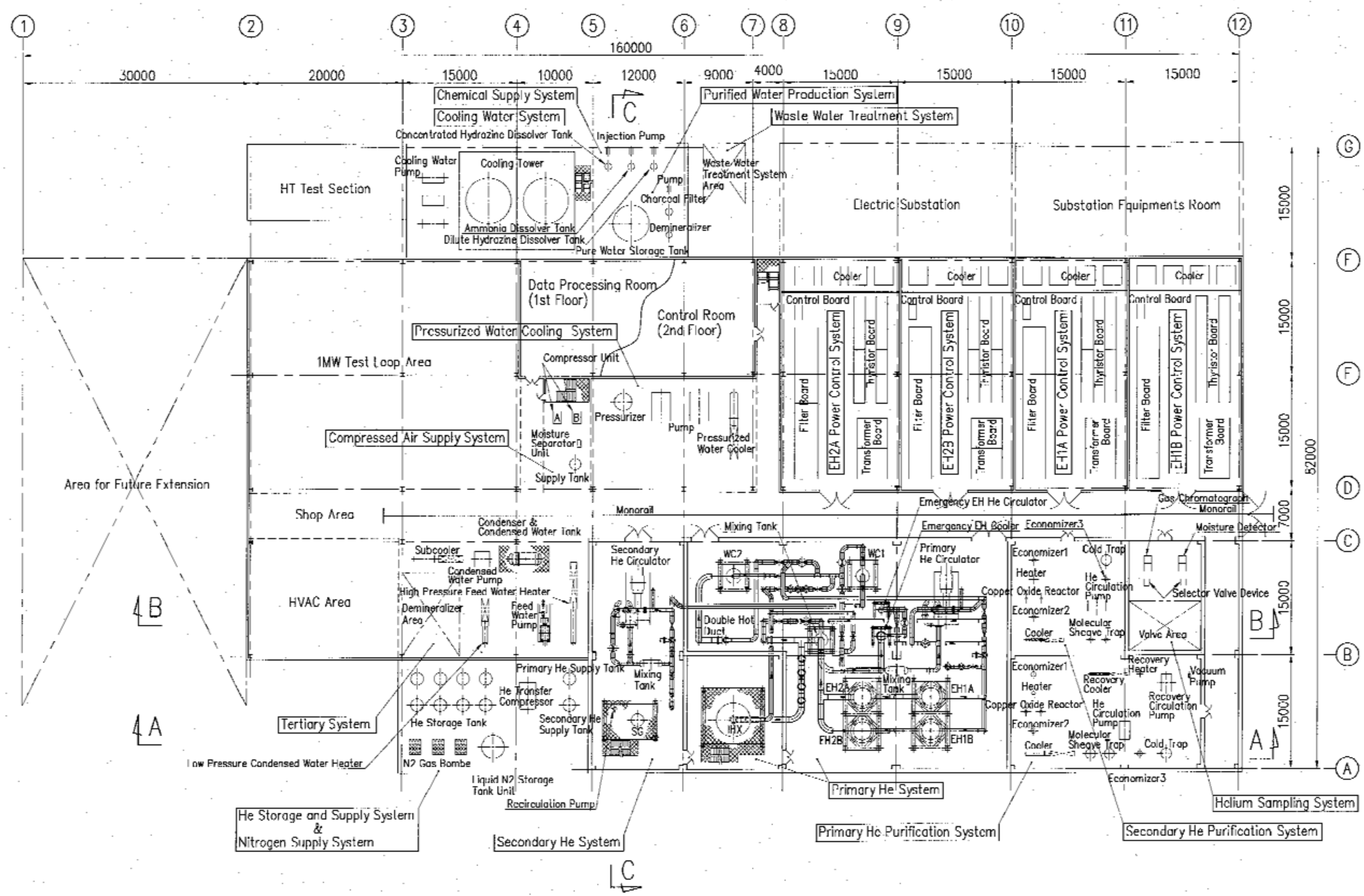


Figure 7-15: Equipment Layout – Plan View – (RF)

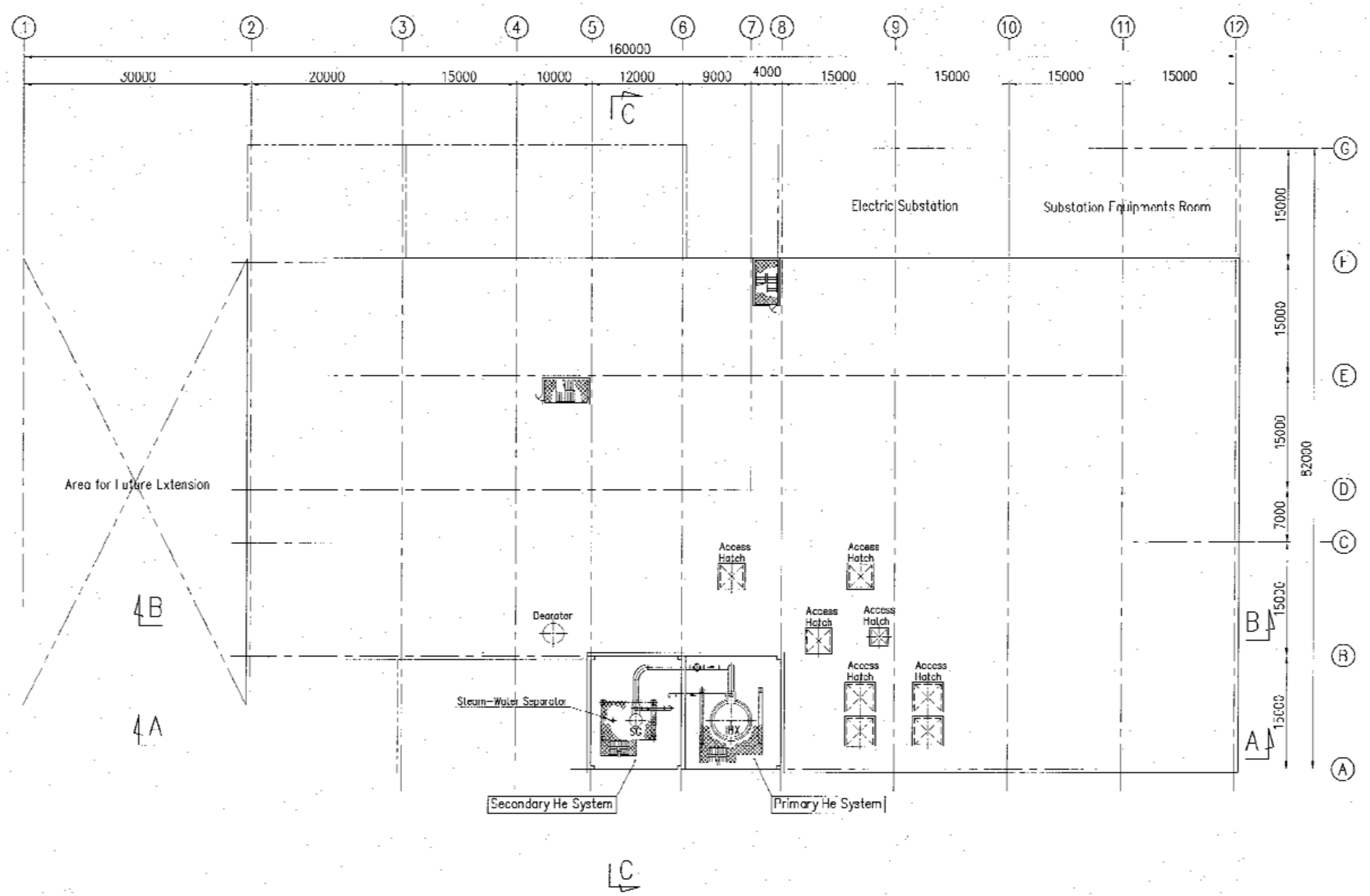
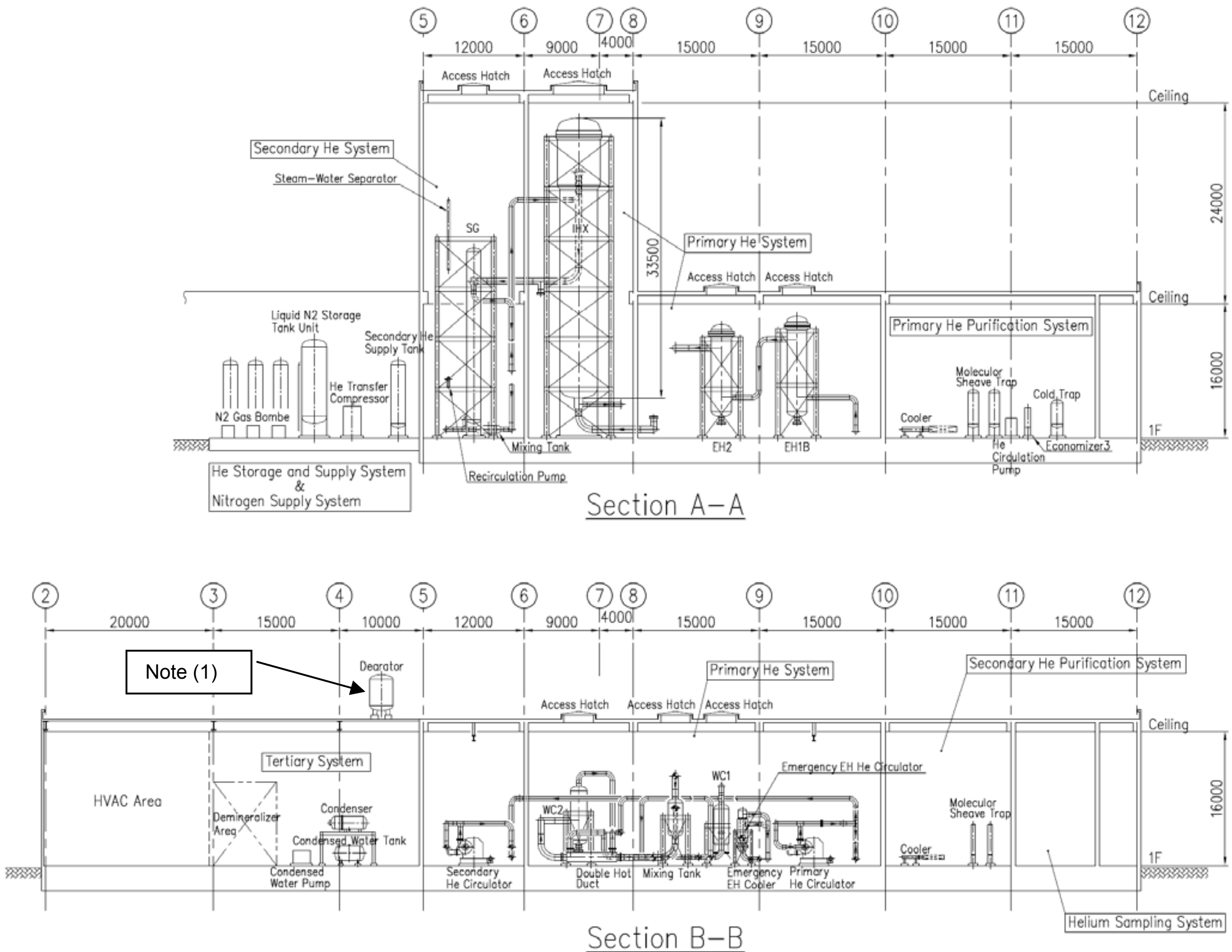


Figure 7-16: Equipment Layout- Sections and Elevations



Note (1) -
Deaerator will not be mounted on the roof.

7.4 Components and Subsystems Description

7.4.1 Components Description

The design descriptions of following major components of primary and secondary system in CTF 30 MWt Test Loop are summarized in this section.

- Electric heaters (EH1, EH2)
- Water coolers (WC1, WC2)
- Helium circulators (PHC, SHC)
- Hot gas duct elements

7.4.1.1 Electric Heaters (EH1, EH2)

(1) Objectives

Two candidates of helium heating method were evaluated. One is combustion gas heater and the other is electric heater. As a result of study, the electric heater was selected from the manufacturing cost effective point of view. Figure 7-17 shows the position of electric heaters in flow sheet of Primary loop of CTF 30 MWt Test Loop. The function of electric heater is to supply high temperature helium gas to the test equipment (e.g. IHX, DHD). Helium gas from primary helium circulator is heated to about 1000°C by two stages of electric heater (EH1 and EH2).

(2) Design Specification

Table 7-3 shows the design specification of electric heaters. EH1 heats helium gas of 10kg/s up from 427 °C to 714 °C and EH2 heats the helium gas up from 714 °C to 1000 °C in the next stage. Design pressure of two vessels is 8.4 MPa, and outer shell is designed by the design code ASME Sec VIII Div.1. Internal parts such as heater elements, insulator, etc. are designed by maker standard.

(3) Schematic Drawing

Considering availability of forging material and graphite plate for heater tube sheet, EH1 and EH2 have 2 units for each heater as shown in Figure 7-18.

Figure 7-18 shows the schematic drawing of low temperature heater EH1. Heating device is electric heating pipe, which is well adapted to high temperature system such as HENDEL. Heating pipes are arranged vertically to save the space and to be free for axial thermal expansion. The pressure vessel has internal thermal insulation and a water jacket, and is highly reliable as a pressure boundary for the high temperature helium side. A bolted flange joint of the pressure vessel upper head to shell is used for the convenience of assembly and maintenance of the heater elements. The pipe heater material and insulation liner are Incoloy 800H.

Figure 7-19 shows the schematic drawing of high temperature heater EH2. Design philosophy is as same as EH1. Major differences are shown below:

- Pipe heater elements are made by graphite
- Insulation liner is made by Hastelloy X.

(4) Design Data Sheet

Table 7-4 shows the design data sheet of electric heater EH1 and EH2. Major differences are the pipe heater material, and thickness and length of heater elements. In order to reduce the engineering and manufacturing cost, the diameter of both pressure vessels is the same size.

Table 7-5 shows the power controller design data. Voltage to the pipe heater element is regulated by a thyristor to control the heater output power, which precisely controls the helium gas temperature exiting the electrical heaters.

7.4.1.2 Water Coolers (WC1, WC2)

(1) Objectives

Figure 7-20 shows the position of water coolers in process flow sheet of the primary loop of CTF 30 MWt Test Loop. The function of water cooler is to cool the high temperature helium gas returning from test equipment.

Helium gas from the test equipment is cooled from about 1000°C by two water coolers (WC1 and WC2). The cooled helium gas flows to primary helium circulator.

(2) Design Specification

Table 7-6 shows the design specification of the water coolers. WC2 cools the helium gas temperature from 950 °C to 467 °C, and in the next stage, WC1 cools the helium gas from 467 °C to 360 °C. The design pressure of two vessels is 9.0 MPa, and outer shell is designed to the ASME Code Sec. VIII Div.1. Internal parts such as heat transfer tubes, insulator, etc. are designed by maker standard.

(3) Schematic Drawing

Figure 7-21 and Figure 7-22 shows the schematic drawing of WC1 and WC2. Shell and Tube type heat exchanger with a mixing chamber in helium outlet zone.

Characteristics of the water coolers are summarized as follows:

- The position of vessel is vertical to reduce arrangement space.
- U-bend type of cooling tubes are selected, which is free from a longitudinal thermal expansion difference between shell and tubes.
- Mixing chamber is installed in the outlet zone of U-tube bundle to minimize thermal stratification of the helium gas exiting the vessel.
- Welded vessel joints are used to minimize helium leakage.
- Internal thermal insulation and a water jacket are installed within the vessels for following reasons:
    - high reliability of pressure boundary of high temperature helium
    - availability of carbon steel (saving material cost)
    - past experience with HENDEL loop

(4) Design Data Sheet

Table 7-7 shows the design data sheet of water cooler WC1 and WC2. A major difference is the tube material.

7.4.1.3 Helium Circulators (PHC, SHC)

(1) Objectives

Figure 7-23 shows the position of helium circulators in process flow sheet of primary loop and secondary loop of CTF 30 MWt Test Loop. The function of helium circulator is to circulate the helium gas in the primary and secondary loop.

(2) Design Specification

Table 7-8 shows the design specification of helium circulators. Rated flow of primary helium circulator (PHC) is 13.6 kg/s and rated flow of secondary helium circulator (SHC) is 13.8 kg/s. Design pressure of PHC is 8.4 MPa, and design pressure of SHC is 9 MPa.

Casing and internal parts will be designed based on the manufacturer’s standard. Driving motor will be designed based on National Electrical Manufacturers Association standard.

(3) Schematic Drawing

Figure 7-24 and Figure 7-25 shows the schematic drawings of helium circulator. PHC and SHC are almost the same size and design except for the drive motor and gear. The gas circulator consists of an impeller, casing, gear and driving motor. The oil bearing and dry gas seal system for helium gas sealing between rotor and casing is chosen in order to eliminate the development cost compared with a magnetic bearing system.

(4) Design Data Sheet

Table 7-9 shows the design data sheet of helium circulators.

Primary helium circulator and secondary helium circulator should be commonly designed as much as possible to be share maintenance parts.

Table 7-10 shows the design data sheet of driving motor for helium circulators.

7.4.1.4 Hot Gas Duct Elements

(1) Objectives

Figure 7-26 shows the position of hot gas duct including hot gas mixing tank in the primary loop and secondary loop of CTF 30 MWt Test Loop.

The hot gas duct is utilized for the high temperature helium gas piping in the primary and secondary loop. Hot gas duct is used in following lines:

- EH1 ~ EH2
- EH2 ~ Test equipment (IHX, DHD, etc.)
- Test equipment ~ WC2
- IHX ~ SG
- Hot gas mixing tank

As shown in Figure 7-26, EH1 ~ EH2 line is divided two lines with each heater section (A - line and B - line) to eliminate branch pipe elements.

(2) Design specification

Table 7-11 to Table 7-13 shows the design specification of hot gas duct and hot gas mixing tank.

Pressure pipe of hot gas duct and pressure vessel of hot gas mixing tank are designed based on ASME Code Sec. VIII Div.1, and internal parts such as liner, insulator and baffle plate are designed by maker standard.

(3) Schematic Drawing of Hot Gas Duct

Hot gas ducts have internal insulation made of ceramic fiber. The pressure pipe is carbon steel (SA515-70), and the liner material is Hastelloy X or Incoloy 800H. This design concept is based on the HENDEL experience.

Figure 7-27 shows the schematic drawing of hot gas duct elements used in following lines:

- EH2 ~ Test equipment (IHX, DHD, etc.)
- Test equipment ~ WC2
- IHX ~ SG

Figure 7-28 shows the schematic drawing of hot gas duct elements used in EH1 ~ EH2 line.

Figure 7-29 shows the schematic drawing of hot gas mixing tank.

(4) Design Data Sheet

Table 7-14 shows the design data sheet of hot gas duct. Liner material of EH1 ~ EH2 line is Incoloy 800H and that of other lines is Hastelloy X.

Table 7-15 shows the design data sheet of hot gas mixing tank.

Table 7-3: Design Specification of Electric Heater

	Electric Heater 1	Electric Heater 2
Design Temperature	745°C	1030°C
Design Pressure	8.4 MPa	8.4 MPa
Operating Temperature	427°C (Inlet)/ 714°C (Outlet)	714°C (Inlet)/ 1000°C (Outlet)
Operating Pressure (Inlet)	7.02 MPa	7.01 MPa
Pressure Loss	under 0.01 MPa	under 0.01MPa
Flow Rate	10 kg/s	10 kg/s
Heating Capacity	~15MWt	~15 MWt
Design Code	Pressure Vessel : ASME Sec. VIII Div.1 Internal Parts (ex. heater element, insulator) : non Code	

Table 7-4: Design Data Sheet of Electric Heater

	Electric Heater 1	Electric Heater 2
Type	Electric heating pipe	Electric heating pipe
No. of Unit	2	2
Element Material	Incoloy 800H	Graphite
Vessel Material	SA515-70	SA515-70
No. of Element	66/unit	60/unit
Element Size [mm]	OD54, t6.5, L5040(effective length)	OD70, t15, L3850(effective length)
Vessel Size [mm]	OD2430, t90, L12000	OD2430, t90, L11000

Table 7-5: Design Data Sheet of Power Controller

	Electric Heater 1	Electric Heater 2
Type	Thyristor voltage control	Thyristor voltage control
No. of Unit	2	2
Input Voltage	3Φ 13.8kV, 60Hz	3Φ 13.8 kV, 60Hz
Current Rating	13.6 kA × 2 set	13.6 kA × 2 set
Rated Capacity	5440 kVA × 2 set	5440 kVA × 2 set
Control range(Target)	10% to 100% Continuous	10% to 100% Continuous
Accuracy(Target)	under ±2%	under ±2%

Table 7-6: Design Specification of Water Cooler

	Water Cooler 1	Water Cooler 2
Design Condition of Hydraulic Performance		
Cooling Capacity	5.6 MWt	25.1 MWt
Helium Temperature (Inlet / Outlet)	467°C / 360°C	950°C / 467°C
Helium Inlet Pressure	7.5MPa	
Helium Flow Rate	10kg/s	
Water Temperature (Inlet / Outlet)	30°C /52°C	100°C / 150°C
Water Pressure	0.2 MPa	7 MPa
Water Flow Rate	60 kg/s	120 kg/s
Design Condition for Pressure Parts		
Design Code	ASME Sec. VIII Div. 1, U Stamp	
Helium Side Design Temperature / Pressure	350°C / 9MPa	350°C / 9MPa
Water Side Design Temperature / Pressure	350°C / 0.5 MPa	350°C / 9 MPa
Design Condition for Internal and Non Pressure Parts		
Design Code	non Code	
Design Temperature	< 550°C	< 1050°C

Table 7-7: Design Data Sheet of Water Cooler

	Water Cooler 1	Water Cooler 2
Internal Thermal Insulator	installed	installed
Water Jacket	installed	installed
Cooling Surface Area	27 m^2	53 m^2
Tube Size [mm] and Quantity	OD31.8, t4.0, 73U-tubes	OD25.4, t2.6, 136U-tubes
Max. Tube Temperature (Inside / Outside)	150 °C / 81°C	267 °C / 176°C
Pressure Loss (Helium / Water)	10kPa / 40kPa	10kPa/60kPa
Shell Material	Carbon Steel (SA-515 Gr.70, SA-266 Gr.2)	
Tube Material	Carbon Steel (SA-210 A-1)	Stainless Steel (SA-213 TP316)
Vessel size [mm]	OD1780, L5800	OD1980, L7000

Table 7-8: Design Specification of Helium Circulator

	Primary He Circulator	Secondary He Circulator
Design Temperature	530°C	450°C
Design Pressure	8.4 MPa	9 MPa
Operating Temperature	490°C (Inlet)	405°C (Inlet)
Operating Pressure (Inlet)	4.9MPa	5.4MPa
Compression Ratio	1.044	1.067
Flow Rate	13.6 kg/s	13.8 kg/s
Design Code	Casing : non Code Internal parts (ex. impeller, gas seal) : non Code Drive motor : NEMA (National Electrical Manufacturers Association)	

Table 7-9: Design Data Sheet of Helium Circulator

	Primary He Circulator	Secondary He Circulator
Type	Centrifugal	Centrifugal
No. of Stage	2	2
Operating Speed	8000rpm	11000rpm
Control System	By-pass control	By-pass control
Gas Seal Type	Dry gas seal	Dry gas seal
Amount of Cooling Water	70 m^3/h	70 m^3/h
Inlet Temperature of Cooling Water	30°C	30°C

Table 7-10: Design Data Sheet of Drive Motor

	Primary He Circulator	Secondary He Circulator
Type	Cage type induction	Cage type induction
No. of Pole	6	6
Operating Speed	1200 rpm	1200 rpm
Rating	1500 kW	2000 kW
Input Voltage	3Φ 13.8kV, 60Hz	3Φ 13.8kV, 60Hz
Installation Site	Indoor	Indoor

Table 7-11: Design Specification of Hot Gas Duct (1/2)

	EH1 ~ EH2	EH2 ~ IHX
Design Temperature	750°C	1030°C
Design Pressure	8.4MPa	8.4MPa
Operating Temperature	714°C (IHX)/ 700°C (IHX & SG)	1000°C (IHX)/ 900°C (IHX & SG)
Operating Pressure (Inlet)	7.01MPa (IHX)* / 5.01MPa (IHX & SG)*	7.0MPa (IHX) / 5.0MPa (IHX & SG)
Flow Rate	10kg/s (IHX) / 13.6kg/s (IHX & SG)	10kg/s (IHX) / 13.6kg/s (IHX & SG)
Design Code	Pressure Pipe : ASME Code Sec. VIII Div.1 Internal Parts (ex. liner, insulation) : non Code	

Note : (IHX) : 1000°C operation mode (IHX & SG) : IHX and SG operation mode

Table 7-12: Design Specification of Hot Gas Duct (2/2)

	IHX ~ SG	DHD ~ WC2
Design Temperature	980°C	1030°C
Design Pressure	9 MPa	9 MPa
Operating Temperature	950°C (IHX)/ 825°C (IHX & SG)	1000°C
Operating Pressure (Inlet)	7.5 MPa (IHX) / 5.5 MPa (IHX & SG)	7.5 MPa
Flow Rate	10 kg/s (IHX) / 13.8 kg/s (IHX & SG)	10 kg/s
Design Code	Pressure Pipe : ASME Code Sec. VIII Div.1 Internal Parts (ex. liner, insulator) : non Code	

Table 7-13: Design Specification of Hot Gas Mixing Tank

Design Temperature	1030°C
Design Pressure	8.4 MPa
Operating Temperature	1000°C (IHX) / 900°C (IHX & SG)
Operating Pressure (Inlet)	7.0 MPa (IHX) / 5.0 MPa (IHX & SG)
Flow Rate	10 kg/s (IHX) / 13.6 kg/s (IHX & SG)
Design Code	Pressure Pipe : ASME Code Sec. VIII Div.1 Internal Parts (ex. liner, insulation) : non Code

Table 7-14: Design Data Sheet of Hot Gas Duct

	EH1 ~ EH2	EH2 ~ IHX, IHX ~SG, DHD ~ WC2
Type	Internal insulation	Internal insulation
Liner Material	Incoloy 800H	Hastelloy X
Piping Material	SA515-70	SA515-70
Insulator Material	Ceramic fiber	Ceramic fiber
Inner Liner Size [mm]	OD240, t7	OD370, t7
Outer Piping Size [mm]	OD457.2, t19	OD711.2, t35
Insulator Size [mm]	t89.6	t135.6

Table 7-15: Design Data Sheet of Hot Gas Mixing Tank

Type	Internal insulation / Baffle plate
Liner Material	Hastelloy X
Piping Material	SA515-70
Insulator Material	Ceramic fiber
Baffle Plate Material	Graphite
Vessel Size [mm]	OD1780, t90, L4450

Figure 7-17: Position of Electric Heaters

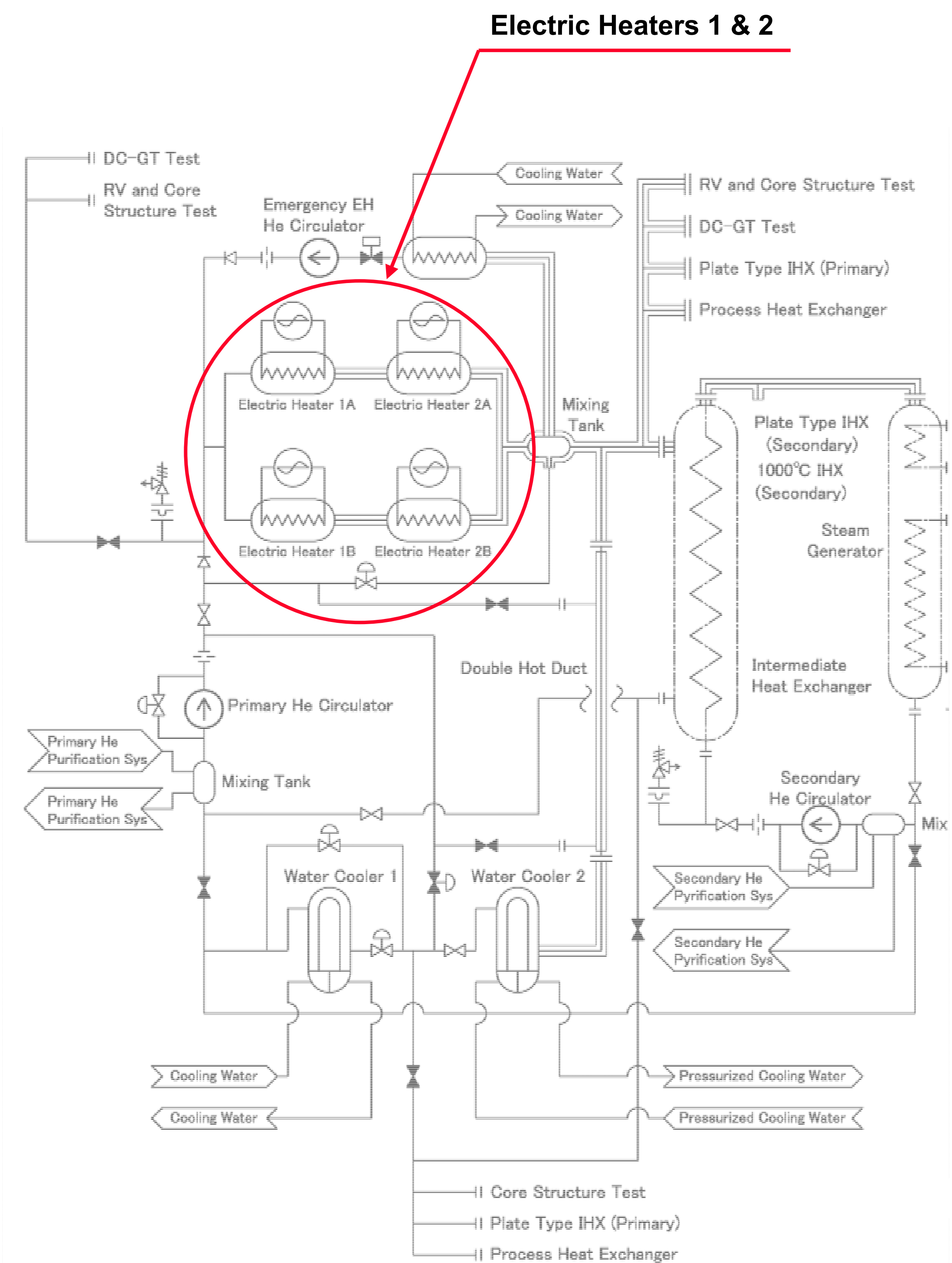


Figure 7-18: Electric Heater 1 (EH1A & EH1B)

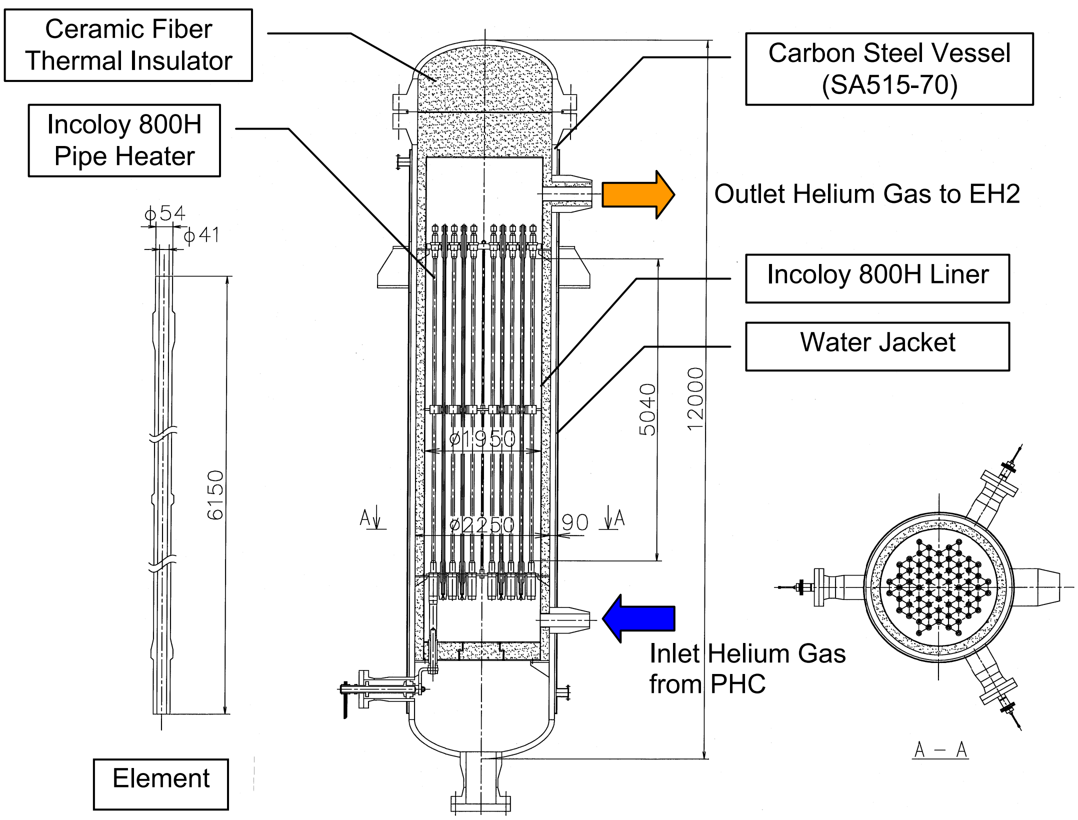


Figure 7-19: Electric Heater 2 (EH2A & EH2B)

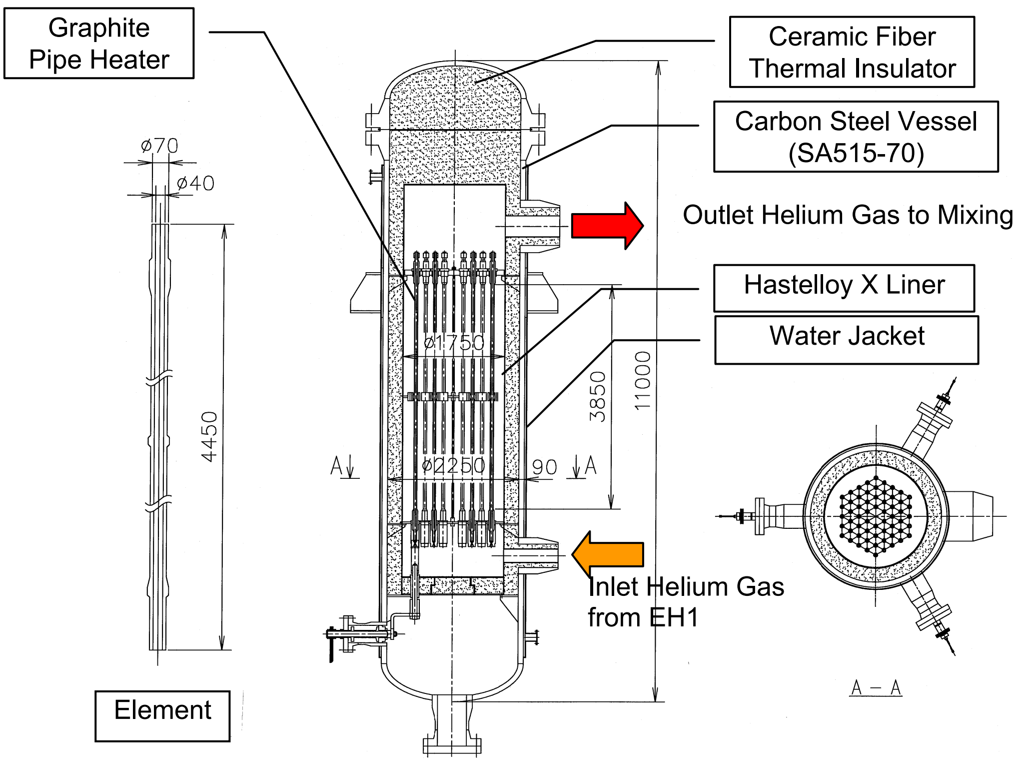
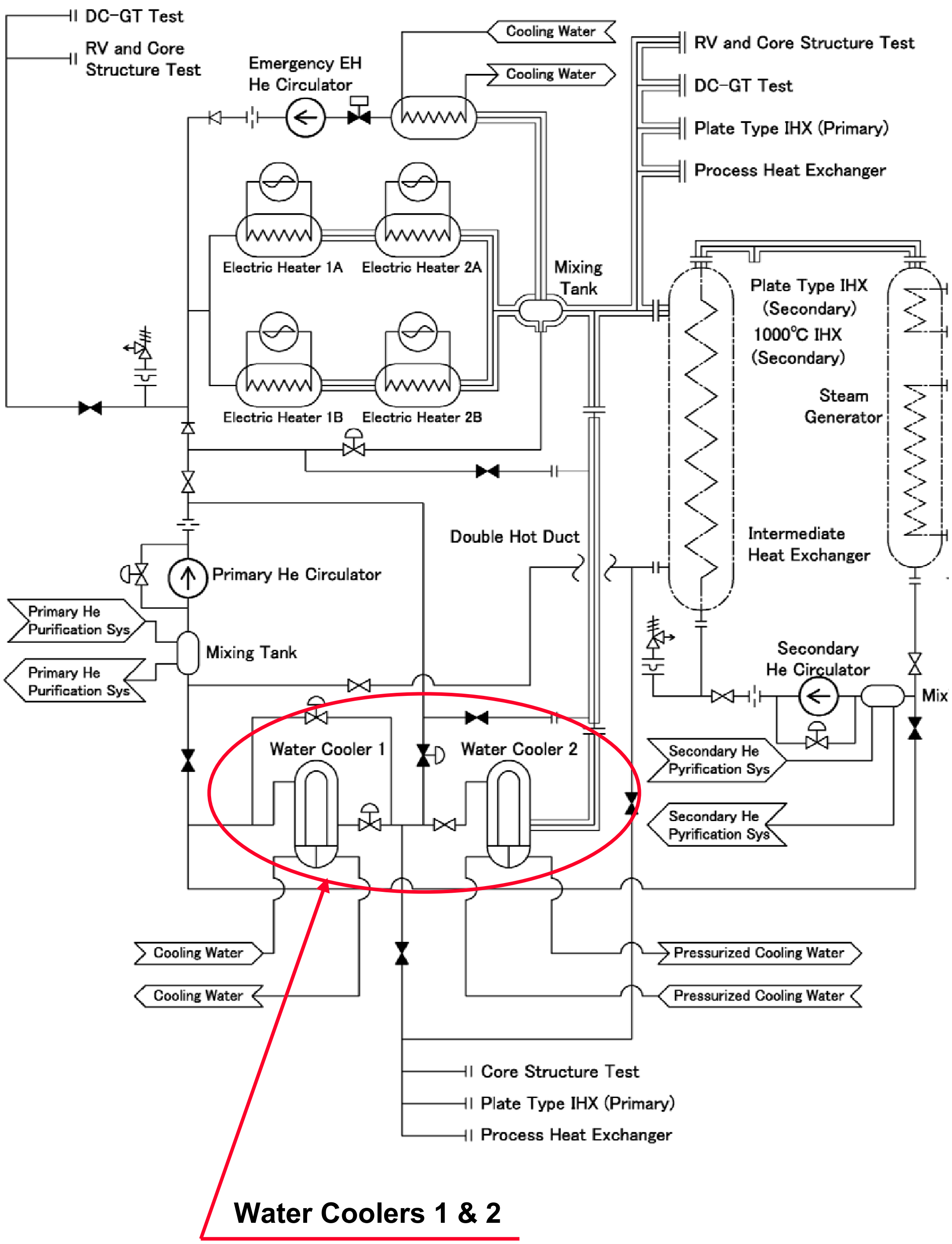


Figure 7-20: Position of Water Coolers



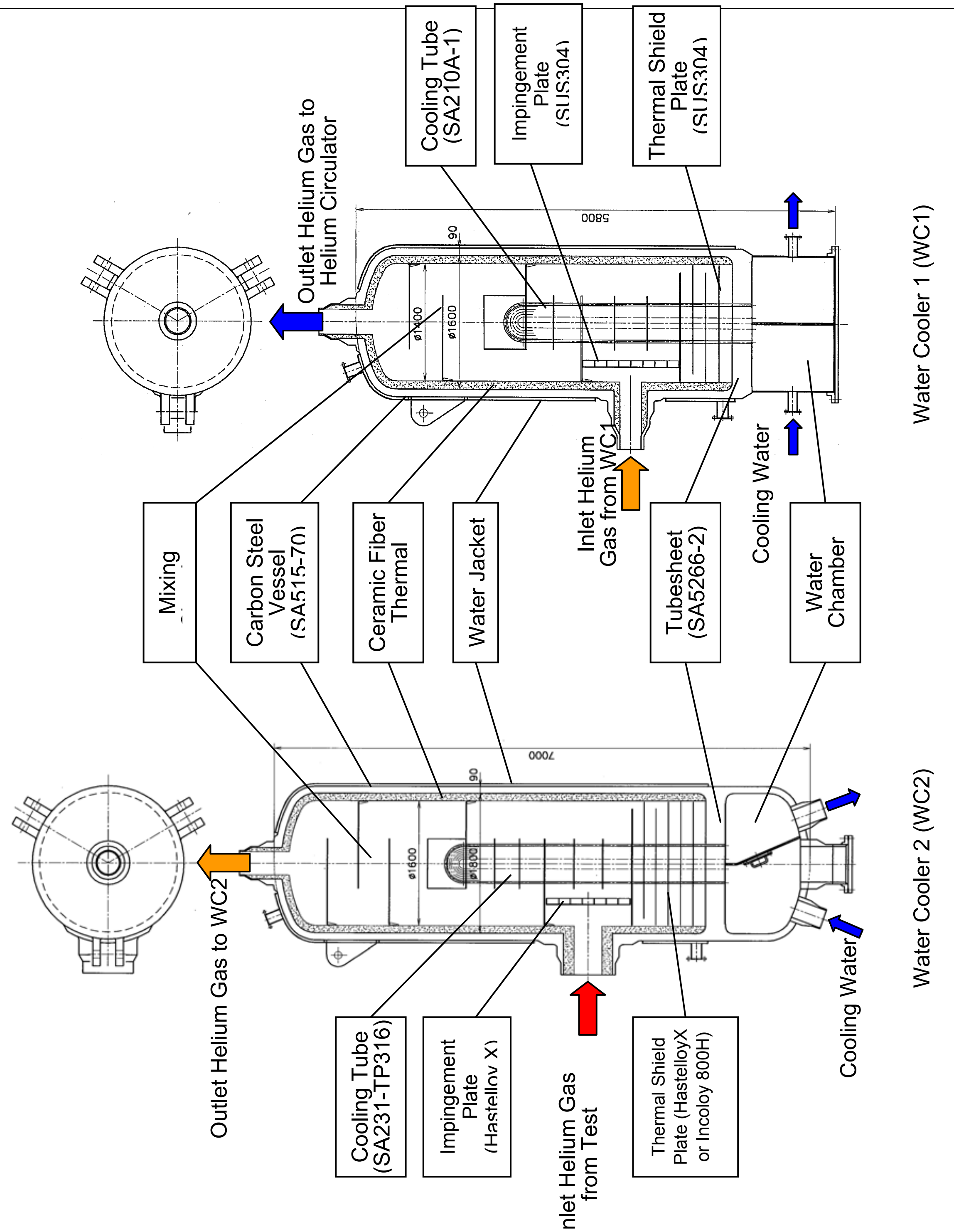


Figure 7-21: Water Cooler 1

Figure 7-22: Water Cooler 2

Figure 7-23: Position of Helium Circulators

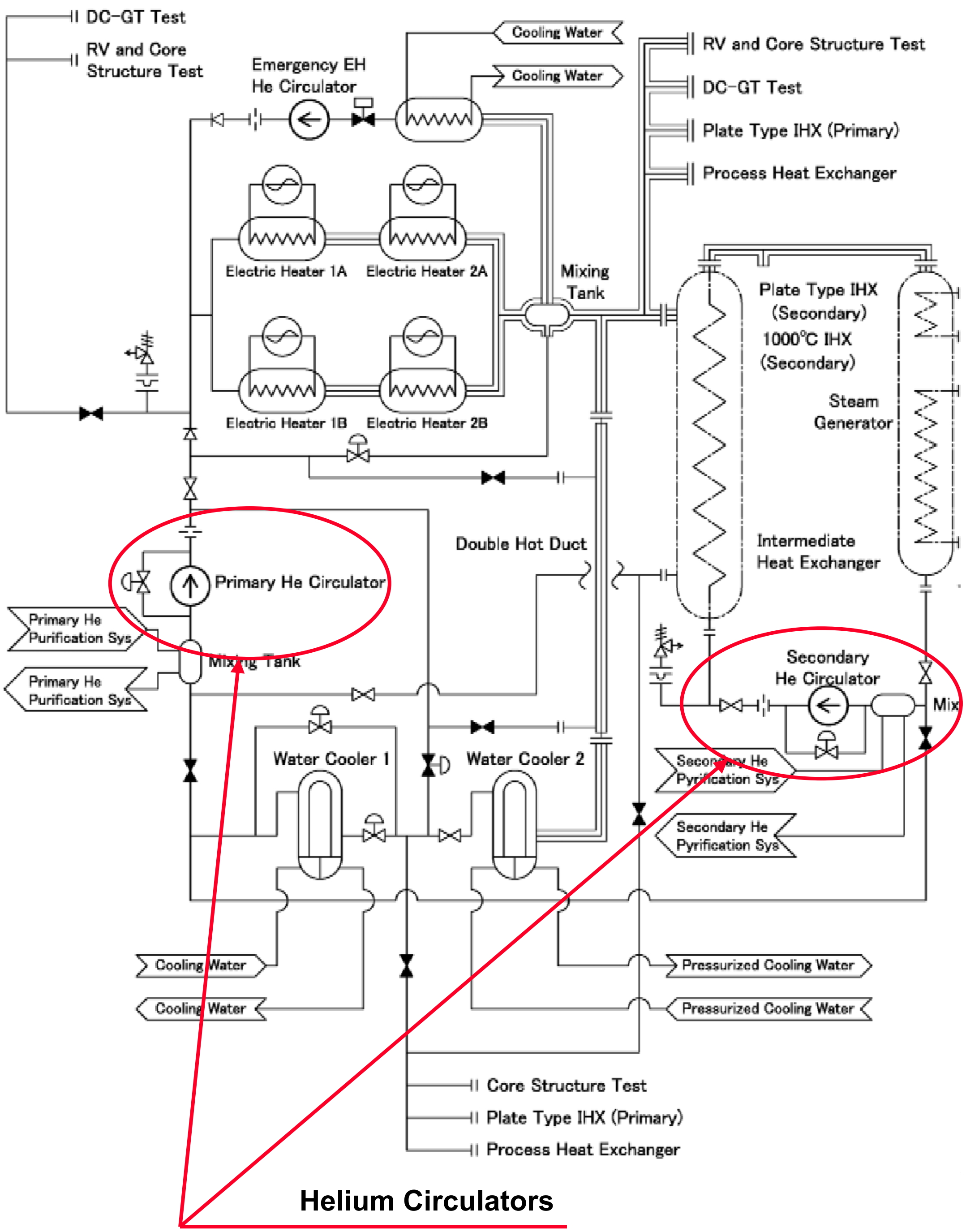


Figure 7-24: Gas Circulators – Primary and Secondary Loop

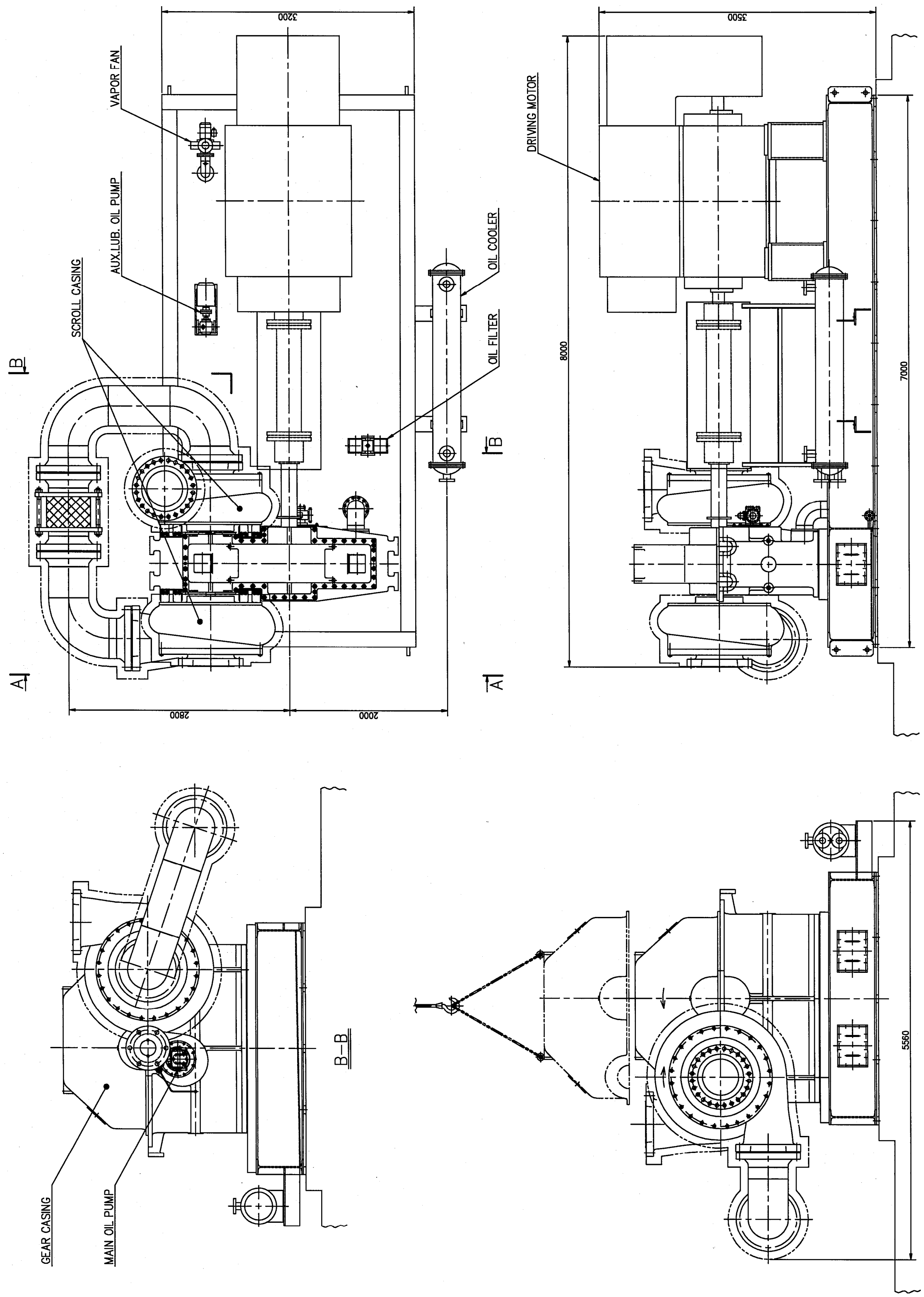


Figure 7-25: Gas Circulator (Primary and Secondary Loop)

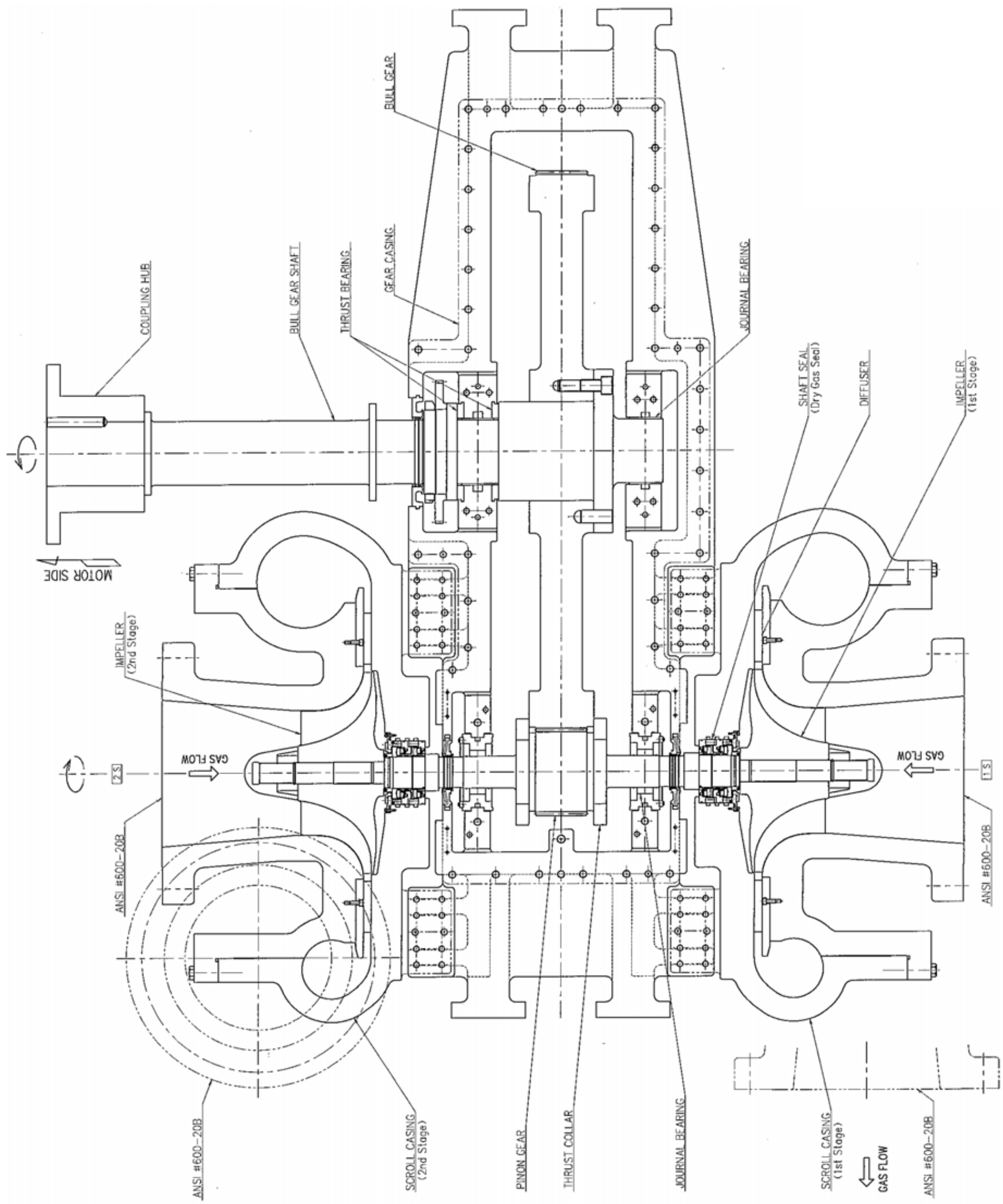


Figure 7-26: Position of Hot Gas Duct

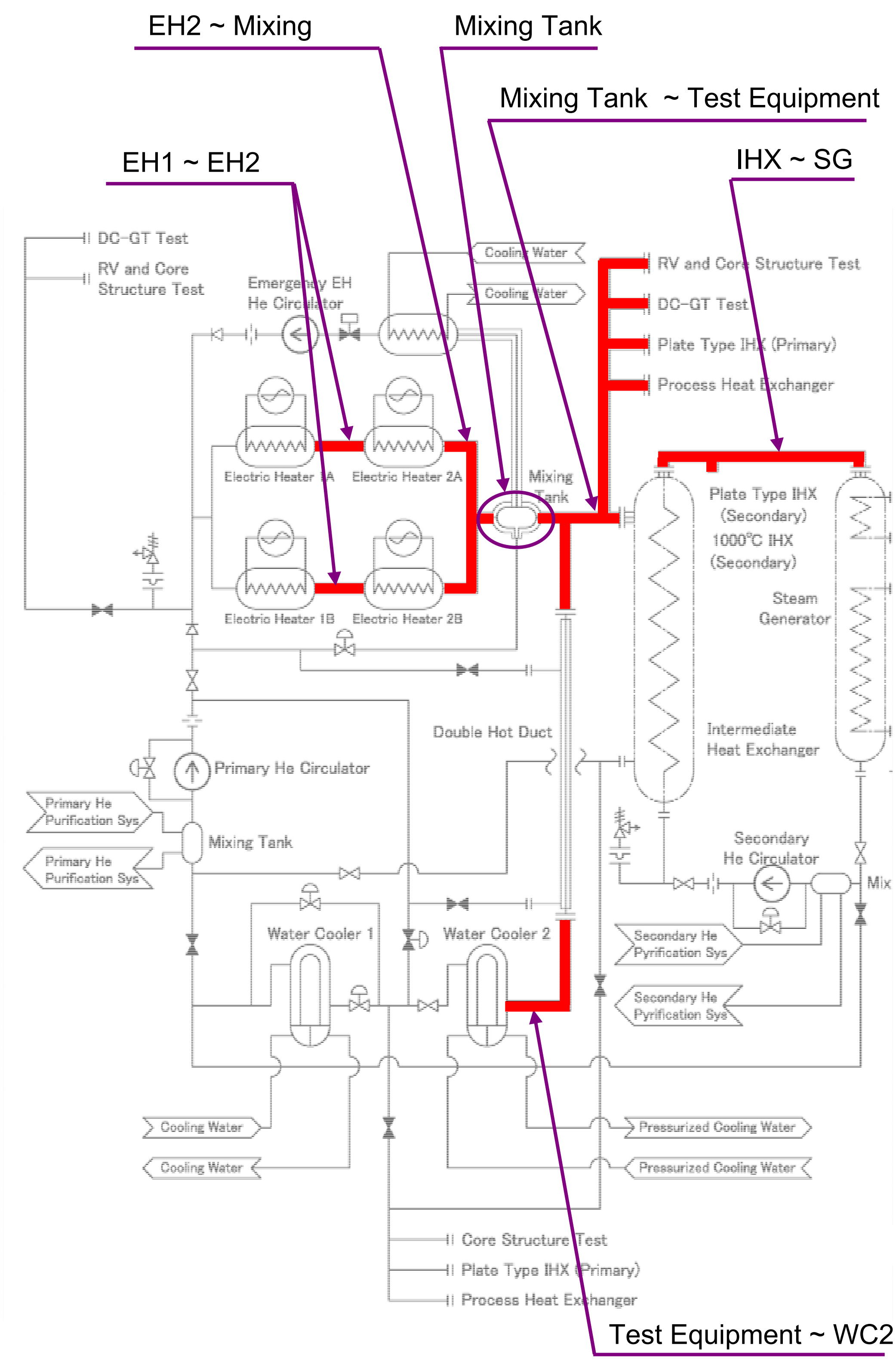
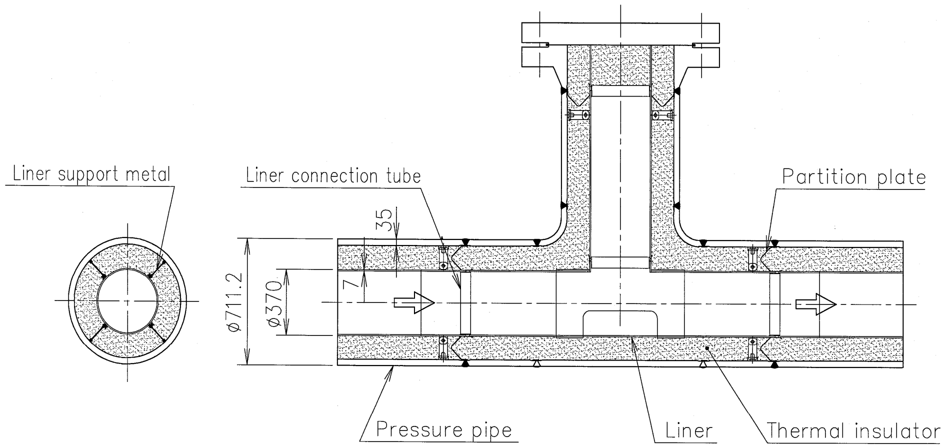
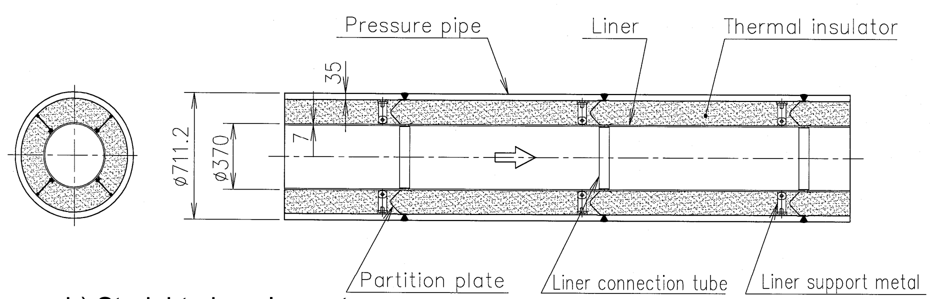


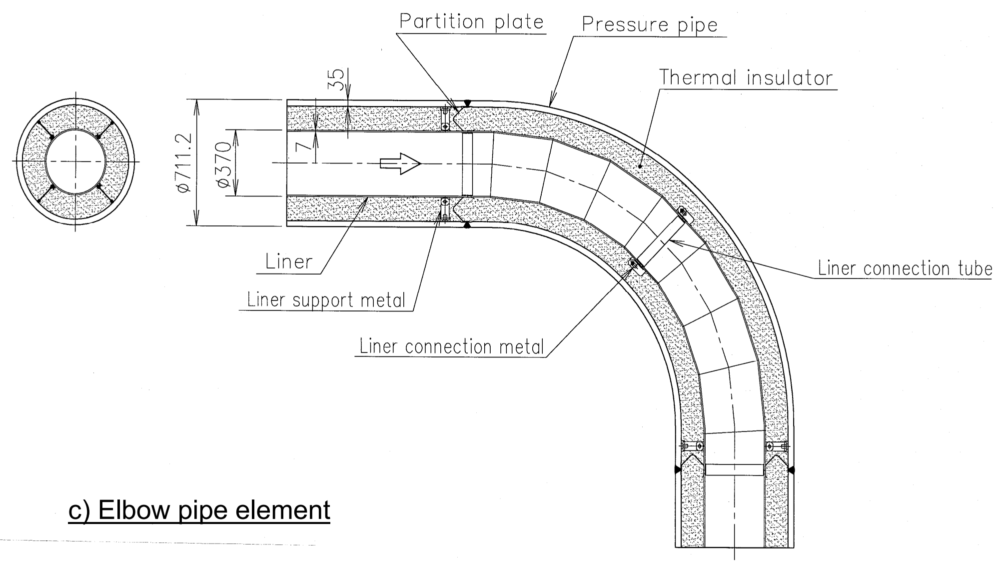
Figure 7-27: Hot Gas Duct Elements



a) Branch pipe element

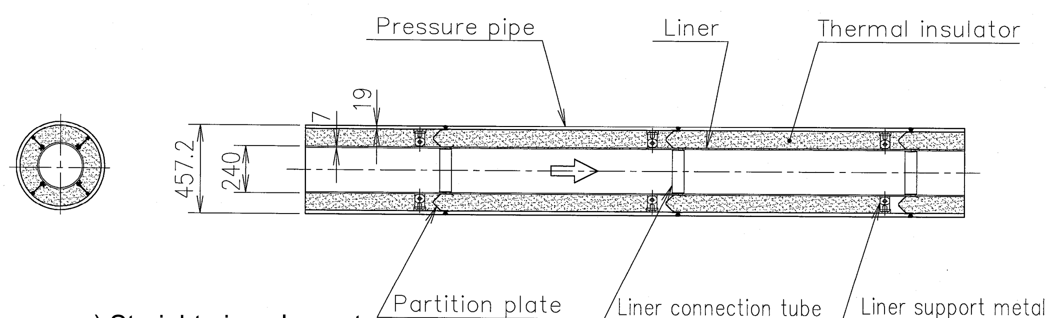


b) Straight pipe element

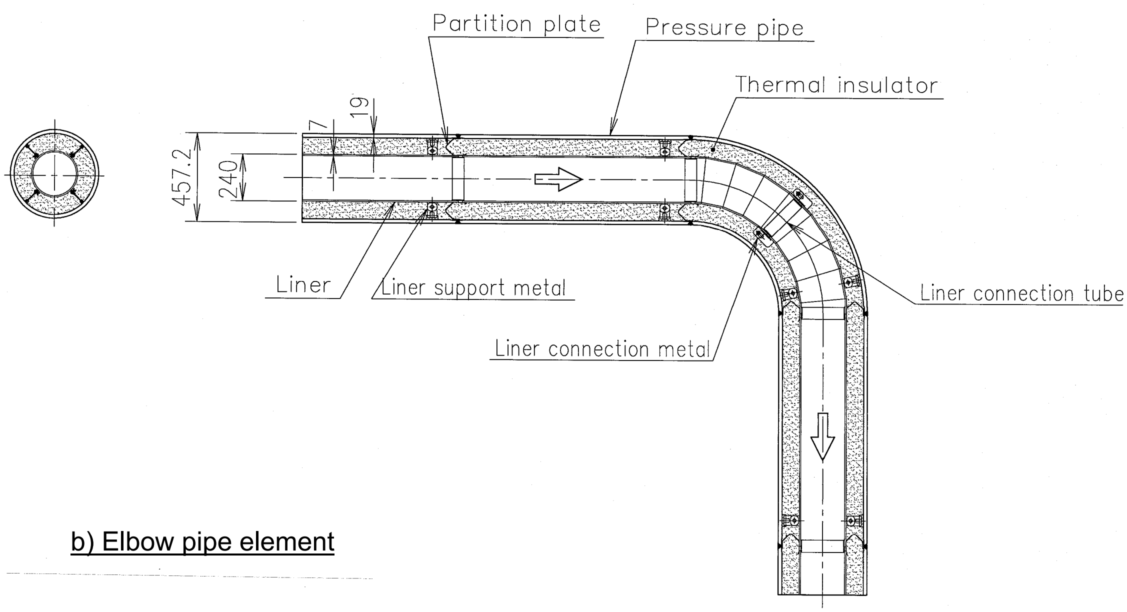


c) Elbow pipe element

Figure 7-28: Hot Gas Duct Elements

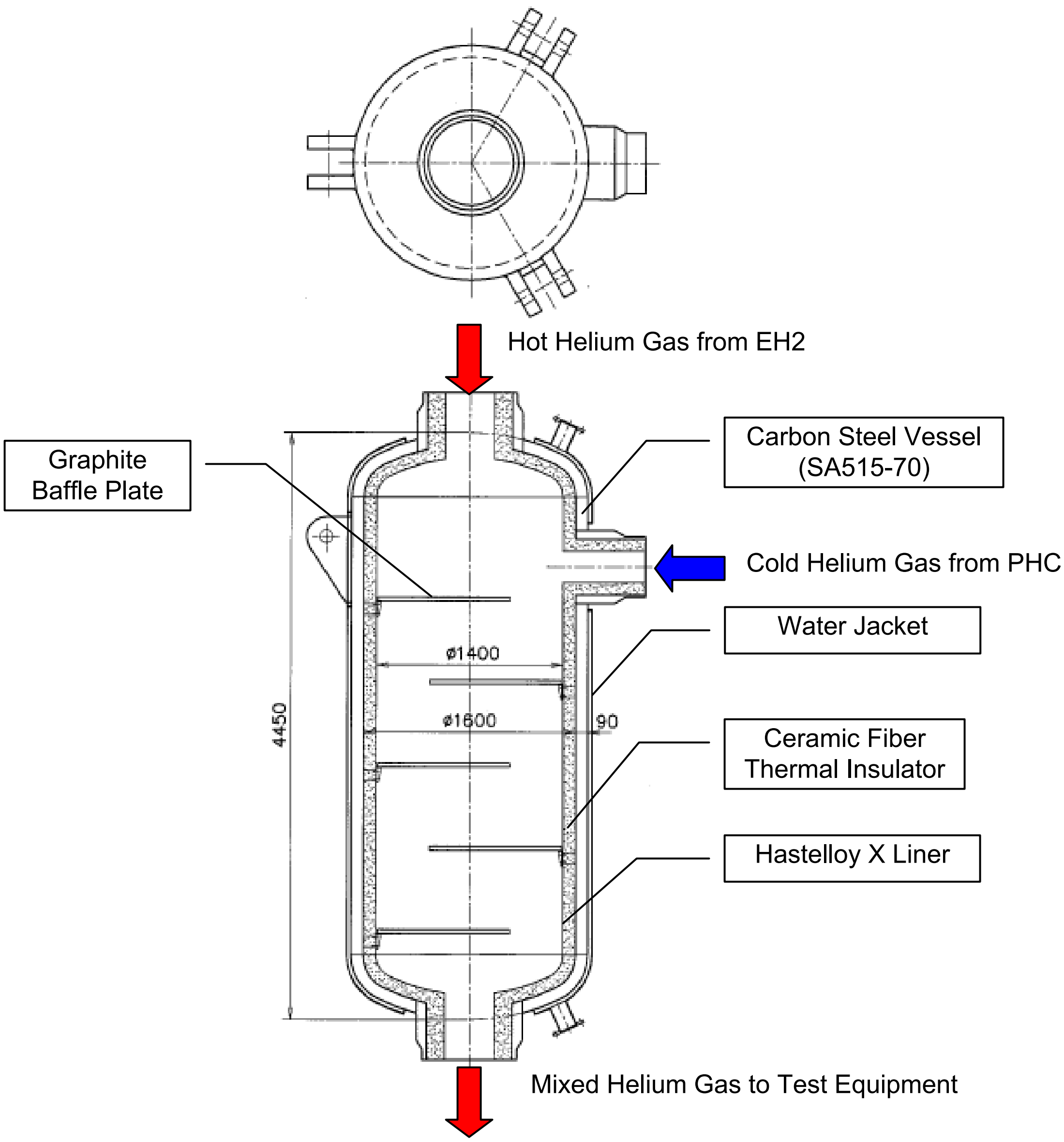


a) Straight pipe element



b) Elbow pipe element

Figure 7-29: Hot Gas Mixing Tank



7.4.2 Subsystems Description

(1) Primary Helium Purification System

- System Function
  The Primary Helium Purification System (PHPS) removes chemical impurities in the primary loop helium. During loop operations the PHPS maintains the loop's helium purity by removing impurities and controls corrosion of the loop's structural components. The impurities captured in the recovery subsystem are accumulated in the PHPS trap and the trap is regenerated for reuse.

- System Configuration
  The PHPS consists of three economizers, two oxidized copper reactors, a cooler, two molecular sieve traps, a cold trap, a gas circulator, piping, and valves. The recovery subsystem consists of a recovery circulator, a recovery cooler, piping, and valves.

  The following subsystems are connected to PHPS.

  - Helium Storage and Supply System to supply the primary helium and control the primary loop pressure
  - Cooling Water System to cool heated helium
  - Chilled Water Cooling System to cool helium
  - Helium Sampling System to analyze impurities in purified helium
  - Compressed Air Supply System to supply instrumentation air

- System Specification
  The CTF primary purification flow rate was specified to balance the primary helium flow rate with PHPS flow rate based on performance in the High Temperature Engineering Test Reactor (HTTR).

HTTR primary helium flow rate	45t/h
HTTR primary purification flow rate	200kg/h
CTF primary helium flow rate at the main loop	10kg/s, 36t/h

  CTF primary purification flow rate is shown below.

  CTF primary purification flow rate is $\frac{36}{45} \times 200 = 160\text{kg/h} = 45\text{g/s}$

  - Number of systems 1
  - CTF primary purification flow rate 45g/s

- System Description
  The primary helium is extracted from the Mixing Tank in the Primary Helium System. The helium temperature is controlled to 300 ºC by the Economizer 1 and a heater. The flow stream is then sent to the oxidized copper reactor to convert

hydrogen and carbon monoxide into water and carbon dioxide by oxidizing reaction. The helium from the oxidized copper reactor is cooled by the Economizer 2 to reduce its temperature to 50 ºC and then cooled to 15 ºC by chilled water in order to accelerate the adsorption reaction of water and carbon dioxide in the molecular sieve trap. After passing through the molecular sieve trap, the helium is further cooled by Economizer 3 to remove methane, oxygen, and nitrogen in the cold trap.

Figure 7-30 shows PFD and heat balance of PHPS.

(2) Secondary Helium Purification System

- System Function
  The Secondary Helium Purification system (SHPS) removes chemical impurities in the secondary helium during main loop operation to control corrosion of structure materials. Thus, maintaining the helium purity.

  The recovery system for SHPS uses typically one of PHPS to regenerate the trap for reuse.

- System Configuration
  The purification system consists of three economizers, two oxidized copper reactors, a cooler, two molecular sieve traps, a cold trap, a gas circulator, piping, and valves.

  The following subsystems are connected to SHPS.

  - Helium Storage and Supply System to supply the secondary helium and control the secondary loop pressure
  - Cooling Water System to cool heated helium
  - Chilled Water Cooling System to cool helium
  - Helium Sampling System to analyze impurities in purified helium
  - Compressed Air Supply System to supply instrumentation air

- System Specification
  The CTF secondary purification flow rate was specified to balance the secondary helium flow rate with SHPS flow rate based on performance in the High Temperature Engineering Test Reactor (HTTR).

HTTR	Secondary helium flow rate	5t/h
HTTR	Secondary purification flow rate	10kg/h
CTF	Secondary helium flow rate at the main loop	10kg/s, 36t/h

CTF secondary purification flow rate is shown below.

CTF secondary purification flow rate is $\frac{36}{15} \times 10 = 24kg/h = 6.7g/s$

- Number of systems 1
- CTF secondary purification flow rate 6.7g/s

- System Description
  The secondary helium is extracted from the MT in the Secondary Helium System and temperature controlled to 300 ºC by Economizer 1 and a heater, and is sent to the oxidized copper reactor to convert hydrogen and carbon monoxide into water and carbon dioxide by oxidizing reaction. Helium from the oxidized copper reactor is cooled by Economizer 2 to reduce its temperature to 50 ºC and then cooled to 15 ºC by chilled water in order to accelerate the adsorption reaction of water and carbon dioxide at the molecular sieve trap. After passing through the molecular sieve trap, the helium is further cooled by Economizer 3 to remove methane, oxygen, and nitrogen in the cold trap.

  Figure 7-31 shows PFD and heat balance of SHPS.

(3) Helium Storage and Supply System

- System Function
  The Helium Storage and Supply System (HSSS) controls pressure at the Primary Helium System and the Secondary Helium System to the specified value. HSSS supplies helium gas to the Primary Helium System, the Secondary Helium System, the Primary Helium Purification System, and the Secondary Helium Purification System.

- System Configuration
  HSSS consists of eight helium storage tanks, a primary helium supply tank, a secondary helium supply tank, a helium transfer compressor, piping and valves.

  The following subsystem is connected to HSSS.

  - Compressed Air Supply System to supply instrumentation air

- System Specification
  Table 7-16 shows the Primary Helium System and the Secondary Helium System inventory. The number of the helium storage tanks and the storage pressure are based on the quantity of the helium inventory. The primary helium supply tank and the secondary helium supply tank are equipped with one unit each with the same specification as the helium storage tank.

  - Number of systems 1 system

o Flow rate of He transfer compressor	12g/s

Helium Storage Tanks

o Storage pressure	15MPa
o Number of units	8 units
o Dimension (Diameter x Height/unit)	1.5m×5m

Primary Helium Supply Tank

o Storage pressure	15MPa
o Number of units	1 unit
o Dimension (Diameter x Height/unit)	1.5m×5m
o Secondary helium supply tank	
o Storage pressure	15MPa
o Number of units	1 unit
o Dimension (Diameter x Height/unit)	1.5m×5m

- System Description

  The Helium Storage Tanks have a capacity to store helium in the Primary and the Secondary Helium Systems during loop maintenance. During normal operation, the helium storage tank recovers the helium from the Primary and the Secondary helium systems to regulate the pressure. The Primary and the Secondary Helium Supply Tanks store helium at high pressure, and supply helium to the Primary and Secondary Helium Systems through the Helium Purification System. Additionally, the helium supply tanks recharge during recovery of the Helium Purification System.

  The Helium Transfer Compressor (HTC) pressurizes helium in the storage tanks at 15 MPa for high pressure storage. HTC is also used to transfer helium from the helium storage tanks to the helium supply tanks.

  Operation mode and heat balance of HSSS are described below.

- Helium Charge to Primary and Secondary Helium System

  Helium is charged to the Primary Helium System from the Primary Helium Supply Tank and to the Secondary Helium System from the Secondary Supply Tank.

  Helium in both the supply tanks is pressurized from the helium storage tanks using the helium transfer compressor or its bypass line.

  Figure 7-32 shows this operation mode and heat balance.

- Helium Recovery to Helium Storage Tank
  Helium in the Primary Helium System is recovered via the helium storage tanks through the Primary Helium Purification System, and the Secondary Helium System is recovered via the Secondary Helium Purification System using the helium transfer compressor or its bypass line.

  Figure 7-33 shows this operation mode and heat balance.

- Pressure Control at SG Normal Operation
  The pressure in the Primary Helium System is controlled by switching ON-OFF of the Primary Helium Supply valve and the recovery valve of HSSS.

  When the pressure of the Primary Helium System exceeds a control limit value, the primary helium recovery valve of HSSS is opened to recover the primary helium to the helium storage tanks and to reduce the Primary Helium System pressure.

  When the pressure of the Primary Helium System is below a control limit value, the supply valve of HSSS is opened to supply helium from the primary helium supply tank and to raise the Primary Helium System pressure.

  Pressure difference between the primary helium system and the secondary helium system is controlled by switching ON-OFF of the secondary helium supply valve and the recovery valve of HSSS.

  When the pressure difference between the Primary Helium System and the Secondary Helium System exceeds the control limit value, the secondary helium supply valve is opened to supply the secondary helium from the helium supply tank and to raise the secondary helium pressure.

  When the pressure difference between the Primary Helium System and the Secondary Helium System is below the control limit value, the secondary helium recovery valve of HSSS is opened to recover helium to the helium storage tanks and to reduce the secondary helium pressure.

  Figure 7-34 shows this operation mode and heat balance.

(4) Pressurized Water Cooling System

- System Function
  The Pressurized Water Cooling System's (PWCS) function is to remove heat from the Primary and Secondary Helium Systems through the Water Cooler 2 and transfer the heat to the Cooling Water System.

- System Configuration

PWCS consists of two recirculation pumps, a pressurizer, a pressurized water cooler, piping and valves.

The following subsystems are connected to PWCS.

- Cooling Water System to remove heat from pressurized water
- Nitrogen Gas Supply System for pressure control of pressurizer
- Compressed Air Supply System to supply instrumentation air

- System Specification
  The heat removal capacity of PWCS is 25MWt. The PWCS is pressurized for operation to slightly lower than that of the primary and Secondary Helium Systems in order to prevent cooling water from boiling in Water Cooler 2 and leaking from the heat transfer tube into helium environment.

  - Number of systems: 1
  - Circulation flow rate: 598kg/s
  - Heat removal rate: 25MWt
  - Operating pressure: less than Primary helium pressure or secondary helium pressure
  - Cooling water inlet temperature: 100 ºC
  - Cooling water outlet temperature: 150 ºC

- System Description
  Pressurized water at 100 ºC circulated by the pump receives heat from Water Cooler 2 to raise temperature to 150 ºC. The pressurized water at 150 ºC is cooled to 100 ºC by cooling water in the pressurized water cooler and returned to the recirculation pump.

  The pressurized water cooler is equipped with a bypass line and a control valve to control the supply temperature of the pressurized water in Water Cooler 2. Piping connects the pressurized water cooler outlet and the pressurizer to keep the pressure slightly lower than the helium pressure in the Primary and Secondary Helium Systems.

  The pressure in the pressurizer is controlled by switching ON-OFF of the supply valve and discharge valve of highly pressurized nitrogen.

  Figure 7-35 shows PFD and heat balance of PWCS.

(5) Cooling Water System

- System Function

The Cooling Water System (CWS) removes heat generated in the main loop and discharges the removed heat to the atmosphere via the cooling tower.

- System Configuration
  CWS consists of three cooling water pumps, a cooling tower, piping, and valves.

  The following subsystems are connected to CWS.

  - Chemical Supply System controls the cooling water chemistry
  - Fresh Water Supply System supplies the cooling tower's fresh water

- System Specification
  CWS removes heat from the condenser and sub-cooler water stream of the IHX and SG operation, and heat from the Water Cooler 1, pressurized water cooler from the double hot gas duct or 1000 ºC IHX operation.

  Other than the above requirement, the CWS removes heat at thyristors that regulates electric power for Electric Heater 1 and Electric Heater 2, and supplies cooling water to the Emergency EH Cooler, the helium circulator, helium compressor, pump, and the small coolers in other subsystems. Table 7-17 shows the cooling loads.

o Number of systems	1
o Cooling water circulation flow rate	952kg/s
o Cooling capacity	36.3MWt
o Cooling water supply temperature	30 ºC
o Cooling system	wet type cooling tower

- System Description
  During the IHX and SG operations, stop valves in the water stream to the Water Cooler 1 and pressurized water cooler are closed. Cooling water at 30 ºC from the cooling water pump cools the condenser, sub-cooler, and other equipment. Cooling water exits the condenser, sub-cooler and other equipment at 40 ºC. The water is cooled to 30 ºC via the cooling tower and is returned to the cooling water pumps.

  During the hot gas duct or 1000 ºC IHX operations, stop valves in the water stream to the condenser and the sub-cooler are closed to cool the Water Cooler 1 and pressurized water cooler, and other equipments.

  Figure 7-36 and Figure 7-37 show PFD and heat balance of CWS.

(6) Helium Sampling System

- System Function
  Helium Sampling System (HSS) takes a sample of helium from the primary helium system, the secondary helium system, primary helium purification system and the secondary helium purification system for moisture detection in helium, impurity analysis and helium sampling.

- System Configuration
  HSS consists of a selector valve, a moisture detector, a gas chromatograph, a sampler, piping, valves, a carrier gas cylinder, and a standard gas cylinder.

- System Specification
  Helium sampling points are located at high temperature and low temperature areas of the Primary Helium System and the Secondary Helium System, and inlet/outlet of the Primary Helium Purification System and the Secondary Helium Purification System. A moisture detector, a gas chromatograph and a sampler are used as the analytical equipment.

  - Sampling Points
    - IHX primary inlet helium
    - IHX primary outlet helium
    - Primary Purification System inlet helium
    - Primary Purification System outlet helium
    - IHX secondary inlet helium
    - IHX secondary outlet helium
    - Steam Generator inlet helium
    - Steam Generator outlet helium
    - Secondary Purification System inlet helium
    - Secondary Purification System outlet helium

  - Analytical Equipments
    - Moisture detector
    - Gas chromatograph
    - Sampler

- System Description
  Helium gas is sampled through a flow-limiting orifice by opening sampling valves at each sampling point. The gas is guided to the moisture detector or the gas chromatograph through the selector valve device for moisture detection or component analysis of impurities in gas.

The sampling gas can also be taken by a sampler, and discharged to HVAC duct after analysis.

Figure 7-38 shows PFD of HSS.

(7) Make Up Water System

- System Function
  The Make Up Water System (MWS) feeds pure water to the Pressurized Water Cooling System.

- System Configuration
  MWS consists of a make up pump, a pure water tank, a strainer, piping, and valves.

  The following subsystems are connected to MWS.

  - Purified Water Production System to make up pure water to the pure water tank.
  - Chemical Supply System injects hydrazine in to the pressurized water for water chemistry control.

- System Specification
  Make up capacity for adding water and hydrazine to the pressurized water cooling system under pressurized environment.

  - Number of systems 1
  - Make up flow rate 5kg/min

- System Description
  The Pressurized Water Cooling System is filled with pure water from the pure water supply header through the strainer under atmospheric condition.

  Under the pressurized condition, water and hydrazine is charged from the pure water tank and the chemical supply system using the make up pump.

  Figure 7-39 shows PFD of MWS.

(8) Chemical Supply System

- System Function

The Chemical Supply System (CSS) injects hydrazine and ammonia to the tertiary system to control corrosion, and hydrazine to the Pressurized Water Cooling System through the Make Up Water System, and the Cooling Water System.

- System Configuration
  CSS consists of a concentrated hydrazine dissolver, a dilute hydrazine dissolver, an ammonia dissolver, and three injection pumps, piping, and valves.

- System Specification
  The Chemical Supply System was designed to regulate dissolved oxygen and pH in feed water, and dissolved oxygen in the pressurized water and the cooling water.

  - Number of systems 1
  - Dissolver
    - Concentrated Hydrazine Dissolver
    - Dilute Hydrazine Dissolver
    - Ammonia Dissolver

  - Injection flow rate 25~50cc/min

- System Description
  Concentrated hydrazine is used when the concentration of the dissolved oxygen is high at start up of operations. Dilute hydrazine is continuously injected into the feedwater as an oxygen scavenger and ammonia is continuously added as a pH regulator.

  Hydrazine and ammonia are dissolved and stored in its dissolver and injected to the Make Up Water System, the Cooling Water System, and the Tertiary System by the injection pump.

  Figure 7-40 shows PFD of CSS.

(9) Purified Water Production System

- System Function
  The Purified Water Production System (PWPS) produces pure water from the filtrated water, stores it in the pure water storage tank and feeds it by the make up water pump.

- System Configuration
  PWPS consists of a charcoal filter, a demineralizer, a pure water storage tank, a transfer pump, a make up water pump, piping, and valves.

- System Specification
  The following items are specified as a capacity to produce, store, and supply pure water required in each system of CTF.

  - Number of systems 1
  - Pure water production capability $3m^3/h$
  - Storage tank capacity $60m^3$
  - Pure water supply flow rate $40m^3/h$

- System Description
  The Purified Water Production System collects filtrated water by the transfer pump to feed the charcoal filter and demineralizer to produce pure water and stores it in the pure water storage tank. Stored pure water is supplied by the make up water pump to each system of CTF.

  Figure 7-41 shows PFD of PWPS.

(10) Compressed Air Supply System

- System Function
  The Compressed Air Supply System (CASS) pressurizes air to supply instrumentation air to pneumatic operated valves and others.

- System Configuration
  The Compressed Air Supply System (CASS) consists of two compressed air units, two pre-filters, a moisture separator unit, a supply tank, two after filters piping and valves.

- System Specification
  CASS was specified as a supplying capacity of pressurized air required at each system of CTF.
  - Number of systems 1
  - Compressed air supply rate 4N m^3/min

- System Description
  The pressurized air at the compressor unit is filtrated at the pre-filter, sent to moisture separator to eliminate humidity, and further filtrated at the after-filter through the supply tank, and then is supplied to each system of CTF.

  Figure 7-42 shows PFD of CASS.

(11) Nitrogen Supply System

- System Function
  The Nitrogen Supply System (NSS) supplies liquid nitrogen to the cold trap at the Primary and the Secondary Helium Purification System and feeds pressurized nitrogen gas from nitrogen gas cylinder to the pressurizer of the Pressurized Water Cooling system.

- System Configuration
  NSS consists of the liquid N_2 storage tank unit, nitrogen gas cylinders, piping, and valves.

- System Specification
  NSS was designed to have a capacity to feed liquid nitrogen to the cold trap and N_2 gas to the pressurizer as follows.

  - Number of systems 1
  - Liquid N_2 storage tank capacity 30 m^3
  - Number of N_2 gas cylinders 20 cylinders/curdle x 3 sets

- System Description
  The liquid nitrogen storage tank unit receives liquid nitrogen from the tank track and pressurizes the tank using a built-in evaporator to feed liquid nitrogen to the cold trap at the Primary and the Secondary Helium Purification system.

  High-pressure nitrogen gas is supplied from 20 cylinder cradled units to the pressurizer of the Pressurized Water Cooling System.

  Figure 7-43 shows PFD of NSS.

(12) Waste Water Treatment System

- System Function
  The Waste Water Treatment System (WWTS) receives regenerative waste water at resin regeneration from the demineralizer and make up water processing unit to regulate its pH using hydrochloric acid or caustic soda and then discharges.

- System Configuration
  The WWTS consists of a neutralized water pit, a neutralized water transfer pump, a blower, a hydrochloric acid water storage tank, a sodium hydroxide water storage tank, piping and valves.

- System Specification

The WWTS is designed to have a capacity to neutralize and discharge regenerative waste water.

- Number of systems 1
- Neutralized water pit capacity $100m^3$

- System Description
  The WWTS receives regenerative waste water in the neutralization pit. Hydrochloric acid or sodium hydroxide water is added to the waste water and is agitated by the blower/bubbler and is recirculation by the neutralized waste water pump. The neutralized water is discharged from the neutralized water pit to the exhaust water pit.

  Figure 7-44 shows PFD of WWTS.

(13) Heat Trace System

- Prevention of freezing
  The cooling water will likely freeze when the equipment is out of service during the winter, because the cooling water and pure water production systems are located outdoors. To prevent cooling water from freezing, heaters and thermal insulation are fitted to the appropriate piping and tanks to maintain the temperature of the cooling water higher than its freezing temperature.

- Mitigation of Piping Thermal Stress
  The Primary and Secondary Helium Systems are designed to switch the flow paths according to the different test conditions. The Heat Tracing System maintains the system bypassed pipes at an elevated temperature to minimize thermal stresses that can occur due to large differential temperatures.

  In addition, some lines including the Emergency EH Cooler and circulator, which are normally out of service and start up in the event of station power loss or other contingencies. The temperature of those lines rise rapidly after start up.

  To mitigate such thermal transient, the lines are preheated by Heat Trace System. The details about which lines are preheated to what temperatures will be developed during the detailed design phase.

Table 7-16: Helium Inventory

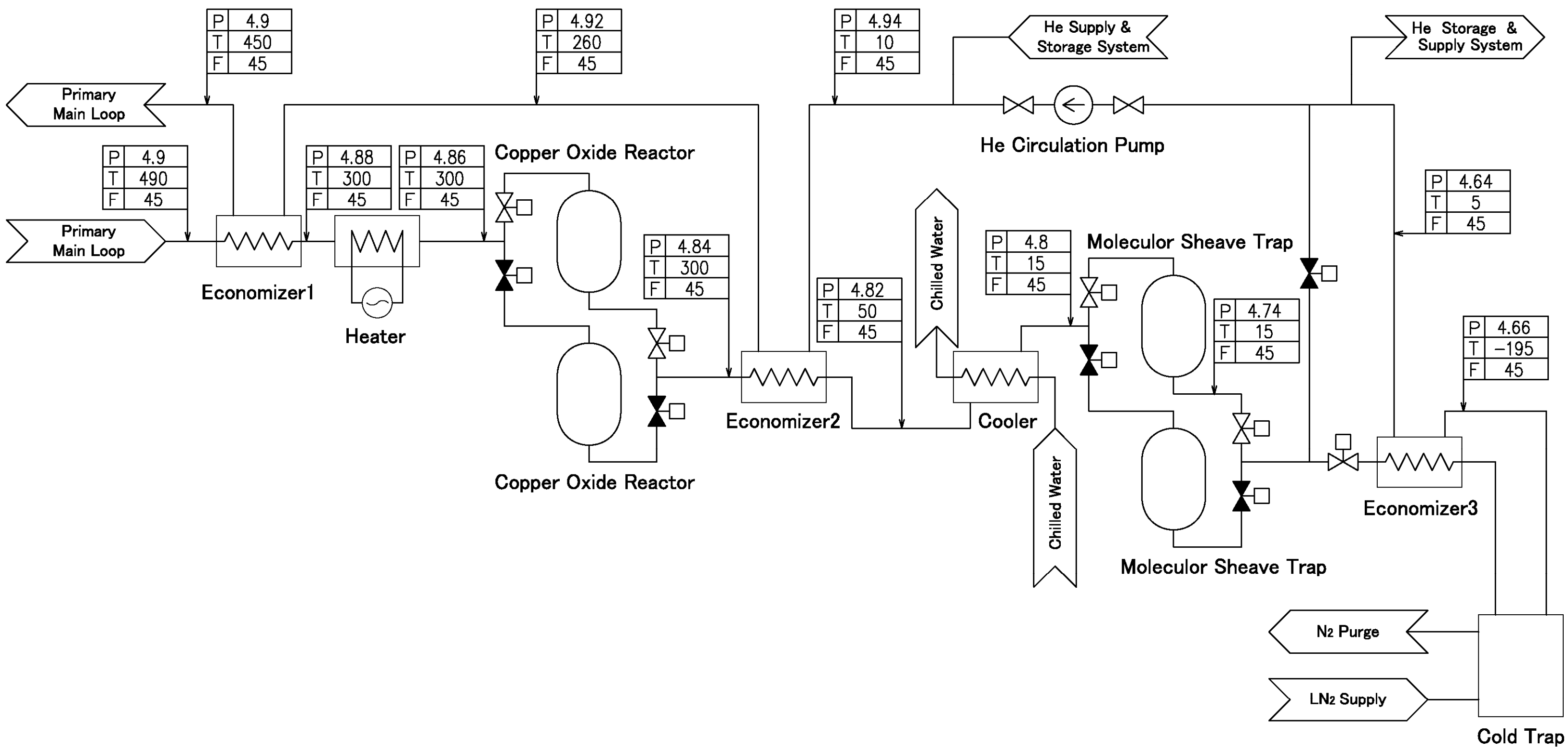
	Number	Volume (m3)	Pressure (MPa)	Inventory (Kg)
Electric Heater 1	2	95	7	378
Electric Heater 2	2	87	7	259
Water Cooler 1	1	10	7.5	50
Water Cooler 2	1	14	7.5	52
Mixing Tank	1	9	7	24
Intermediate Heat Exchanger	1	74	7	250
Steam Generator	1	35	7.5	396
Piping	1	16	7	50
			Total	1458

Table 7-17: Cooling Water System Heat Load

	IHX, SG, Operation	Hot Duct or 1000°C Operation
Condenser	28.5 MWt	—
Subcooler	1.5 MWt	—
Water Cooler 1	—	5 MWt
Pressurized Water Cooler (Water Cooler 2)	—	25 MWt
Other Components	6.3 MWt	6.3 MWt
Emergency EH Cooler	(3.5 MWt)*	(3.5 MWt)*
Total	36.3 MWt	36.3 MWt

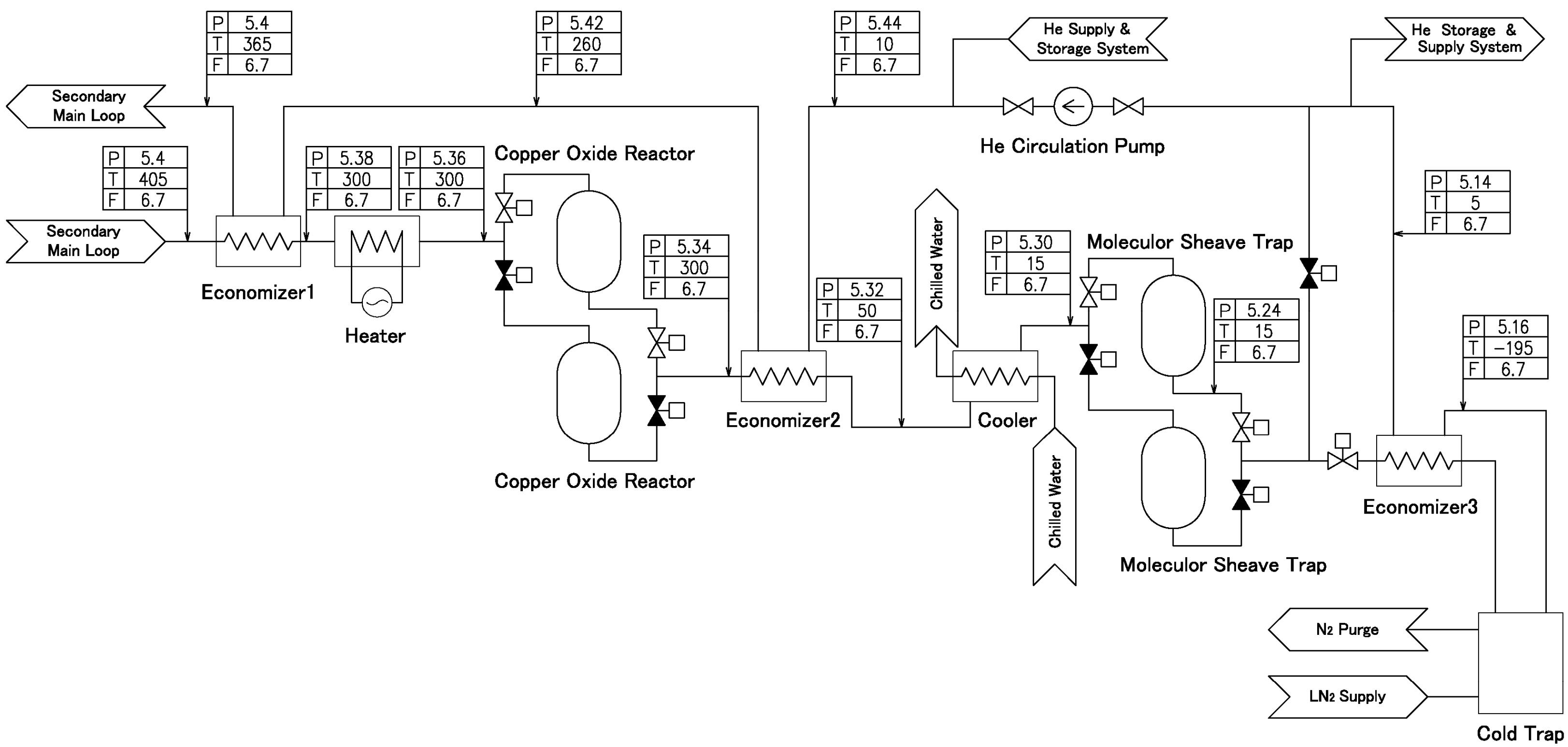
* Heat Load after Loss of Power

Figure 7-30: PFD with Heat & Mass Balance of Primary Helium Purification System



P	Pressure	MPa
T	Temperature	℃
F	Flow Rate	g/s

Figure 7-31: PFD with Heat & Mass Balance of Secondary Helium Purification System



P	Pressure	MPa
T	Temperature	℃
F	Flow Rate	g/s

Figure 7-32: PFD with Heat & Mass Balance of Helium Storage and Supply System (Helium Charge to Primary and Secondary System)

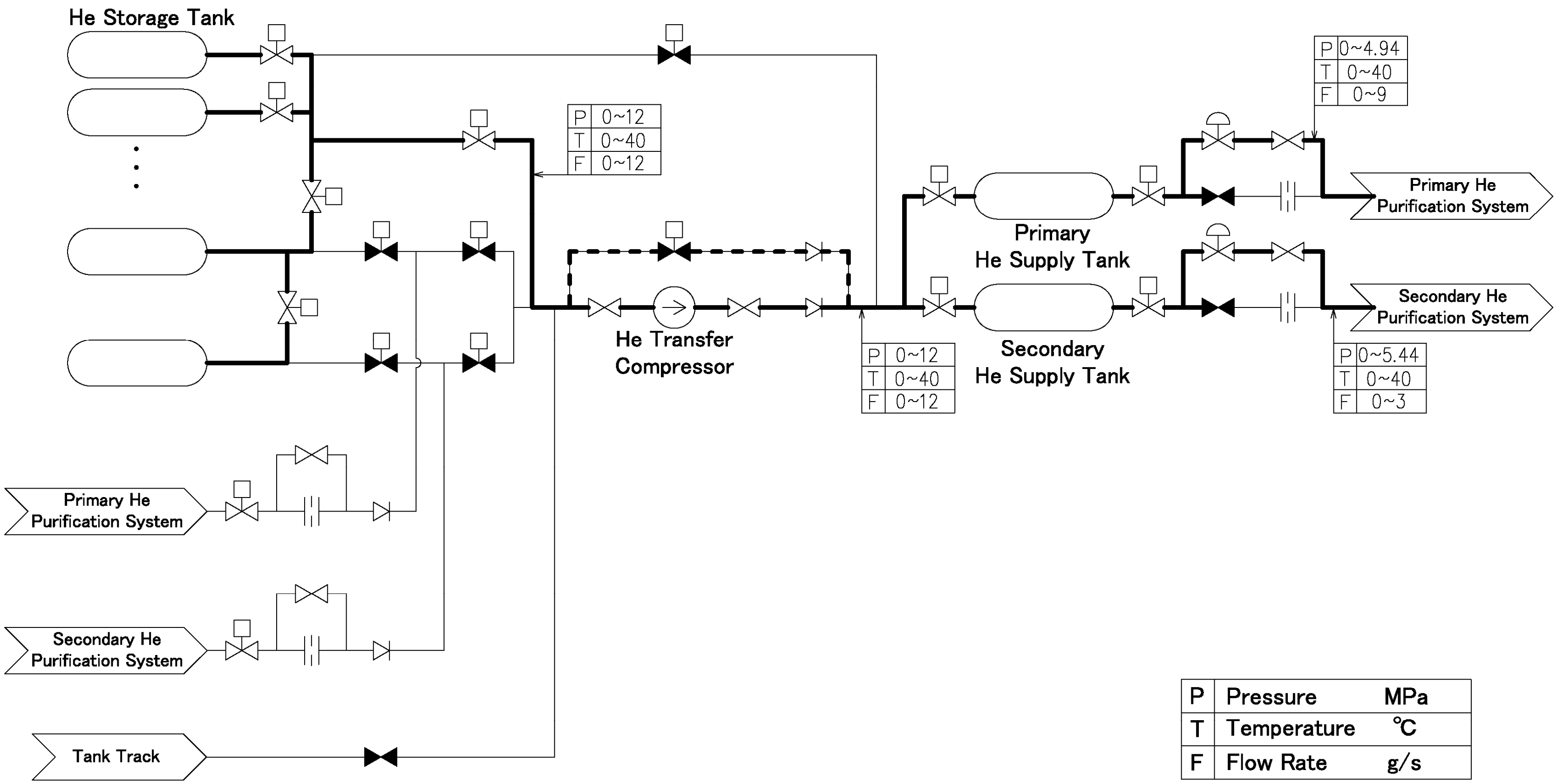
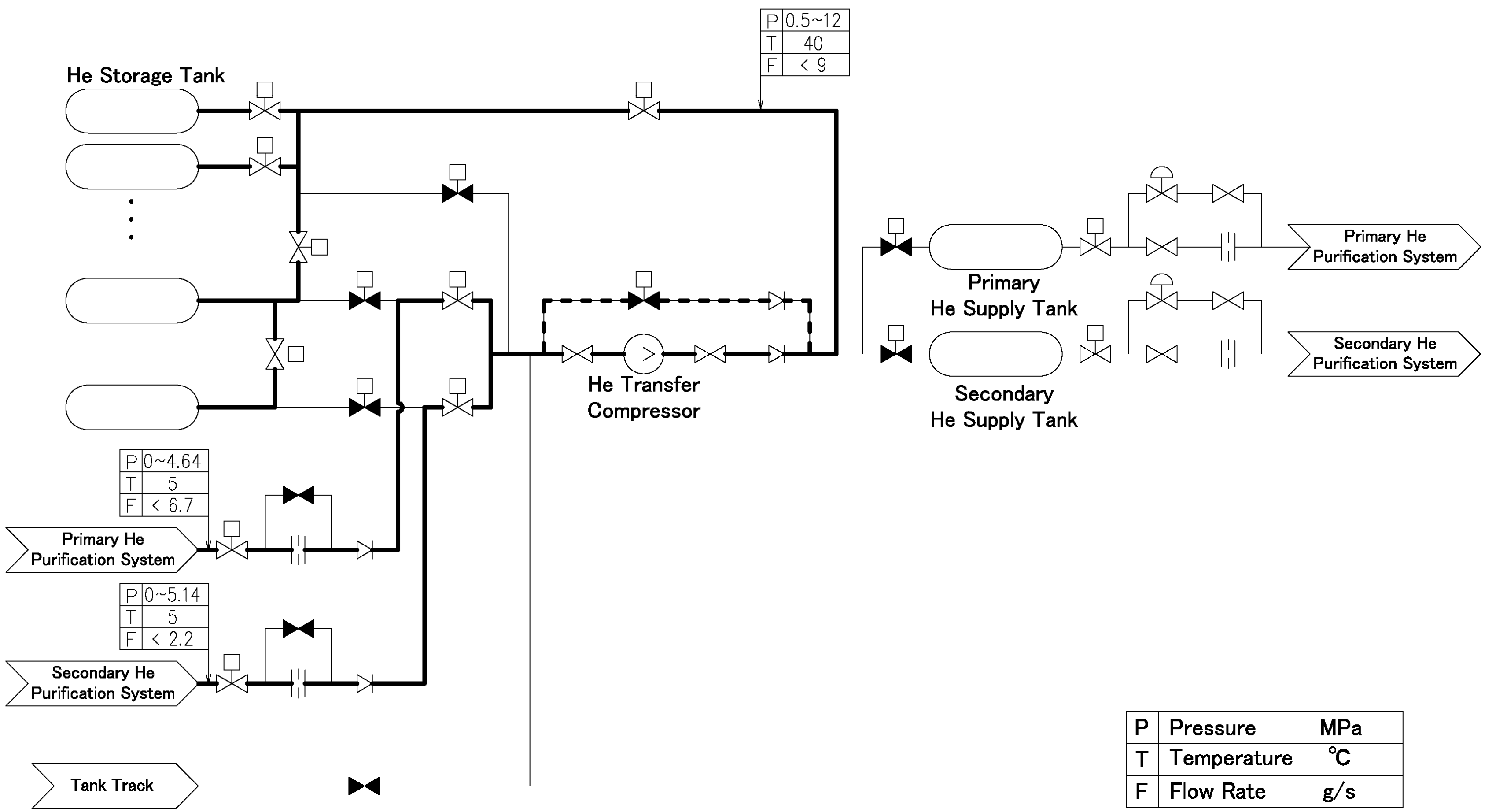


Figure 7-33: PFD with Heat & Mass Balance of Helium Storage and Supply System (Helium Exhaust to Helium Storage Tank)



P	Pressure	MPa
T	Temperature	℃
F	Flow Rate	g/s

Figure 7-34: FPD with Heat and Mass Balance of Helium Storage and Supply System (Pressure Control at SG Normal Operation)

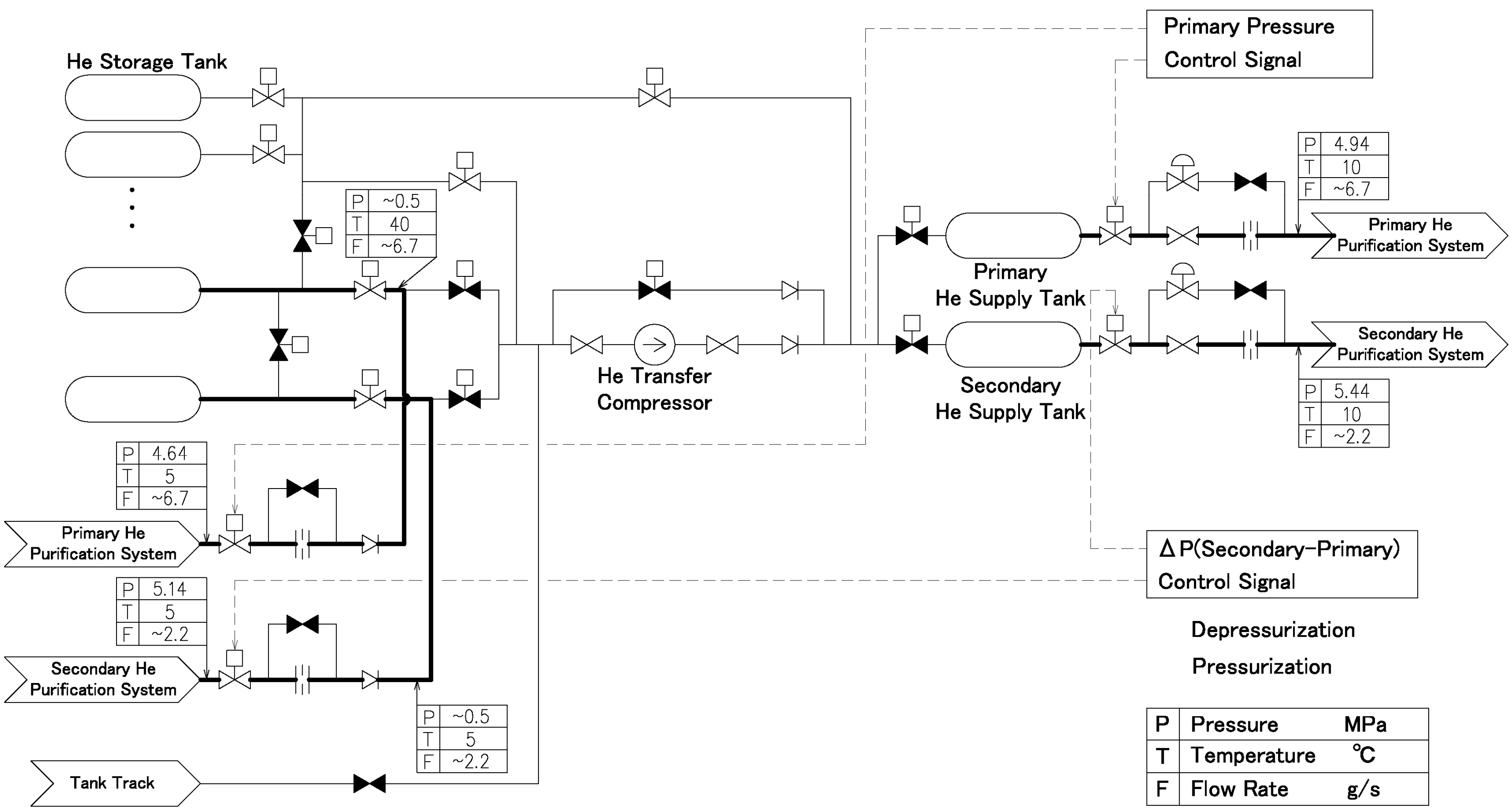


Figure 7-35: PFD with Heat and Mass Balance of Pressurized Water Cooling System (Hot Duct or 1000°C IHX Operation)

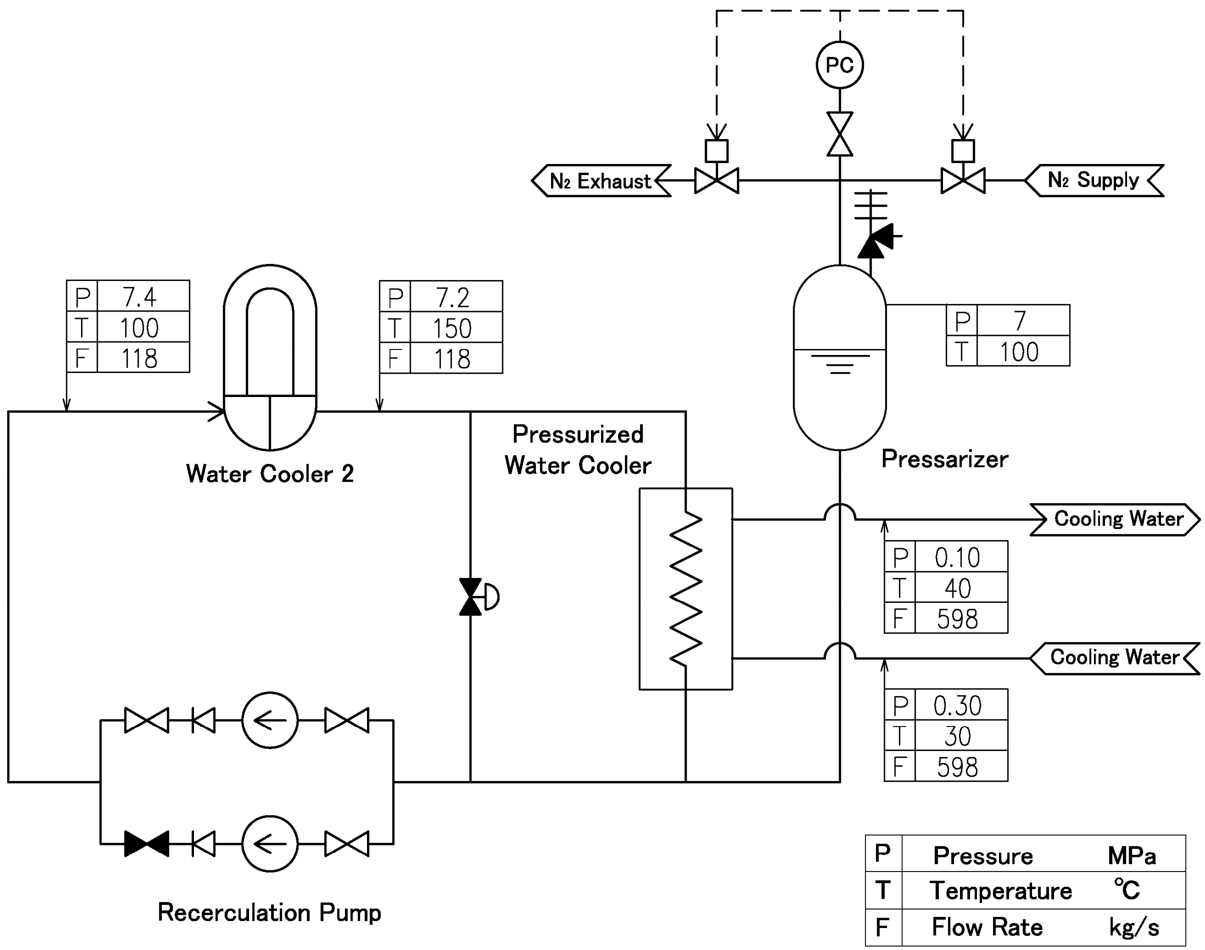
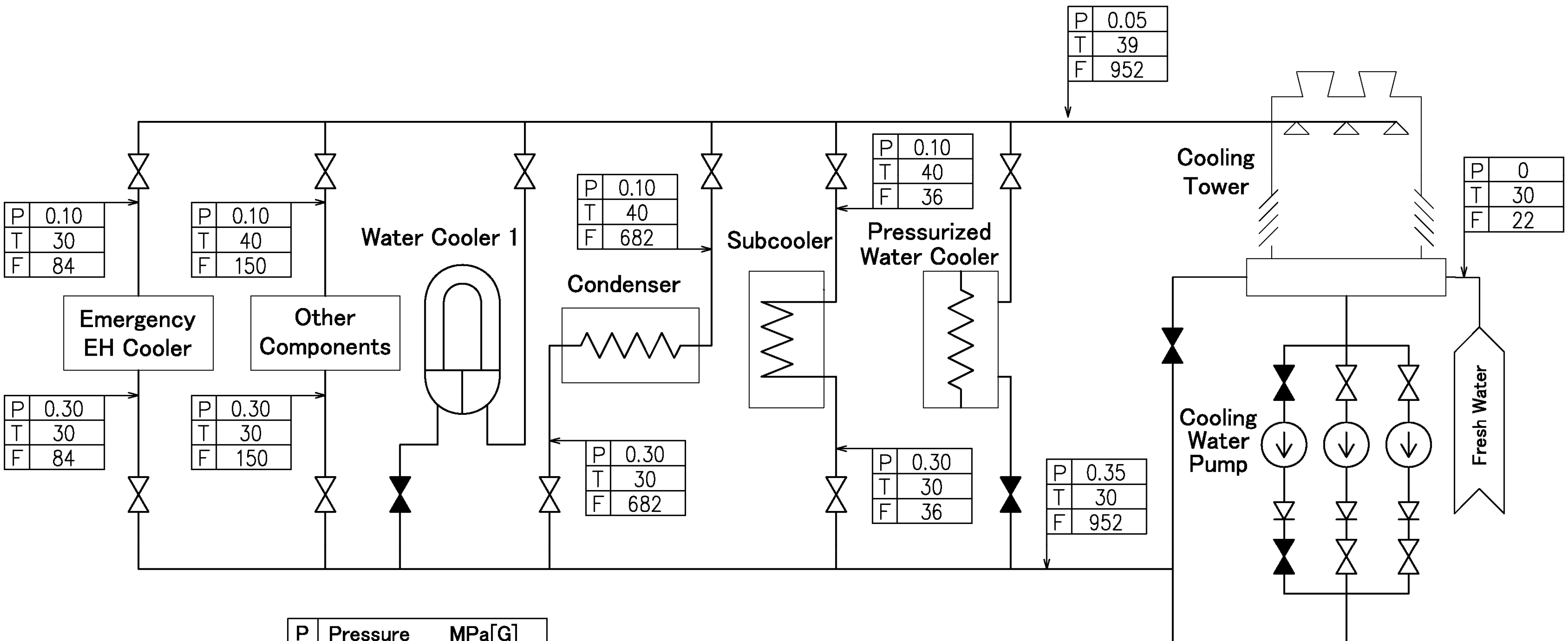
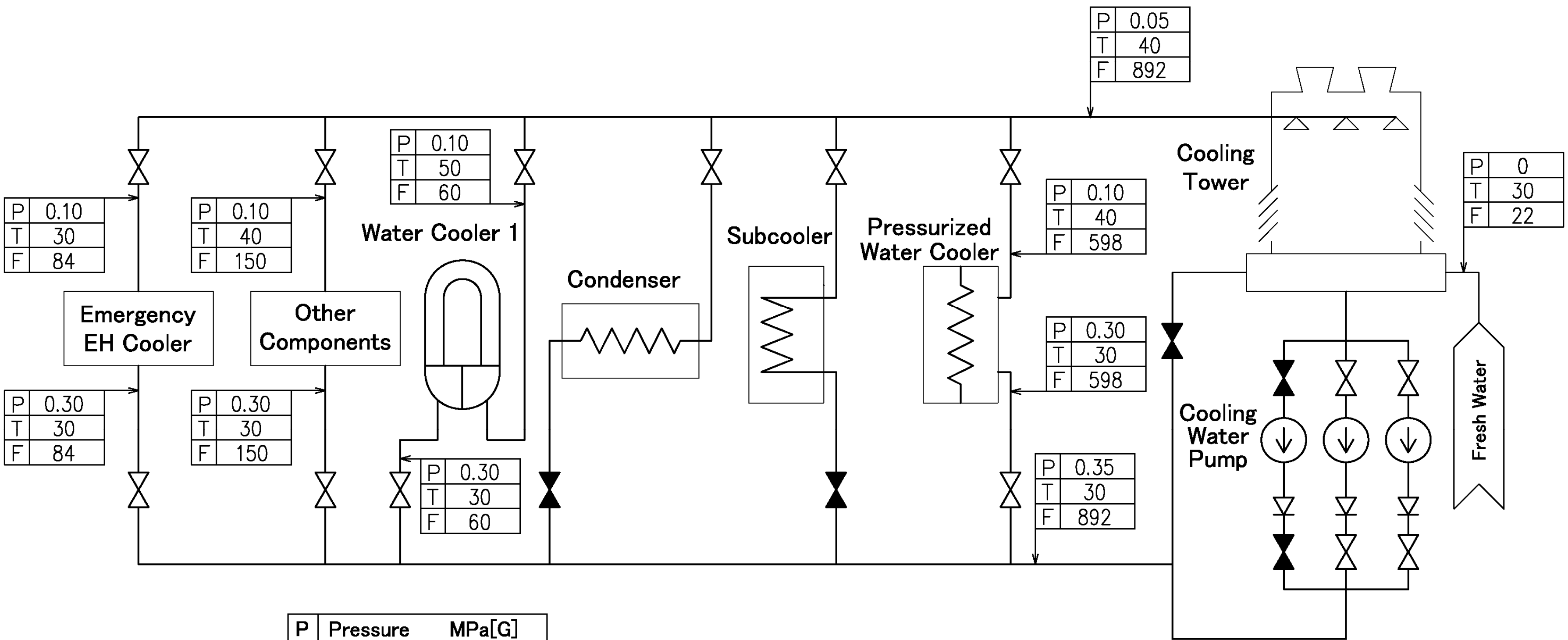


Figure 7-36: PFD with Heat & Mass Balance of Cooling Water System (IHX and SG Operation)



P	Pressure	MPa[G]
T	Temperature	℃
F	Flow Rate	Kg/s

Figure 7-37: PFD with Heat & Mass Balance of Cooling Water System (Hot Duct or 1000°C IHX Operation)



P	Pressure	MPa[G]
T	Temperature	℃
F	Flow Rate	Kg/s

Figure 7-38: Helium Sampling System

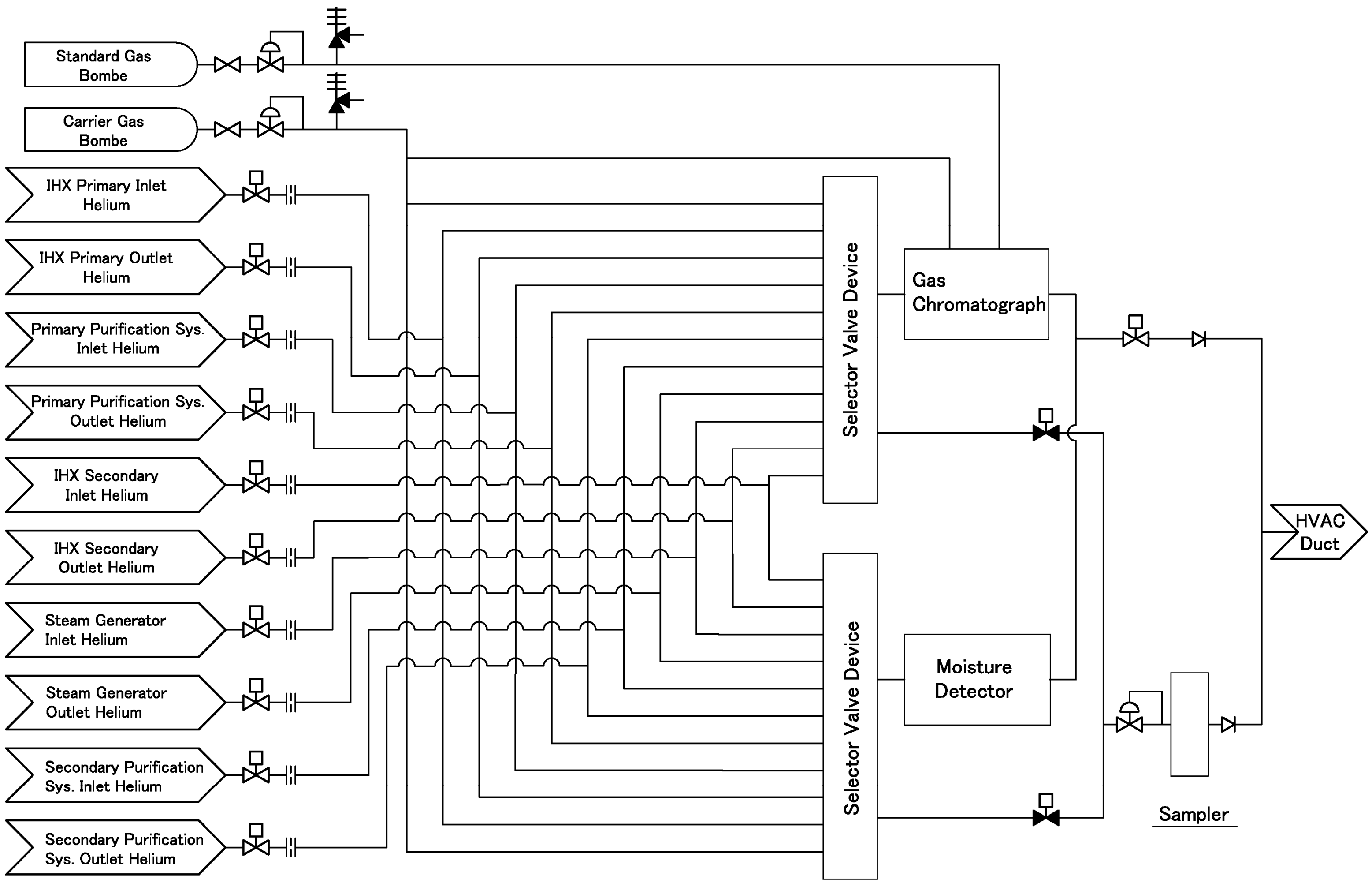


Figure 7-39: Makeup Water System

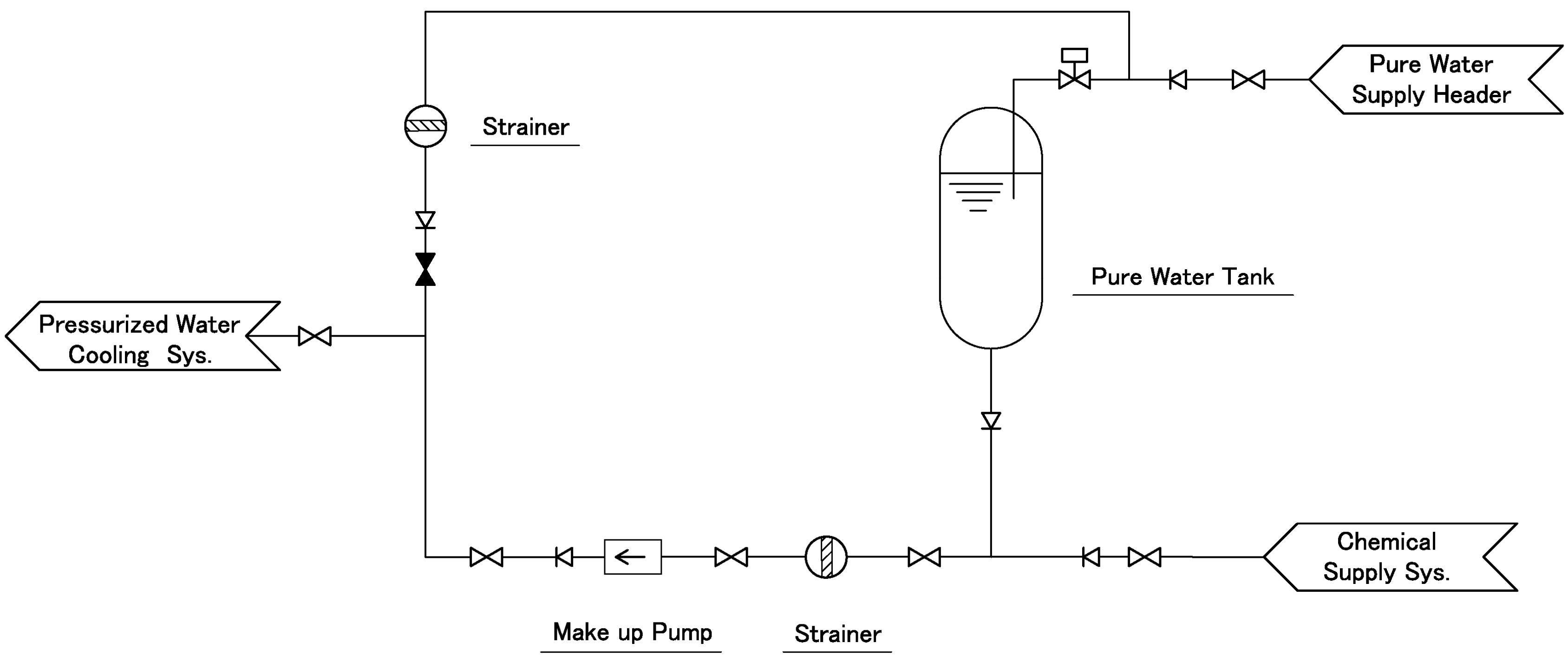


Figure 7-40: Chemical Supply System

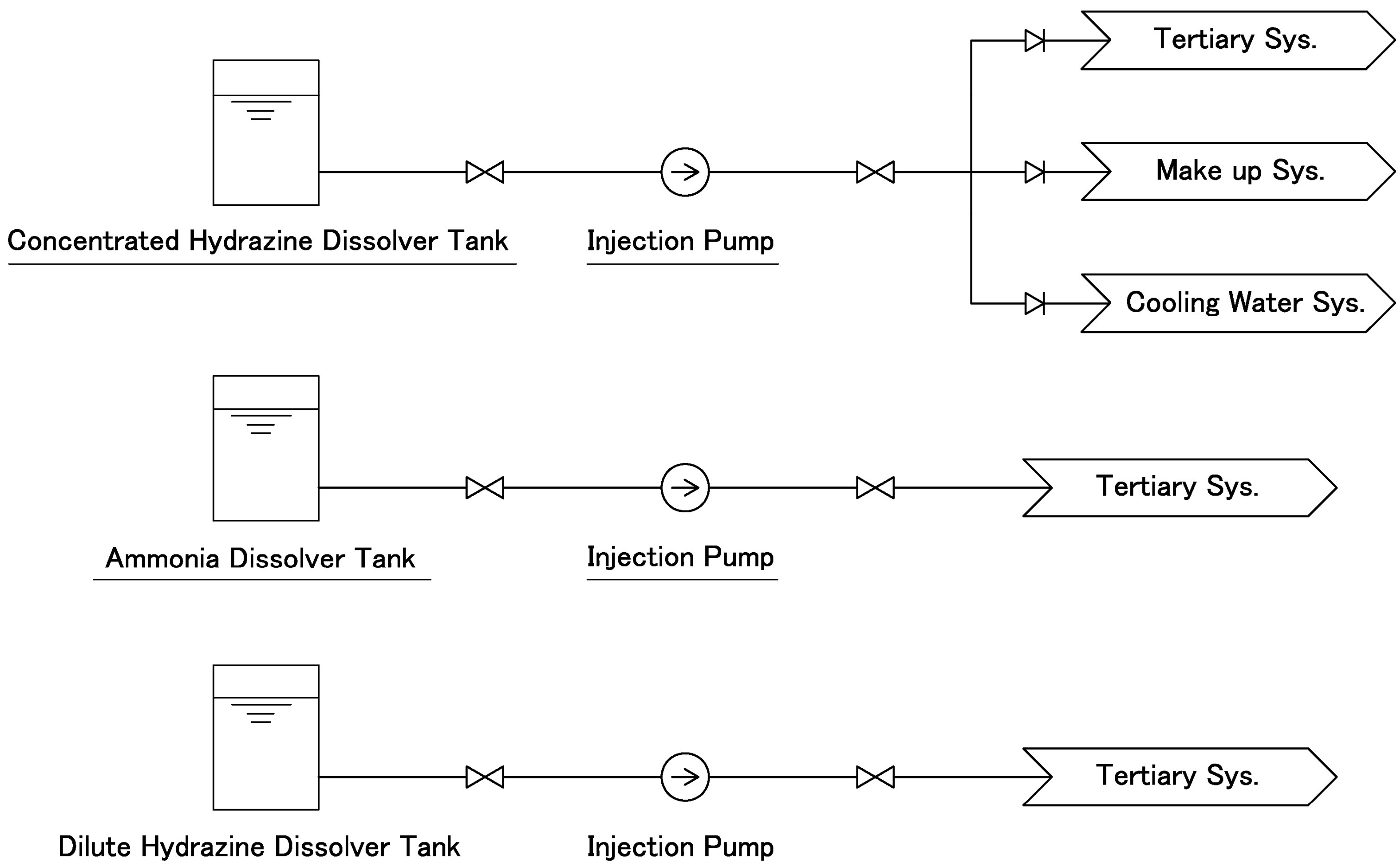


Figure 7-41: Purified Water Production System

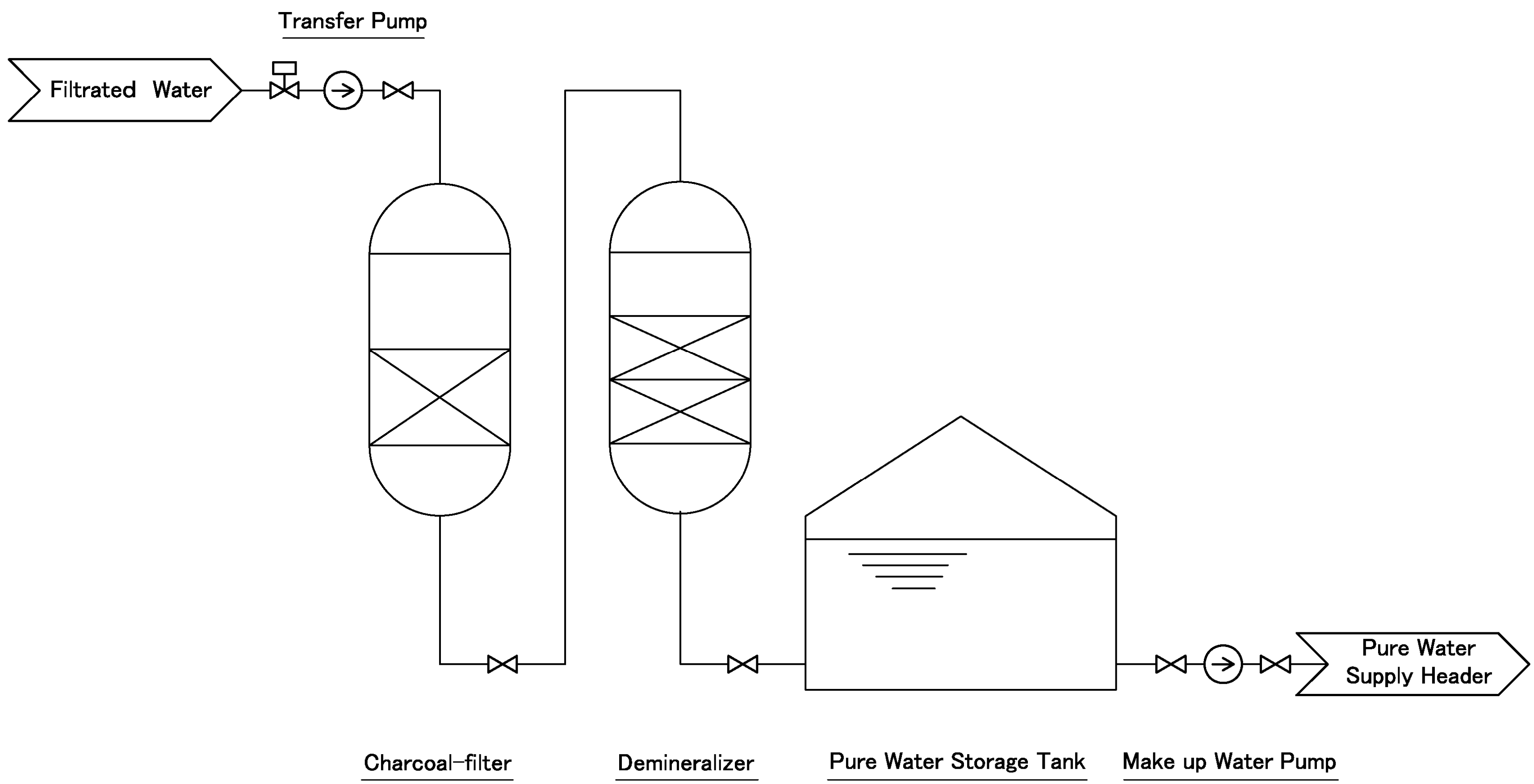


Figure 7-42: Compressed Air System

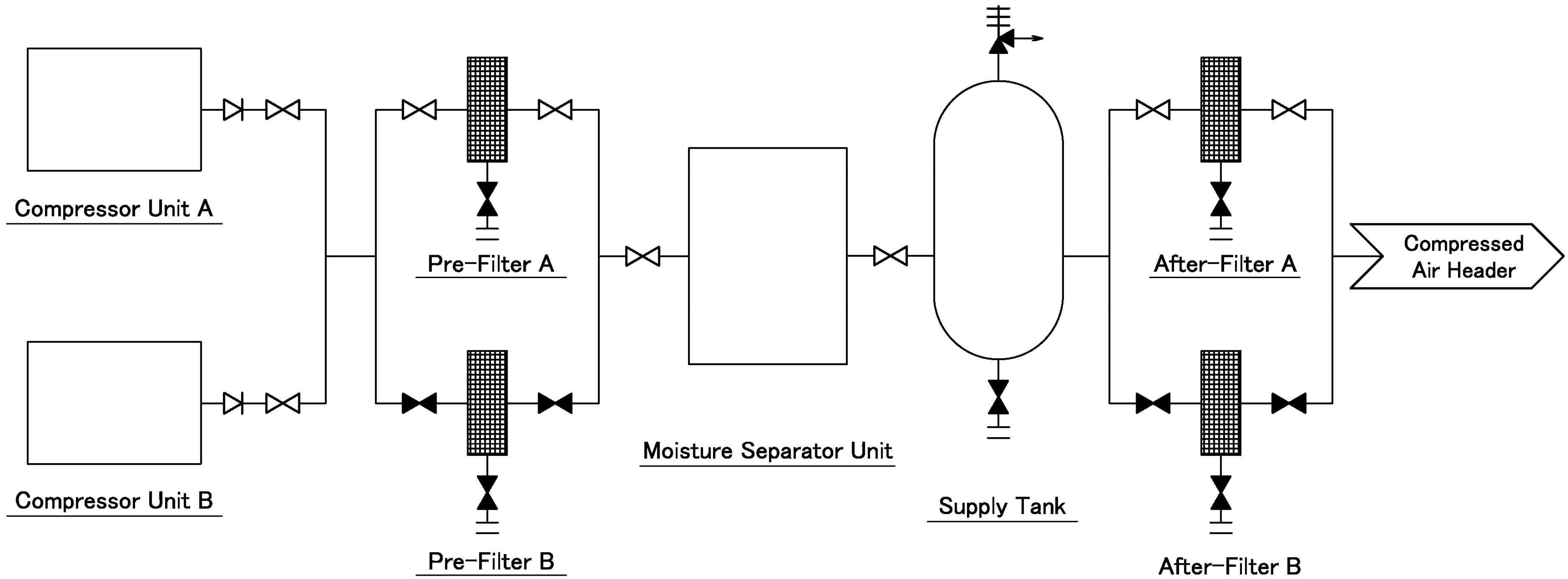


Figure 7-43: Nitrogen Supply System

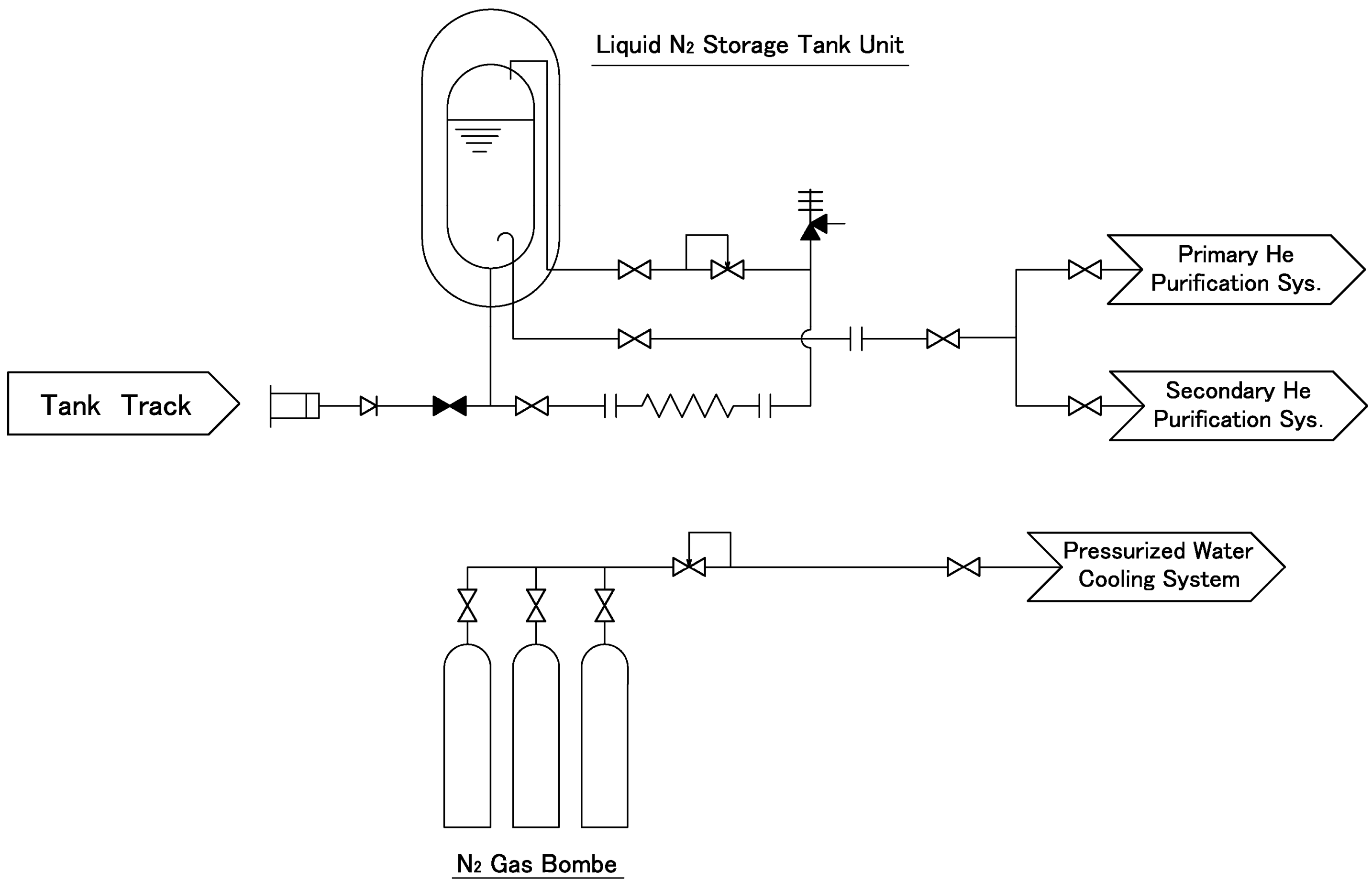
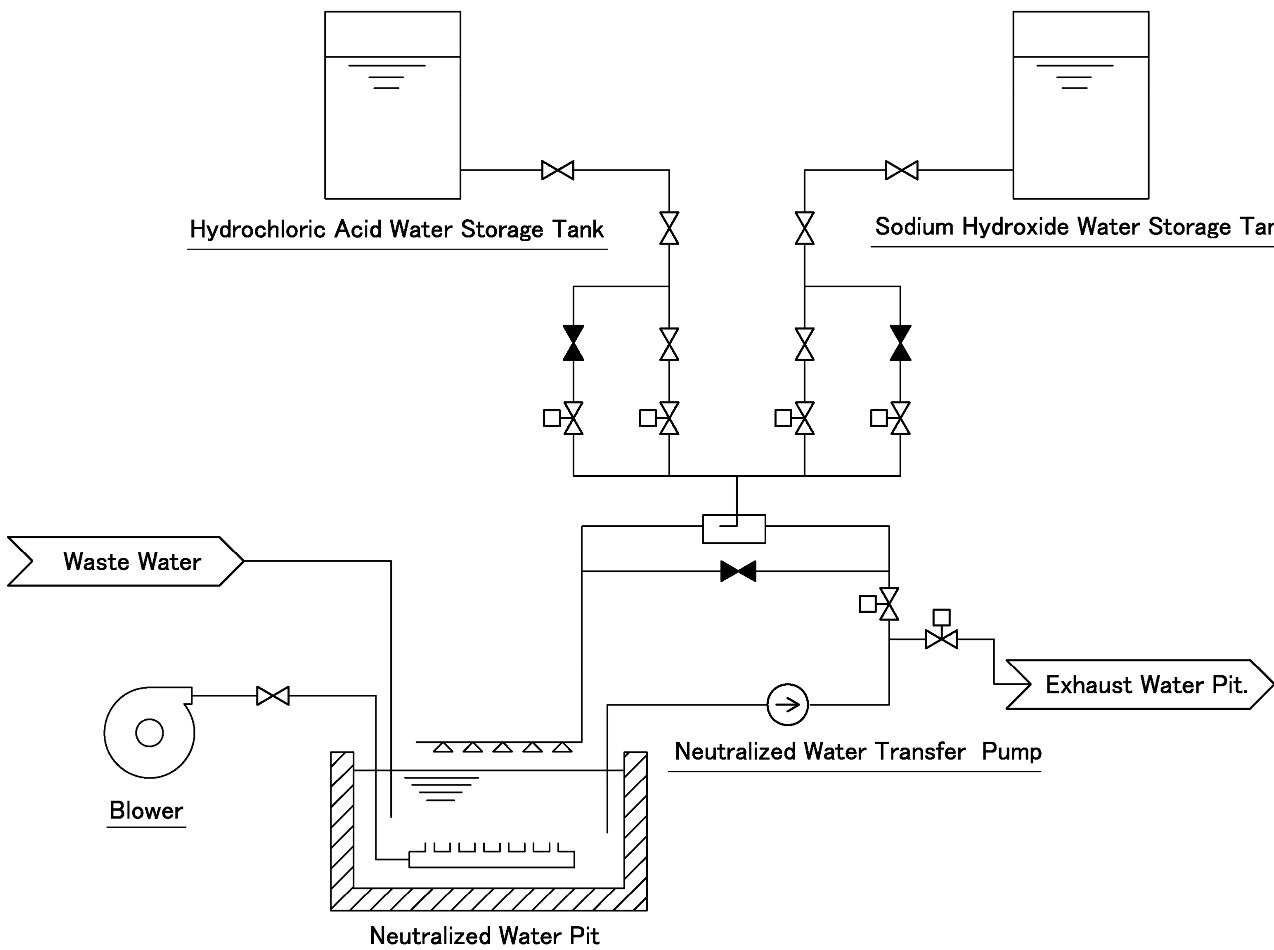


Figure 7-44: Waste Water Treatment System



7.5 Control and Instrumentation

7.5.1 Control and Instrumentation System

(1) Design Condition

The Control and Instrumentation System shall be designed so as to comply with the requirements below. The design shall provide easy and efficient operation of the test equipment and allow easy refurbishment of the equipment as practically possible.

- 30MWt test equipment because they are optimal in terms of the signal sizes of input from and output to the field test equipment and interface with 1 MWt test equipment.

- The Control and Instrumentation System shall be connected via the automation bus to the operator station and network printer and thereby ensure that the system is safely and easily operated, controlled and monitored by a limited number of operators.

  It is assumed that additional switches for the equipment involved will be added as appropriate in the vicinity of the area where it is installed in order to adjust its operation more conveniently. Eventual decisions whether these switches shall be set up, however, will be made during the detailed design phase.

- An emergency monitoring control board shall be implemented as a back up the system to recover a potential failure of digital control and instrumentation system.

- The signals (including values for temperature, flow and pressure) for equipment operation and test shall be transferred to the data acquisition system via the network.

(2) General Design Requirements

The Control and Instrumentation System shall be designed in accordance with the requirements as below.

- Design grade
  Common industrial design grade for the Control and Instrumentation System is required

- Temperature and Humidity
  The Control and Instrumentation Systems which are installed in the central control room and at the field sites within the building may be designed under the

assumption that their ambient temperatures and humidity are maintained over the ranges as below:

- Central control room
  Temperatures : +17~+28ºC
  Humidity : 40~70%RH

- Field sites within the building
  Temperature: TBD
  Humidity: TBD

- Electrical room
  Temperatures: ~+40ºC
  Humidity : 20~85%RH
  (the air shall not condensate when the temperature varies)

- Dust
  The control and instrumentation systems to be installed in the central control room or at the field sites within the building shall be designed under the assumption that the ambient dust concentration is kept at less than 0.3mg/m^3 by the filters set on the building HVAC.

- Grounding
  Two different grounding systems shall be installed on the building side to reduce noise failure of the Control and Instrumentation Systems

  - Clean earth: Grounding the common circuit of the Control and Instrumentation system

  - Dirty earth: Grounding the equipment

(3) Design Description
The Control and Instrumentation system was designed in accordance with the design requirements (1) and (2). Figure 7-45 shows one-line instrumentation schematic.

- Design for Equipment

  - The Control and Instrumentation Systems allows for potential extension in anticipation of upgrade of the test equipment. Eighty percent or less of hardware implementation rate and software load rate is targeted to provide adequate allowance.

- The PLC power supply and hard disc for human machine interface (HMI) server has redundancy in order to increase the reliability in the Control and Instrumentation System.

- Operating Equipment

  - Operator Station (OPS)
    Operation of the 30MWt test equipment and monitoring of plant status and alarm display is centralized in the OPS.

  - Control Panel for Emergency
    A manually operable control panel for emergency is implemented to respond to any unexpected failure in the network system or emergency and protect the test equipment as property. The control panel shall cover the minimum startup and shutdown operations. It is installed in the central control room and configured as a control board consisting of relays. The control board is connected to the motor control center (MCC) with hard wire cables. It is envisaged that the board stops electric heaters, primary or secondary helium circulators, and start up the Emergency EH Cooling System. The other details will be developed in the detailed design phase.

- Control Equipment
  The control equipment includes a Programmable Logic Controller (PLC) and input/ output (I/O) panel.

  - PLC
    The PLC is installed in the central control room and; receives signals from the field equipment for logic processing or analogue control processing and sends outputs to the valves or pumps if necessary. Send the status information on the equipment to be monitored, alarms and signal volume to be processed to the monitoring to the automation bus. Receive the operation instructions from the OPS operators via the monitoring and control system network, and send operation instruction signals to the valves and pumps via I/O panel.

  - I/O Panels
    I/O panels in principle are installed in the field because better layout reduces required cable volume for wiring. The final decision about the layout will be made during the detailed design phase, taking into account the environmental conditions including temperature, and space options available.

- Interface between Control and Instrumentation Systems

  The following design is applicable for the interface between control and instrumentation systems.

  - Interface between PLCs and I/O panels
    The interface between PLCs and I/O panels forms a remote I/O network using optical fiber cables and based on bus architecture.

  - Interface between Automation Buses and PLCs
    The interface between automation buses and PLCs is Ethernet-based connection.

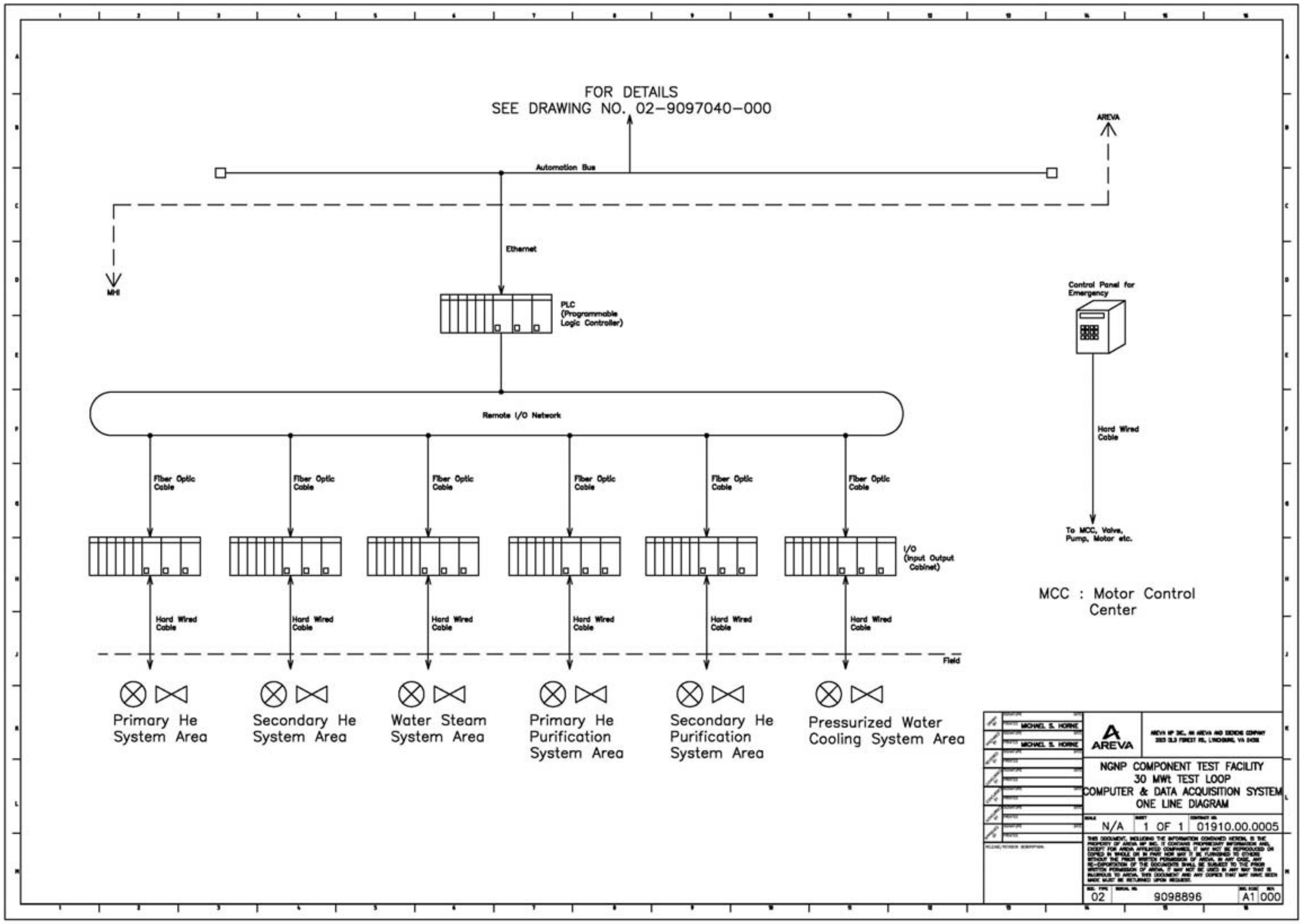
  - Interface with the Control Panel for Emergency
    The interface between the control panel for emergency and electric power board/field equipment or instruments is based on a cable connection.

  - Interface between I/O panels and field equipment
    The interface between I/O panels and field equipment is based on cable connection.

7.5.2 Data Collection and Storage System

The 30 MWt test loop transmits its signals to the automation bus for recording in the data collection and storage system as shown in Figure 7-45, One-line instrumentation schematic.

Figure 7-45: One Line Instrumentation Schematic



8.0 LOOPS ELECTRICAL DISTRIBUTION SYSTEM

8.1 Power Requirement (Reference Appendix B for electrical one-line drawings and Appendix C for electrical equipment list)

Initial power requirements estimate of the CTF 1MWt and 30 MWt test loops with generic facility loads is 55 MVA. This value is based on both the small and large test loops operating simultaneously. The estimate does not take into account additional test loops with their circulators, heaters, and coolers which may require the addition of one or more high voltage to medium voltage transformers to the new CTF. Power requirements for a hydrogen generating facility are beyond the scope of this report.

One 13.8 kV, 3000 A rated switchgear shall be fed via a circuit breaker directly from the 230 kV/13.8 kV 55 MVA stepdown transformer. Utilization of a utility type underground vault is the preferred method for carrying the 13.8 kV feeder cables to the metal-clad switchgear from the substation. All low voltage feeders to and inside the CTF facility can be housed in standard rigid metal conduit.

8.2 CTF Substation Power Supply

A commercial utility transmission line rated at 230 kV, 3 phase, 60 Hz shall supply the new CTF dedicated electrical substation. The INL site utility normally has ownership and maintenance responsibility over the 230 kV primary and the 13.8 kV secondary of the main power transformer in series with the secondary circuit breakers. Utility power metering and CTF facility ownership and maintenance responsibility will begin at the secondary circuit breakers.

One oil filled pad mounted 55 MVA stepdown transformer with a secondary load tap changer shall be located within the substation. Differential relays and current transformers shall provide both phase and ground fault protection for the transformer and associated circuit breakers. All medium and high voltage circuit breakers and switches shall be either vacuum or SF_6 type. The substation will be provided with adequate lightning arrestors, grounding and have security-type fencing around its perimeter. Electrical status signals from circuit breakers and transformer sensors will be incorporated into the CTF facility's computerized monitoring system (Supervisory Control and Data Acquisition) which will also monitor medium and low voltage switchgear components.

8.3 1 MWt Test Loop Electrical Supply

Two medium voltage switchgear 110 ampere trip circuit breakers supply 13.8 kV to one each 2 MVA stepdown transformers supplying separate 480 VAC switchgear assemblies. Both switchgear units utilize drawout fully electronic circuit breakers supplying local and remote data such as trip status and power quality. Features such as fully adjustable trip settings and delays along with trip inhibit capability will enhance circuit breaker coordination with down stream breakers.

One switchgear supplies the primary test loop first stage heater which is divided into two heater banks, with each bank being controlled by electronically fused thyristor controllers. A 200 Hp helium compressor, 20 Hp secondary loop helium purification pump, and a 200 ampere rated 480 VAC power panelboard for loop water cooled heat exchanger systems are also fed from this switchgear.

The second switchgear provides power to two variable frequency drive (VFD) controlled 282 Hp circulators, with one located in the primary helium test loop and the other in the secondary helium test loop. An instrumentation panelboard receives it's 3 phase 120/208 VAC power via stepdown transformer from this switchgear. This switchgear also supplies a thyristor controlled primary test loop second stage high temperature heater along with a 20 Hp primary helium purification pump. Automatic transfer switches are in series with the instrumentation transformer, water cooled heat exchanger panelboard, and both test loop circulator VFDs. Loss of site supplied power is sensed by automatic transfer switches and facilitate a transfer to generator standby power allowing a safe and orderly cool down of both primary and secondary test loops.

8.4 30 MWt Test Loop Electrical Supply

The 30 MWt electrical distribution is similar to the 1 MWt system except the switchgear is rated for a medium voltage level of 13.8 kV. Medium voltage in the range 4160 VAC to 13.8 kV is preferable when loads exceed the 1 MWt value. Medium voltage maintains the currents at acceptable levels and allows bus and feeder cable sizes to remain reasonable. Circuit breakers will be activated by solid state or microprocessor protective relays sensing the associated current with potential transformers sensing line voltage. These relays can also provide breaker status and power quality information to the CTF's data monitoring system.

The primary test loop heaters are composed of two 15 kW heater circuits which are then stepped-down to 480 VAC and then subdivided into1875 kW rated thyristor controlled heater units each. A modified VFD acting as a type of thyristor power controller will regulate the amount of electrical power to each heater.. Due to the nature of medium voltage, partial discharges sometimes referred to as surface tracking or corona damage can present a significant design challenge especially in a helium atmosphere at high temperatures. This is why the heaters were broken into numerous smaller units that could be powered by low voltage. This was not required for the helium circulators and main test loop feed water pump, which are supplied with 13.8 kV power, because temperatures are lower, the power penetrations can be better controlled, and partial discharge monitoring can be applied to check for insulation deterioration.

A 2000 Hp (1500 kW) primary test loop circulator and a 2700 Hp (2000 kW) secondary test loop circulator along with a 800 Hp (600 kW) feed water pump are powered from the switchgear via fused 15 kV rated motor starters with overload protection and partial discharge monitoring. Separate 480 VAC motor control centers (MCC) supply the cooling water system and the helium purification system along with pipe heat trace, helium storage, water treatment, and main loop valves. Other 480 volt circuits feed power to instrumentation and control power panels.

Provisions are made to have a standby electric heater circulator, cooling water systems, and instrumentation system power panel transferred to standby power due to loss of the normal supply.

8.5 Standby Electrical Supply System

Standby power used in the 30 MWt test loop is received via the standby power bus. The cooling water system and pressurized water cooling system must continue their pump operations to keep high temperature equipment cooling when main power is interrupted. The standby electrical heater cooling system is also required to be activated for the same reason. The systems are switched to the standby bus for the required electrical power. The control and instrumentation systems switch into the standby power bus to continue plant status monitoring.

8.6 CTF Facility Generic Electrical Supply

A standard switchgear arrangement, using similar components as the 1 MWt loop electrical distribution, will furnish power for much of the CTF facilities non helium test loop related loads. A 13.8 kV to 480 VAC, 3 MVA stepdown transformer will receive power from the 13.8 kV medium voltage switchgear and supply the facility low voltage switchgear. This switchgear is rated 3200 amperes at 480 VAC 3 phase. Electrical power will be supplied to two 3 phase 480 VAC 200 ampere power panels that will supply, via delta-wye stepdown transformers, 7 lighting and appliance panels rated 120/208 VAC, 3 phase, and positioned throughout the facility. Two other 480 VAC 3 phase power panels of which one shall supply HVAC facility loads, and one shall energize 10 sixty ampere rated welding receptacles. The welding receptacles distributed throughout the facility can serve as miscellaneous temporary power feeds. An 800 ampere rated motor control center shall provide the necessary voltage and current to gantry drive and hoisting VFDs and induction motors on the 200-ton and 50-ton overhead cranes. One 200 ampere rated power panel is reserved for miscellaneous small motor loads. One 75 Hp general air compressor is also supplied from the facility power bus. All switchgear and circuit breakers shall be rated at 100% with the circuit breakers being drawout type with electronic sensing and control.

Facility grounding should make use of both grounding electrode ring and ground rods around its perimeter and the conductive foundation reinforcing rods (rebar) commonly referred to as a “Ufer” ground.

9.0 LOOPS I&C DESIGN AND DATA COLLECTION SYSTEM

9.1 Computer and Data Collection System

The computer and data acquisition system is common to both the loops and Balance of Plant (BOP) systems and is based on Siemens Power Plant Automation SPPA T3000 distributed control system. The system is highly reliable and has high availability due to its redundant and fault tolerant design.

This subsection provides details for the functions and capabilities of the T3000 distributed control system. For one line schematic see drawing number 02-9097040 in Appendix B

9.1.1 Input/Output Cabinets

Three sets of Input Output (IO) cabinets are provided, one set for the small (1MWt) test loop, one set for the large (30 MWt) test loop, and one set for the BOP. The cables will run from the IO cabinets to the field devices. The IO cabinets will be located as close to the loops as possible but protected from the hazardous area so that it is easy to change, deleted or add the IO points in the future to accommodate the various test sections.

A large number of IO points will be provided for both of the test loops for data collection and loop operation. This will ensure plenty of spare IO points for future expansion and for multiple loop operations. The final decision about the number of IO cabinets and their location, and the number and the type of IO points will be made during the detailed design phase. IO points for the BOP cabinets are not determined yet.

The following common types of signals can be processed by the I/O modules

4-20 mA
0-1 Vdc
0-10Vdc
1-5 Vdc
Thermocouple signals (Type E, K, T and N etc.)
RTD 100 ohm platinum (3 wire or 4 wire)
Digital signals

9.1.2 Automation Processor

Two Automation Processor (AP) cabinets are provide, one for 1MWt test loop and one for the BOP Systems. The processors are fully redundant and of fault tolerant design. Failure of a single processor will not impact the performance of the associated IO or programmable control functions. The redundant processors are hot swappable. The AP cabinets will be located near their associated IO cabinets and communicate with them through a Process Field Bus (ProfiBus) network. AP cabinets process the data from the IO cabinets and place it on the automation highway.

The 30 MWt test loop uses a Programmable Logic Controller and IO cabinets to process the data and place it on the automation bus. This is described further in subsection 9.1.13.2.

9.1.3 Application Server

The Application servers are fault tolerant and perform the following functions:

- Stores all signal data acquired from the plant
- Stores data on a large hard drive
- Stores and manages alarm functions
- Provides dynamic information to the operator workstation

The application servers are redundant, with one running in master mode and the other unit running in hot standby. The failure of the master unit will cause the hot standby unit to take over, without any interruption in process or information.

9.1.4 Communication Networks

Communications between system components and peripherals use a standard industrial Ethernet bus using the TCP/IP protocol. The system is a fault tolerant. It will remain functional even if one transmissions path fails.

Networking equipment is located in the network cabinet in the equipment room.

9.1.5 Operator Workstation

Two workstations are provided in the control room, each workstation can control both the loops and the BOP systems. The workstation provides a screen based monitoring and control system. Each workstation consists of a terminal (thin client), keyboard and a mouse.

Three monitors will be provided for each workstation, to provide flexibility in controlling and monitoring the loops. Temperatures, pressures, flows, helium chemistry and other parameters in the primary and secondary loops are controlled from these workstations. Screens will display simple loop P&ID with temperatures, pressure and flow at selected locations. Operator can place the curser on a desired equipment display and a controller template will open up and operator can select the desired mode of operation, manual- automatic, open-close or start-stop etc. to control pressure, temperature and flows in the loops depending upon the test plan requirements. For a typical control loop see Appendix B.3.1.

Software can be modified using function blocks to automatically run a test sequence within loop bounding capabilities, which can be selected and activated by the operator from the control room.

To protect against excessive temperatures, pressures, chemical gas composition and flows, an automatic loop shut down will be provide to place the loop in the safe condition.

9.1.6 Engineering Workstation

An engineering workstation is provided in the control room to add, delete points and make system software and configuration changes. This workstation has two monitors, one monitor shows the existing configuration and the second monitor is used to make the changes.

9.1.7 Power Supply

Redundant power supplies are provided for all the major equipments from 120 VAC distribution panels. Redundant, battery backup UPS are provided for orderly shutdown of the loops and to ensure no data is lost incase 120 VAC power is lost

9.1.8 Human System Interface (HSI)

The system displays and controls are designed to incorporate accepted human factors principles so that the displayed information can be readily viewed and comprehended by the operators. This allows the operator to control and monitor all plant parameters easily and safely. The HSI system used will be equivalent to nuclear power plant Human System Interface requirements.

9.1.9 Alarms

The T3000 system generates audible and visual alarms to alert the operator about important changes in the system operation and parameters. A separate alarm screen is provided on the workstations for all the alarms. Any abnormal condition will be alarmed (audible and visual) on the workstation alarm screen.

The alarms are divided into several types (i.e., functional alarms, I&C alarms etc.). Each alarm is assigned a priority attribute based upon its importance. Each alarm can be individually configured. All the alarms are printed on the alarm printer for operator reviews.

9.1.10 System Security

The selected software architecture of the T3000 system provides a very powerful user management. Different users can be allowed individual views of the information and the access of each individual user can be accurately defined. Access rights can also be set up according to process area.

9.1.11 Diagnostics

On line system health monitoring is provided for verifying the health status of system components and to support software and hardware maintenance and trouble shooting activities.

9.1.12 Archiving

The PI server will be used for long term historical data storage and retrieval. It gathers archives and processes data and provides tools needed to manipulate and distribute the data and make it readily available to everyone who needs it anywhere in the client system.

The PI system protects data by determining the appropriate permissions for all user accounts.

9.1.13 Additional Details for 30 MWt Test Loop

The data acquisition and controls systems for the 1 MWt and 30 MWt test loops will be integrated into one seamless system during detailed design phase.

9.1.13.1 Emergency Control Panel

A manually operable control panel for emergency is implemented to respond to any unexpected failure in the network system or emergency and protect the test equipment as property. The control panel shall cover the minimum startup and shutdown operations. It is installed in the central control room and configured as a control board consisting of relays. The control board is connected to the motor control center (MCC) with hard wire cables. It is envisaged that the board stops electric heaters, primary or secondary helium circulators, and starts up the emergency electrical heater (EH) cooling system. The other details will be developed in the detailed design phase.

9.1.13.2 Programmable Logic Controller (PLC)

The PLC is installed in the central control room and;

- Receives signals from the field equipment for logic processing or analogue control processing and send outputs to the valves or pumps if necessary.
- Sends the status information on the equipment to be monitored, alarms and signal volume to be processed to the monitoring to the automation bus.

- o Receives the operation instructions from the OPS operators via the monitoring and control system network, and send operation instruction signals to the valves and pumps via I/O panel.

9.2 Instrumentation

Various types of instrumentations are provided for the control and monitoring of the loops and the test sections. Some of the instrumentation is listed below:

9.2.1 Flow Measurement

Helium mass flow in the loops is measured using Coriolis mass flow meter for accurate flow measurement. Flow will be measured at the discharge of the circulator where the temperature is low. These flow meters can be used for a maximum process temperature of 427^{o} C and have an accuracy of +/- 0.35 %.

In addition, one flow meter is installed in the high temperature test section at a temperature of 1000^{o} C and another flow meter is installed in the medium temperature test section at a temperature of 500^{o} C. Selecting these mass flow meters at such a high temperature will be a challenge.

9.2.2 Temperature Measurement

To measure the high temperatures in the loops Type K or N thermocouples will be used. These thermocouples have an accuracy of +/- 0.75%. If required for process monitoring, special thermocouples with higher accuracy can be supplied. Most of the thermocouples will require thermo-wells.

9.2.3 Pressure Measurement

Pressure measurement at high temperature and pressure is a challenge. We plan to use Rosemount Transmitters and tubing runs so that the temperature drops down to an acceptable value for the transmitter. Remote seal is another option, which can be used at a higher temperature and provides isolation from Helium.

9.2.4 Additional Instrumentation

The following additional instrumentation maybe required for the loop control and monitoring

- Additional instrumentations for test sections, depending on the nature of the test (strain gauges, vibrations, etc)
- Helium impurity monitors at the inlet and outlet of the hot test sections
- Helium chemistry and impurity monitors in the loop
- Moisture content in the loops
- External air monitors to provide helium concentration level around the loop for personal safety

9.3 Control Loops For 1MWt Test Loop

SPPA T3000 system has a very robust design, achieved through the selected software architecture with the runtime containers and function blocks. Control system will be capable of providing controls for temperatures, flows, pressures and other parameters at various points in the loop and the test sections by controlling various valves, heaters and circulator speed. The control system can be programmed to automatically startup and shutdown the loop within certain parameters if initiated by the operator.

9.3.1 Flow Control

Helium flow through the primary and secondary loops is independently controlled by adjusting the speed of the helium circulator. A mass flow meter is installed at the discharge of the circulator which provides input to the variable frequency drive. The Circulator speed is adjusted to maintain required flow through the loops.

9.3.2 Temperature Control

9.3.2.1 Heater Temperature Control

A 480 VAC power supply to the stage 1 and 2 heaters is controlled by separate thyristor control, to control the Helium temperature. Temperature sensors located at the discharge of the heaters provide input to the thyristor.

9.3.2.2 Heat Exchanger Temperature Control

Helium temperature in the high temperature, medium temperature and low temperature heat exchanges in the primary and secondary loops is independently controlled by adjusting the flow of cooling water to the heat exchangers. Air operated valves are used in the cooling water lines to modulate the water flow. Temperature sensors located at the discharge of the heat exchangers provide input to the controller. The temperature is compared to the controller setpoint and a signal is sent to the valve to open or close. Low temperature heat exchangers in the primary and secondary loops are used to control the helium temperature so that it is within allowable range for the circulators.

9.3.3 High and Medium Temperature Test Section Control

The following controls are provide to create pressure, temperature and flow fast transients to test the various configurations of the high and medium temperature test sections.

9.3.3.1 Temperature Control

A temperature transient can be induced by injecting helium from the cold leg upstream of the mock-up test section. Helium flow is controlled by an air operated valve. A temperature sensor located at the inlet of the test section provides input to the controller to modulate the valve to obtain the desired temperature changes. Opening this valve will reduce the helium temperature through the test section and closing this valve will increase the temperature.

9.3.3.2 Pressure Control

The pressure transient through the test section can be created by venting helium at the inlet of the test section via an air operated valve. A pressure sensor located at the inlet of the test section provides input to the pressure controller which will modulate the air operated valve to provide desired pressure drop through the test section. Pressure measurement can be a challenge due to high temperature and pressure.

9.3.3.3 Flow Control

The flow transient is introduced by opening or closings a test mock-up air operated bypass valve. The transient will last as long as the valve is opening or closing and then it will stabilize at the set value. A Coriolis mass flow meter is installed at the inlet of the test section which provides input to the flow controller. The flow controller controls the air operated valve to achieve the desired flow and flow transient. Finding a mass flow meter for a high temperature application will be challenge.

9.4 Control Loops for 30MWt Test Loop

9.4.1 Loop Control Strategy and Instrumentation

The loop control system and instrumentation of 30 MWt test loop shall establish to have ability of performing four categories of tests as below:

- IHX, SG Operation
  - Simulation test for NGNP power conversion system (PCS)
  - Tests for the components included in the PCS
    - IHX (Shell and Tube Type, Printed Circuit Type)
    - SG
    - Auxiliary System
    - Components of NGNP Loop System
    - Instrumentation

- 1000°C IHX Test
  - 1000°C IHX Test

- Double Hot Duct (DHD) Test
  - DHD Test
  - Isolation valve test
  - Other heat exchanger test (e.g. Cooler)

- Tests to be planned in future
  - Direct-cycle power conversion component test
  - Nuclear Hydrogen Initiative (NHI) tests
  - Reactor vessel and core structure test

The high level loop control strategy and instrumentation of 30 MWt test loop are described as follows:

(1) Control of primary and secondary He flow rate
The primary helium circulator (PHC) and secondary helium circulator (SHC) are operated on a constant rotation speed. To allow the primary and secondary helium flow rate to vary for different test conditions, the bypass lines and control valves are set up in the PHC and SHC as shown in Figure 7-3. The setting allows the primary and secondary helium flow rate to control the specified flow rate.

(2) Control of helium temperature at the outlet of the EH1 and EH2
The EH 1 heats up helium to approximately 700°C, while the EH2 heat up helium to 1000°C. As the heater outlet temperature varies depending on the test conditions, the helium temperature at the outlet of the EH1 and EH2 is controlled by heater power control system so as to achieve the specified level, as shown in Figure 7-2.

(3) Correction of heat removal capacity by water cooler
The water cooler (WC) consists of WC1 and WC2, which have heat removal capacities for 5MWt and 25MWt, respectively. The WC1 has a bypass line and control valve, which control the flow rate at the WC1 to correct the total heat removal throughout the entire water cooler system.

(4) Temperature Transient Tests
The design should be enable IHX to provide temperature transients ranging over +/- 200°C /min. The electric heaters cannot realize such a large helium temperature change in a minute. It was therefore decided to

provide temperature transients by changing mixing ratio of hot and cold helium.

Specifically, the mixing tank (MT) is set up at the EH2 outlet and a helium line and a control valve are set up between the MT and EH1 inlet to bypasses EH1 and EH2 and directly transport cold helium to the MT from PHC. The design allows the MT to mix the cold helium with the helium heated through EH1 and EH2.

The bypass line control valve delivers a temperature transient of +200°C /min, as shown in Figure 7-5. Specifically, the valve is initially set to deliver a mixed helium flow at 800°C by blending a helium flow of at 428°C coming from the bypass line with another helium flow at 1000°C from EH2 and then the valve is gradually closed to reduce a 428°C helium flow, resulting in increased temperature of helium at the MT outlet. The mechanism allows the change in valve closing rate to adjust the temperature rising rate.

Figure 7-6 shows how a temperature transient of -200°C /min is operated. The low-temperature helium flow to the MT is initially set at 0 while 1000°C helium alone is allowed to flow into the MT. Then, the bypass line control valve is gradually opened to deliver 428°C helium into the MT, resulting in temperature reduction of mixed helium at MT outlet. The mechanism again allows the change in valve opening rate to adjust temperature falling rate.

(5) Common use of WC1 and WC2 for primary and secondary He system
The operational temperature limit for SG is 825°C, which is the secondary helium temperature at the IHX outlet, which is one of the PCS operational limits. When the IHX is operated under 1000°C, the secondary helium temperature, which is measured at 925°C at the IHX outlet, is over the PCS operational limits. Therefore, the secondary helium temperature has to be reduced via heat removal at the WC1 and WC2 instead of SG. The line connecting the primary and secondary systems is set up so that the WC1 and WC2 can serve as secondary helium system cooler, as shown in Figure 7-7.

(6) Primary He Pressure Control
The primary helium pressure is maintained at a specified level by adjusting the helium supply and discharge from the primary helium purification system and helium storage and supply system, as shown in Figure 7-8.

(7) Secondary He Pressure Control
The secondary helium pressure is controlled to maintain a differential pressure between the primary and secondary helium systems at 0.5MPa. As shown in Figure 7-9, the differential pressure between the primary helium pressure at the IHX outlet and the secondary helium pressure at the IHX inlet, can be maintained by adjusting the helium supply or discharge from the secondary helium purification system and helium storage and supply system.

(8) Connection with the helium purification systems
Mixing tanks (MTs) are installed upstream to the PHC and SHC and connected to the primary and secondary helium purification systems. The setting precludes any effect on the main He flow rate.

(9) Emergency EH Cooling
The EH1 and EH2 should be cooled to prevent the EH components from over heating after loss of power accident because of the large heat capacity of heater elements.
The emergency EH cooler, helium circulator, piping and valves are set up between EH1 inlet and EH2 outlet and the emergency EH to helium circulator is connected to emergency power supply bus.

9.5 Loop Protection System

In case loop control system malfunctions and temperature, pressure, flow or other parameters exceed their limits, the protection system will automatically trip the loop and place it in the safe condition. The protection system will use separated sensors and hardware than the control system to provide some redundancy.

10.0 CTF SAFETY AND QUALITY

The key requirements for the NGNP CTF safety and quality program are provided in DOE O 413.3A and 10 CFR 830 [Reference 12.10]. The statement of work requires a preliminary hazards analysis of the NGNP CTF pre-conceptual design. This section documents that analysis. AREVA's quality assurance program for the NGNP CTF project is described in QA-3000798-002 NGNP CDS CTF Project QA Plan [Reference 12.14). The quality assurance plan identifies the implementing procedures that apply to the current design effort.

This section identifies and defines preliminary hazards associated with the CTF test loops. It also documents the preliminary analysis that was performed to ensure that safety is fully integrated into the design. The tests planned in the CTF test loops, described in TDR-30001031-000, Technical Development Road Mapping Report [Reference 12.12], do not involve the use of radioactive material nor do they involve the use of materials identified in 29 CFR 1910 .119 Appendix A, List of Highly Hazardous Chemicals, Toxins, and Reactants. They do involve hazards identified in 29 CFR 1910, Occupation Safety and Health Standards. These analyses include the SSCs included in the test loop pre-conceptual design but not the auxiliary systems (i.e. helium purification system, helium inventory and pressure control system, heat rejection system, control instrumentation air system, and water treatment system) that are included in the scope test loop design.

10.1 Hazard Identification

The principal hazards are: 1) high pressure (up to 10 MPa), high temperature (up to 1000 C) helium and 2) electrical (up to 13,800 volts).

Helium is classified as an atmospheric hazard (29 CFR 1910 Section 2) with an ACGIH TLV "Simple Asphyxiant" (29 CFR 1910, Table Z-1, Toxic and Hazardous Substances). Helium is non flammable, non corrosive, non-toxic, chemically stable, and non-hazardous. Helium's gas density is 0.14 relative to air. Work areas have to be designed to maintain oxygen levels above 19.5% outside of containment areas and have oxygen monitors. Entry permits are required for confined work spaces.

The 1 MWt test loop is estimated to contain approximately 100 m^{+3} or approximately 300 kg of helium. Approximately half of that quantity is in the primary heat transfer loop with the other half in the secondary loop. The 30 MWt test loop is estimated to contain 340 m^{+3} or approximately 1500 kg of helium.

The test loop will be used to test the IHX and Helium Purification System with gas mixtures with a fixed concentration of N_2, CO, CO_2, H_2O, H_2, O_2, NO, NO_2, CH_4 in helium. The concentration of these gases is expected to vary from few volumetric parts per million (2 in general) to 100 volumetric parts per million. At these concentrations the hazards associated with the helium gas mixture is assumed to be the same as pure helium.

10.2 Preliminary Hazards Analysis

Table 10-1 documents significant hazards identified with the Small Test Loop and Table 10-2 documents significant hazards identified with the Large Test Loop. Those tables also document the component failure modes and effects associated with each hazard. The scope of this preliminary hazards analysis does not include detailed failure modes and effects of the test sections or associated special test conditions (i.e., injection of simulated impurities such as N_2, CO, CO_2, H_2O, H_2, O_2, NO, NO_2, CH_4, and particulates). The scope of this report does not include the test sections. This analysis assumes that the hazards associated with establishing representative helium chemistry conditions will be included in the detailed test plans and procedures for the IHX and qualification of the helium purification system.

10.3 Preventative and Mitigative design features and safety systems

Table 10-1 and Table 10-2 document the preventative and mitigative design features included in the Large and Small Test Loop designs. Among the design features included in the design are: 1) pressure relief valves and rupture disks to prevent over pressurization of the test loops, 2) failure detection I&C, 3) and design features that should be studied during the CTF conceptual design.

10.4 Interfaces with facility design

The test loops should be inside a containment area with a dedicated HVAC system. The test loop pressure relief system should either vent to the helium recovery system or to an outside restricted access area, preferably on the facility roof. The restricted access area should provide a safe separation distance from projectiles that might be generated if one of the SSCs being tested failed or if the test loops over pressurized. The containment, the containment area HVAC exhaust, and test loop pressure relief discharge should be restricted access areas. The containment area should have oxygen meters and self-contained breathing apparatus at egress areas.

The hazards associated with the CTF auxiliary systems are documented in INL/EXT-08-14152 Rev 1, Pre-Conceptual Facility Configuration Study of the High Temperature Gas-Cooled Reactor Test Facility [Reference 12.15].

Table 10-1: Small Test Loop Preliminary Hazards Analysis

Test Loop 1MWt
Drawing: NGNP CTF 1 MWt Test Loop P&ID, 02-9097037-000 and 02-9097038-000 (Appendix B, Section B.4.2 and B.4.3)

S. No.	System / Component	Description	Function	Operating Mode	Failure Modes	Failure Cause	Failure Effect	Failure Detection	Recommendation / Remark
1	Primary Loop First stage Heater (850 °C)	0.85 MW electric immersion heaters with metallic heating elements	Heats 0.4 kg/s of He at 5.0 MPa from 400 °C to 850 °C	Startup	No heating	Loss of power, breaker trip, I&C failure, heater elements fails	Test run failure	Temperature, current and breaker indication and/or alarm	Maintainable heater, I&C
				Normal operation	No heating	Loss of power, breaker trip, I&C failure, heater elements fails	Test run failure	Temperature, current and breaker indication and/or alarm	Maintainable heater, I&C
				Shutdown	No heating	Loss of power, breaker trip, I&C failure, heater elements fails	None	Temperature, current and breaker indication and/or alarm	Maintainable heater, I&C
				All	Leak	Thermal mechanical stress	High temperature pressure wave, projectiles	P & T monitors	Facility barriers are required around high temperature / pressure areas
						Human error	High temperature gas jet, test run failure	P & T monitors	Facility barriers are required around high temperature / pressure areas
2	Primary Loop High Temperature Heater (1000 °C)	0.4 MW electric immersion heaters with non-metallic	Heats 0.4 kg/s of He at 5.0 MPa from 805 °C to 1000 °C	Startup	No heating	Loss of power, breaker trip, I&C failure, heater	Slow startup	Temperature, current and breaker	Maintainable heater, I&C

S. No.	System / Component	Description	Function	Operating Mode	Failure Modes	Failure Cause	Failure Effect	Failure Detection	Recommendation / Remark
		(CERMET, carbon) heating elements				elements fails		indication and/or alarm	
				Normal operation	No heating	Loss of power, breaker trip, I&C failure, heater elements fails	Low temperature test or test run failure	Temperature, current and breaker indication and/or alarm	Maintainable heater, I&C
				Shutdown	No heating	Loss of power, breaker trip, I&C failure, heater elements fails	None	Temperature, current and breaker indication and/or alarm	Maintainable heater, I&C
				All	Leak	Thermal mechanical stress	High temperature gas jet, test run failure	P & T monitors	Facility barriers are required around high temperature / pressure areas
				All	Leak	Human error	High temperature gas jet, test run failure	P & T monitors	Facility barriers are required around high temperature / pressure areas
3	High Temperature Heat Exchanger (used as part of the primary loop test configuration when an IHX is not being tested)	A 830 kW single pass U-tube heat exchanger with helium flow inside the tube, with co-current water on the shell side.	1) 950 °C/500 °C He, 2) 30 °C/50 °C water, 3) 8 MPa design pressure and 5.0 MPa nominal operating pressure	All	Leak from water loop to He loop	Tube failure due to thermal mechanical stress	Steam in He loop	I&C, P readouts	Moisture detector required
				All	Loss of coolant	Pipe failure, coolant pump failure, heat exchanger failure, I&C failure, human error	Low temperature equipment overheats	P & T indication and alarm	Provide automatic trip to circulator motor on high He temperature
4	Primary Loop Recuperator	800 kW He:He heat exchanger	1) first stage of heating 0.4 kg/s 70 °C He from circulator to 420 °C, 2)	All	Leak	Thermal mechanical stress	High temperature pressure wave,	P & T monitors	Facility barriers are required around high temperature /

S. No.	System / Component	Description	Function	Operating Mode	Failure Modes	Failure Cause	Failure Effect	Failure Detection	Recommendation / Remark
		(recuperator)	8 MPa design pressure, 2) recovers heat from 0.4 kg/s of 500 °C He gas returning from high temperature test sections to 120 °C, 3) 8 MPa design pressure and 5.0 MPa nominal operating pressure				projectiles		pressure areas
5	Primary Loop Low Temperature Heat Exchanger	410 kW He: water heat exchanger	1) cools 0.4 kg/s of 5.0 MPa He from approximately 120 °C to 50 °C, 2) 8 MPa design pressure, 3) sized with recuperator to lower high temperature loop from 900 °C to 400 °C in 100 s	All	Leak	Thermal mechanical stress	Steam in He loop	I&C P, readouts	Moisture detector
				All	No coolant	Human error	Low temperature equipment overheats	I&C, T readouts	Spare circulator motor
6	Primary Test Loop Gas Circulator	He circulator	1) Provides 0.4 kg/s of He at 5.0 MPa, against a pressure drop of 0.4 MPa, 2) provides flow control from 0.1 to 0.4 kg/s at 5.5 MPa by varying rotational speed, 3) circulates gas designed to operate from 0.4 MPA to 8 MPa	All	Motor stops	Human error, I&C fails, motor overheats, off-site power loss	Loss of flow and test run	n/a	n/a
				All	Motor overspin	Human error, I&C failure	Impeller fails	Flow and motor speed indicators	Circulator designed to prevent projectiles

S. No.	System / Component	Description	Function	Operating Mode	Failure Modes	Failure Cause	Failure Effect	Failure Detection	Recommendation / Remark
7	Primary Loop He Purification and Pressure Control System	This system has three subsystems: 1) He Purification, 2) He Gas Composition and 3) He Inventory & Pressure Control		n/a	n/a	n/a	n/a	n/a	n/a
7a	He Purification System	Filters, oxidizer, oxygen tank, cooler, cyclone separator, molecular sieves, activated carbon bed, getter	1) Removes particulates, combustable gases, and N2 impurities from circulating He, 2) 20 g/s He flow rate over 180 °C to 400 °C and 0 to 8 MPa, 3) purification level < 1 ppmV	All	Carbon bed fire	Oxygen system fails	He loop contaminated	He Gas Composition subsystem; T monitors	Oxygen detector at carbon bed inlet
7b	He Gas Composition	N2, CO, CO2, H20, H2, O2, NO NO2 gas analyzers	Detection level < 1 ppmV, sensitivity and accuracy TBV	All	No output	Detector failure	He loop contaminated	n/a	Redundant detectors, diverse technology
7c	He inventory & Pressure Control (HPC)	He feed tanks, flow regulators, and pressure controls	See descriptions of subsystems	All	Leak	Mechanical damage	Personnel asphyxiation	Flow control valves and isolation waves	Personnel protective gear for any enclosed areas, facility designed per OSHA
		He storage tank	1) pressurize both loops in 8 hours, 2) all season operation [-30 to 100 °C]	All	Leak	Mechanical damage	Personnel asphyxiation	n/a	Personnel protective gear for any enclosed areas, facility designed per OSHA
		Pressure control valves	1) one valve sized to depressurize the system from 5.5 to 2.5 MPa in 15 sec. 2) the other valve sized to control the system pressure at 5.5 MPa	All	Leak	Mechanical damage	Personnel asphyxiation	n/a	Personnel protective gear for any enclosed areas, facility designed per OSHA

S. No.	System / Component	Description	Function	Operating Mode	Failure Modes	Failure Cause	Failure Effect	Failure Detection	Recommendation / Remark
		Isolating valves	Located at each pressure boundary (system or test section inlet outlet piping)	All	Leak	Mechanical damage	Personnel asphyxiation	n/a	n/a
		Rupture disk (design pressure)	Depressurizes system at 8 MPa	All	Leak	Mechanical damage	Personnel asphyxiation	n/a	Vent to roof
8	Primary Loop Instrumentation & controls	The loop measured parameters are pressures (differential and gage), flow rates and temperatures to monitor each system and test section during the different operating modes.	The electric heaters have independent electrical supply, control, and monitoring (inlet/outlet). The controls loop logic is: (1) High Temperature test sections are controlled by the heaters thermal power; (2) circulator temperature controlled by low temperature heat exchanger cooling water flow rate; (3) gas composition is controlled by directing helium stream downstream of the circulator back to the main flow path after passing through the purification system; (4) system pressure is controlled (2 to 8 MPa) by two regulating valves on He Purification and Pressure Control inlet and outlet piping; the	all	1) Test section temp. can not be controlled (2) Circulator temp can not be controlled. (3) Gas impurity levels exceed corrosion control limits (4) System pressure exceeds design limit (5) He flow can not be controlled	(1) sensor failure, loss of power, heater failure, contoller failure (2) sensor failure, controller failure, loss of cooling water, cooling water valve malfunction (3) Human error or mechanical failure (4) Design error (5) circulator malfunction, speed sensor failure, power supply failure, high frequency drive failure, controller failure	(1) Test run failure (2) Test run failure, high temp may damage the circulator. (3) Loop becomes unreliable, moisture causes corrosion, particulates plug instrument lines (4) high pressure and temperature gas leaks, possible pressure wave and production of projectiles (5) Test run failure, high speed may damage the circulator	(1) Temperature, current and breaker indication and/or alarm (2) temp. and flow indication and/or alarm 3) alarm high readings (4) high pressure alarm (5) flow and speed indication and/or alarm	(1)Trouble shoot, repair or replace the damaged parts. (2) an interlock is recommended to trip the circulator on high temp. (3) test impurities at end of test sequence (4) Redundant rupture disk (5) an interlock is recommended to trip the circulator on high speed.

S. No.	System / Component	Description	Function	Operating Mode	Failure Modes	Failure Cause	Failure Effect	Failure Detection	Recommendation / Remark
			(5) He flow rate is controlled by varying the rotating speed of the circulator.						
9	Primary Loop High Temperature Piping	High temperature (>500 °C) piping with internal and external insulation	Heat loss < [100 kW] with [50 °C] surface temperature; 8 MPa design pressure, temperature [500 °C]; design temperature of the gas [1000 °C]	All	Leak	Thermal mechanical stress	High temperature pressure wave, projectiles	P & T monitors	Facility barriers
10	Primary Loop Low Temperature Piping	Low temperature (<500 °C) piping with external insulation	Design pressure of 8 MPa at [500] °C. Contact temperature of [50] °C	All	Leak	Thermal mechanical stress	High temperature pressure wave	P & T monitors	Facility barriers
11	Secondary Loop Recuperator	800 kW He:He heat exchanger	1) First stage of heating 0.4 kg/s 70 °C He from circulator to 400 °C, 2) recovers heat from 0.4 kg/s of 500 °C He gas returning from high temperature test sections to 150 °C, 3) 8 MPa design pressure and 5.5 MPa operating pressure	All	Leak	Thermal mechanical stress	High temperature pressure wave, projectiles	P & T monitors	Facility barriers
12	High Temperature Heat Exchanger (configured for testing IHX)	Same as above	1) Cools 0.4 kg/s of 950 °C 5.5 MPa He from IHX to 500 °C, 2) 8 MPa design pressure	All	Leak	Thermal mechanical stress	Steam in the He loop	I&C, P readouts	Moisture detector
				All	No coolant	Human error	Low temperature equipment overheats	I&C, T readouts	Spare circulator motor
13	Medium Temperature Heat		1) Cools 0.4 kg/s of 5.5 MPa He to specified	All	Leak	Thermal mechanical stress	Steam in the He loop	I&C, P readouts	Moisture detector

S. No.	System / Component	Description	Function	Operating Mode	Failure Modes	Failure Cause	Failure Effect	Failure Detection	Recommendation / Remark
	Exchanger (configured for controlling the IHX secondary side coolant temperature)		IHX inlet temperature (nominally 475 °C), 2) 8 MPa design pressure	All	No coolant	Human error	Low temperature equipment overheats	I&C, T readouts	Spare circulator motor
14	Secondary Loop Low Temperature Heat Exchanger	410 KW He:water heat exchanger	1) Cools 0.4 kg/s of 5.5 MPa He from 150 °C, 2) 8 MPa design pressure, 3) sized with recuperator to lower high temperature loop from 900 °C to 400 °C in 100 s	All	Leak	Thermal mechanical stress	Steam in the He loop	I&C, P readouts	Moisture detector
				All	No coolant	Human error	Low temperature equipment overheats	I&C, T readouts	Spare circulator motor
15	Secondary Test Loop Gas Circulator	He circulator	1) Provides 0.4 kg/s of 5.5 MPa He at 50 °C against a pressure drop of 0.4 MPa, 2) Provides flow control from 0.1 to 0.4 kg/s at 5.5 MPa by varying rotational speed, 3) circulates gas designed to operate from 0.4 MPa to 8MPa	All	Motor stops	Human error, I&C fails, motor overheats, off-site power loss	Loss of flow and test run	n/a	n/a
				All	Motor overspin	Human error, I&C failure	Impeller fails	Flow and motor speed indicators	Circulator designed to prevent projectiles
16	Secondary Loop He Purification and Pressure Control System	This system has three subsystems: 1) He Purification, 2) He Gas Composition, 3) He Inventory & Pressure Control	See descriptions of subsystems	All	Leak	Mechanical damage	Personnel asphyxiation	Flow control valves and isolation valves	Personnel protective gear for any enclosed areas, facility designed per OSHA
16a	He Purification System [HEPUR)	Filters, oxidizer, oxygen tank, cooler, cyclone separator, molecular sieves, activated carbon bed,	1) Removes particulates, combustible gases, and N2 impurities from circulating He, 2) 20 g/s	All	Carbon bed fire	Oxygen system fails	He loop contamination	He Gas Composition subsystem; T monitors	Oxygen detector at carbon bed inlet

S. No.	System / Component	Description	Function	Operating Mode	Failure Modes	Failure Cause	Failure Effect	Failure Detection	Recommendation / Remark
		getter	He flow rate over 180 °C to 400 °C and 0 to 8 MPa, 3) purification level < 1 ppmV						
16b	He Gas Composition [POLLUHE]	N2, CO, CO2, H2O, H2, O2, NO, NO2 gas analyzers	Detection level < 1 ppmV, sensitivity and accuracy TBV	All	No output	Detector failure	He loop contaminated	n/a	Redundant detectors, diverse technology
		He feed tanks, flow regulators, and pressure controls		All	Leak	Mechanical damage	Personnel asphyxiation	Flow control valves and isolation valves	Personnel protective gear for any enclosed areas, facility designed per OSHA
16c	He Inventory & Pressure Control [HPC]	He storage tank	1) Pressurize both loops in 8 hours, 2) all season operation [-30 °C to 100 °C]	All	Leak	Mechanical damage	Personnel asphyxiation	n/a	Locate outside buildings
		Pressure control valves	1) One valve sized to depressurize the system from 5.5 to 2.5 MPa in 15 sec.; 2) The other valve sized to control the system pressure at 5.5 MPa	All	Leak	Mechanical damage	Personnel asphyxiation	n/a	Vent to roof
		Isolating valves	Located at each pressure boundary (system or test section inlet outlet piping)	All	Leak	Mechanical damage	Personnel asphyxiation	n/a	n/a
		Rupture disk (design pressure)	Depressurizes system at 8 MPa	All	Leak	Mechanical damage	Personnel asphyxiation	n/a	n/a
17	Secondary Loop Instrumentation & controls	The loop measured parameters are pressures (differential and gage), flow rates	The control loop logic is: high temperature test loop temperatures are controlled by varying cooling water flow rate	All	No output	Sensor failure or loss of power	I&C system receives false input	Redundant sensors	Diverse sensors

S. No.	System / Component	Description	Function	Operating Mode	Failure Modes	Failure Cause	Failure Effect	Failure Detection	Recommendation / Remark
		and temperatures to monitor each system and test section during the different operating modes	to the high temperature heat exchanger; circulator temperature controlled by low temperature heat exchanger cooling water flow rate; gas composition is controlled by directing helium stream downstream of the circulator back to the main flow path after passing through the purification system; system pressure is controlled (2 to 8 MPa) by two regulating valves on He Purification and Pressure Control inlet and outlet piping; the He flow rate is controlled by varying the rotating speed of the circulator.						
18	Secondary Loop High Temperature Piping	High temperature (>500 °C) piping with internal and external insulation	Heat loss , [100 kW] with [50 °C] surface temperature ; 8 MPa design pressure, temperature [500 °C]; design temperature of the gas [1000 °C]	All	Leak	Thermal mechanical stress	High temperature pressure wave, projectiles	P & T monitors	Facility barriers
19	Secondary Loop Low Temperature Piping	Low temperature (<500 °C) piping with external insulation	Design pressure of 8 MPa at [500] °C. Contact temperature of [50] °C	All	Leak	Thermal mechanical stress	High temperature pressure wave	P & T monitors	Facility barriers

Table 10-2: Large Test Loop Preliminary Hazards Analysis

S. No.	System / Component	Description	Function	Operating Mode	Failure Modes	Failure Cause	Failure Effect	Failure Detection	Recommendation / Remark
1	Primary Loop First stage Electric heater (714 °C) : EH1	7.5 MW electric pipe heaters with metallic heating element	Heats 5kg/s of He at 7.02 MPa from 427 °C design pressure: 8.4 MPa	Startup	No heating	Loss of power, breaker trip, I&C failure, heater element fails	Test run failure	Temperature, current and breaker indication and/or alarm	Heater which can be maintained, I&C
				Normal operation	No heating	Loss of power, breaker trip, I&C failure, heater element fails	Test run failure	Temperature, current and breaker indication and/or alarm	Heater which can be maintained, I&C
				Shutdown	No heating	Loss of power, breaker trip, I&C failure, heater element fails	None	Temperature, current and breaker indication and/or alarm	Heater which can be maintained, I&C
				All	Leak	Thermal mechanical stress	High temperature pressure wave, projectiles, personnel asphyxiation	P & T monitors, oximeter	Facility barriers are required around high temperature / pressure areas, vent to roof
				All	Leak	Human error	High temperature gas jet, test run failure, personnel asphyxiation	P & T monitors, oximeter	Facility barriers are required around high temperature / pressure areas, vent to roof
2	Primary Loop 2nd stage Electric heater	7.5 MW electric pipe heaters with non-metallic (Graphite) heating elements	Heats 5 kg/s of He at 7.01 MPa from 714 °C to 1000 °C design pressure: 8.4 MPa	Startup	No heating	Loss of power, breaker trip, I&C failure, heater element fails	Slow startup	Temperature, current and breaker indication and/or alarm	Heater which can be maintained, I&C
				Normal operation	No heating	Loss of power, breaker trip, I&C failure, heater element fails	Low temperature test or test run failure	Temperature, current and breaker indication and/or alarm	Heater which can be maintained, I&C

S. No.	System / Component	Description	Function	Operating Mode	Failure Modes	Failure Cause	Failure Effect	Failure Detection	Recommendation / Remark
				Shutdown	No heating	Loss of power, breaker trip, I&C failure, heater element fails	None	Temperature, current and breaker indication and/or alarm	Heater which can be maintained, I&C
				All	Leak	Thermal mechanical stress	High temperature pressure wave, projectiles, personnel asphyxiation	P & T monitors, oximeter	Facility barriers are required around high temperature / pressure areas, vent to roof
				All	Leak	Human error	High temperature gas jet, test run failure, personnel asphyxiation	P & T monitors, oximeter	Facility barriers are required around high temperature / pressure areas, vent to roof
3	Water cooler 2 (used as part of the primary loop when a double hot gas duct is tested): WC2	25.1mW U-tube shell and tube type heat exchanger (pressurized water: tube inside, helium gas; tube outside)	1) 905 °C/467 °C 10kg/s He, 2) 100 °C/150 °C pressurized water, 3) 9 MPa design pressure and 7 MPa nominal operating pressure	All	Leak from water loop to He loop	Tube failure due to thermal mechanical stress	Steam in He loop	I&C, P readouts	Moisture detector required
				All	Loss of coolant	Pipe failure, coolant pump failure, heat exchanger failure, I&C failure, human error	Low temperature equipment overheats	P & T indication and alarm	Provide automatic trip for circulator motor on high He temperature and low cooling water flow rate
4	Water cooler 1 (used as part of the primary loop or temporarily as part of secondary loop): WC1	5.6MW U-tube shell and tube type heat exchanger (cooling water: tube inside, helium gas: tube outside)	1) Cools 10 kg/s of 7.5 MPa He from approximately 467 °C to 360 °C, 2) 9 MPa design pressure, 3) Cooling water from 30 °C to 52 °C	All	Leak	Thermal mechanical stress	Steam in He loop	I&C, P readouts	Moisture detector
				All	No coolant	Human error	Low temperature equipment overheats	I&C, T readouts	Spare circulator motor
5	Primary Loop Gas Circulator: PHC	HE circulator	1) Provides 13.6 kg/s of He at 4.9 MPa,	All	Motor stops	Human error, I&C fails, motor	Loss of flow and test run	n/a	n/a

S. No.	System / Component	Description	Function	Operating Mode	Failure Modes	Failure Cause	Failure Effect	Failure Detection	Recommendation / Remark
			2) Flow rate is controlled with by-pass flow, 3) Operating speed is 800 rpm			overheats, off-side power loss			
				All	Surging	Human error, I&C failure	Impeller fails	Flow and differential pressure indicators	Surge protection line provided
6	Primary Loop He Purification and Pressure Control	This system has two subsystems: 1) He Purification, 2) He Inventory & Pressure Control		n/a	n/a	n/a	n/a	n/a	n/a
6a	He Purification System	Economizer, Filters, Copper oxide reactor, cooler, molecular sieves, cold trap, He circulation pump	1) Remove impurities from circulating He, 2) 45 g/s He flow rate and 0 to 8 MPa, 3) Purification level < 1 ppmV	All	Carbon bed fire	Oxygen system fails	He loop contaminated	He loop contaminated He Gas Composition subsystem; T monitors	Oxygen detector at carbon bed inlet
6b	He Storage and Supply System [for Primary loop and Secondary loop]	He feed tanks flow regulators, and pressure controls	He storage and supply loop pressure and pressure difference between primary He loop and secondary He loop, and supplies He to main loop and storages He from main loop	All	Leak	Mechanical damage	Personnel asphyxiation	Flow control valves and isolation valves	Personnel protective gear for any enclosed areas, facility designed per OSHA
		He storage tank	All season operation [-30 to 100 °C]	All	Leak	Mechanical damage	Personnel asphyxiation	n/a	Locate outside buildings
		Pressure control valves		All	Leak	Mechanical damage	Personnel asphyxiation	n/a	Vent to roof
		Isolating valves	Located at each pressure boundary (system or test section inlet outlet piping)	All	Leak	Mechanical damage	Personnel asphyxiation	n/a	n/a
		Rupture disk (design pressure)	Depressurizes system	All	Leak	Mechanical damage	Personnel asphyxiation	n/a	Vent to roof

S. No.	System / Component	Description	Function	Operating Mode	Failure Modes	Failure Cause	Failure Effect	Failure Detection	Recommendation / Remark
7	Primary Loop Instrumentation & controls	The loop measured parameters are pressures (differential and gage), flow rates and temperatures to monitor each system and test section during the different operating modes.	The electric heaters have independent electrical supply, control, and monitoring (inlet/outlet). The controls loop logic is: (1) High Temperature test sections are controlled by the heaters thermal power; (2) circulator temperature controlled by low temperature heat exchanger cooling water flow rate; (3) gas composition is controlled by directing helium stream downstream of the circulator back to the main flow path after passing through the purification system; (4) system pressure is controlled (2 to 8 MPa) by two regulating valves on He Purification and Pressure Control inlet and outlet piping; the (5) He flow rate is controlled by varying the by-pass flow rate of the circulator.	All	1) Test section temp. can not be controlled (2) Circulator temp can not be controlled. (3) Gas impurity levels exceed corrosion control limits (4) System pressure exceeds design limit (5) He flow can not be controlled	(1) sensor failure, loss of power, heater failure, controller failure (2) sensor failure, controller failure, loss of cooling water, cooling water valve malfunction (3) Human error or mechanical failure (4) Design error (5) circulator malfunction, speed sensor failure, power supply failure, high frequency drive failure, controller failure	(1) Test run failure (2) Test run failure, high temp may damage the circulator. (3) Loop becomes unreliable, moisture causes corrosion, particulates plug instrument lines (4) high pressure and temperature gas leaks, possible pressure wave and production of projectiles (5) Test run failure, high speed may damage the circulator	(1) Temperature, current and breaker indication and/or alarm (2) temp. and flow indication and/or alarm 3) alarm high readings (4) high pressure alarm (5) flow and speed indication and/or alarm	(1)Trouble shoot, repair or replace the damaged parts. (2) an interlock is recommended to trip the circulator on high temp. (3) test impurities at end of test sequence (4) Redundant rupture disk (5) an interlock is recommended to trip the circulator on surging.
8	Primary Loop High Temperature Piping	High temperature (>700 °C) piping with internal insulation.	8 MPa design pressure, temperature [350 °C]; design temperature of the gas [1030 °C].	All	Leak	Thermal mechanical stress	High temperature pressure wave, projectiles	P & T monitors	Facility barriers
9	Primary Loop Low	Low temperature	Design pressure of 8	All	Leak	Thermal	High temperature	P & T monitors	Facility barriers

S. No.	System / Component	Description	Function	Operating Mode	Failure Modes	Failure Cause	Failure Effect	Failure Detection	Recommendation / Remark
	Temperature Piping	(<500 °C) piping with external insulation	MPa at [550] °C; Contact temperature of [50] °C.			mechanical stress	pressure wave		
10	Secondary Loop Gas Circulator: SHC	He circulator	"1) Provides 13.8 kg/s of He at 5.4 MPa, 2) Flow rate is controlled with by-pass flow. 3) Operating speed is 11000rpm."	All	Motor stops	Human error, I&C fails, motor overheats, off-site power loss	Loss of flow and test run	n/a	n/a
				All	Surging	Human error, I&C failure	Impeller fails	Flow and differential pressure indicators	Surge protection line provided
11	Secondary Loop He Purification System	This system has one subsystem: 1) He Purification		All	Leak	Mechanical damage	Personnel asphyxiation	Flow control valves and isolation valves	Personnel protective gear for any enclosed areas, facility designed per OSHA
11a	He Purification System	Economizer, Filters, Copper oxide reactor, cooler, molecular sieves, cold trap, He circulation pump	1) Removes impurities from circulating He, 2) 6.7 g/s He flow rate and 0 to 8 Mpa, 3) Purification level < 1 ppmV."	All	Carbon bed fire	Oxygen system fails	He loop contaminated	He Gas Composition subsystem; T monitors	Oxygen detector at carbon bed inlet
12	Secondary Loop Instrumentation & controls	The loop measured parameters are pressures (differential and gage), flow rates and temperatures to monitor each system and test section during the different operating modes.	(1) Gas composition is controlled by directing helium stream downstream of the circulator back to the main flow path after passing through the purification system; (2) System pressure is controlled (2 to 8 MPa) by two regulating valves on He Purification and Pressure Control inlet and outlet piping; (3) He flow rate is controlled by varying the by-pass flow rate of	All	No output	Sensor failure or loss of power	I&C system receives false input	Redundant sensors	Diverse sensors

S. No.	System / Component	Description	Function	Operating Mode	Failure Modes	Failure Cause	Failure Effect	Failure Detection	Recommendation / Remark
			the circulator."						
13	Secondary Loop High Temperature Piping	High temperature (>825°C) piping with internal insulation.	9 MPa design pressure, temperature [350 °C]; design temperature of the gas [980 °C].	All	Leak	Thermal mechanical stress	High temperature gas jet, test run failure, personnel asphyxiation	P & T monitors, oximeter	Facility barriers are required around high temperature/pressure areas, vent to roof
14	Secondary Loop Low Temperatures Piping	Low temperature (<450 °) piping with external insulation.	Design pressure of 9 Mpa at [450] °C. Contact temperature of [50] °C.	All	Leak	Thermal mechanical stress	High temperature gas jet, test run failure, personnel asphyxiation	P & T monitors, oximeter	Facility barriers are required around high temperature/pressure areas, vent to roof

11.0 CTF OPERATIONS

11.1 1 MWt Test Loop Operations

The 1 MWt test loop is designed to operate independently from the Large Test Loop. The CTF facility is assumed to provide the necessary utilities and support systems (Helium supply and storage system, Helium Purification System, cooling water, electrical power, and HVAC) and structures (helium confinement and personnel protection). The 1 MWt test loop was designed to provide a capability for tests of the compact IHX and Primary Loop Instrumentation documented in AREVA Document TDR-3001031-000, NGNP Technology Development Road Mapping Report [Reference 12.12]. The test loop includes additional flexibility to support qualification of the Helium Purification System and provides a flexible R&D platform to serve the needs of future HTGR development needs.

The 1 MWt test loop is based on the HELITE design [Reference 12.8]. The 1 MWt loop design is flexible and its test capabilities can be expanded as needed to support the test program. The transition to the primary and secondary loop configuration simulating the HTGR indirect steam cycle configuration and operating environment can be performed in stages (Appendix A, CTF Initial Requirements Manual). This approach allows early tests of Primary Loop Instrumentation (Appendix A, Configuration 1) and Compact IHX mock-ups, supporting the selection of the most appropriate design concept during NGNP conceptual design, before conducting more representative tests. The IHX mock-ups can be tested using a single helium loop if the helium is cooled and re-circulated in the secondary side of the IHX mock-up (Appendix A, Configuration 2). The two loop (primary and secondary) design configuration is required to test the compact IHX at representative environmental conditions (Appendix A, Configuration 3). Both loops have individual HPS systems to control the helium impurity concentrations at the levels specified in the Compact IHX test plans. The HPS systems are used to control the concentration of N2, CO, CO2, CH4, H2O, H2, O2, NO, NO2, carbon dust and He pressure. The secondary loop can be modified to operate with a mixed gas (Helium and Nitrogen or Argon) coolant.

The approach of testing the Compact IHX and Primary Loop Instrumentation using a single loop and adding equipment as needed to conduct more representative tests has several advantages. The first is that the NGNP design activity has not developed specifications for the primary or secondary helium coolant chemistry, which the test plans and HPS design should be based on. The second is that IHX testing with carbon dust in the primary loop will contaminate the loop, since there is no way to completely remove dust from the system once it has been introduced. Provisions have been made for adding a dedicated loop (piping, circulator, and high temperature heat exchanger) between the primary loop and the IHX. This loop would prevent contamination of the primary loop. The facility can accommodate this loop if the high and medium temperature test sections are removed during dust testing.

The 1MWt test loop is designed to allow independent control of the temperature in the high temperature and medium temperature test sections. The primary loop HT (high temperature) test section can be controlled between 850 °C and 1000 °C by varying the power to the electrical heaters. The secondary loop HT test section temperature is established by the IHX test module (a heater could be added if independent temperature control or independent operation of the primary and secondary loop was desired).The MT (medium temperature) test sections can be controlled between 300 ° and 500 °C by controlling the amount of heat removed by the high temperature water cooled heat exchanger (Appendix B, B.1.1, Configuration 1), or by adding gas from the circulator outlet line (before it enters the recuperator) if required to cool gas leaving the IHX test section in the primary loop (Appendix B, B.1.2, Configuration 2, B.1.3, Primary Loop, Configuration 3 and B.1.4, Secondary Loop Configuration 3). Each test section is designed to create the transient conditions (temperature, pressure, and flow rates) required by the test plans (Appendix B, B.1.5. Details of the test sections are shown in Appendix B on P&ID 02-9097035. Lower temperature (100 – 300 °) tests of the Primary Loop Instrumentation can be performed by lowering the heater control setting or by adding a lower temperature test section to the low temperature side of the primary loop.

The helium flow leaving the primary loop circulator is heated in the recuperator heat exchanger, then the helium is further heated in the First Stage and Second Stage Heaters until it reaches the required temperature at the HT test section. The gas either enters a high temperature water cooled heat exchanger (Appendix B, B.1.1 Configuration 1) or the IHX test section (Appendix B, B.1.2, Configuration 2 and B.1.3 Configuration 3), before it enters the MT test section. After going through this test section, the helium enters again into the recuperator heat exchanger, where the heat is transferred to the helium leaving the circulator. A water cooled heat exchanger cools the helium below the circulator inlet temperature limit. The primary loop has an additional line, not shown on the schematics, which can provide cooler gas, if needed, to meet test conditions in the MT test section. This line allows cold gas from the circulator side of the “figure-8” test loop to be mixed with the hot gas (from the IHX or HT Heat Exchanger) before it enters the MT test section. This line is shown on the primary loop P&ID diagram, AREVA Drawing 02-9097037, in Appendix B. The gas flow from the cold side is modulated by a control valve. By-pass and isolation valves are provided for all of the test sections. Connections are provided to connect to a dedicated loop for simulating dust contamination and performing special effects on the IHX (channel choking or plugging on the primary side).

The secondary loop is very similar to the primary loop, in a “figure-8” configuration, to perform Compact IHX mock-up testing in conditions representative of normal operation (pressure, temperature, helium gas chemistry). The secondary loop has an independent HPS to provide the capability of testing the IHX with representative helium chemistry in the primary and secondary loops. A simplified schematic of the secondary loop is shown in Appendix A, Figure 4. The P&ID diagram, AREVA Drawing 02-9097038, is in Appendix B.

The HT and MT test sections will be used to test Primary Loop Instrumentation. IHX test section will be used to test the IHX. The mechanical and piping design of the test section, but not the test mock-up, is described in Section 6.0.

The 1 MWt test loops are operated from a central control room. Section 6.5 describes the loop instrumentation and controls. Section 9.0 describes the control room instrumentation and control system and the data acquisition system. The test loop is a hazardous work area due to high temperatures and pressures, and helium. The preliminary hazards assessment is described in Section 10. Access to the test area should be controlled (confined space permit). The test loop area should not be occupied during testing. Test set-up, maintenance, and repairs should be planned and performed after review and approval by the designated site safety authority.

The operation of the auxiliary systems (including the helium purification system, helium inventory and pressure control system, heat rejection system, control instrumentation air system, and water treatment system) is described in INL/EXT-08-14132, Pre-Conceptual Facility Configuration Study of the High Temperature Gas-Cooled Reactor Component Test Facility, Revision 1 [Reference 12.16].

11.1.1 Loop Configurations

The 1 MWt test loop can be configured as follows:

Configuration 1 – Single Test Loop (with out IHX)

The primary loop has a “figure-8” configuration with a recuperator heat exchanger, which allows operating the circulator at low temperature. The functional schematic of the phase 1 loop is illustrated in Appendix B, B.1.1. The loop can be operated with the first stage heater alone for tests up to 850 °C or with both the first stage and second state heaters for temperatures up to 1000 °C. The HT and MT test sections are used for testing the Primary Loop Instrumentation. The Primary Loop Instrumentation tests require controlling the moisture level. The HPS is used for controlling helium chemistry (including moisture) and pressure.

Configuration 2 – Single Test Loop with IHX

Most tests of the compact IHX and Primary Loop Instrumentation can be performed using a single gas loop (Configuration 2) by changing the valve positions shown on AREVA Drawing 02-9097037 (Appendix B) from the positions used for the single loop configuration (Configuration 1). The functional schematic of this configuration is illustrated in Appendix B, B.1.2. In Configuration 2 helium flows from the IHX primary side outlet to the high temperature water cooled heat exchanger, then to the compact IHX secondary side inlet, and the gas leaving the compact IHX secondary side outlet flows to the primary loop MT test section.

Configuration 3 – Multi-Purpose (IHX, Instrumentation, other)

This configuration includes both the primary and secondary loops. Both loops have a "figure-8" configuration and independent HPS. The IHX test section is used to heat the secondary loop in this configuration, simulating the NGNP Indirect Steam Cycle configuration. The functional schematic of this test configuration is illustrated in Appendix B, B.1.3 and B.1.4. The HPS is used to control the helium chemistry and pressure. The electric heaters are used to control the temperature. The HT and MT test sections are used for testing the Primary Loop Instrumentation. The Primary Loop Instrumentation tests require controlling the moisture level. The Compact IHX tests require controlling the concentration of N2, CO, CO2, CH4, H2O, H2, O2, NO, NO2, carbon dust, helium pressure, and temperature in the primary loop. The secondary loop can be reconfigured to test alternate coolant gas mixtures (He, He:Ar, He:N_2) with representative chemical impurity concentrations.

11.1.2 Primary Loop Operating Sequence

Operations of the 1 MWt test loop depend of the configuration of the loop. In configuration 1, 2 and 3 the primary loop startup, testing and shutdown sequences are discussed below.

11.1.2.1 Start-up

a. Test preparation: review test plans and procedures; modify the test loop configuration (if required); install test components; inspect and repair test loop equipment; perform pre-test non-destructive examinations (NDE) of the equipment that will be tested; verify all work station set points and control functions (circulator performance curves, control logic, selector switches); verify that all instruments (flow meters, humidity sensors, pressure gauges and transducers, thermocouples, and indicators) and controllers are in calibration; verify that the computer and data acquisition system is ready; verify that there are adequate gas supplies; verify that the helium purification system (including chemical analytical equipment) heat rejection system, instrument air, and water treatment systems are mission ready; complete pre-operational check-lists, safety briefings, and staff briefings.

b. Establish test loop confinement and access controls.

c. Pressurize the test loop and verify leak tightness. Leak tightness can be tested by monitoring gas flow rates from the helium supply system or by isolating the helium supply system and monitoring the loop pressure.

d. Turn on auxiliaries. Cooling water flow rates should be based on the heat exchanger performance curves and expected conditions estimated from the process flow and heat balance (see Appendix B process flow diagrams and heat balances for nominal conditions for each loop configuration). The helium purification system gas supply and system flow rates should be based on the test plan and test procedures.

e. Turn on the gas circulator and adjust the motor speed to the rate required to achieve the mass flow rate specified in the test plan (circulator performance curve temperature algorithm can be programmed into the control logic).

f. Start-up the secondary loop required (IHX testing using Configuration 3).

g. Turn on the first stage heater and heat the circulating gas.

h. Turn on the second stage heater if required to meet test conditions.

i. Adjust the cooling water flow rates as required to meet test conditions.

j. Initiate the injection of chemical species, using the helium purification system, if required (IHX testing with impurities).

11.1.2.2 Testing

The operating conditions and durations will be defined in test plans and detailed test procedures. The preliminary test plans for the Compact IHX and Primary Loop Instrumentation are described in AREVA Document TDR-3001031-000, NGNP Technology Development Road Mapping Report [Reference 12.12]. That document shows the schedule for finalizing the test plans and procedures.

11.1.2.3 Shutdown

a. Turn off the electrical heaters
b. Turn off the gas circulators after the loop temperature drops below TBD.
c. Depressurize the system using the test loop pressure control and storage system (see AREVA Drawing 02-909707037 in Appendix B.) and the facility helium inventory and pressure control system [Reference 12.16].
d. Turn off the helium purification system chemical analyzer and oxygen supply.
e. Turn off the cooling water flow to the test loop heat exchangers.
f. Shut off electrical power to the test loop.
g. Shut down work stations and make a back-up record of data from data acquisition system.
h. Verify the oxygen concentration in the test loop operating area before allowing access for post test examination of test items or post test inspection, maintenance and repair of the test loop.

11.1.3 Secondary Loop Operations

When the 1 MWt test loop is in Configuration 2 the secondary loop is heated by the Compact IHX mock-up. The loop in this configuration is used to test the thermo-hydraulic performance of the IHX secondary side with representative coolant. This configuration also is used to measure the IHX heat transfer effectiveness with representative coolant on both the primary and secondary side. The secondary loop cannot be used with out an IHX. The secondary loop startup, testing and shutdown sequences are discussed below.

11.1.3.1 Start-up

a. Test preparation: review test plans and procedures; modify the test loop configuration (if required); install test components; inspect and repair test loop equipment; perform pre-test NDE of the equipment that will be tested; verify all work station set points and control functions (circulator performance curves, control logic, selector switches); verify that all instruments (flow meters, humidity sensors, pressure gauges and transducers, thermocouples, and indicators) and controllers are in calibration; verify that the computer and data acquisition system is ready; verify that there are adequate gas supplies; verify that the helium purification system (including chemical analytical equipment) heat rejection system, instrument air, and water treatment systems are mission ready; complete pre-operational check-lists and staff briefings.
b. Establish test loop confinement and access controls.
c. Pressurize the test loop and verify leak tightness. Leak tightness can be tested by monitoring gas flow rates from the helium supply system or by isolating the helium supply system and monitoring the loop pressure.
d. Turn on auxiliaries. Cooling water flow rates should be based on the heat exchanger performance curves and expected conditions estimated from the process flow and heat balance (see AREVA Drawing 02-9097043-A1-000, Process Flow Diagram Heat Balance for nominal conditions in Appendix B). The helium purification system gas supply and system flow rates should be based on the test plan and test procedures.
e. Turn on the gas circulator and adjust the motor speed to the rate required to achieve the mass flow rate specified in the test plan (circulator performance curve temperature algorithm can be programmed into the control logic).
f. Initiate the injection of chemical species, using the helium purification system, if required (IHX testing with impurities).

11.1.3.2 Testing

The operating conditions and durations will be defined in test plans and detailed test procedures. The preliminary test plans for the Compact IHX and Primary Loop Instrumentation are described in AREVA Document TDR-3001031-000, NGNP Technology Development Road Mapping Report [Reference 12.12]. That document shows the schedule for finalizing the test plans and procedures.

11.1.3.3 Shutdown

a. Turn off the electrical heaters
b. Turn off the gas circulators after the loop temperature drops below TBD.
c. Depressurize the system using the test loop pressure control and storage system (see AREVA Drawing 02-909707038 in Appendix B) and the facility helium inventory and pressure control system [Reference 12.16].
d. Turn off the helium purification system chemical analyzer and oxygen supply.

e. Turn off the cooling water flow to the test loop heat exchangers.
f. Shut off electrical power to the test loop.
g. Shut down work stations and make a back-up record of data from data acquisition system.
h. Verify the oxygen concentration in the test loop operating area before allowing access for post test examination of test items or post test inspection, maintenance and repair of the test loop.

11.1.4 1 MWt Test Loop Emergency Operations

The test loops are operated at high pressure and temperature. The preliminary hazards analysis and the preventative and mitigative safety features of the loop design are described in Section 10. The loop is designed with self-actuating pressure relief valves and rupture disks to prevent over pressurization. This applies to all three configurations.

Over pressurization or equipment failure, including failure of test equipment, would quickly fill the area around the test loop with helium and possibly create pressure waves and projectiles. That area should be an enclosed confined space with protective barriers. Emergency shutdown is performed from the control room. Personnel entry into the confined area for maintenance or repair should controlled (confined access permit). The facility should be designed with self contained breathing apparatus and oxygen detectors at the confined area egress and outside areas that are occupied during testing.

INL/EXT-08-14132, Pre-Conceptual Facility Configuration Study of the High Temperature Gas-Cooled Reactor Component Test Facility, Revision 1 describes the facility interfaces and preliminary safety analysis.

11.2 30 MWt Test Loop Operations

The 30 MWt test loop is designed to operate independently with the 1MWt Test Loop. The CTF facility is assumed to provide the necessary utilities and support systems (Helium supply and storage system, Helium Purification System, cooling water, electrical power, and HVAC) and structures (helium confinement and personnel protection). The 30 MWt test loop was designed to provide a test capability for tests of the full or engineering scale mock-ups of the components planned for the NGNP indirect steam cycle , which includes three heat transfer loops. The test loop includes additional flexibility to support testing of engineering scale hydrogen generation processes.

The 30 MWt test loop was based on the HENDEL and the KVK design [Reference 12.8].

The 30 MWt test loop is designed to allow independent control of 1 MWt test loop. The helium is heated in the First Stage and Second Stage Heaters until it reaches the required temperature at the IHX test section.

The secondary loop is very similar to the primary loop, to perform steam generator (SG) mock-up testing in conditions representative of normal operation (pressure, temperature, helium gas chemistry).

A simplified schematic and the P&ID diagram of 30 MWt test loop are shown in Appendix B.

The 30 MWt test loops are operated from a central control room. Section 7.5 describes the loop instrumentation and controls. Section 9.0 describes the control room instrumentation and control system and the data acquisition system. The test loop is a hazardous work area due to high temperatures and pressures, and helium. The preliminary hazards assessment is described in Section 10. Access to the test area should be controlled (confined space permit). The test loop area should not be occupied during testing. Test set-up, maintenance, and repairs should be planned and performed after review and approval by the designated site safety authority.

11.2.1 Loop Configurations

The 30 MWt test loop can be configured typically as follows:

- Configuration 1 – IHX, SG Operation at NGNP Operating Conditions

  The IHX and SG can be used to test the power conversion system for NGNP. Their test operation modes and heat balance is shown in Figure 7.1-10. In the primary helium system, the primary helium is transferred from the primary helium circulator (PHC) to the electrical heaters (EH1 and EH2) and is heated to 900°C. The IHX provides heat exchange and cools the primary helium down to 490°C. The helium is returned to the PHC and allowed to circulate within the primary helium system.

  In the secondary helium system the secondary helium is transferred from the secondary helium circulator (SHC) to the IHX to be heated at 825°C. The secondary helium cooled down to 405°C in the SG and is returned to the SHC. In the tertiary system, the feed water is pressurized by the feed water pump to 17.2MPa and heated to 282°C by the high pressure feed water heater before it is transferred to the SG. The steam evaporating region of the SG generates steam at 566°C. Once it goes out of the SG, the steam pressure and temperature are reduced to 3.7MPa and 362°C, respectively. The depressurized and cooled steam is transferred to the reheating region of SG for heating to 538°C. Once it goes out of the SG, the reheated steam is again cooled down and depressurized before it is condensed in the condenser and transferred to the condensate tank. The condensate water is pumped into the subcooler and then the demineralizer. The purified condensate water is heated at low pressure condensed water heater, dearated at the deaerator and returned to the feed water pump.

- Configuration 2 – Double Hot Gas Duct (DHGD) Operation

The system configuration and heat mass balance of the test operation are shown in Figure 7.1-11. The helium discharged from the PHC flows through the outer pipe to cool the inner pipe in the DHGD. Helium is then discharged from the outer line and transferred to the EH1 and EH2 for heating to 1000°C. The heated helium is then allowed to go through the DHGD inner pipe. The water coolers (WC1 and WC2) cool the helium to 422°C. The cooled helium returns into the PHC and circulates through primary helium system. The DHGD is replaceable to an isolation valve to test the valve for durability under 1000°C helium condition.

- Configuration 3 – 1000 ºC IHX Operation

The system configuration and heat mass balance of the test operation is shown in Figure 7.1-12. The operation involves exclusively the secondary helium system. The primary helium system and SG are not involved. Instead of the SG, the WC1 and WC2 are used as cooler in the secondary helium system. The DHD is, therefore, removed and a high temperature single line is installed to directly connect the IHX secondary outlet and WC2 inlet. In the primary helium system the primary helium is transported from the PHC to the EH1 and EH2, where the helium is heated to 1000°C before it is transferred to the IHX. The IHX provides heat exchange to cool the primary helium down to 422°C. It is returned to the PHC and allowed to circulate in the primary helium system. In the secondary helium system the secondary helium is transferred from the SHC to the IHX and heated to 925°C. The helium is then cooled down to 335°C in the WC2 and WC1. It is returned to the SHC and allowed to circulate in the secondary helium system.

- Configuration 4 – Transient test Operation

The design should be enable IHX to provide temperature transients ranging over +/- 200°C /min. The electric heaters cannot realize such a large helium temperature change in a minute. It was therefore decided to provide temperature transients by changing mixing ratio of hot and cold helium. Specifically, a mixing tank (MT) is set up at the EH2 outlet and a helium line and a control valve are set up between the MT and EH1 inlet to bypasses EH1 and EH2 and directly transport cold helium to the MT from PHC. The design allows the MT to mix the cold helium with the helium heated through EH1 and EH2. The bypass line control valve delivers a temperature transient of +200°C /min, as shown in Figure 7.1-5. Specifically, the valve is initially set to deliver a mixed helium flow at 800°C by blending a helium flow of at 428°C coming from the bypass line with another helium flow at 1000°C from EH2 and then the valve is gradually closed to reduce a 428°C helium flow, resulting in increased temperature of helium at the MT outlet. The mechanism allows the change in valve closing rate to adjust the temperature raising rate. Figure 7.1-6 shows how a temperature transient of -200°C /min is operated. The low-temperature helium flow to the MT is initially set at 0 while 1000°C helium alone is allowed to flow into the MT. Then, the bypass line control valve is gradually opened to deliver 428°C helium into the MT, resulting in temperature reduction of mixed helium at MT outlet. The mechanism again allows the change in valve opening rate to adjust temperature falling rate.

11.2.2 Primary Loop Operating Sequence

Operations of the 30 MWt test loop depend of the configuration of the loop. The primary loop startup, testing and shutdown sequences for configuration 1, 2, 3, and 4 are discussed below.

11.2.2.1 Start-up

a. Test preparation: review test plans and procedures; modify the test loop configuration (if required); install test components; inspect and repair test loop equipment; perform pre-test NDE of the equipment that will be tested; verify all work station set points and control functions (circulator performance curves, control logic, selector switches); verify that all instruments (flow meters, humidity sensors, pressure gauges and transducers, thermocouples, and indicators) and controllers are in calibration; verify that the data logger is ready; verify that there are adequate gas supplies; verify that the helium purification system (including helium sampling system), cooling water system and/ or pressurized water cooling system, instrument air, and water treatment systems are mission ready; complete pre-operational check-lists, safety briefings, and staff briefings.
b. Establish test loop confinement and access controls.
c. Pressurize the test loop and verify leak tightness. Leak tightness can be tested by monitoring gas flow rates from the helium supply system or by isolating the helium supply system and monitoring the loop pressure.
d. Turn on auxiliaries. Cooling water flow rates should be based on the heat exchanger performance curves and expected conditions estimated from the process flow and heat balance. The helium purification system gas supply and system flow rates should be based on the test plan and test procedures.
e. Turn on the gas circulator and adjust the bypass flow control valve to the rate required to achieve the mass flow rate specified in the test plan.
f. Start-up the secondary loop if required.
g. Turn on the first and second stage heater and heat the circulating gas to meet test conditions.
h. The impurities in the circulating gas should be limited under specified level (TBD) during heat up process in order to protect corrosion of graphite structure and heat resistance metals such as Hastelloy X, Inconel 617 or Incoloy 800H.

11.2.2.2 Testing

The operating conditions and durations will be defined in test plans and detailed test procedures. The preliminary test plans for the helical tube IHX are described in AREVA Document TDR-3001031-000, *NGNP Technology Development Road Mapping Report [Reference 12.12]*. That document shows the schedule for finalizing the test plans and procedures.

11.2.2.3 Shutdown

a. Turn off the electrical heaters
b. Turn off the gas circulators after the loop temperature drops below TBD.
c. Depressurize the system using the test loop pressure control and storage system.
d. Turn off the helium purification system chemical analyzer and oxygen supply.
e. Turn off the cooling water flow and/or pressurized water cooling flow to the test loop heat exchangers.
f. Shut off electrical power to the test loop.
g. Shut down work stations and make a back-up record of data from data acquisition system.
h. Verify the oxygen concentration in the test loop operating area before allowing access for post test examination of test items or post test inspection, maintenance and repair of the test loop.

11.2.3 Secondary Loop Operations

When the 30 MWt test loop is in Configuration 1and 4, the secondary loop is heated by the primary loop through IHX. The loop in this configuration is used to test the thermo-hydraulic performance of the IHX secondary side with representative coolant. This configuration also is used to measure the IHX heat transfer effectiveness with representative coolant on both the primary and secondary side. The secondary loop cannot be used without an IHX. The secondary loop startup, testing and shutdown sequences are discussed below.

11.2.3.1 Start-up

a. Test preparation: review test plans and procedures; modify the test loop configuration (if required); install test components; inspect and repair test loop equipment; perform pre-test NDE of the equipment that will be tested; verify all work station set points and control functions (circulator performance curves, control logic, selector switches); verify that all instruments (flow meters, humidity sensors, pressure gauges and transducers, thermocouples, and indicators) and controllers are in calibration; verify that the data logger is ready; verify that there are adequate gas supplies; verify that the helium purification system (including helium sampling system) cooling water system, instrument air, and water treatment systems are mission ready; complete pre-operational check-lists and staff briefings.
b. Establish test loop confinement and access controls.
c. Pressurize the test loop and verify leak tightness. Leak tightness can be tested by monitoring gas flow rates from the helium supply system or by isolating the helium supply system and monitoring the loop pressure.
d. Turn on auxiliaries. Cooling water flow rates should be based on the heat exchanger performance curves and expected conditions estimated from the process flow and heat

balance. The helium purification system gas supply and system flow rates should be based on the test plan and test procedures.

e. Turn on the gas circulator and adjust the bypass flow control valve to the rate required to achieve the mass flow rate specified in the test plan.
f. The impurities in the circulating gas should be limited under specified level (TBD) during heat up process in order to protect corrosion of graphite structure and heat resistance metals such as Hastelloy X , Inconel 617 or Incoloy 800H.

11.2.3.2 Testing

The operating conditions and durations will be defined in test plans and detailed test procedures. The preliminary test plans for the helical tube IHX are described in AREVA Document TDR-3001031-000, *NGNP Technology Development Road Mapping Report [Reference 12.12]*. That document shows the schedule for finalizing the test plans and procedures.

11.2.3.3 Shutdown

a. Turn off the gas circulators after the loop temperature drops below TBD.
b. Depressurize the system using the test loop pressure control and storage system.
c. Turn off the helium purification system chemical analyzer and oxygen supply.
d. Turn off the cooling water flow to the test loop heat exchangers.
e. Shut off electrical power to the test loop.
f. Shut down work stations and make a back-up record of data from data acquisition system.
g. Verify the oxygen concentration in the test loop operating area before allowing access for post test examination of test items or post test inspection, maintenance and repair of the test loop.

11.2.4 Tertiary Loop Operations

When the 30 MWt test loop is in Configuration 1and 4, the tertiary loop is heated by the secondary loop through the SG. The loop in this configuration is used to test the thermo-hydraulic performance of the SG secondary side with representative coolant. This configuration also is used to measure the SG heat transfer effectiveness with representative coolant on both the secondary and tertiary side. The tertiary loop cannot be used without an SG. The tertiary loop startup, testing and shutdown sequences are discussed below.

11.2.4.1 Start-up

a. Test preparation: review test plans and procedures; modify the test loop configuration (if required); install test components; inspect and repair test loop equipment; perform pre-test NDE of the equipment that will be tested; verify all work station set points and control functions (circulator performance curves, control logic, selector switches); verify that all instruments (flow meters, humidity sensors, pressure gauges and transducers, thermocouples, and indicators) and controllers are in calibration; verify that the data logger is ready; verify that there are adequate gas supplies; verify that cooling water system, instrument air, and water treatment systems etc. are mission ready; complete pre-operational check-lists and staff briefings.

b. Establish test loop confinement and access controls.
c. Turn on auxiliaries. Cooling water flow rates should be based on the heat exchanger performance curves and expected conditions estimated from the process flow and heat balance.
d. Turn on the feed water pump and adjust the flow rate and pressure by control systems which will be decided on NGNP Conceptual Design Stage in future.

11.2.4.2 Testing

The operating conditions and durations will be defined in test plans and detailed test procedures. The preliminary test plans for the helical tube IHX are described in AREVA Document TDR-30001031-000, *NGNP Technology Development Road Mapping Report*. That document shows the schedule for finalizing the test plans and procedures.

11.2.4.3 Shutdown

a. Turn off the feed water pump after the loop temperature and pressure drops below TBD.
b. Turn off the cooling water flow to the test loop heat exchangers.
c. Shut off electrical power to the test loop.
d. Shut down work stations and make a back-up record of data from data acquisition system.

11.2.5 30 MWt Test Loop Emergency Operations

The test loops are operated at high pressure and temperature. The preliminary hazards analysis and the preventative and mitigative safety features of the loop design are described in Section 10. The loop is designed with self-actuating pressure relief valves and rupture disks to prevent over pressurization. This applies to all configurations.

Over pressurization or equipment failure, including failure of test equipment, would quickly fill the area around the test loop with helium and possibly create pressure waves and projectiles. That area should be an enclosed confined space with protective barriers. Emergency shutdown is performed from the control room. Personnel entry into the confined area for maintenance or repair should be controlled (confined access permit). The facility should be designed with self contained breathing apparatus and oxygen detectors at the confined area egress and outside areas that are occupied during testing.

INL/EXT-08-14132, *Pre-Conceptual Facility Configuration Study of the High Temperature Gas-Cooled Reactor Component Test Facility*, Revision 1 [Reference 12.16] describes the facility interfaces and preliminary safety analysis.

12.0 REFERENCES

12.1 INL/MIS-08-14156, High Level Requirements, High Temperature Gas Reactor Component Test Facility

12.2 INL/EXT-08-14150, Technical and Functional Requirements, High Temperature Gas Reactor Component Test Facility

12.3 INL/EXT-07-13146, High Temperature Gas Reactor Component Test Facility

12.4 INL/EXT-06-116648, Conceptual Design for a High Temperature Gas Loop Test Facility

12.5 INL/EXT-07-12967, Rev 01, Next Generation Nuclear Plant Pre-conceptual Design Report

12.6 AREVA 12-9051191-001– NGNP and Hydrogen Production Pre-conceptual Design Studies Report

12.7 AREVA 12-9072397-000 – High Temperature Gas Cooled Reactor Test Facility - Mission Needs and Justification Study

12.8 AREVA 12-9076931-000 – NGNP Component Test Facility – Conceptual Configuration, Cost and Schedule Estimate

12.9 INL/EXT-08-14052 – Site Selection Study for the High Temperature Gas-Cooled Reactor Component Test Facility

12.10 Department of Energy Order, DOE O 413.3A, Program and project Management for the Acquisition of Capital Assets

12.11 ASME NQA-1-2000, “Quality Assurance Requirements for Nuclear Facility Applications”

12.12 NGNP Technology Development Road Mapping Report, AREVA FEDERAL SERVICES Document TDR-3001031-000

12.13 AREVA 51-9096878-000, HTGR CTF Pre-Conceptual Design System Requirements Manual

12.14 NGNP CDS CTF Project QA Plan, AREVA Federal Services Document QA-3000798-002

12.15 INL/EXT-08-14152 Rev 1, Pre-Conceptual Facility Configuration Study of the High Temperature Gas-Cooled Reactor Test Facility

12.16 INL/EXT-08-14132, Pre-Conceptual Facility Configuration Study of the High Temperature Gas-Cooled Reactor Component Test Facility, Revision 1

12.17 AREVA 51-9072396-000, NGNP Conceptual Design Studies Baseline Document for Indirect Steam Cycle Configuration

APPENDIX A: CTF INITIAL SYSTEM REQUIREMENTS MANUAL (51-9096878-001)

20004-015 (09/30/2008)

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HTGR CTF Preconceptual System Requirements Manual

Safety Related? ☐ YES ☒ NO

Does this document contain assumptions requiring verification? ☐ YES ☒ NO

Signature Block

Name and Title/Discipline	Signature	P/LP, R/LR, A/A-CRF	Date	Pages/Sections Prepared/Reviewed/ Approved or Comments
Robert D. Zimmerman, System Engineering	R.D. Zimmerman	P	Dec 15, 2008	All
W.J. DeCooman, Supervisory Engineer	W.J. DeCooman	R	Dec. 15, 2008	All
F. Shahrokhi, Advisory Engineer	F. Shahrokhi	A	Dec 15, 2008	All

Note: P/LP designates Preparer (P), Lead Preparer (LP)
R/LR designates Reviewer (R), Lead Reviewer (LR)
A/A-CRF designates Approver (A), Approver of Customer Requested Format A-CRF

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HTGR CTF Preconceptual System Requirements Manual

Record of Revision

Revision No.	Date	Pages/Sections/ Paragraphs Changed	Brief Description / Change Authorization
000	November 2008	All	Initial issue
001	December 2008	Section 2, 4.2.1 and 5.	Added design code to 4.2.1. Removed brackets from point design values in 5. Deleted discussion of brackets in 2.

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1) 12-9076325-001, NGNP - IHX AND SECONDARY HEAT TRANSPORT LOOP ALTERNATIVES
2) 51-9072396-001, NGNP Conceptual Design Studies Baseline document for Indirect Steam Cycle Configuration
3) TDR-3001031-000, NGNP Technology Development Road Mapping Report
4) INL/EXT-08-14150 Rev. 0, High Temperature Gas-Cooled Reactor (HTGR) Component Test Facility (CTF) Technical and Functional Requirements

1. PURPOSE

This document provides technical requirements for the Next Generation Nuclear Plants (NGNP) High Temperature Gas-Cooled Reactor (HTGR) Component Test Facility (CTF). This document is prepared as an Engineering Information Record (EIR) under AREVA procedure 0412-59, Engineering Technical Documents. As such, it contains facility functional and operating requirements and design parameters necessary to guide the pre-conceptual design being conducted by the AREVA CTF design team.

The system requirements document consists of five parts. Section 2.0 documents the methodology and assumptions. Section 3.0 defines the CTF test loops' functional and operational requirements are defined. Sections 4.0 documents the design requirements and Section 5.0 facility point design parameters are provided representing the steady state and transient plant conditions for the low power (1 MWt) and high power (30 MWt) test loops.

The system requirements document is created for use by the entire AREVA CTF design team as the latest agreed upon listing of facility design parameters, configuration, operation and performance. The contents of this document guides further test facility design.

The mission needs of the CTF is defined as a facility that can simulate NGNP HTGR plant thermal and fluid dynamic conditions in test loops that provide representative plant conditions in terms of temperature, pressure, fluid flow and chemical environment. This test capability is necessary to support the selection of preferred design options for the first of a kind NGNP HTGR and for the very high temperature process heat HTGR. The mission needs include development, testing, and demonstration of critical systems, structures and components (SSCs). These tests will be used for qualification of NGNP HTGR components and ultimately for subsequent commercial HTGR component testing applications.

The development needs and test conditions are documented in a separate Technology Development Road Mapping (TDRM) and Test Planning (TP) activities which defines the test conditions and specifications. The CTF test loops have to be designed with sufficient test loop flexibility to support changing test equipment and capable of supplying high temperature process heat to the Hydrogen Production pilot plant. The 1 MWt and 30 MWt test loops must be capable of operating independently.

The test mission will spread out over time, from very short term preliminary tests for selecting options for the design of components during the NGNP HTGR conceptual design phase to component qualification and later to test needs in case of operational problems / troubleshooting on NGNP or in support of future commercial plants.

Some of the components and technologies of the test loop will not be "off-the-shelf" items and will require special developmental tests before finalizing their design and qualifying them for operation in the test loop. The TDRM test plans define which tests need to be performed in the CTF and which might be addressed in other facilities that already exist or that can be developed within a short delay.

2. METHODOLOGY AND ASSUMPTIONS

The design requirements in this document were developed from the *High Temperature Gas-Cooled Reactor (HTGR) Component Test Facility (CTF) Technical and Functional Requirements* (Reference 4)

2. METHODOLOGY AND ASSUMPTIONS

The design requirements in this document were developed from the *High Temperature Gas-Cooled Reactor (HTGR) Component Test Facility (CTF) Technical and Functional Requirements* (Reference 4) and the configuration and test conditions identified in the Technology Development Road Maps for the NGNP HTGR (Reference 3) for testing at the CTF. The Technology Development Roadmaps identified the critical systems and components, which required research and development testing and identified where those tests should be performed. The test loop configurations and design conditions identified in the Technology Development Road Maps are based on the NGNP HTGR indirect steam cycle configuration (Reference 1 and 2). The design information in Section 5 represents the best estimate of test loop configurations and "Point Design" parameters required for those test. It includes multiple test configurations to support those tests and parameter ranges that cover the full range of test conditions to provide a capability for testing the direct steam cycle prismatic block HTGR and the pebble bed HTGR heat transfer loops. The requirements in this document include the functional and operating requirements, system requirements, and design requirements required to support those tests. The design parameters are for information only.

The data being provided here are provisional and are intended for use and reference by the AREVA CTF design team. Data provided in this document shall be used as follows:

- The design team members that are involved in designing test facility systems, structures, and components and establishing design parameters and configuration should consider the data in this document as the initial estimates or the starting point for the design.
- The design team members that are not directly involved with the development of design features or establishing design parameters should use the data as the best data available at the time this document is issued.
- Others may use the data for information only.

This document was prepared and issued by the System Integration function with concurrence from the NGNP Project Engineer.

Note – In Section 5 Tables, all values are best estimates and are subject to change. Please advise the NGNP System Integration function if there is any difficulty complying with the information provided in this document.

The HTGR Component Test Facility project is in pre-conceptual design phase. The information in this document will be validated by formal design calculations in this and subsequent phases of the facility design. As the design progresses and references become available the design parameters in the system requirements document will be updated with revised values and references to engineering calculations.

3. FUNCTIONAL AND OPERATIONAL REQUIREMENTS

The High Temperature Gas-Cooled Reactor component test facility consists of two independent test loops. The facility provides a component test capability for the high temperature gas cooled reactors. The functional and operational requirements for the CTF include: 1) supporting the technology development plans for the NGNP HTGR indirect steam cycle design, 2) providing flexibility to test SSCs for other NGNP HTGR reactor configurations, and 3) providing high temperature helium for future engineering tests of the hydrogen production process. The CTF includes two test loops. A low powered test loop that simulates the primary and secondary loops of the NGNP HTGR indirect steam cycle design and a higher powered test loop that provides full height test configuration for NGNP HTGR heat exchanger and steam generator and capability for testing core flow conditions, control rod drives, and other reactor components.

3.1 INL Functional Requirements

The following functional requirements are from INL/EXT-08-14150 Rev. 0, High Temperature Gas-Cooled Reactor (HTGR) Component Test Facility (CTF) Technical and Functional Requirements (Reference 4). The assigned requirement identification number is identified as INL XXXX, and the assigned ID number is the same as the section number in the source document. This approach was chosen to provide traceability of the flow down of requirements into this document.

3.1.1 Enable NGNP primary loop component tests with consideration of test scales, types, scenarios, components, heat transfer (HT) gas environment, and impurity control. (INL 3.1.3.1)

The CTF shall provide helium (i.e., the NGNP primary loop coolant) at the representative or scaled pressures, temperatures (including temperature transient rate), mass flow rates, energies, and purity (impurity controls) anticipated for the primary loop.

3.1.2 Enable NGNP secondary loop component tests with consideration of test scales, types, scenarios, components, high-temperature gas environment, and impurity control. (INL 3.1.3.2)

The CTF shall provide high-temperature working fluids- simulating the conditions of the NGNP secondary loop – at the representative or scaled pressures, temperatures and temperature transients, mass flow rates, energies, and purity or impurities necessary to support the range and scales of tests identified for development of anticipated NGNP components and subsequent HTGR user-facility component tests.

The primary heat transfer capability (PHTC) and the secondary heat transfer capability (SHTC) need to interface with each other to perform IHX testing.

3.1.3 Enable tertiary/process heat applications component test with consideration of test scales, types, and scenarios; components; HT gas environment; and impurity control. (INL 3.1.3.3)

The tertiary heat transfer capability (THTC) shall include a minimum of one test station capable of accepting national hydrogen initiative (NHI) components or processes measuring up to approximately

40 meters high (Sulfur-Iodine [S-I] cycle). The THTC needs the capability to accommodate different heat transfer fluids and heat exchanger designs.

The THTC shall have the capability to collect and remove unwanted gases (e.g., oxidizer emissions, fugitive emissions, flare emissions, other emergency releases) from the tests, as well as the analytical laboratory capability necessary to support NHI processes and components testing.

3.1.4 Enable testing of scaled models of the NGNP reactor vessel and associated components/systems (INL 3.1.3.4) – no testing is planned (TDR-3001031-000, NGNP Technology Development Road Mapping Report)

3.1.5 Enable full-scale circulator testing capability (INL 3.1.3.5) – no testing is planned (TDR-3001031-000, NGNP Technology Development Road Mapping Report)

3.1.6 Provide off-line trouble shooting of component and system problems (INL 3.1.3.6)

3.1.7 Enable coolant and heat transfer fluid tests (INL 3.1.3.7)

3.1.8 Enable direct-cycle power conversion component testing capability (INL 3.1.3.8) – no testing is planned (TDR-3001031-000, NGNP Technology Development Road Mapping Report)

3.1.9 Equip areas for conducting instrumentation testing, qualification, and calibration (INL 3.1.3.9)

3.1.10 Enable test data collection, processing, recording, storage, transmission, and archiving capability (INL 3.1.3.12)

3.1.11 Enable vibration and seismic testing capability – HT fluid conditions (INL 3.1.3.19)

3.1.12 Enable materials testing capability – HT fluid conditions (INL 3.1.3.20)

3.1.13 Enable development and qualification capabilities (INL 3.1.3.22)

The CTF needs to enable the development and qualification capabilities including various test scales, types, scenarios, components, and HT fluid conditions.

3.2 Low Power Test Loop

The low power test loop (CTF-1) shall be designed for conducting tests for the following applications [AREVA requirement number CTF GEN-001] (Note: see Section 4):

- Thermal hydraulic, material, and design testing of the plate IHX and provisions for mock-up testing of other components under representative operating conditions
- Validation and qualification of the Helium Purification System design
- Provide a basis for final recommendations on which compact IHX concept should be selected
- Qualification testing of candidate materials
- Qualification of Components for the high power test loop
- Qualification of HTR System Analysis Codes

The design of this test loop is tailored to the needs of the NGNP HTGR R&D during the preliminary and final design phases. The system consists of primary and a secondary high temperature gas test facility with a figure eight configuration where gas circulator is in the low temperature part of the loop.

3.3 High Power Test Loop

The high powered test loop (CTF-2) shall be designed with higher flow and thermal capacity for the following applications [AREVA requirement number CTF-GEN-002] (Note: see Section 4):

- Accommodates full or partial mock-ups of the components planned for the NGNP HTGR indirect steam cycle, which includes three heat transfer loops
- Provide core flow rates conditions and power levels needed for core component design verification and code qualification
    - Core lower plenum hot streaks (hot channel conditions)
    - Mixing of hot streaks in the lower plenum and hot duct
    - Hot plumes in the upper plenum during pressurized conduction cooldown
    - Bypass flow characterization
- IHX (tubular style)
- Hot Gas Duct (HD)
- Coaxial double pipe mock up (CHD)
- Full-scale hot valves
- Steam Generator (SG) mock up
- Piping to major components in the tertiary loop.
- Testing of the SG system.
- Support engineering scale hydrogen generation processes
    - High temperature process heat exchanger
    - Hydrogen plant interface dynamics assessment
    - Hydrogen processes load rejection tests

The flow and power specification of the higher powered test loop shall be tailored to the needs of the NGNP HTGR and the hydrogen production process components' qualification and validation of codes and methods during the final design phase. [AREVA requirement number CTF-GEN 003] (Note: see Section 4)

3.4 Safety and Operability Requirements

INL/EXT-08-14150 Rev. 0, High Temperature Gas-Cooled Reactor Component Test Facility Technical and Functional Requirements, Section 3.3.10.2 requires that the CTF design ensures protection of its occupants, equipment, components, and materials safety (test-adjacent areas) in the event of an operations, component, or integrated test failure.

3.4.1 Provide preventative and/or mitigative safety measures for the test loops (INL 3.3.10.2) :

3.4.2 All industrial hazards associated with the operation of high temperature and high pressure Helium equipment in an enclosed environment shall be identified and positive preventive or mitigation measure included in the design.

3.4.2.1 Environmental Hazards (heat) (INL 3.3.2)

3.4.2.2 Electromagnetic Hazards (INL 3.3.6)

3.4.2.3 Physical/Chemical Hazards (INL 3.3.7)

3.4.3 Recommendations for facility safety features and interface requirements shall be documented

4. DESIGN REQUIREMENTS

This section identifies both customer requirements from INL/EXT-08-14150 Rev. 0, High Temperature Gas-Cooled Reactor (HTGR) Component Test Facility (CTF) Technical and Functional Requirements (Reference 4) and requirement developed by AREVA. Each requirement is assigned a discrete requirement number as follows:

INL XXX for customer requirements
CTF-GEN XXX for general requirements
CTF-CIVIL XXX for structural and civil requirements
CTF-MECH XXX for mechanical requirements
CTF-ELEC XXX for electrical requirements
CTF-I&C XXX for instrumentation and control requirements

4.1 System Requirements

4.1.1 In-service Reliability (INL 4.1)

The CTF shall provide and in-service reliability greater than TBD. The in-service reliability plan shall be developed during design.

4.1.2 Maintainability (INL 4.2)

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

4.1.3 Design Life (INL 4.3)

The CTF shall have a design life of 40 years, the standard for DOE capital assets.

4.1.4 Availability of Materials (INL 4.4)

To meet NGNP program needs, the availability of materials shall be addressed in the engineering design and procurement of the facility, furnishings, tools, and equipment needs.

4.1.5 Codification (INL 4.6)

The design, procurement, and construction of the facility shall adhere to applicable local, state, and federal building codes.

4.1.6 Flexibility [AREVA requirement number CTF-GEN 004]

The CTF test loops shall be designed with optimum flexibility.

4.2 Civil and Structural Design Requirements

4.2.1 The loop shall be designed to maintain its structural integrity for the maximum acceleration caused by IBC 2006, Occupancy Category II [AREVA requirement number CTF-Civil 001]

4.3 Control and Instrumentation Requirements

4.3.1 All control loops, process monitoring points, and data logging shall be performed by an industrial grade distributed digital control and monitoring system with ample capacity. [AREVA requirement number CTF-I&C 001]

4.3.2 The loop operation and control shall be conducted from a central control room area away from any potential loop hazards. [AREVA requirement number CTF-I&C 002]

4.3.3 The data logging computer system shall provide sufficient number of data points for 1MWt and 30MWt loops test sections. [AREVA requirement number CTF-I&C 002)

4.3.4 Software Verification and Validation (V&V) shall be performed. [AREVA requirement number CTF-I&C 003]

4.3.5 CTF shall provide equipment to enable test data collection, processing, recording, transmission, storage and archiving capability. [AREVA requirement number CTF-I&C 004]

4.3.6 CTF shall provide instrumentation to measure and record pressures, temperatures, temperature transients and mass flow rates. [AREVA requirement number CTF-I&C 005]

4.3.7 Temperatures shall be measured at the inlet and outlet of each cooler, heat exchanger and recuperator. [AREVA requirement number CTF-I&C 006]

4.3.8 Circulator speed control shall be used to control He flow rate in the loop. The circulator speed shall be measured and recorded. [AREVA requirement number CTF-I&C 007]

4.3.9 The control loops shall provide automatic shutdown protection against dangerous pressures, temperatures, and flows. [AREVA requirement number CTF-I&C 008]

4.3.10 Oxygen/Helium shall be monitored in the air around the loops for personal safety. [AREVA requirement number CTF-I&C 009]

4.3.11 Codes and Standards

DOE STD 1039	Guide to Good Practices for Control of Equipment and System Status
ISA S5.1	Instrumentation Symbols and Identification
ISA 5.3	Graphic Symbols for Distributed Control/Shared Display Instrumentation, Logic and Computer Systems
ISA 5.4	Instrument Loop Diagrams

ISA 5.5	Graphic Symbols for Process Displays
IEEE-1050	IEEE Guide for Instrumentation and Control Equipment Grounding in Generating Stations
IEEE-1046	Application Guide for Distributed Digital Control and Monitoring for Power Plant
UL-1998	UL Standard for Safety for Software in Programmable Components
IEC 61508	Functional Safety – Safety Related Systems
IEC 6000-3	Electromagnetic Compatibility (EMC) – Part 3, Limits
IEC 6000-4	Electromagnetic Compatibility (EMC) – Part 4, Testing and Measurement Techniques
IEC 6000-6	Electromagnetic Compatibility (EMC) – Part 6, Generic Standards
ANSI B11-19	American National Standard for Machine Tools – Safeguarding when referenced by the other B11 Machine Tool Safety Standards – Performance Criteria for design, construction, care, and operation
IEEE-C37.96	IEEE Guide for AC Motor Protection
UL-1998-1998	UL Standard for Safety for Software in Programmable Components
NEMA	ICS Standards
IEEE-1046	Application Guide for Safety for Software in Programmable Components
IEEE-1100	Recommended Practice for Powering and Grounding Sensitive Electron Equipment – Emerald Book
IEEE-1012	Software Verification and Validation
IEEE-1042	Guide to Software Configuration Management
ANSI/HFS 100	American National Standard for Human Factors Engineering of Visual Display Terminal Workstations

4.4 Electrical Requirements

4.4.1 The CTF external power source shall be from the local electric utility. A 230 kv line is required from the Antelope substation to a new substation next to the CTF facility. [AREVA requirement number CTF-ELEC 001]

4.4.2 The CTF substation shall have one 230 kv to 13.8 kv, 55 MVA step-down transformer. [AREVA requirement number CTF-ELEC 002]

4.4.2.1 The smaller capacity 13.8 kv secondary transformer shall run two underground lines to two pad mounted oil filled 13.8 kv to 480 VAC step-down transformers. Two of these pad mounted transformers shall be rated at 2 MVA and supply the 1 MW test loop consisting of primary and secondary loop circulators, instrumentation panel board, and other loads supporting the loop. One 3 MVA rated transformer shall furnish power to the generic facility loads (i.e. lighting and appliance panels, overhead cranes, etc.).

4.4.2.2 The larger capacity 13.8 kv secondary transformer (rated about 55 MVA) shall supply a 15 kv rated medium voltage load-center inside the facility to supply the 30 MW test loop. From this medium voltage load-center other lower voltage loads associated with the 30 MW CTF can be accommodated with additional step-down transformers and load-centers installed in the facility.

4.4.3 Backup power for emergency cool-down of the loops, emergency facility lighting and the site computer and data logging system shall be provided by an onsite diesel generator set. [AREVA requirement number CTF-ELEC 002]

Note: The supply of local utility power, substation, transformers and onsite backup power source is not in the scope of the loop design.

4.4.4 Codes and Standards

29 CFR 1910 Sub part S	Occupational Safety and Health Standards, Electrical
NFPA 70-2008	National Electrical Code (NEC)
ANSI C80.1	Rigid Steel Conduit – Zinc Coated (GRC)
ANSI/IEEE C2-2007	National Electrical Safety Code (NESC)
IEEE 1202	Standard for Flame Testing of Cables for Use in Cable Tray in Industrial and Commercial Occupancies
IEEE 141-1993	IEEE Recommended Practice for Electric Power Distribution for Industrial Plants
IEEE 242-2001	IEEE Recommended Practice for Protection and Coordination of Industrial and Commercial Power Systems
IEEE 446-1995	IEEE Recommended Practice for Emergency and Standby Power Systems for Industrial and Commercial Applications
IEEE 142-1991	IEEE Recommended Practice for Grounding of Industrial and Commercial Power Systems
IEEE 112	Test procedure for Poly-phase Induction Motors and Generators

IEEE 519-1992	Recommended Practices and Requirements for Harmonic Control in Electric Power Systems.
IEEE C57.12.00 2000	General Requirements for liquid-Immersed Distribution, Power and Regulating Transformers
IEEE C57.12.26 1992	Pad-mounted, Compartmental-type, Self-cooled, Three-phase Distribution Transformers for Use with Separable Insulated High-voltage Connectors
IEEE C57.90 1992	Standard Test Code for Liquid-Immersed Distribution, Power, and Regulating Transformers
NEMA ICS-1	Industrial Control and Systems General Requirements
NEMA RN1	Polyvinyl Chloride (PVC) Externally Coated Galvanized Rigid Steel Conduit and Intermediate Metallic Conduit
NEMA MG 1-1998	Motors and Generators
NEMA MG-2	Safety Standard for Construction and Guide for Selection, Installation, and Use of Electric Motors
NEMA WC 55	Instrumentation Cables and Thermocouple Wire – ICEA S-82-552
NEMA WC 57	Standard for Control Cables – ICEA S-73-532
NEMA WC 70	Non-shield Power Cables Rated 2000 Volts or Less for the Distribution of Electrical Energy – ICEA S-95-658
NFPA 262	Standard Method of Test for Flame Travel and Smoke of Wires and Cables for Use in Air-Handling Spaces
NEMA ICS 7 2000	Industrial Control and Systems: Adjustable Speed Drives
NEMA ICS 7.1 2001	Safety Standards for Construction and Guide for Selection, Installation, and Operation of Adjustable Speed Drive Systems

NEMA ICS 16 2001	Industrial Control and Systems: Motion/Position Control Motors, Controls, and Feedback Devices
UL 6	Electrical Rigid Metal Conduit – Steel
UL 6A	Electrical Rigid Metal Conduit – Aluminum, Red Brass, and Stainless Steel
UL 13	Power-Limited Circuit Cables
UL 67	Panelboards
UL 44	Thermoset Insulated Wires and Cables
UL 50	Enclosures for Electrical Equipment
UL 360	Liquid Tight Flexible Steel Conduit
UL 489	Molded-Case Circuit Breakers, Molded-Case Switches, and Circuit Breaker Enclosures
UL 845	Motor Control Centers
UL 508	Industrial Control Equipment
UL 508A	Industrial Control Panels
UL-508C	Power Conversion Equipment
UL 514B	Conduit, Tubing, and Cable Fittings
UL 1008	Transfer Switch Equipment
UL 1053	Ground-Fault Sensing and Relaying Equipment
UL 1581	Electrical Wires, Cables, and Flexible Cords
UL 1666	Safety Test for Flame Propagation Height of Electrical and Optical-Fiber Cables Installed Vertically in Shafts
UL 2250	Instrumentation Tray Cable

4.5 Mechanical Requirements

4.5.1 The Small and Large Test Loop pressure boundaries shall be designed for the maximum pressure, temperature, and flowrate. [AREVA requirement number CTF-MECH 001]

Codes and Standards:

10 CFR 434	Energy Conservation Voluntary Performance Standards for New Buildings; Mandatory for Federal Buildings
ASME Sec. VIII	Pressure Vessels
ASME B31.3	Process Piping
ASME B31.9	Building Services Piping
ASME/ANSI B16.5	Pipe Flanges and Flanged Fittings
ASME/ANSI B16.20	Metallic Gaskets for Pipe Flanges-Ring-Joint, Spiral-Wound, and Jacketed
ASME/ANSI B16.25	Butt Welded Ends
ASME/ANSI B16.34	Valves – Flanged, Threaded, and Welding End
ASME/ANSI B16.47	Large Diameter Steel Flanges: NPS 26 through NPS 60
DOE O 430.2A	Department Energy and Utilities
IMC	International Mechanical Code

4.6 CTF Heat Sink Requirements

The CTF test loops shall reject excess heat into a plant circulating cooling water (CCW) system with a supply temperature of ≤ 40 °C. [AREVA requirement number CTF-GEN 005]

Provision for piping and distribution layout of the CCW system and the downstream cooling towers or cooling ponds are not in the scope of this work.

4.7 Dimensional Requirements

The test loop design shall be flexible and have provision for a variety of test pieces. Provisions for test loop alteration and adjustment shall be provided. The high power test loop shall accommodate a large full length (20 to 25 meters) heat exchanger test section. [AREVA requirement number CTF-GEN 006]

Note: The test sections for the low power test loop are generally small, two to four meters in length.

5. DESIGN PARAMETERS

5.1 Component Test Facility Lower Power (1MWt) Loop – Point Design

The facility Point Design parameters are presented for information. These parameters represent the expected range of design and operating conditions of the test loops. This information is based on the preliminary test plans in the NGNP HTGR Technology Development Road Mapping Report (Reference 3).

Description	Nominal	Maximum
CTF 1 MW Test Loop–		
Primary Loop – Single Test Loop Configuration (Configuration 1) Figure 1		
Gas	Helium	
Design Power (electric heater)	1.0 MWt	1.5 MWt
Loop Design –	Recuperated design (figure eight design)	
Pressure	4 to 8 MPa	10 MPa
Test Section Pressure Loss (depressurization)	3 MPa	
Loop Pressure Loss (depressurization event)	7.5MPa	
Circulator Compression Ratio	1.2	
Primary Loop First stage heater (Electric)		
Power	1.0 MW	
Flow	0.04-0.4 kg/s	0.4 kg/s
Temperature rise	400 to 850 °C	
Primary Loop High temperature heater (Electric)	0.4 MW	
Flow	0.04 – 0.4 kg/s	0.4 kg/s
Temperature rise	850 to 1000°C	
Primary Loop Recuperator		
Number of units	1	
High Temperature Side (highest/lowest)	500 to 120°C	
Low Temperature Side (highest/lowest)	150 to 420°C	
Number of Water Cooled Heat Exchangers	1	2
Primary Loop Low Temperature Heat Exchanger		
Tin (maximum) – Tout	200 -50°C	
High Temperature Heat Exchanger (used as part of the primary loop test configuration when an IHX is not being tested)		
Tin – Tout	1000 – 500°C	Configuration 1
Primary Test Loop Gas Circulator		
Number of units	1	
Fluid	Helium	
Flow	0.04 to 0.4 kg/s	1.0 kg/s
IHX Test Unit (Heat Transfer to secondary Loop)		
Number of test units installed in loop	0 for Configuration 1	1 for Configuration 2

Description	Nominal	Maximum
Primary Loop He Purification and Pressure Control System		
He Purification System		
He Gas Composition (analyzers)		
He Inventory & Pressure Control (HPC)		
Pressure Relief System	PORV And SRV	
Helium Filter	Two (In-line)	
Helium Supply and Pressure Control	External Tanks	
Primary Loop – Single Loop with IHX (Configuration 2) Figure 2		
Loop Design –	Single Test Loop	
Gas	He	
Mass Flow rate	0.04 to 0.4 kg/s	
Temperature Range	1000 °C to 50 °C	
Maximum Pressure	5.0 MPa	10 MPa
Power transfer (IHX)	From primary loop (1 MWt)	
Number of Recuperators	1	
Number of Circulator	1	
Circulator Flow Rate	0.04 - 0.4 kg/s	
Number of Water Cooled Heat Exchangers	2	
Low Temperature Heat Exchangers	1	
Tin (maximum) – Tout	200 – 50 °C	
High Temperature Heat Exchangers	1	
Tin (maximum) – Tout	900 – 470 °C	900 – 500 °C
Primary Loop – with IHX and Secondary Loop (Configuration 3) Figure 3		
Number of Water Coolers	1	1
Primary Loop Low Temperature Heat Exchanger		
Tin (maximum) – Tout	200 -50°C	
(High Temperature Heat Exchanger used as part of the secondary loop)		
Secondary Loop (Configuration 3) Figure 4		
Loop Design –	Recuperated design (figure eight design)	
Gas	He	
Mass Flow rate	0.04-0.4 kg/s	0.4 kg/s
Maximum Temperature	850 °C	
Maximum Pressure	5.5 MPa	10 MPa
Power transfer (IHX)	From primary	

Description	Nominal	Maximum
	loop (1 MWt)	
Number of Recuperators	1	
Number of Circulators	1	
Circulator Flow Rate	0.04-0.4 kg/s	1.0 kg/s
Number of Water Cooled Heat Exchangers	2	3
High Temperature Heat Exchanger (configured for testing the IHX)	1	1
Medium Temperature Heat Exchanger (controls IHX secondary inlet temperature)	1	1
Secondary Loop Low Temperature Heat Exchanger	1	1
Secondary Helium/Gas Supply and Purification System		
Primary loop (He)		
Secondary loop (He) Test section connection		
Control System		
Pump Controls		
Heater Controls		
Test Section Temperature and Pressure Control		
Bounding Transient Capabilities		
Temperature	High Temperature Test Section: from 850 °C to 480 °C in 100 s (~220 °C/min), then 480 °C to 200 °C in 15 min (~19 °C/min), or 850 °C to 380 °C in 5 min 30 s	
Pressure	+0.9 MPa/min and -0.38 MPa/min in 80 sec	0.3 MPa/s [pressure relief safety valve]
Flow rate	+0.07 kg/s/s and -0.04 kg/s/s	

5.2 Component Test Facility High Power (30 MWt) Loop – Point Design

The facility Point Design parameters are presented here. These parameters represent an operating point at steady state plant conditions.

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Description	Nominal Design Point
CTF 30 MW – Test Loop – Figure 5	
Total loop thermal power	30.0 MW
Primary Loop Design –	Square
Gas	Helium
Temperature	800 to 1000 °C
Flow rate	10kg/s
Thermal Power	Up to 30 MWt
Maximum Design Pressure	8.4 MPa
Pressure Range	4 to 7 MPa
Temperature Transients	±200 °C/min
He – Water Heat rejection	7.5-9 MPa, 350°C
Secondary Loop Design-	
Gas	Helium
Temperature	950 °C
Flow rate	10kg/s
Maximum Design Pressure	9.0 MPa
Thermal Power – from primary loop	Up to 30 MWt
Pressure Range	7.5MPa
Multiple test sections and / or multiple loops	TBD
Gas Supply, Purification System	
Primary He Purification Loop	8.4 MPa
Secondary He Purification Loop	9.0 MPa
He storage and Supply Loop	14.5 MPa
Pressurized Water Cooling System	9.0 MPa
Control System	
Pump Controls	
Heater Controls	
Test Section Temperature and Pressure Controls	
Test Section	
IHX – Compact (full scale module)	
IHX – Tubular (full scale representation)	
Steam Generator (full scale representation)	
Hot Duct (mock up)	

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Figure 1: 1 MW Helium Single Test Loop – Configuration 1

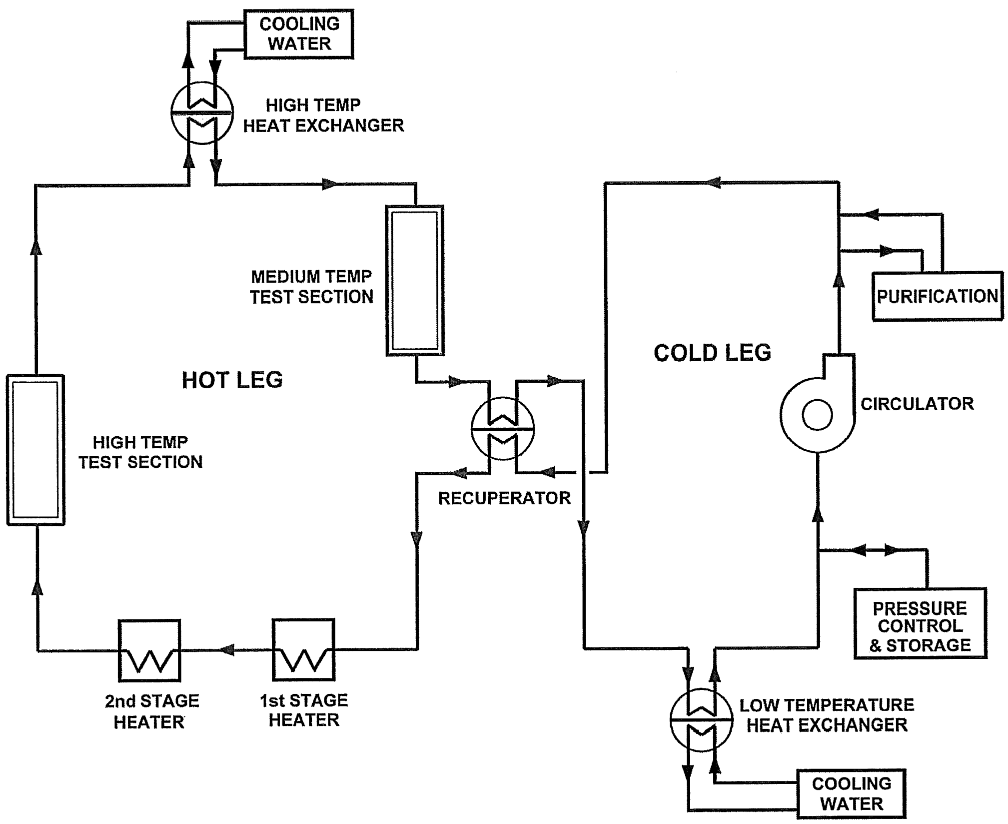

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Figure 2: 1 MW Helium Single Test Loop IHX – Configuration 2

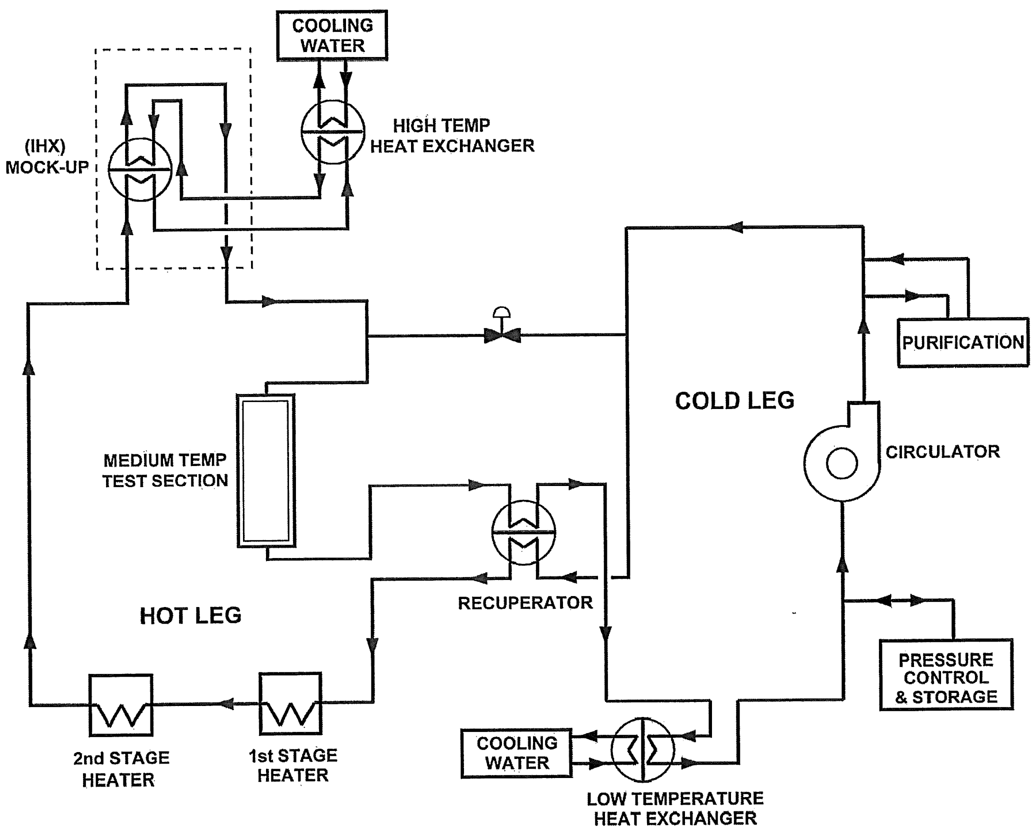

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Figure 3: 1 MW Helium Primary Test Loop – Configuration 3

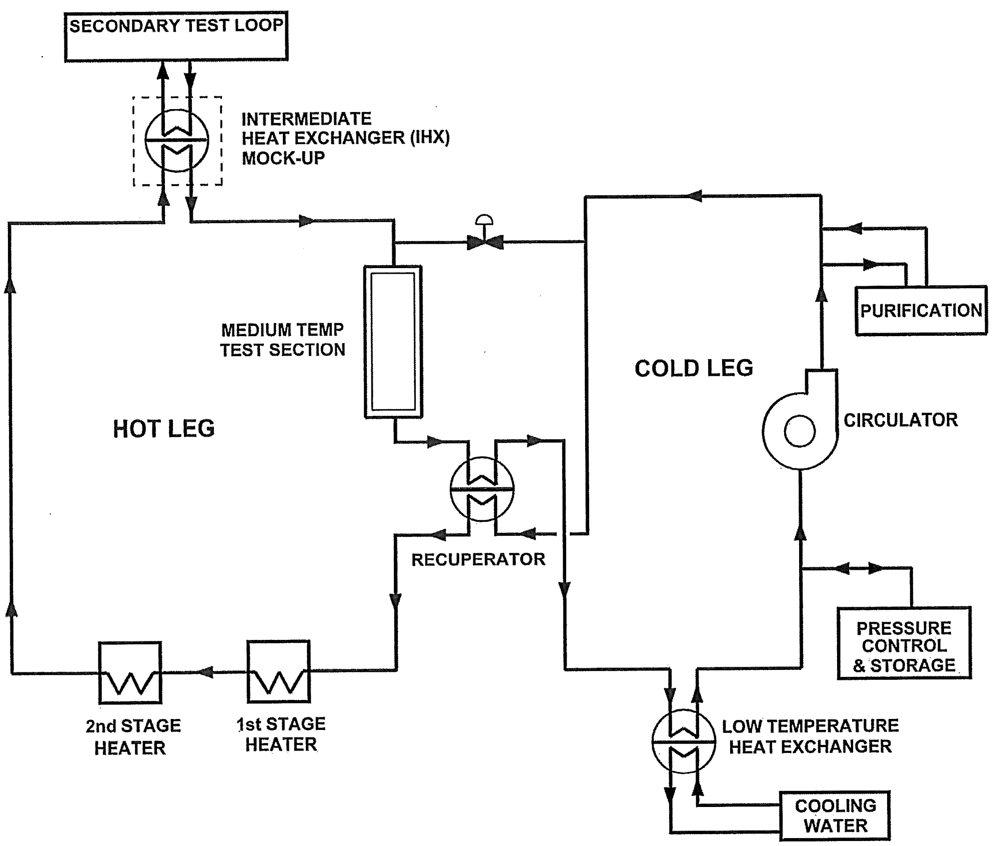


Figure 4: 1 MW Helium Secondary Test Loop – Configuration 3

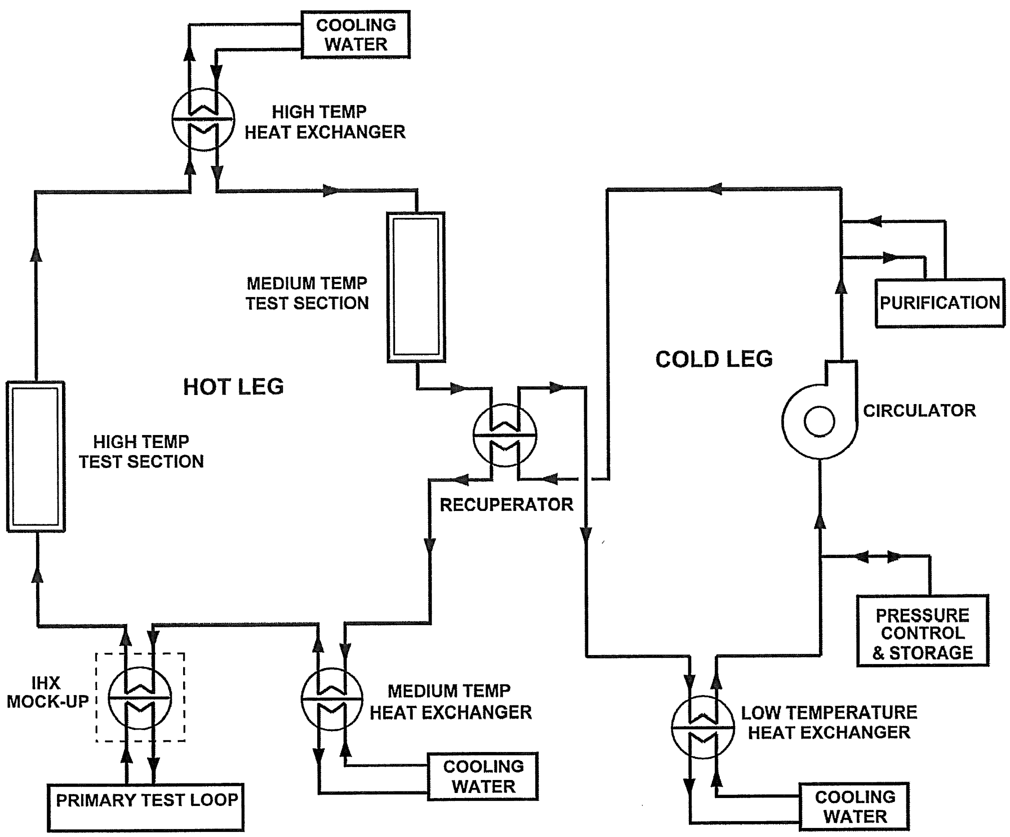
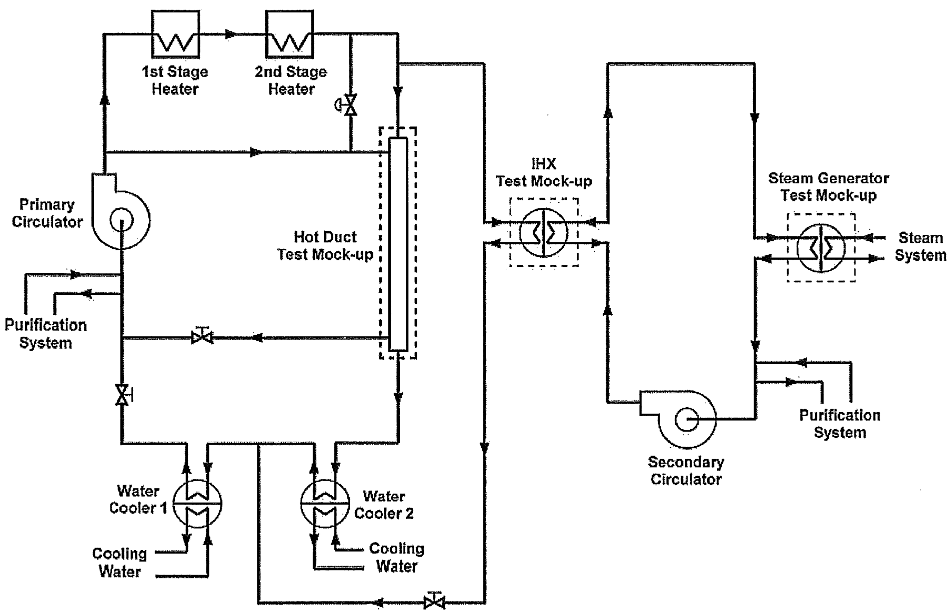


Figure 5: 30 MWt Test Loop with Primary and Secondary Loop Test Sections

Configuration includes the Hot Duct, IHX, and Steam Generator Test Mock-ups



APPENDIX A: CTF INITIAL SYSTEM REQUIREMENTS MANUAL

APPENDIX B: CTF DESIGN DRAWINGS

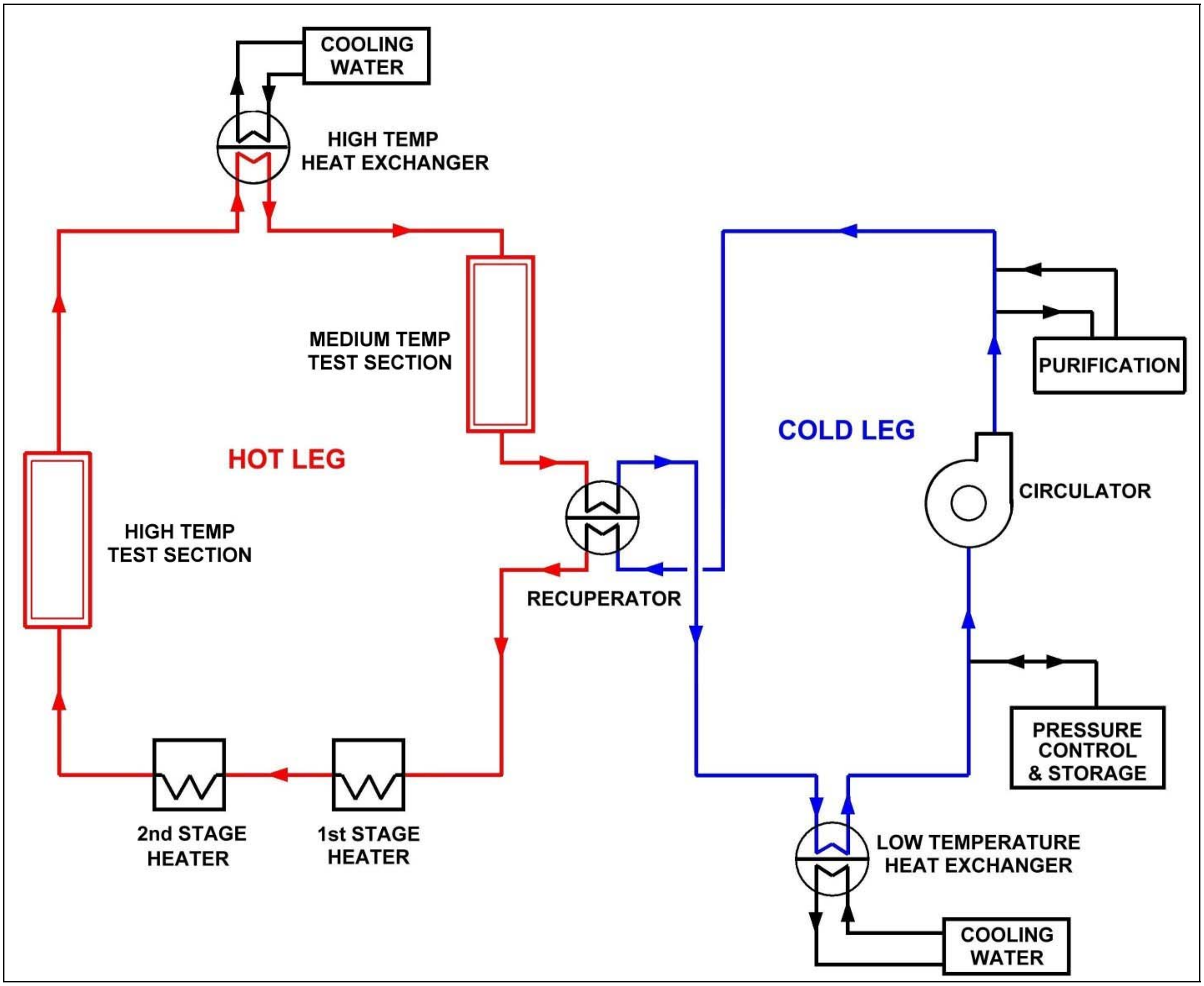
List of NGNP CTF 1 MW Test Loop Drawings

Drawing No	Title
02-9097035-A1-000	NGNP COMPONENT TEST FACILITY 1MWt TEST LOOP P&ID DETAILS, LEGEND AND NOTES
02-9097037-A1-000	NGNP COMPONENT TEST FACILITY 1MWt TEST LOOP P&ID PRIMARY LOOP
02-9097038-A1-000	NGNP COMPONENT TEST FACILITY 1MWt TEST LOOP P&ID SECONDARY LOOP
02-9097040-A1-000	NGNP COMPONENT TEST FACILITY 1MWt TEST LOOP COMPUTER & DATA ACQUISITION SYSTEM ONE LINE DIAGRAM
02-9097041-A1-000	NGNP COMPONENT TEST FACILITY 1MWt TEST LOOP PRIMARY LOOP CONFIGURATION 1 PROCESS FLOW DIAGRAM HEAT BALANCE
02-9097043-A1-000	NGNP COMPONENT TEST FACILITY 1MWt TEST LOOP PRIMARY LOOP CONFIGURATION 1 PROCESS FLOW DIAGRAM HEAT BALANCE
02-9097044-A1-000	NGNP COMPONENT TEST FACILITY 1MWt TEST LOOP PLAN LAYOUT
02-9097047-A1-000 (Sh 1)	NGNP COMPONENT TEST FACILITY 30 MWt TEST LOOP ONE LINE ELECTRICAL SCHEMATIC
02-9097047-A1-000 (Sh 2)	NGNP COMPONENT TEST FACILITY 30 MWt TEST LOOP ONE LINE ELECTRICAL SCHEMATIC
02-9097048-A1-000	NGNP COMPONENT TEST FACILITY 1 MWt TEST LOOP ONE LINE ELECTRICAL SCHEMATIC

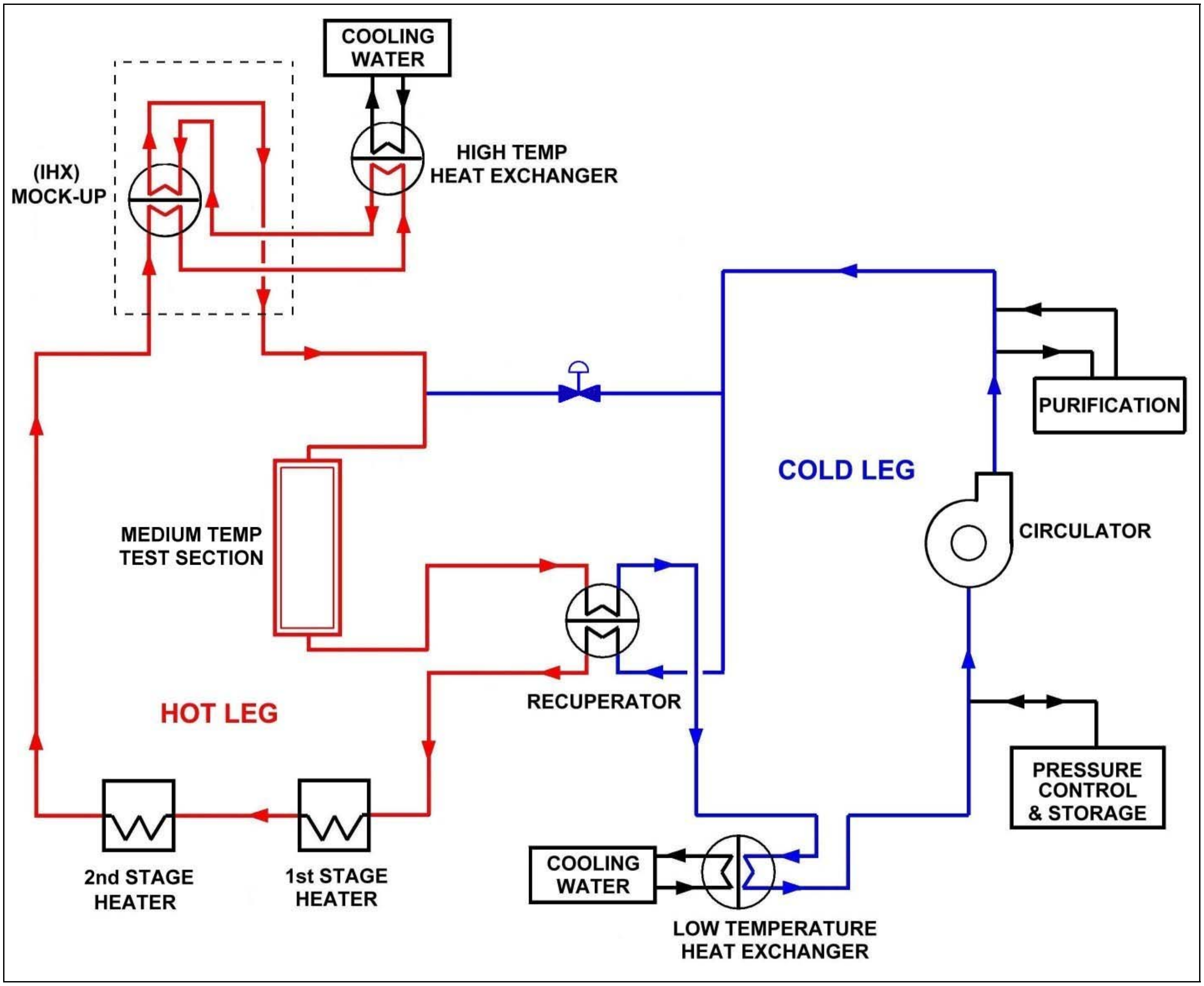
Drawing No	Title
02-9097049-A1-000	NGNP COMPONENT TEST FACILITY 1 MWt TEST LOOP 1 MW HEATER SCHEMATIC
02-9097050-A1-000	NGNP COMPONENT TEST FACILITY FACILITY ONE LINE ELECTRICAL SCHEMATIC
02-9097051-A1-000	NGNP COMPONENT TEST FACILITY 1 MWt TEST LOOP AUTOMATIC TRANSFER SWITCH SCHEMATIC
02-9097052-A1-000	NGNP COMPONENT TEST FACILITY 1 MWt TEST LOOP 400 KW HEATER SCHEMATIC
02-9097843-A1-000	NGNP COMPONENT TEST FACILITY 1MWt TEST LOOP PRIMARY LOOP CONFIGURATION 3 PROCESS FLOW DIAGRAM HEAT BALANCE
02-9097846-A1-000	NGNP COMPONENT TEST FACILITY 1MWt TEST LOOP SECONDARY LOOP CONFIGURATION 3 PROCESS FLOW DIAGRAM HEAT BALANCE
02-9098896-A1-000	NGNP COMPONENT TEST FACILITY 30 MWt TEST LOOP COMPUTER & DATA ACQUISITION SYSTEM ONE LINE DIAGRAM

B.1 Simplifies System Flow Diagrams

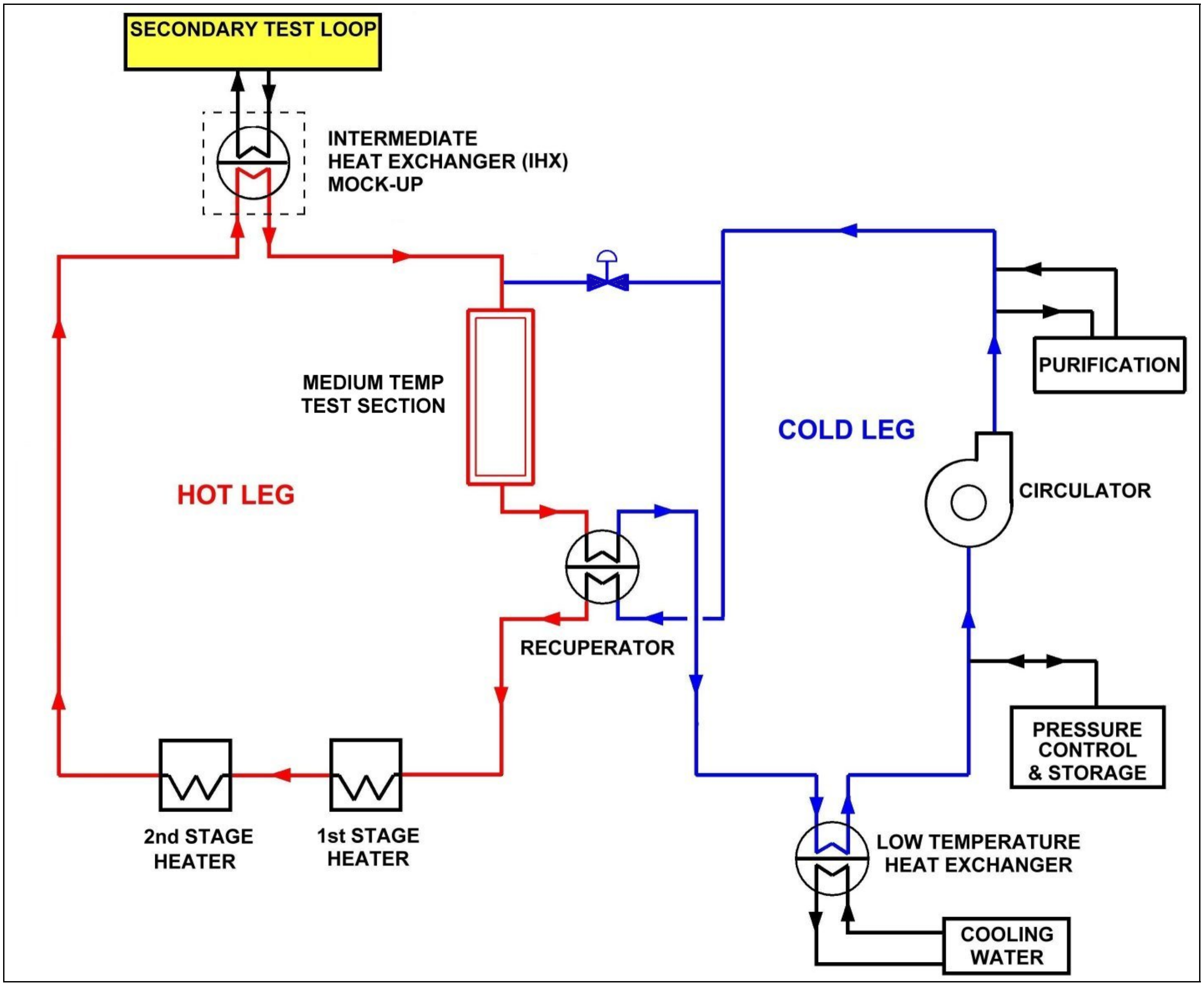
B.1.1 Single Test Loop (Configuration 1)



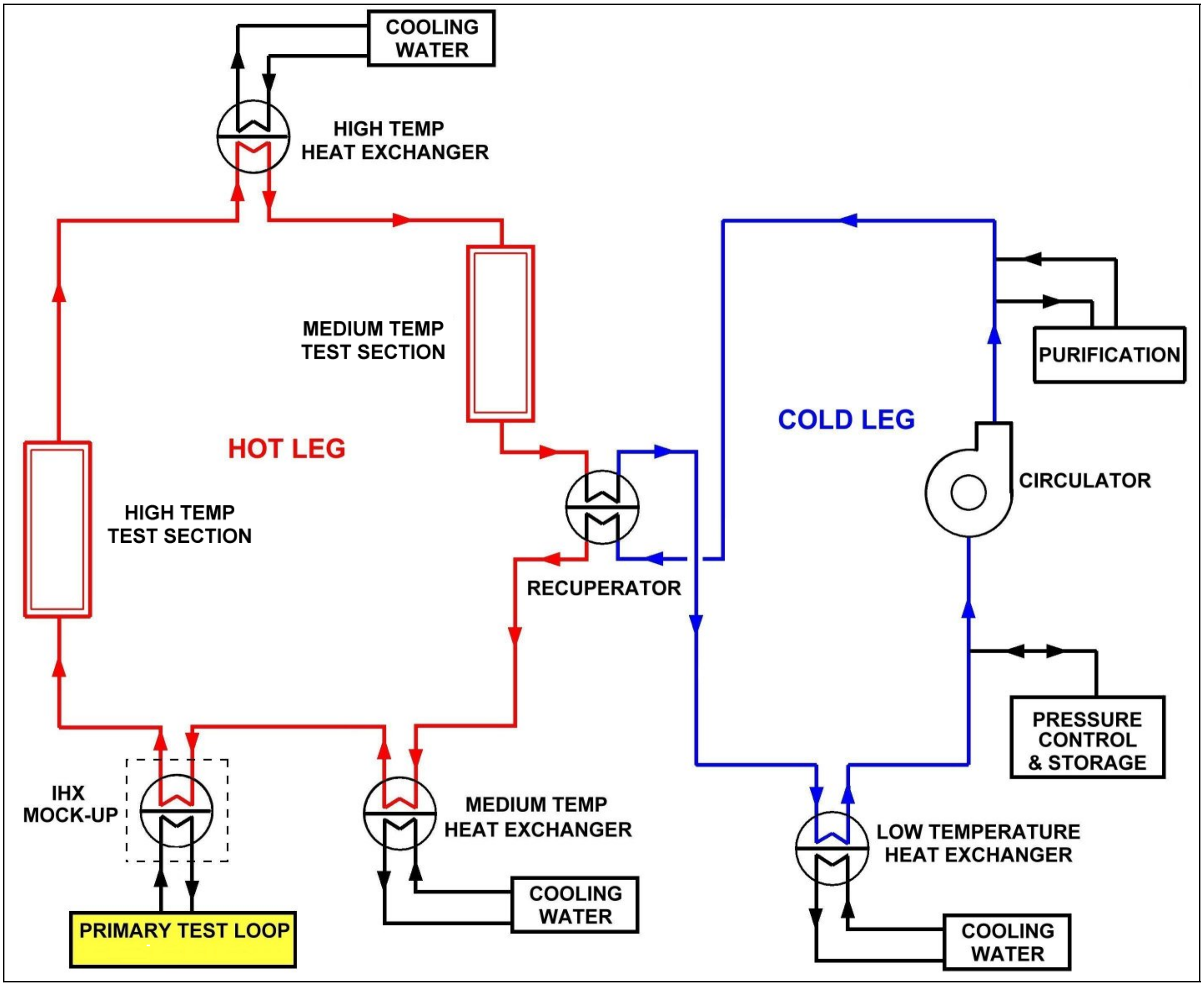
B.1.2 Single Test Loop – IHX (Configuration 2)



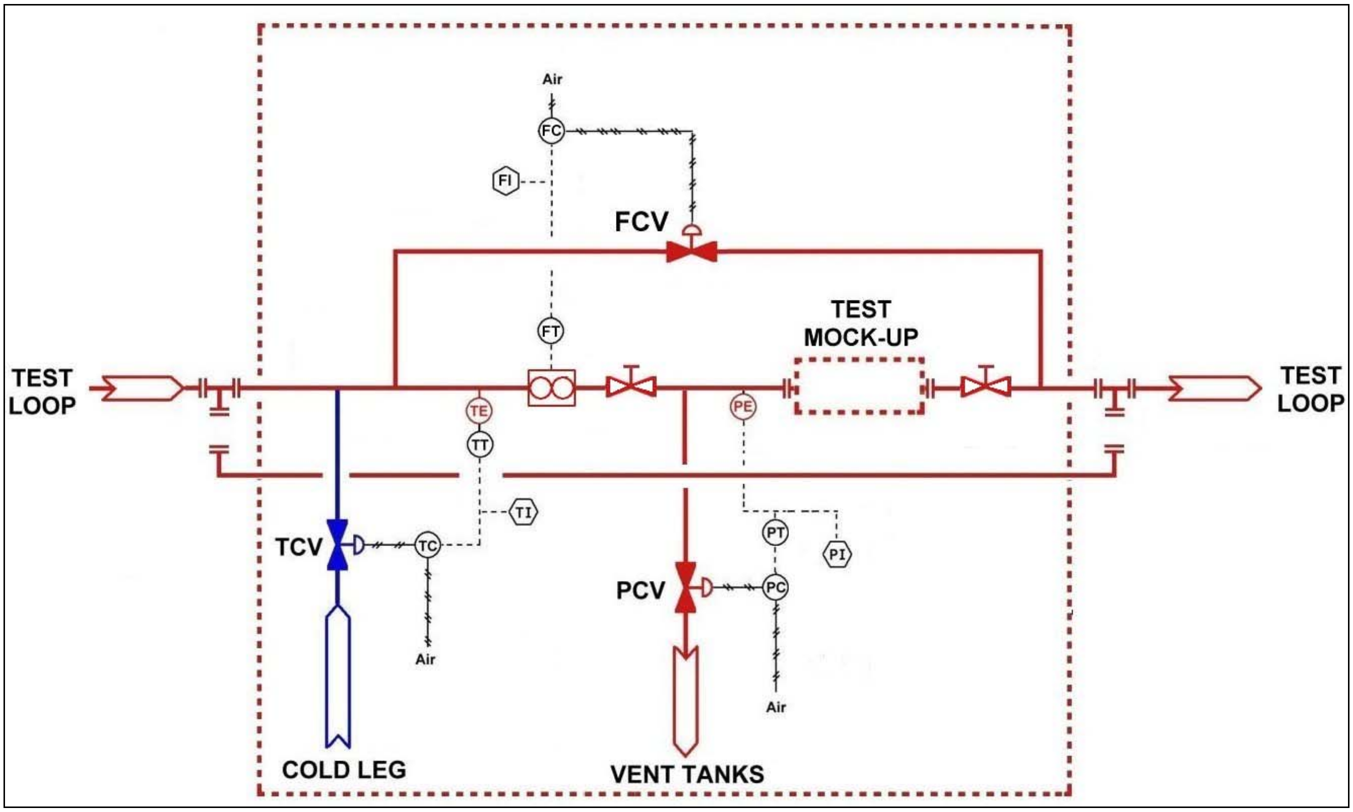
B.1.3 Primary Loop (Configuration 3)



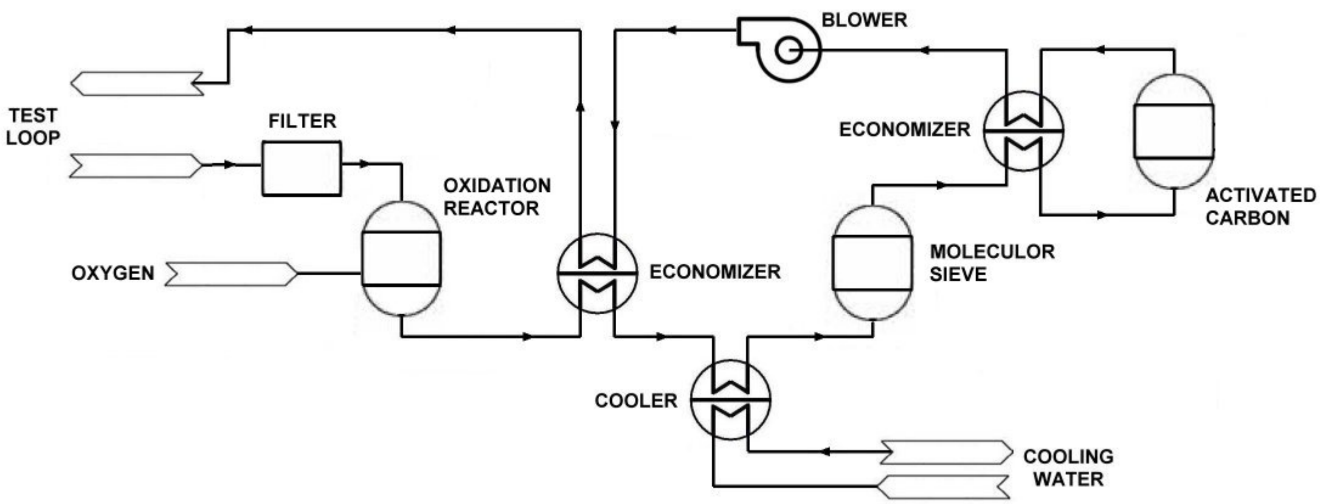
B.1.4 Secondary Loop (Configuration 3)



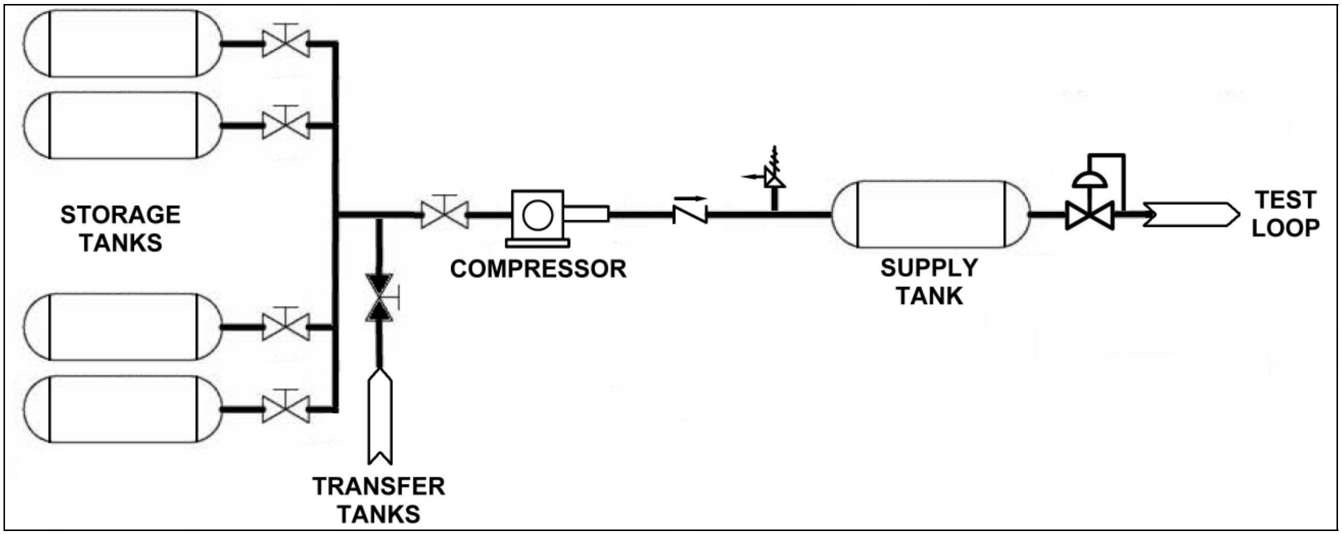
B.1.5 Test Section



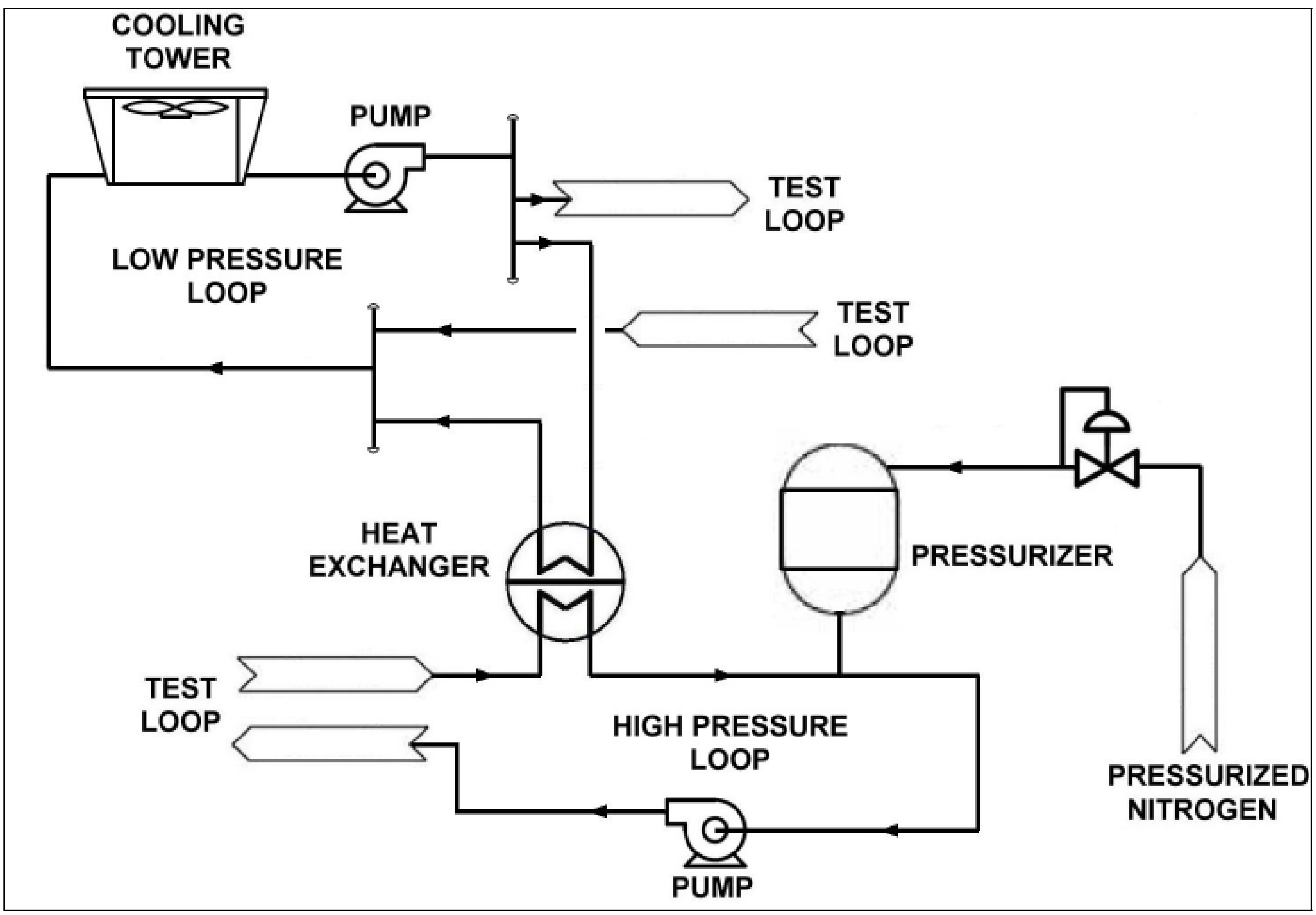
B.1.6 Helium Purification System (Typical)



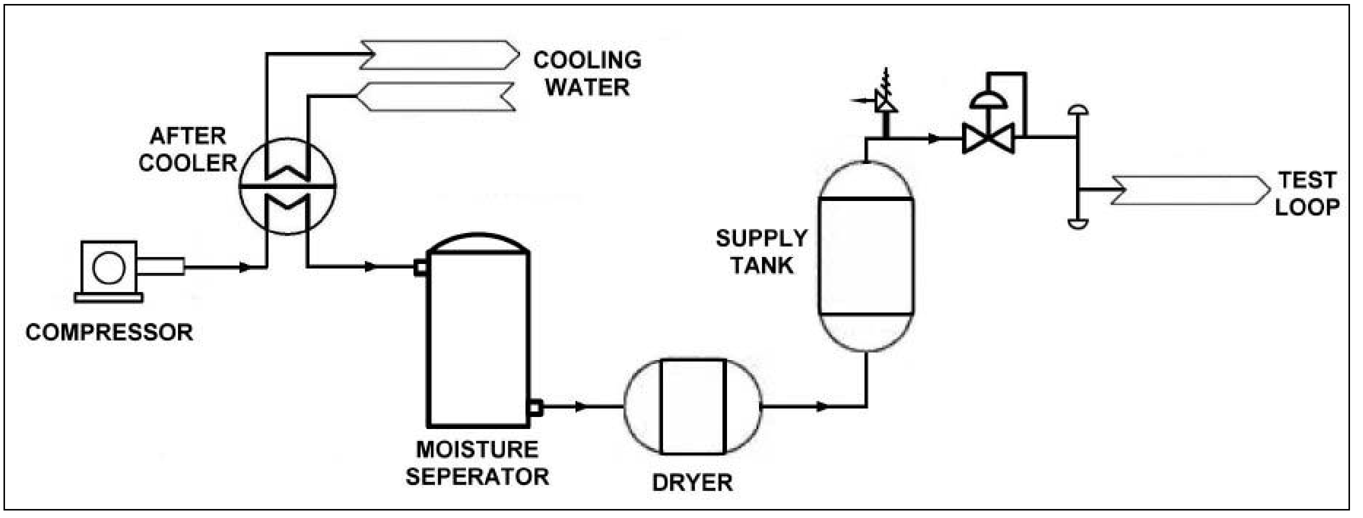
B.1.7 Helium Supply and Storage System (Typical)



B.1.8 Cooling Water System (Typical)



B.1.9 Compressed Air System (Typical)



B.2 One-Line Electrical Schematic

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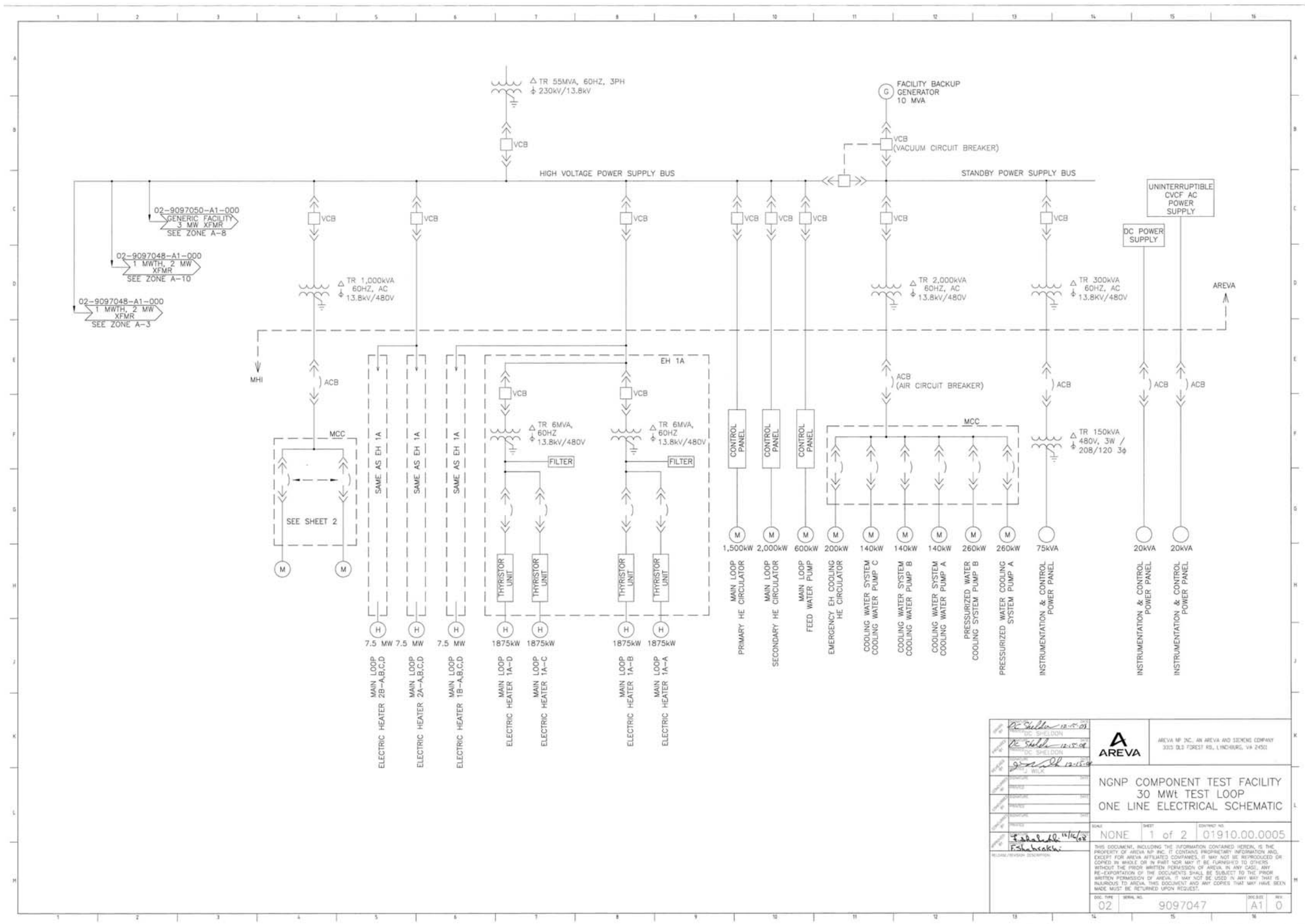
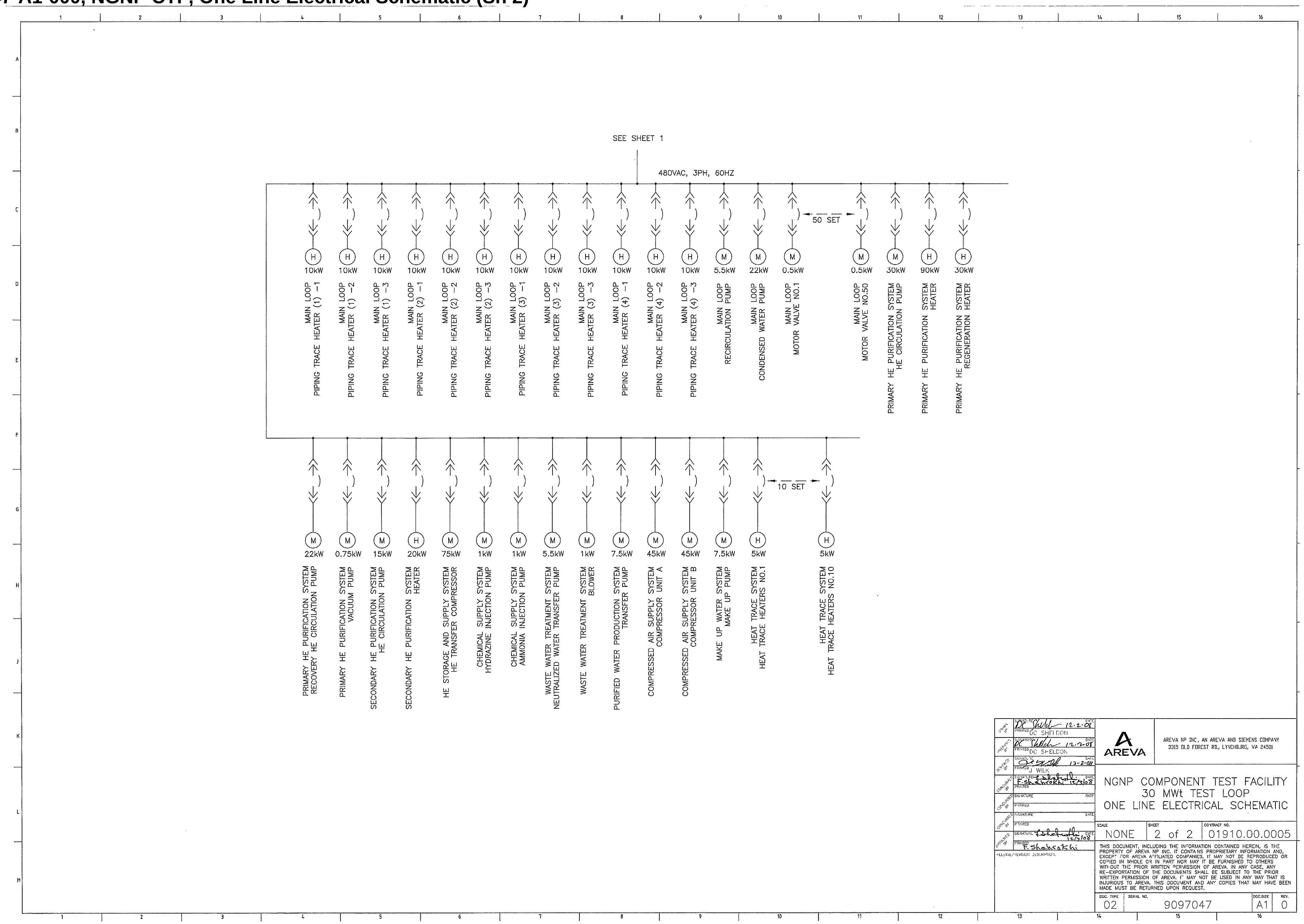
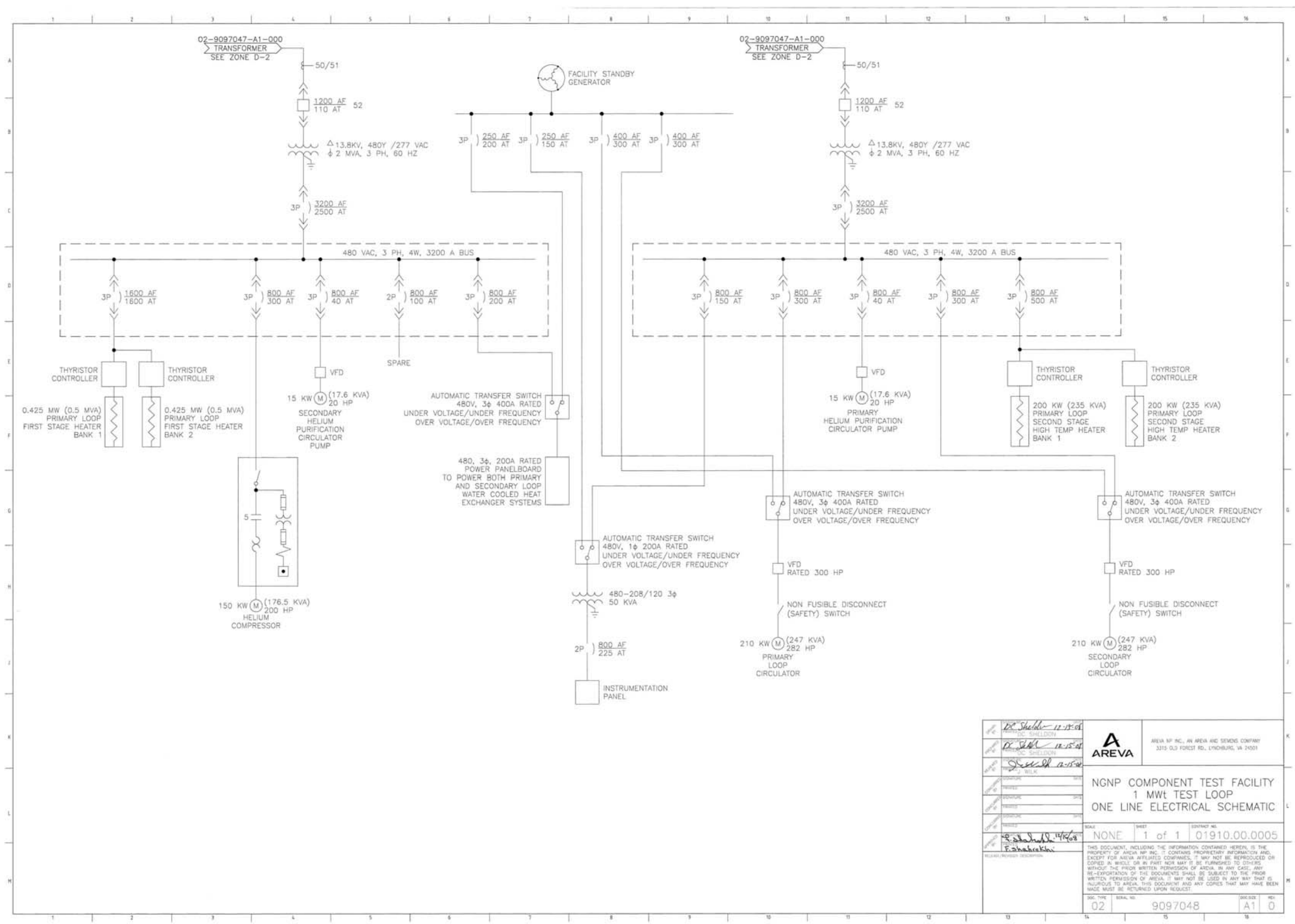
B.2.2 AREVA Drawing 02-9097047-A1-000, NGNP CTF, One Line Electrical Schematic (Sh 1)



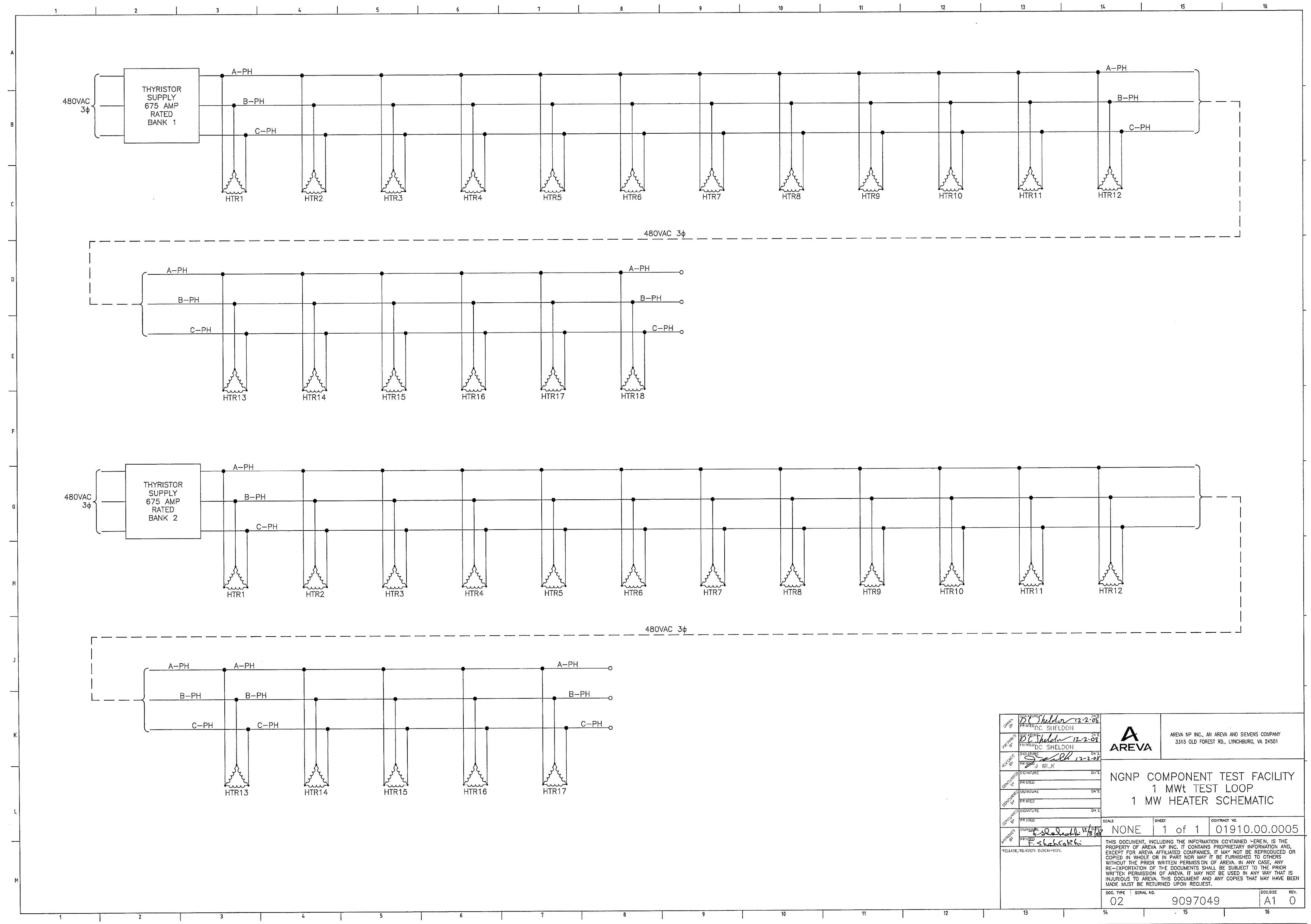
B.2.3 AREVA Drawing 02-9097047-A1-000, NGNP CTF, One Line Electrical Schematic (Sh 2)



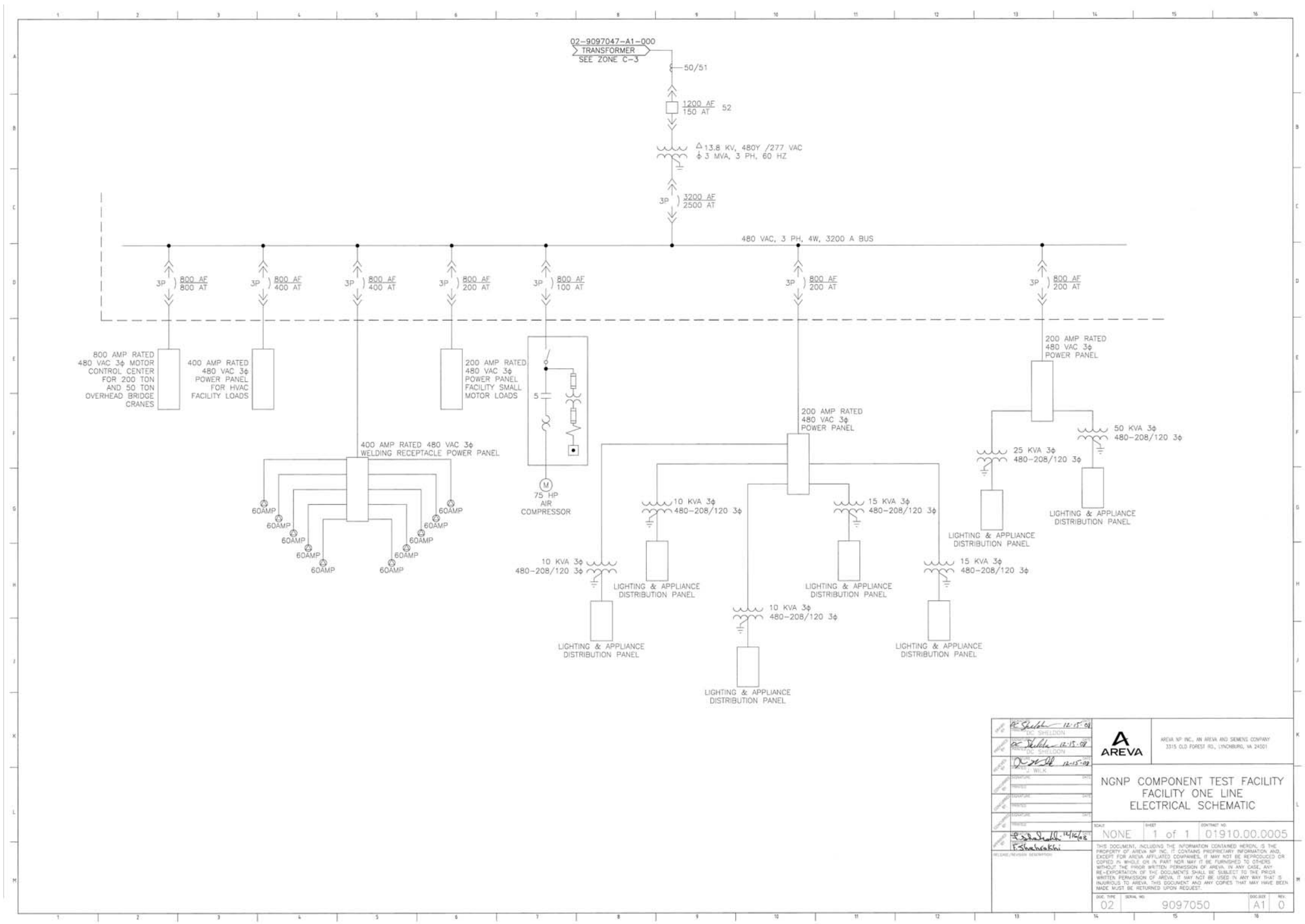
B.2.4 AREVA Drawing 02-9097048-A1-000, NGNP CTF, 1 MWt Test Loop, One Line Electrical Schematic



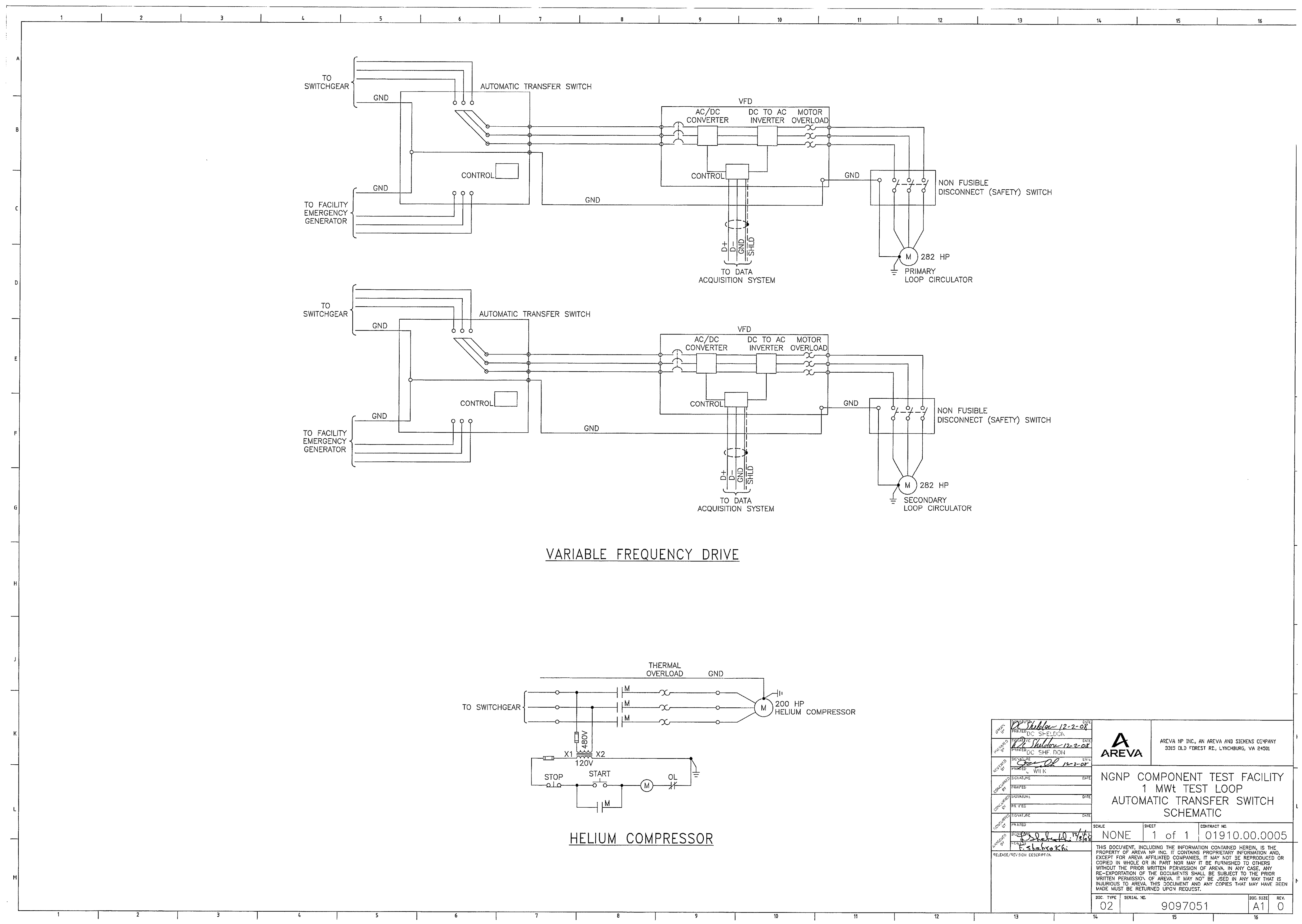
B.2.5 AREVA Drawing 02-9097049-A1-000, NGNP CTF, 1 MWt Test Loop, 1 MW Heater Schematic



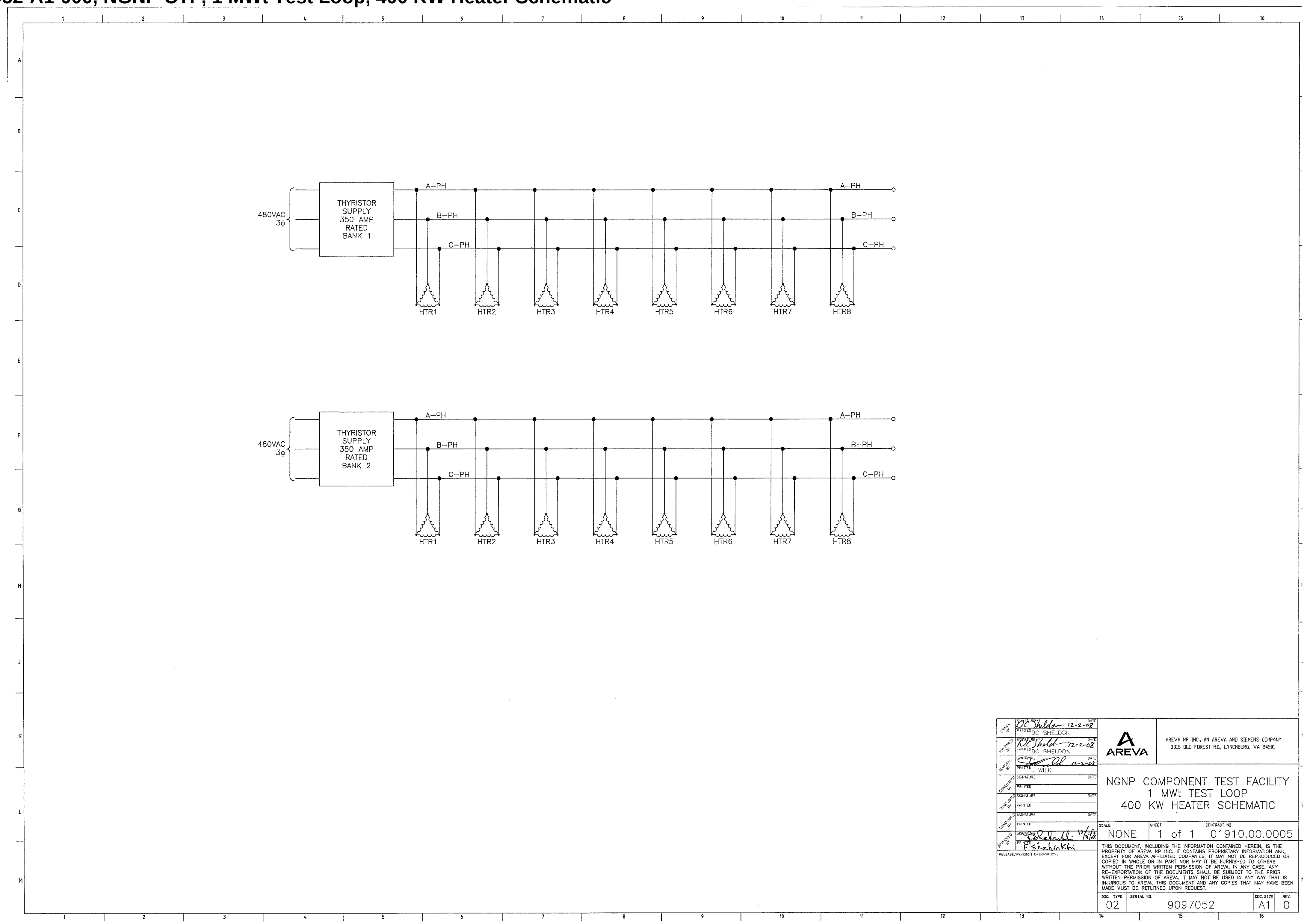
B.2.6 AREVA Drawing 02-9097050-A1-000, NGNP CTF, Facility One Line, Electrical Schematic



B.2.7 AREVA Drawing 02-9097051-A1-000, NGNP CTF, 1 MWt Test Loop, Automatic Transfer Switch Schematic

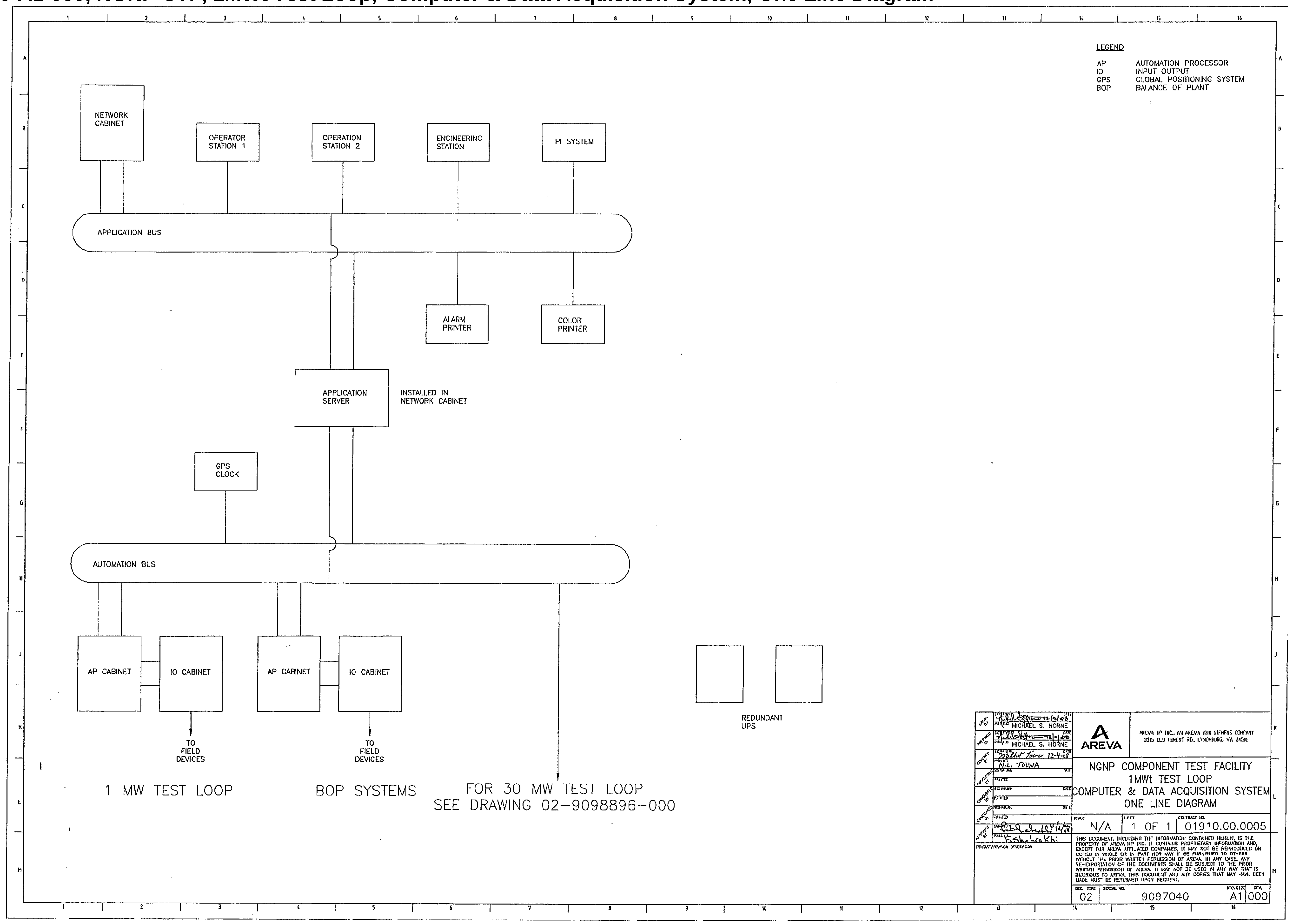


B.2.8 AREVA Drawing 02-9097052-A1-000, NGNP CTF, 1 MWt Test Loop, 400 KW Heater Schematic

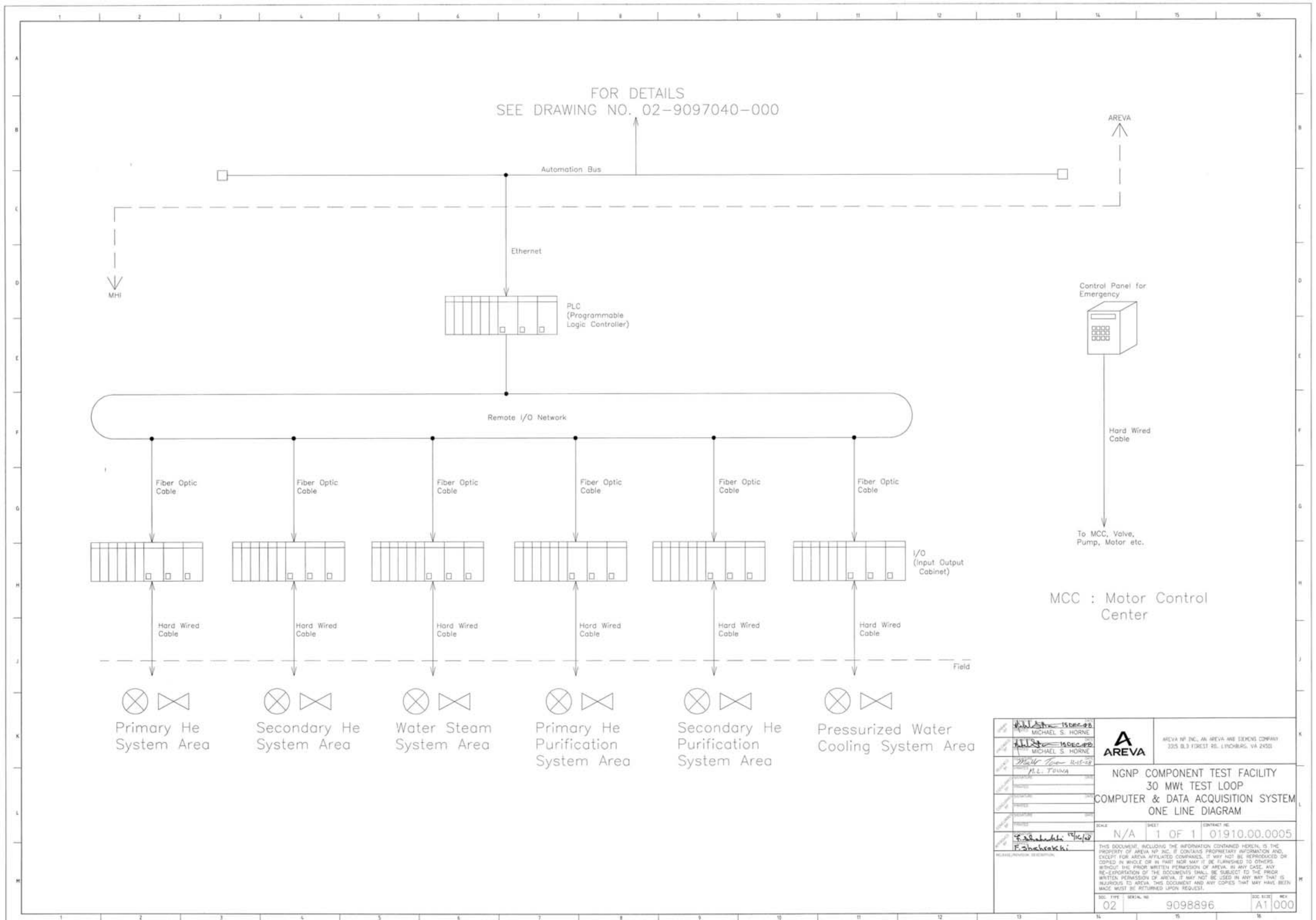


B.3 One-Line Instrumentation Schematic

B.3.1 AREVA Drawing 02-9097040-A1-000, NGNP CTF, 1MWt Test Loop, Computer & Data Acquisition System, One Line Diagram

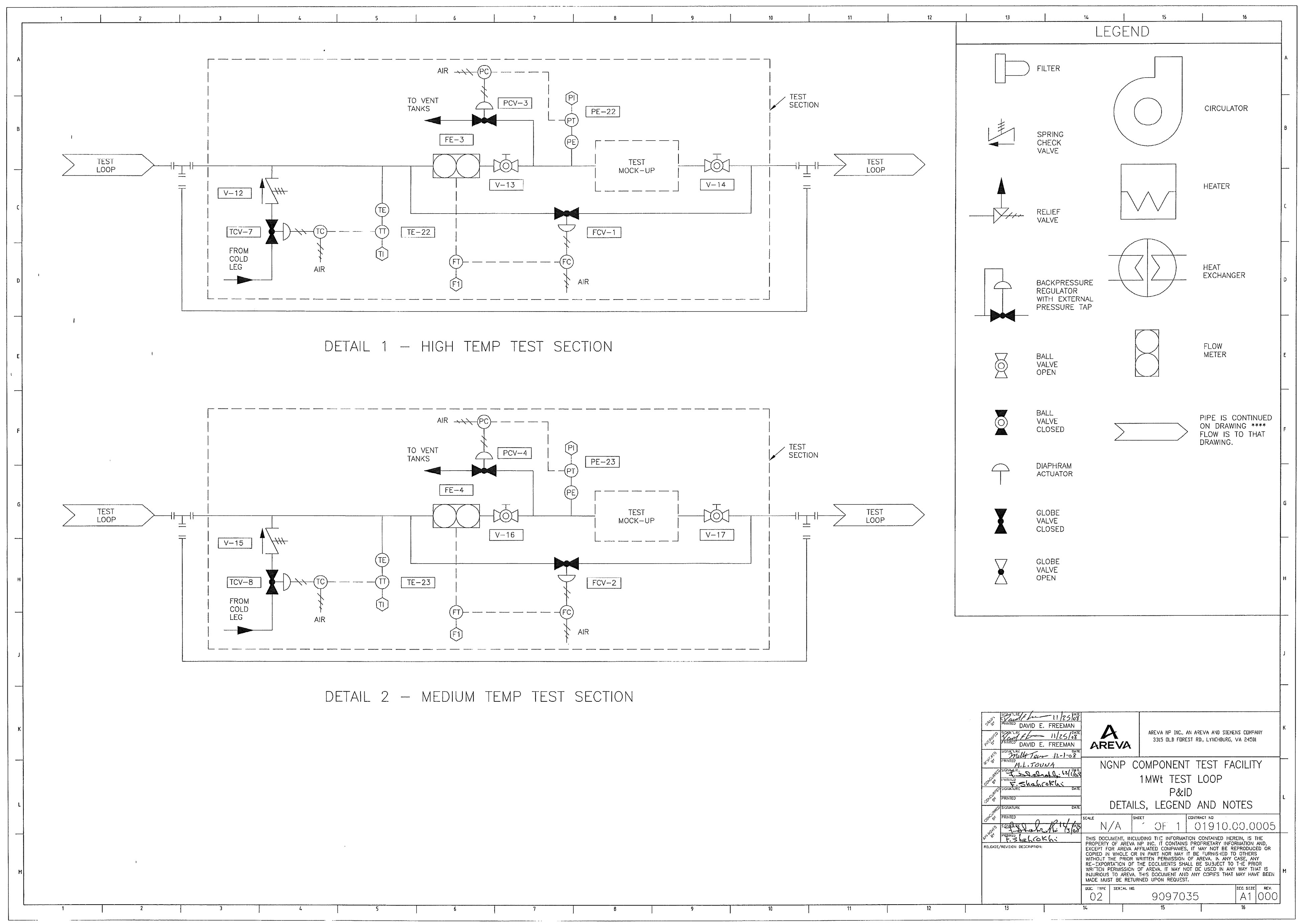


B.3.2 AREVA Drawing 02-9098896-A1-000, NGNP CTF, 30 MWt Test Loop, Computer & Data Acquisition System, One Line Diagram

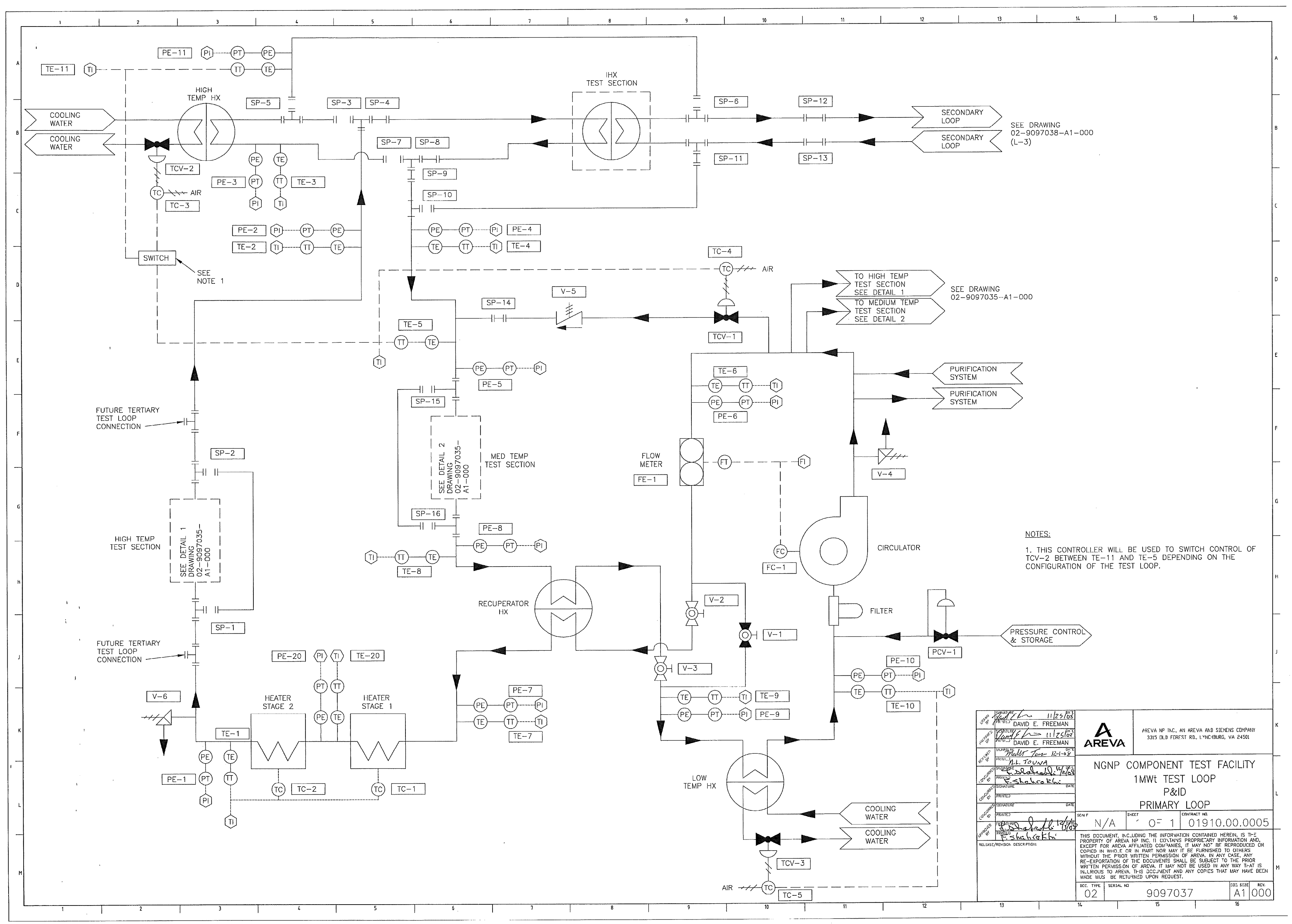


B.4 P&IDs

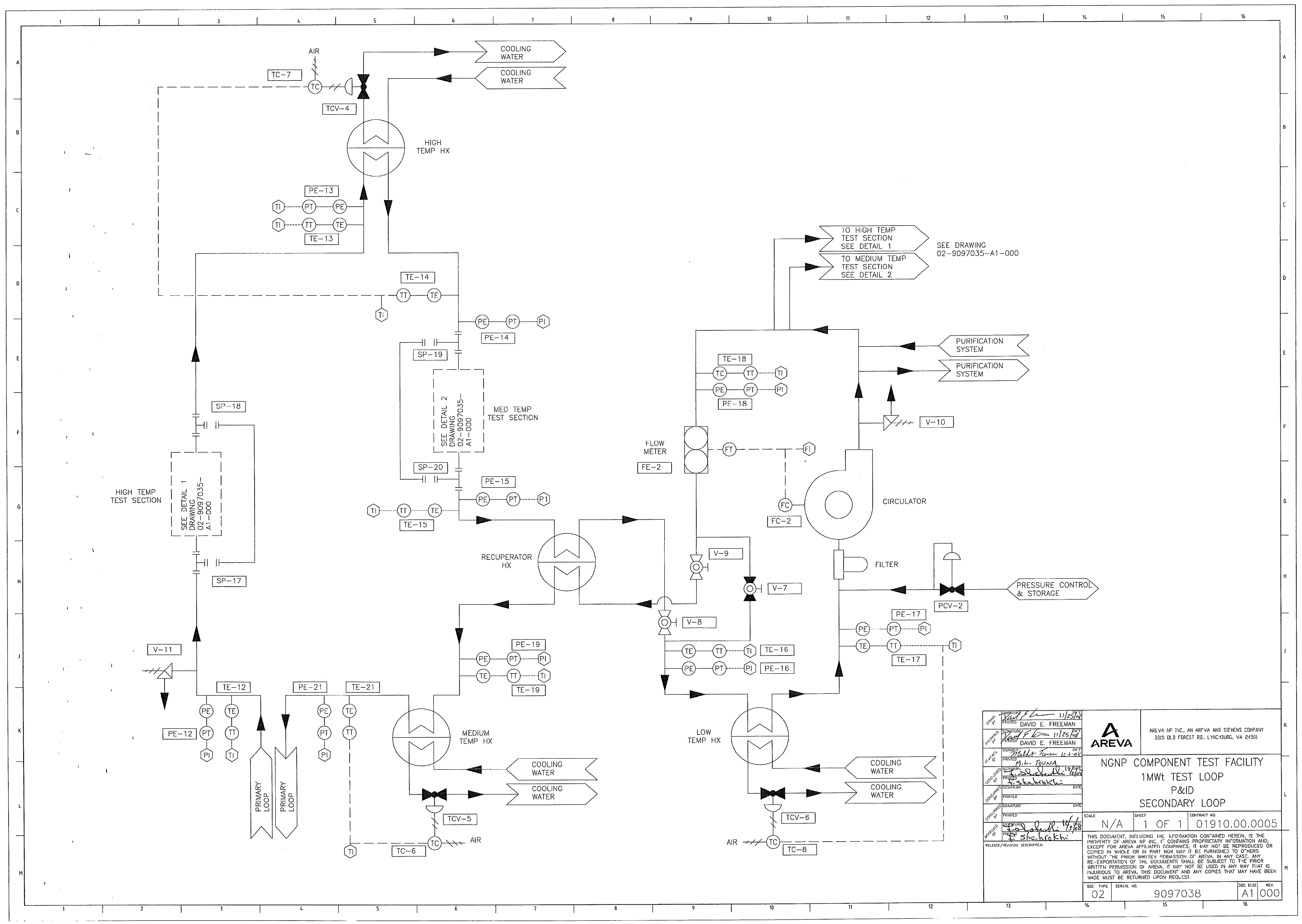
B.4.1 AREVA Drawing 02-9097035-000, NGNP CTF 1 MW Test Loop P&ID, Details, Legend & Notes



B.4.2 AREVA Drawing 02-9097037-000, NGNP CTF 1 MW Test Loop P&ID, Primary Loop

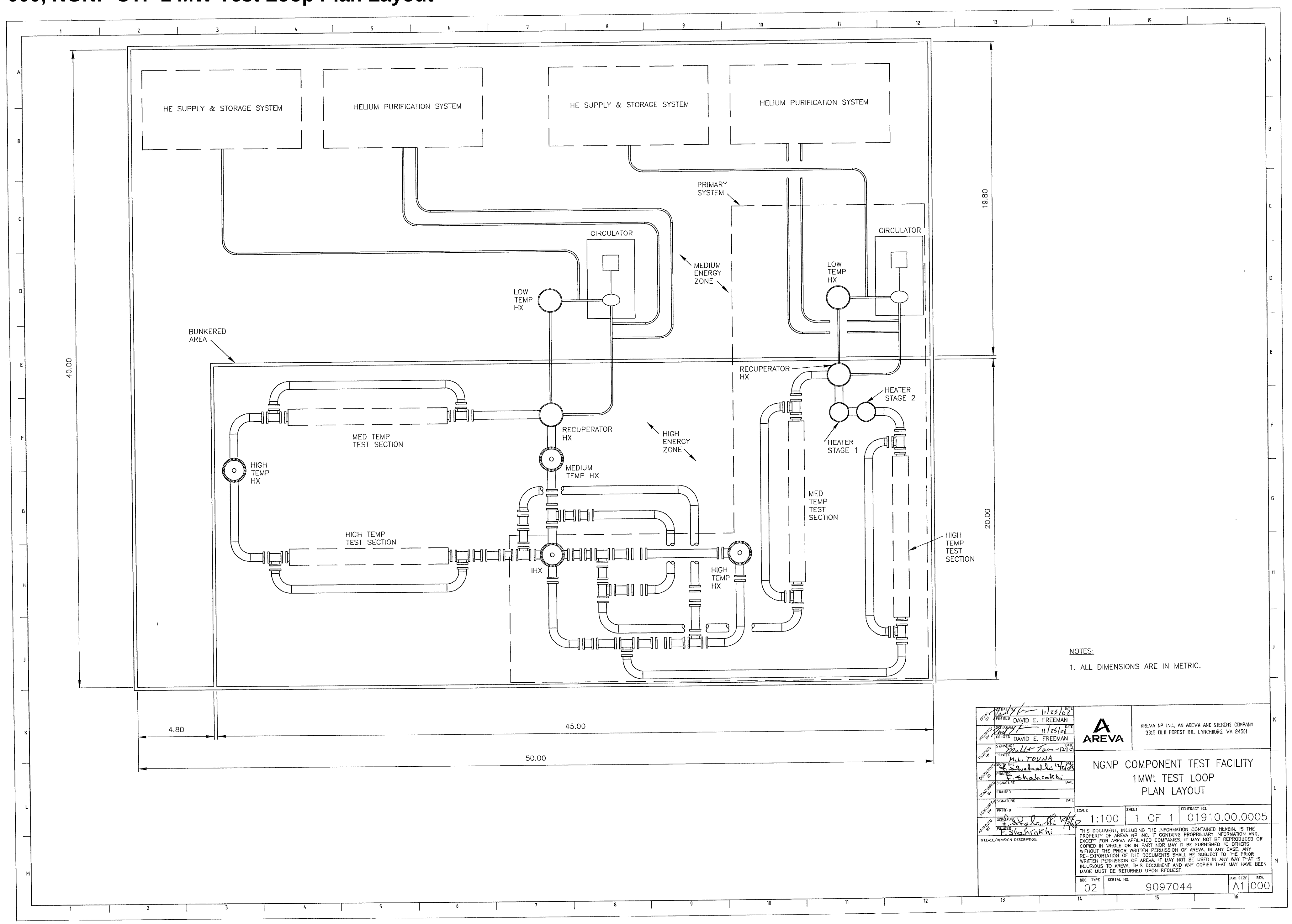


B.4.3 AREVA Drawing 02-9097038-000, NGNP CTF 1 MW Test Loop P&ID, Secondary Loop



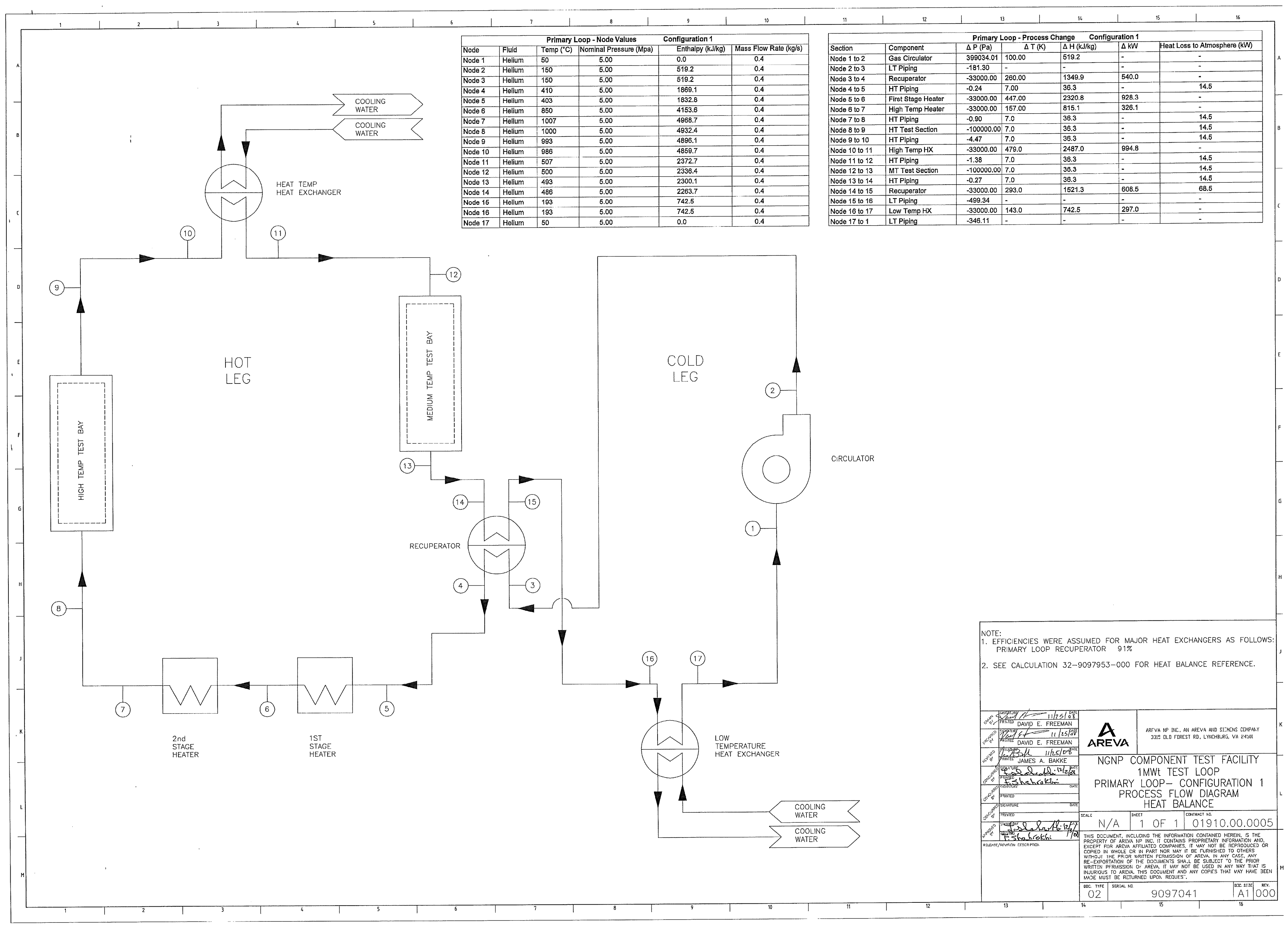
B.5 Equipment Layout – Plan View

B.5.1 AREVA Drawing 02-9097044-000, NGNP CTF 1 MW Test Loop Plan Layout



B.6 Process Block Flow Diagram with Heat Balance

B.6.1 AREVA Drawing 02-9097041-000, NGNP CTF 1 MW Test Loop Primary Loop Configuration 1 Process Flow Diagram Heat Balance



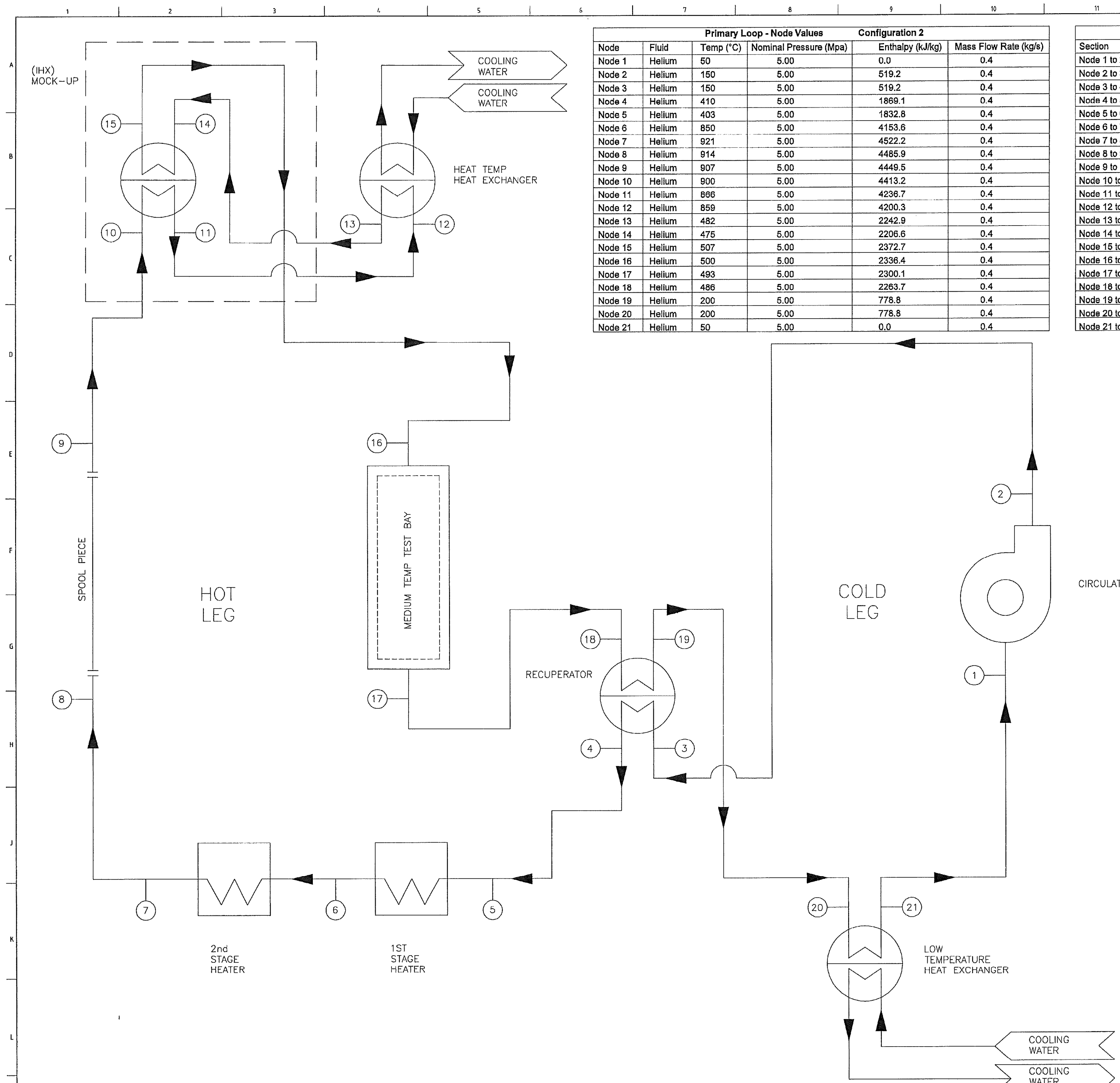
Primary Loop - Node Values — Configuration 1

Node	Fluid	Temp (°C)	Nominal Pressure (Mpa)	Enthalpy (kJ/kg)	Mass Flow Rate (kg/s)
Node 1	Helium	50	5.00	0.0	0.4
Node 2	Helium	150	5.00	519.2	0.4
Node 3	Helium	150	5.00	519.2	0.4
Node 4	Helium	410	5.00	1869.1	0.4
Node 5	Helium	403	5.00	1832.8	0.4
Node 6	Helium	850	5.00	4153.6	0.4
Node 7	Helium	1007	5.00	4968.7	0.4
Node 8	Helium	1000	5.00	4932.4	0.4
Node 9	Helium	993	5.00	4896.1	0.4
Node 10	Helium	986	5.00	4859.7	0.4
Node 11	Helium	507	5.00	2372.7	0.4
Node 12	Helium	500	5.00	2336.4	0.4
Node 13	Helium	493	5.00	2300.1	0.4
Node 14	Helium	486	5.00	2263.7	0.4
Node 15	Helium	193	5.00	742.5	0.4
Node 16	Helium	193	5.00	742.5	0.4
Node 17	Helium	50	5.00	0.0	0.4

Primary Loop - Process Change — Configuration 1

Section	Component	Δ P (Pa)	Δ T (K)	Δ H (kJ/kg)	Δ kW	Heat Loss to Atmosphere (kW)
Node 1 to 2	Gas Circulator	399034.01	100.00	519.2	-	-
Node 2 to 3	LT Piping	-181.30	-	-	-	-
Node 3 to 4	Recuperator	-33000.00	260.00	1349.9	540.0	-
Node 4 to 5	HT Piping	-0.24	7.00	36.3	-	14.5
Node 5 to 6	First Stage Heater	-33000.00	447.00	2320.8	928.3	-
Node 6 to 7	High Temp Heater	-33000.00	157.00	815.1	326.1	-
Node 7 to 8	HT Piping	-0.90	7.0	36.3	-	14.5
Node 8 to 9	HT Test Section	-100000.00	7.0	36.3	-	14.5
Node 9 to 10	HT Piping	-4.47	7.0	36.3	-	14.5
Node 10 to 11	High Temp HX	-33000.00	479.0	2487.0	994.8	-
Node 11 to 12	HT Piping	-1.38	7.0	36.3	-	14.5
Node 12 to 13	MT Test Section	-100000.00	7.0	36.3	-	14.5
Node 13 to 14	HT Piping	-0.27	7.0	36.3	-	14.5
Node 14 to 15	Recuperator	-33000.00	293.0	1521.3	608.5	68.5
Node 15 to 16	LT Piping	-499.34	-	-	-	-
Node 16 to 17	Low Temp HX	-33000.00	143.0	742.5	297.0	-
Node 17 to 1	LT Piping	-346.11	-	-	-	-

B.6.2 AREVA Drawing 02-9097043-000, NGNP CTF 1 MW Test Loop Primary Loop, Configuration 2, Process Flow Diagram, Heat Balance



Primary Loop - Node Values Configuration 2					
Node	Fluid	Temp (°C)	Nominal Pressure (Mpa)	Enthalpy (kJ/kg)	Mass Flow Rate (kg/s)
Node 1	Helium	50	5.00	0.0	0.4
Node 2	Helium	150	5.00	519.2	0.4
Node 3	Helium	150	5.00	519.2	0.4
Node 4	Helium	410	5.00	1869.1	0.4
Node 5	Helium	403	5.00	1832.8	0.4
Node 6	Helium	850	5.00	4153.6	0.4
Node 7	Helium	921	5.00	4522.2	0.4
Node 8	Helium	914	5.00	4485.9	0.4
Node 9	Helium	907	5.00	4449.5	0.4
Node 10	Helium	900	5.00	4413.2	0.4
Node 11	Helium	866	5.00	4236.7	0.4
Node 12	Helium	859	5.00	4200.3	0.4
Node 13	Helium	482	5.00	2242.9	0.4
Node 14	Helium	475	5.00	2206.6	0.4
Node 15	Helium	507	5.00	2372.7	0.4
Node 16	Helium	500	5.00	2336.4	0.4
Node 17	Helium	493	5.00	2300.1	0.4
Node 18	Helium	486	5.00	2263.7	0.4
Node 19	Helium	200	5.00	778.8	0.4
Node 20	Helium	200	5.00	778.8	0.4
Node 21	Helium	50	5.00	0.0	0.4

Primary Loop - Process Change Configuration 2						
Section	Component	Δ P (Pa)	Δ T (K)	Δ H (kJ/kg)	Δ kW	Heat Loss to Atmosphere (kW)
Node 1 to 2	Gas Circulator	365044.10	100.00	519.2	-	-
Node 2 to 3	LT Piping	-181.30	-	-	-	-
Node 3 to 4	Recuperator	-33000.00	260.00	1349.9	540.0	-
Node 4 to 5	HT Piping	-0.24	7.00	36.3	-	14.5
Node 5 to 6	First Stage Heater	-33000.00	447.00	2320.8	928.3	-
Node 6 to 7	High Temp Heater	-33000.00	71.00	368.6	147.5	-
Node 7 to 8	HT Piping	-0.84	7.0	36.3	-	14.5
Node 8 to 9	HT Spool Piece	-1.00	7.0	36.3	-	14.5
Node 9 to 10	HT Piping	-0.83	7.0	36.3	-	14.5
Node 10 to 11	Intermediate HX	-33000.00	34.0	176.5	70.6	-
Node 11 to 12	HT Piping	-4.00	7.0	36.3	-	14.5
Node 12 to 13	High Temp HX	-33000.00	377.0	1957.4	783.0	-
Node 13 to 14	HT Piping	-1.32	7.0	36.3	-	14.5
Node 14 to 15	Intermediate HX	-33000.00	32.0	166.1	66.5	4.2
Node 15 to 16	HT Piping	-0.27	7.0	36.3	-	14.5
Node 16 to 17	MT Test Section	-100000.00	7.0	36.3	-	14.5
Node 17 to 18	HT Piping	-1.34	7.0	36.3	-	14.5
Node 18 to 19	Recuperator	-33000.00	286.0	1484.9	594.0	54.0
Node 19 to 20	LT Piping	-506.84	-	-	-	-
Node 20 to 21	Low Temp HX	-33000.00	150.0	778.8	311.5	-
Node 21 to 1	LT Piping	-346.11	-	-	-	-

NOTE:
1. EFFICIENCIES WERE ASSUMED FOR MAJOR HEAT EXCHANGERS AS FOLLOWS:
   INTERMEDIATE HEAT EXCHANGER 95%
   SECONDARY LOOP RECUPERATOR 91%
2. SEE CALCULATION 32-9097953-000 FOR HEAT BALANCE REFERENCE.

DRAWN BY: SIGNATURE [signed] DATE 11/25/08 PRINTED DAVID E. FREEMAN
PREPARED BY: SIGNATURE [signed] DATE 11/25/08 PRINTED DAVID E. FREEMAN
REVIEWED BY: SIGNATURE [signed] DATE 11/25/08 PRINTED JAMES A. BAKKE
CONCURRED BY: SIGNATURE [signed] DATE 12/2/08 PRINTED F. Shahrokhi
CONCURRED BY: SIGNATURE DATE PRINTED
CONCURRED BY: SIGNATURE DATE PRINTED
APPROVED BY: SIGNATURE [signed] DATE 12/3/08 PRINTED F. Shahrokhi
RELEASE/REVISION DESCRIPTION.

AREVA

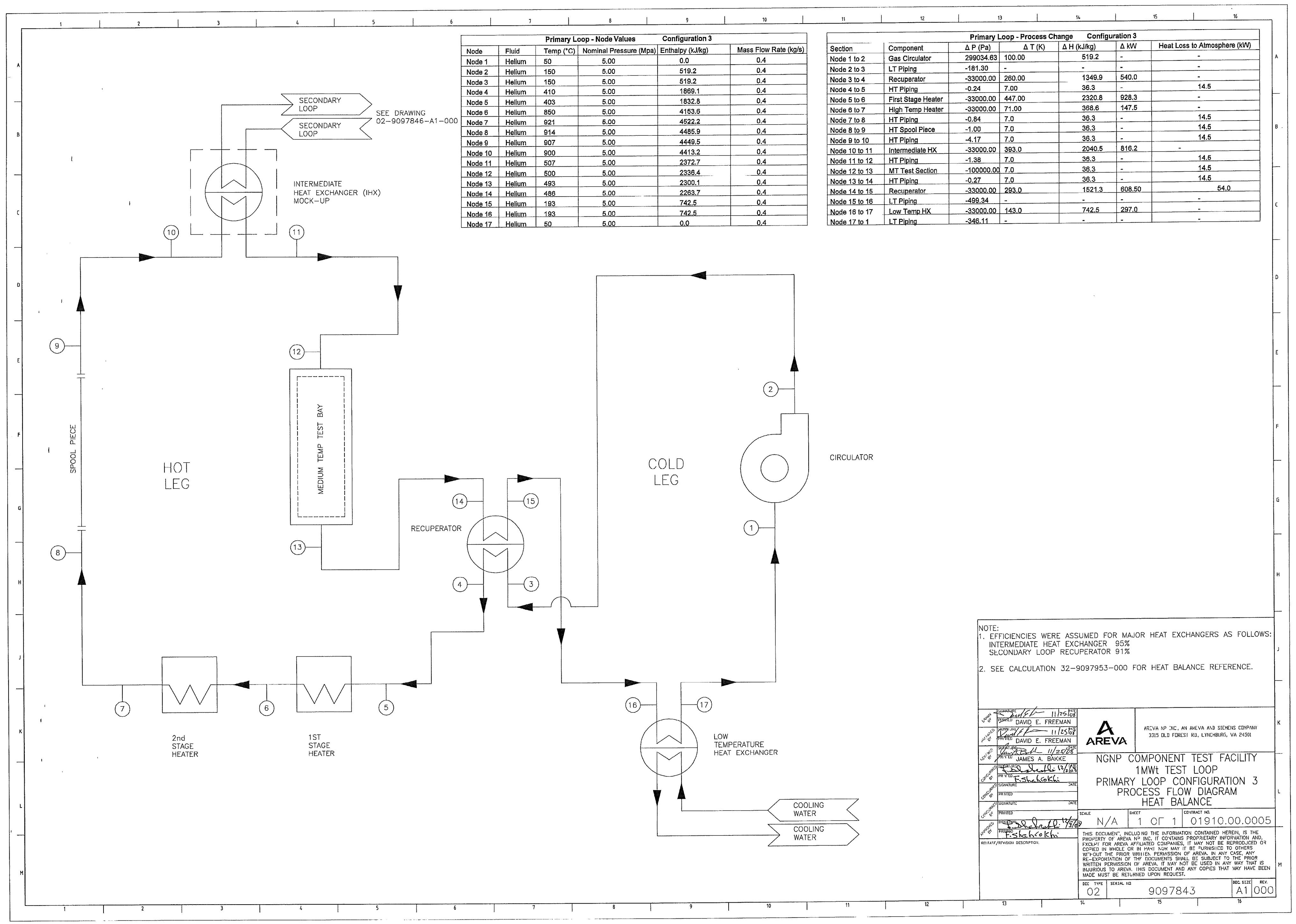
AREVA NP INC., AN AREVA AND SIEMENS COMPANY
3315 OLD FOREST RD., LYNCHBURG, VA 24501

NGNP COMPONENT TEST FACILITY
1MWt TEST LOOP
PRIMARY LOOP CONFIGURATION 2
PROCESS FLOW DIAGRAM
HEAT BALANCE

SCALE N/A | SHEET 1 OF 1 | CONTRACT NO. 01910.00.0005

DOC. TYPE 02 | SERIAL NO. 9097043 | DOC. SIZE A1 | REV. 000

B.6.3 AREVA Drawing 02-9097843-000, NGNP CTF 1 MW Test Loop Secondary Loop, Configuration 3, Process Flow Diagram, Heat Balance



Primary Loop - Node Values		Configuration 3			
Node	Fluid	Temp (°C)	Nominal Pressure (Mpa)	Enthalpy (kJ/kg)	Mass Flow Rate (kg/s)
Node 1	Helium	50	5.00	0.0	0.4
Node 2	Helium	150	5.00	519.2	0.4
Node 3	Helium	150	5.00	519.2	0.4
Node 4	Helium	410	5.00	1869.1	0.4
Node 5	Helium	403	5.00	1832.8	0.4
Node 6	Helium	850	5.00	4153.6	0.4
Node 7	Helium	921	5.00	4522.2	0.4
Node 8	Helium	914	5.00	4485.9	0.4
Node 9	Helium	907	5.00	4449.5	0.4
Node 10	Helium	900	5.00	4413.2	0.4
Node 11	Helium	507	5.00	2372.7	0.4
Node 12	Helium	500	5.00	2336.4	0.4
Node 13	Helium	493	5.00	2300.1	0.4
Node 14	Helium	486	5.00	2263.7	0.4
Node 15	Helium	193	5.00	742.5	0.4
Node 16	Helium	193	5.00	742.5	0.4
Node 17	Helium	50	5.00	0.0	0.4

Primary Loop - Process Change				Configuration 3		
Section	Component	Δ P (Pa)	Δ T (K)	Δ H (kJ/kg)	Δ kW	Heat Loss to Atmosphere (kW)
Node 1 to 2	Gas Circulator	299034.63	100.00	519.2	-	-
Node 2 to 3	LT Piping	-181.30	-	-	-	-
Node 3 to 4	Recuperator	-33000.00	260.00	1349.9	540.0	-
Node 4 to 5	HT Piping	-0.24	7.00	36.3	-	14.5
Node 5 to 6	First Stage Heater	-33000.00	447.00	2320.8	928.3	-
Node 6 to 7	High Temp Heater	-33000.00	71.00	368.6	147.5	-
Node 7 to 8	HT Piping	-0.84	7.0	36.3	-	14.5
Node 8 to 9	HT Spool Piece	-1.00	7.0	36.3	-	14.5
Node 9 to 10	HT Piping	-4.17	7.0	36.3	-	14.5
Node 10 to 11	Intermediate HX	-33000.00	393.0	2040.5	816.2	-
Node 11 to 12	HT Piping	-1.38	7.0	36.3	-	14.5
Node 12 to 13	MT Test Section	-100000.00	7.0	36.3	-	14.5
Node 13 to 14	HT Piping	-0.27	7.0	36.3	-	14.5
Node 14 to 15	Recuperator	-33000.00	293.0	1521.3	608.50	54.0
Node 15 to 16	LT Piping	-499.34	-	-	-	-
Node 16 to 17	Low Temp HX	-33000.00	143.0	742.5	297.0	-
Node 17 to 1	LT Piping	-346.11	-	-	-	-

NOTE:
1. EFFICIENCIES WERE ASSUMED FOR MAJOR HEAT EXCHANGERS AS FOLLOWS:
INTERMEDIATE HEAT EXCHANGER 95%
SECONDARY LOOP RECUPERATOR 91%

2. SEE CALCULATION 32-9097953-000 FOR HEAT BALANCE REFERENCE.

DRAWN BY: DAVID E. FREEMAN 11/25/08
PREPARED BY: DAVID E. FREEMAN 11/25/08
REVIEWED BY: JAMES A. BAKKE 11/25/08
CONCURRED BY: F. Shahrokhi 12/2/08
APPROVED BY: F. Shahrokhi 12/3/08
RELEASE/REVISION DESCRIPTION.

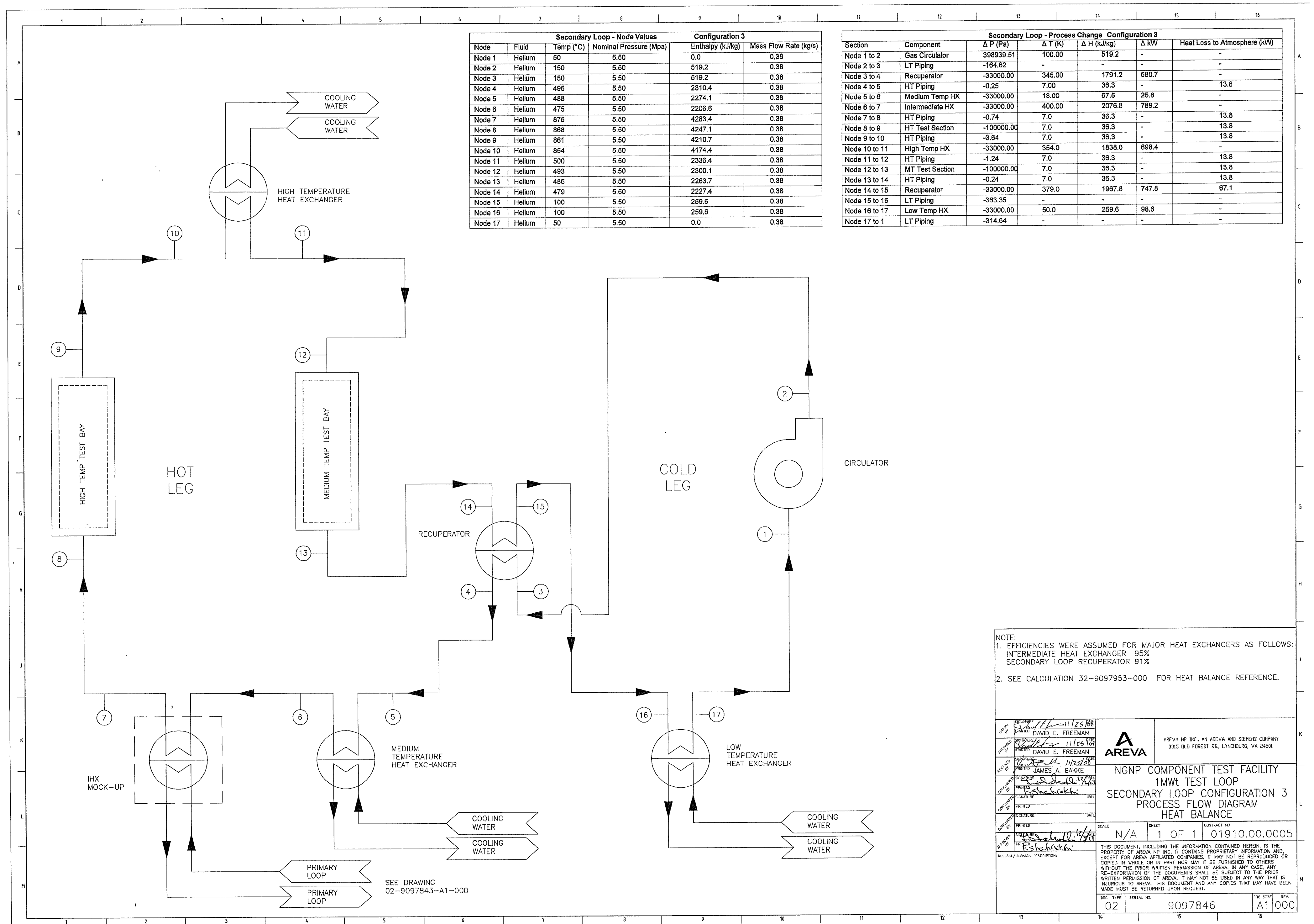
AREVA
AREVA NP INC., AN AREVA AND SIEMENS COMPANY
3315 OLD FOREST RD., LYNCHBURG, VA 24501

NGNP COMPONENT TEST FACILITY
1MWt TEST LOOP
PRIMARY LOOP CONFIGURATION 3
PROCESS FLOW DIAGRAM
HEAT BALANCE

SCALE N/A | SHEET 1 OF 1 | CONTRACT NO. 01910.00.0005

DOC TYPE 02 | SERIAL NO 9097843 | DOC. SIZE A1 | REV. 000

B.6.4 AREVA Drawing 02-9097846-000, NGNP CTF 1 MW Test Loop Secondary Loop Configuration 3 Process Flow Diagram Heat Balance



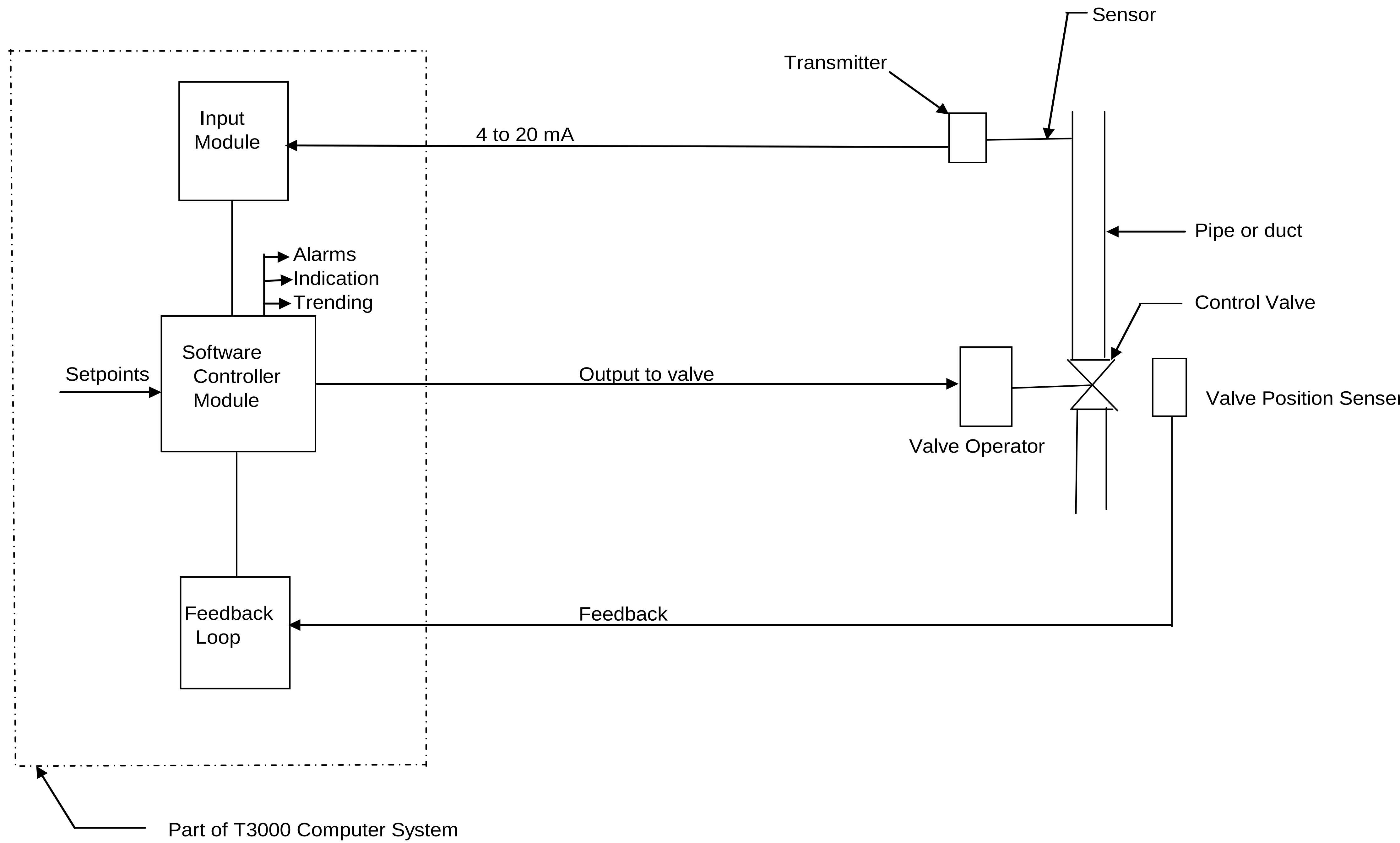
Secondary Loop - Node Values Configuration 3

Node	Fluid	Temp (°C)	Nominal Pressure (Mpa)	Enthalpy (kJ/kg)	Mass Flow Rate (kg/s)
Node 1	Helium	50	5.50	0.0	0.38
Node 2	Helium	150	5.50	519.2	0.38
Node 3	Helium	150	5.50	519.2	0.38
Node 4	Helium	495	5.50	2310.4	0.38
Node 5	Helium	488	5.50	2274.1	0.38
Node 6	Helium	475	5.50	2206.6	0.38
Node 7	Helium	875	5.50	4283.4	0.38
Node 8	Helium	868	5.50	4247.1	0.38
Node 9	Helium	861	5.50	4210.7	0.38
Node 10	Helium	854	5.50	4174.4	0.38
Node 11	Helium	500	5.50	2336.4	0.38
Node 12	Helium	493	5.50	2300.1	0.38
Node 13	Helium	486	5.50	2263.7	0.38
Node 14	Helium	479	5.50	2227.4	0.38
Node 15	Helium	100	5.50	259.6	0.38
Node 16	Helium	100	5.50	259.6	0.38
Node 17	Helium	50	5.50	0.0	0.38

Secondary Loop - Process Change Configuration 3

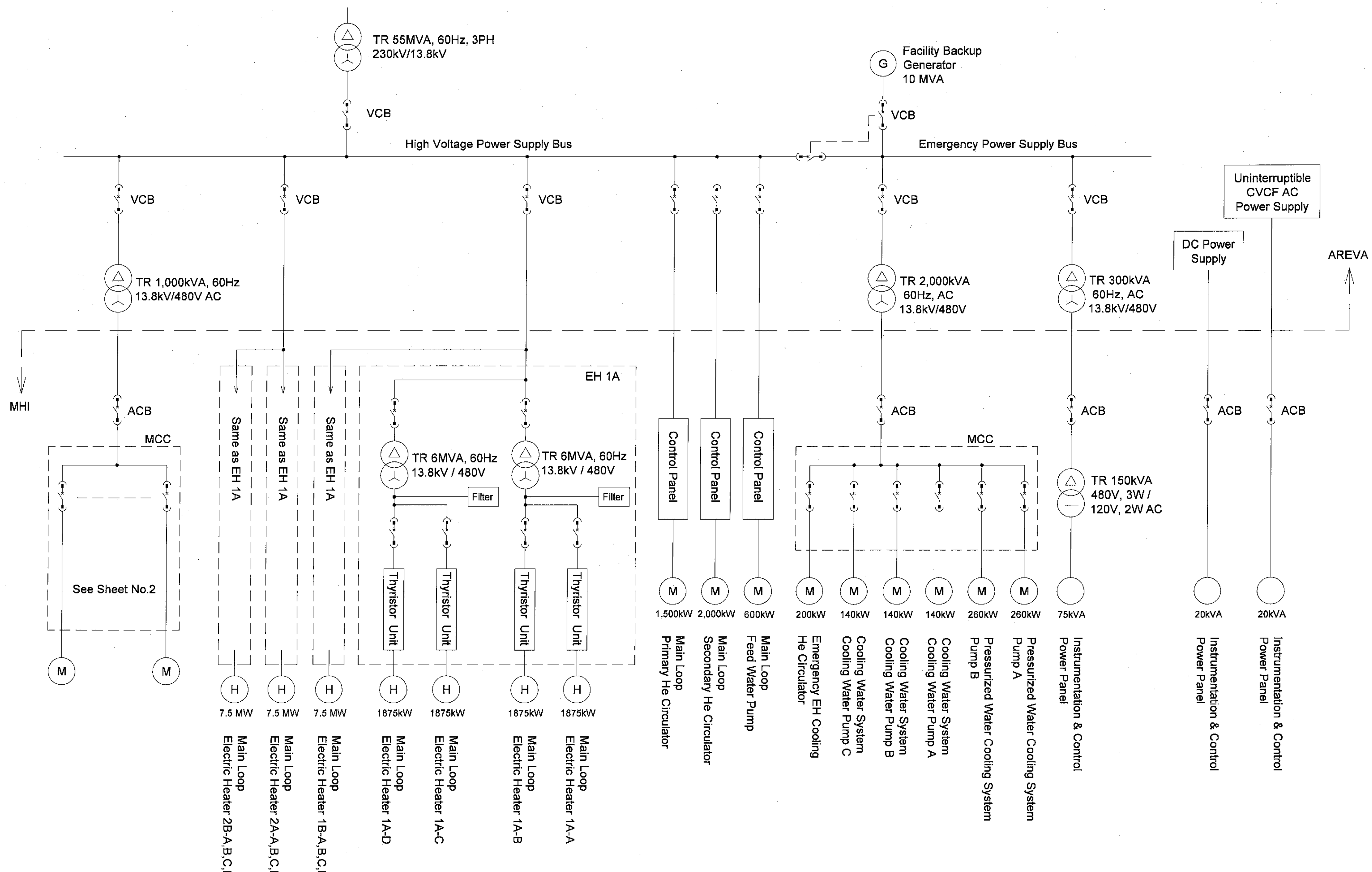
Section	Component	Δ P (Pa)	Δ T (K)	Δ H (kJ/kg)	Δ kW	Heat Loss to Atmosphere (kW)
Node 1 to 2	Gas Circulator	398939.51	100.00	519.2	-	-
Node 2 to 3	LT Piping	-164.82	-	-	-	-
Node 3 to 4	Recuperator	-33000.00	345.00	1791.2	680.7	-
Node 4 to 5	HT Piping	-0.25	7.00	36.3	-	13.8
Node 5 to 6	Medium Temp HX	-33000.00	13.00	67.5	25.6	-
Node 6 to 7	Intermediate HX	-33000.00	400.00	2076.8	789.2	-
Node 7 to 8	HT Piping	-0.74	7.0	36.3	-	13.8
Node 8 to 9	HT Test Section	-100000.00	7.0	36.3	-	13.8
Node 9 to 10	HT Piping	-3.64	7.0	36.3	-	13.8
Node 10 to 11	High Temp HX	-33000.00	354.0	1838.0	698.4	-
Node 11 to 12	HT Piping	-1.24	7.0	36.3	-	13.8
Node 12 to 13	MT Test Section	-100000.00	7.0	36.3	-	13.8
Node 13 to 14	HT Piping	-0.24	7.0	36.3	-	13.8
Node 14 to 15	Recuperator	-33000.00	379.0	1967.8	747.8	67.1
Node 15 to 16	LT Piping	-363.35	-	-	-	-
Node 16 to 17	Low Temp HX	-33000.00	50.0	259.6	98.6	-
Node 17 to 1	LT Piping	-314.64	-	-	-	-

B.6.5 Typical Loop Control Diagram

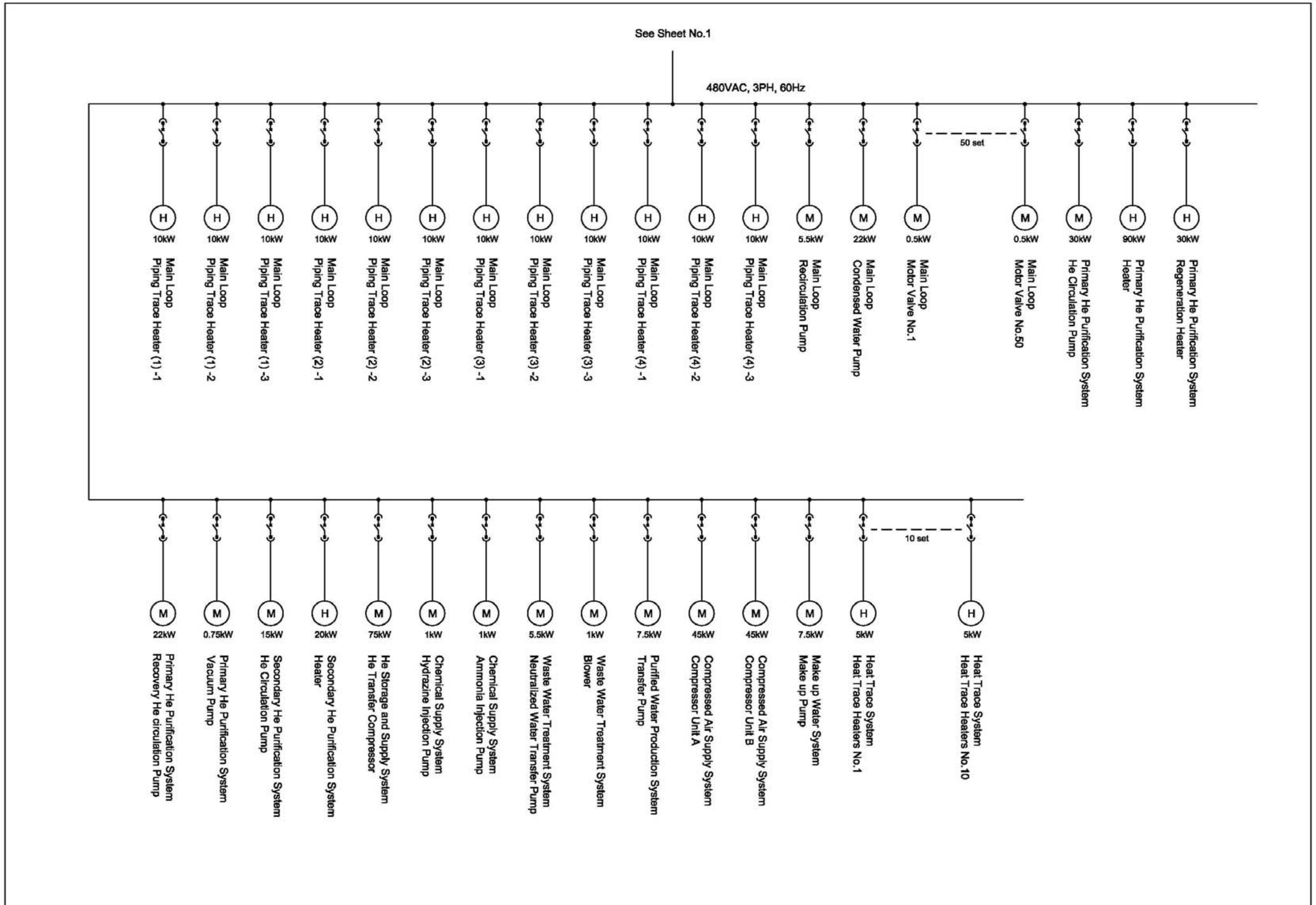


B.7 Design Drawings for 30 MWt Test Loop (MHI)

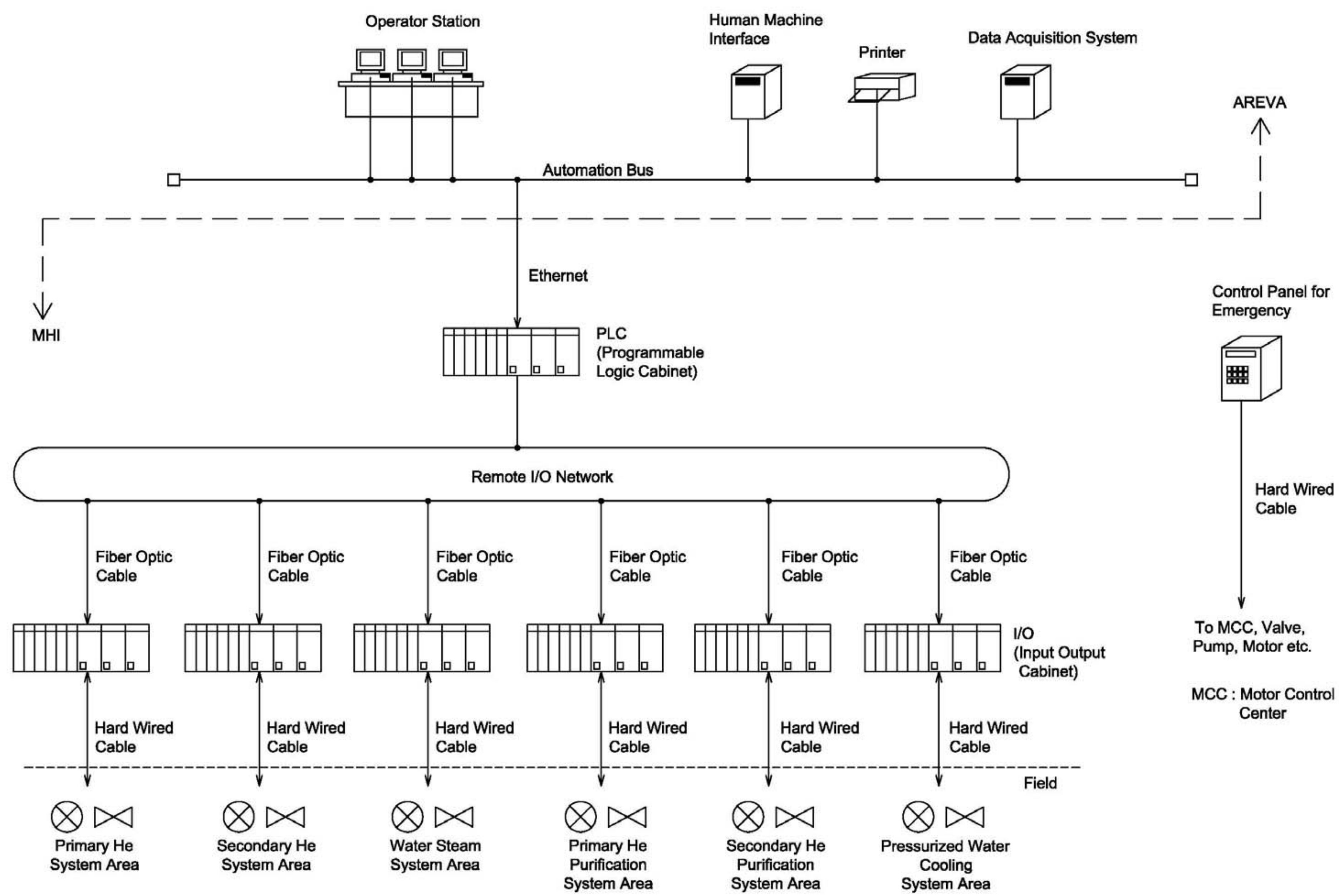
One Line Electrical Schematic (1/2)



One Line Electrical Schematic (2/2)



One-Line Instrumentation Schematic



30 MWt Test Loop P&ID

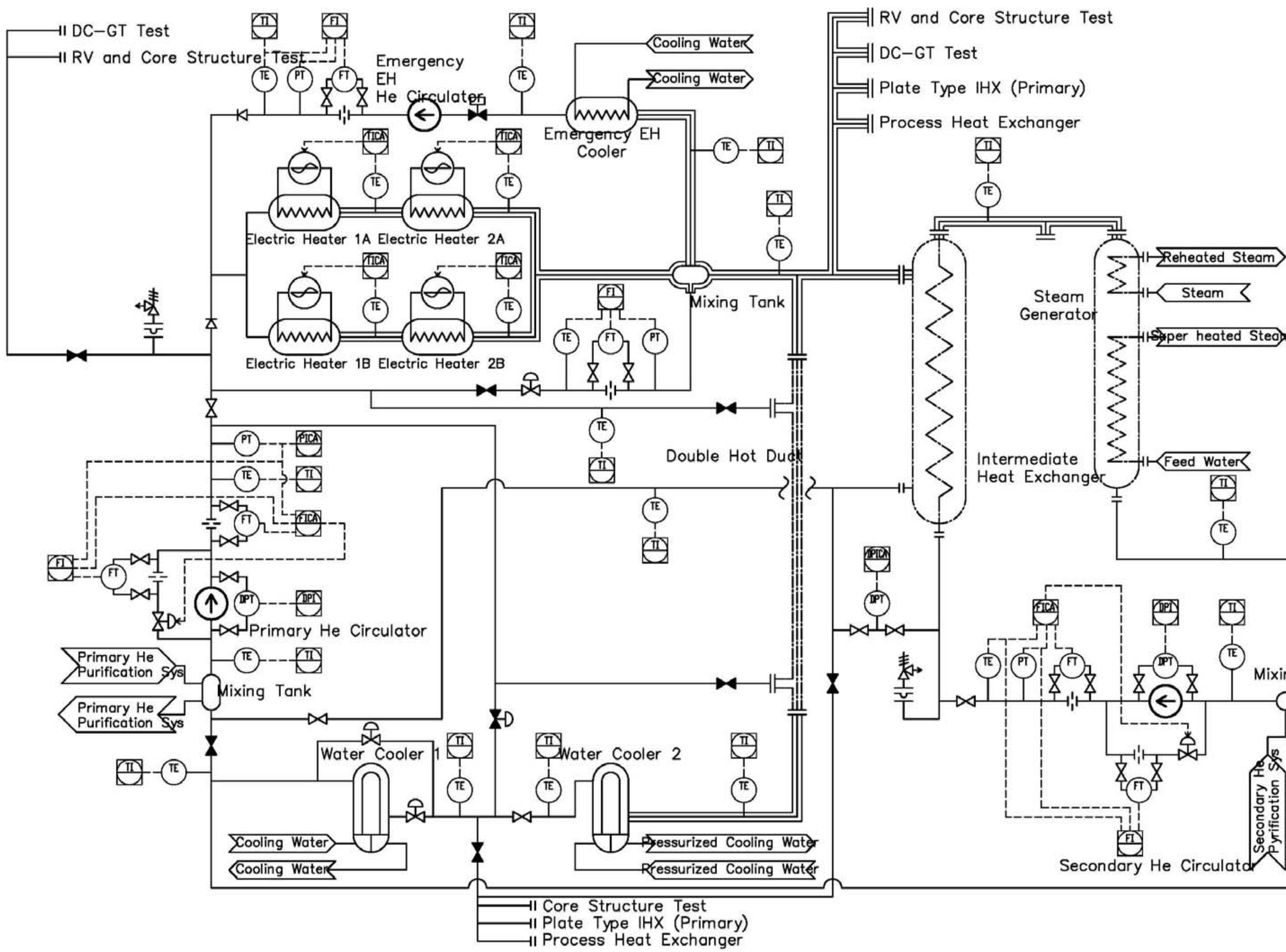
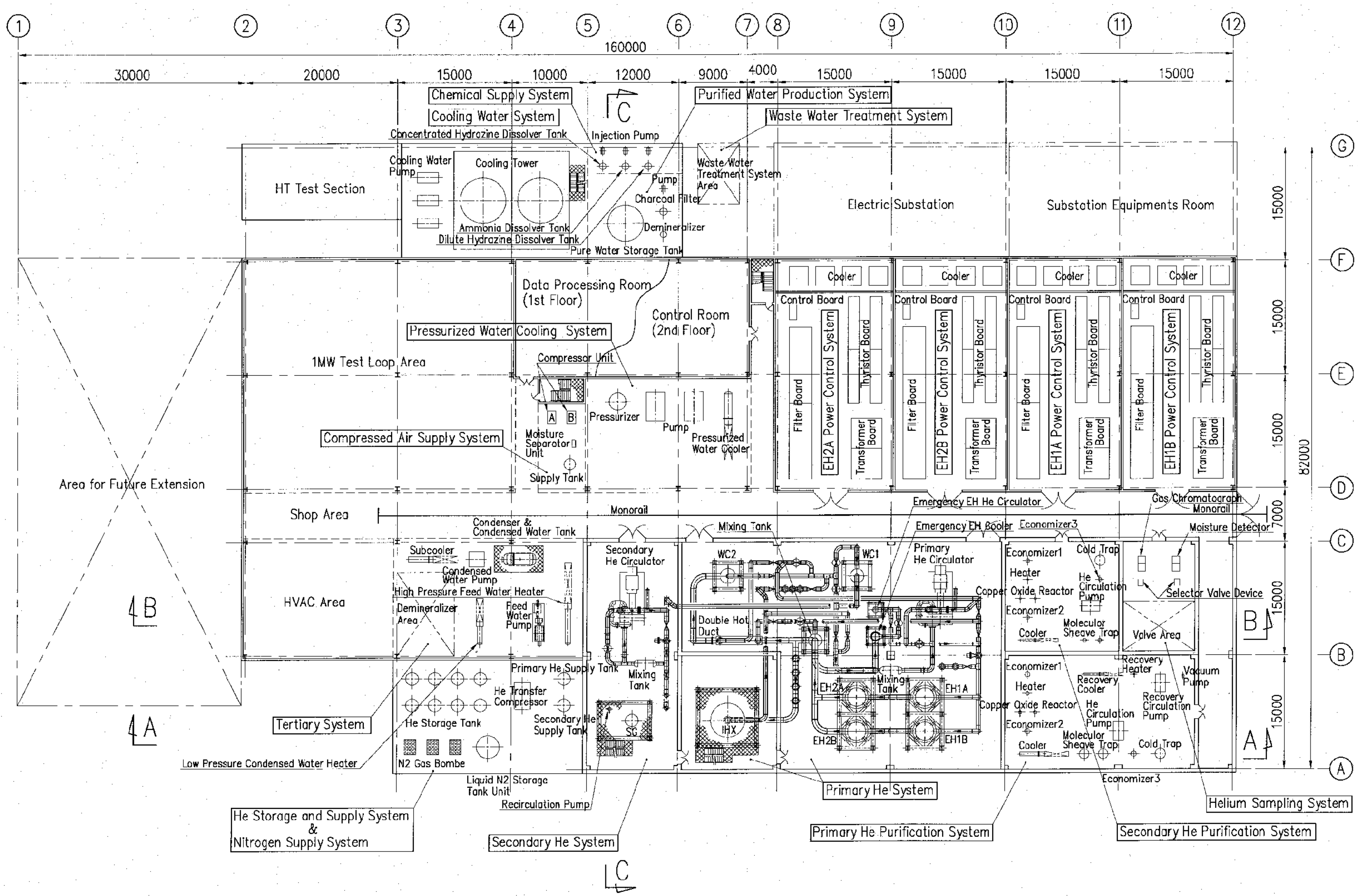
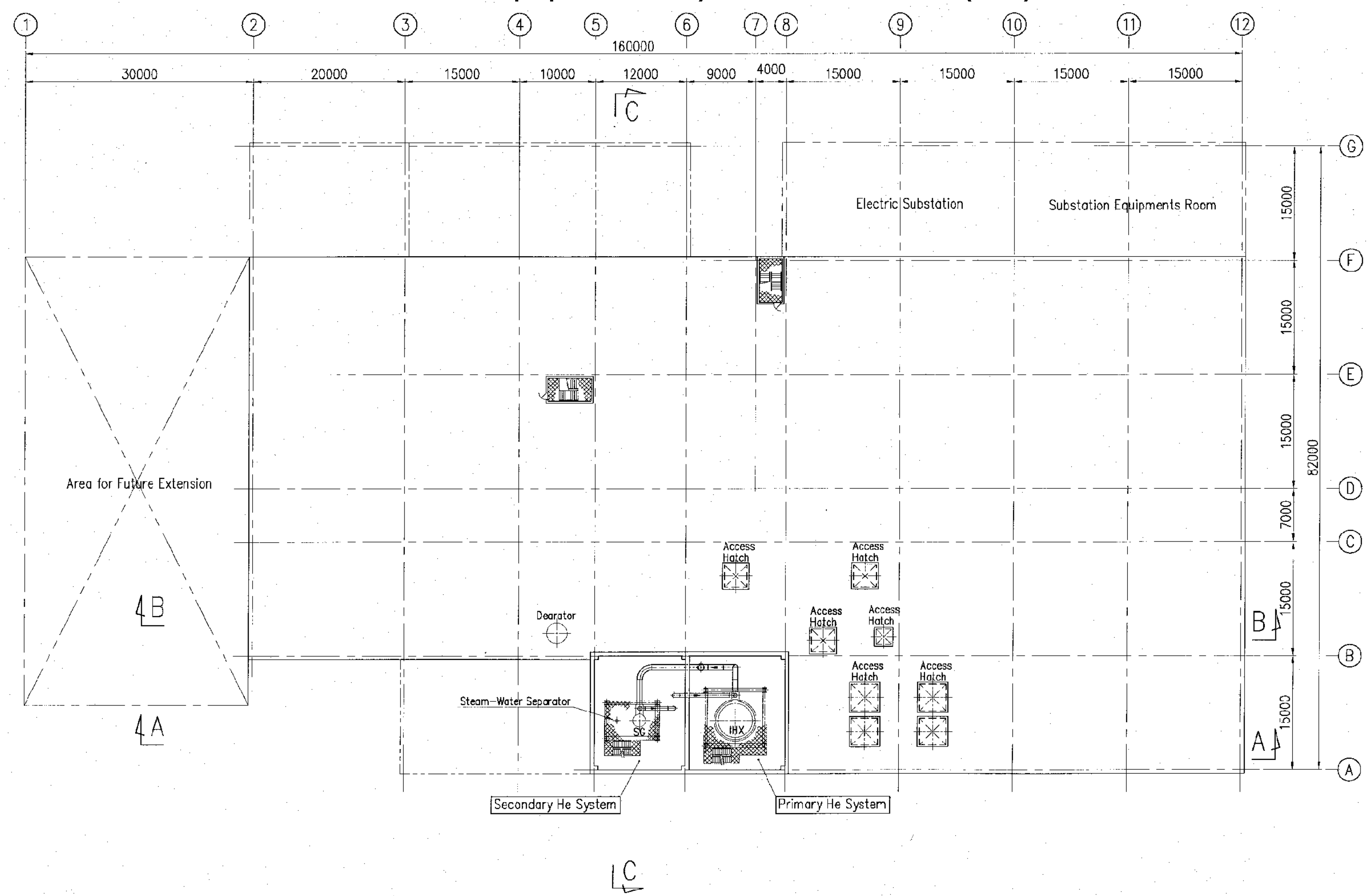


Figure 7.1–13 P & ID of Main He Loop

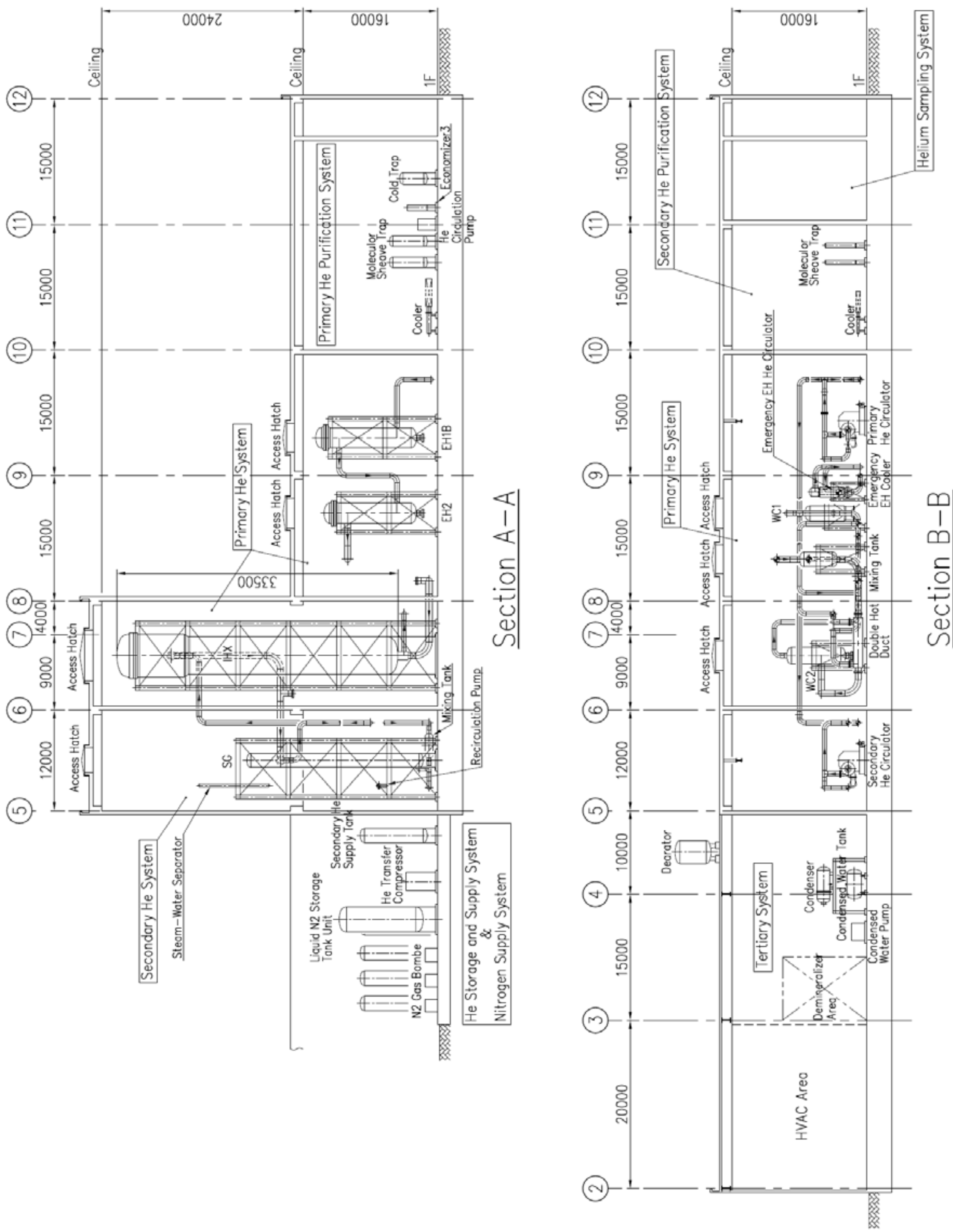
Equipment Layout (1FL – 2FL)



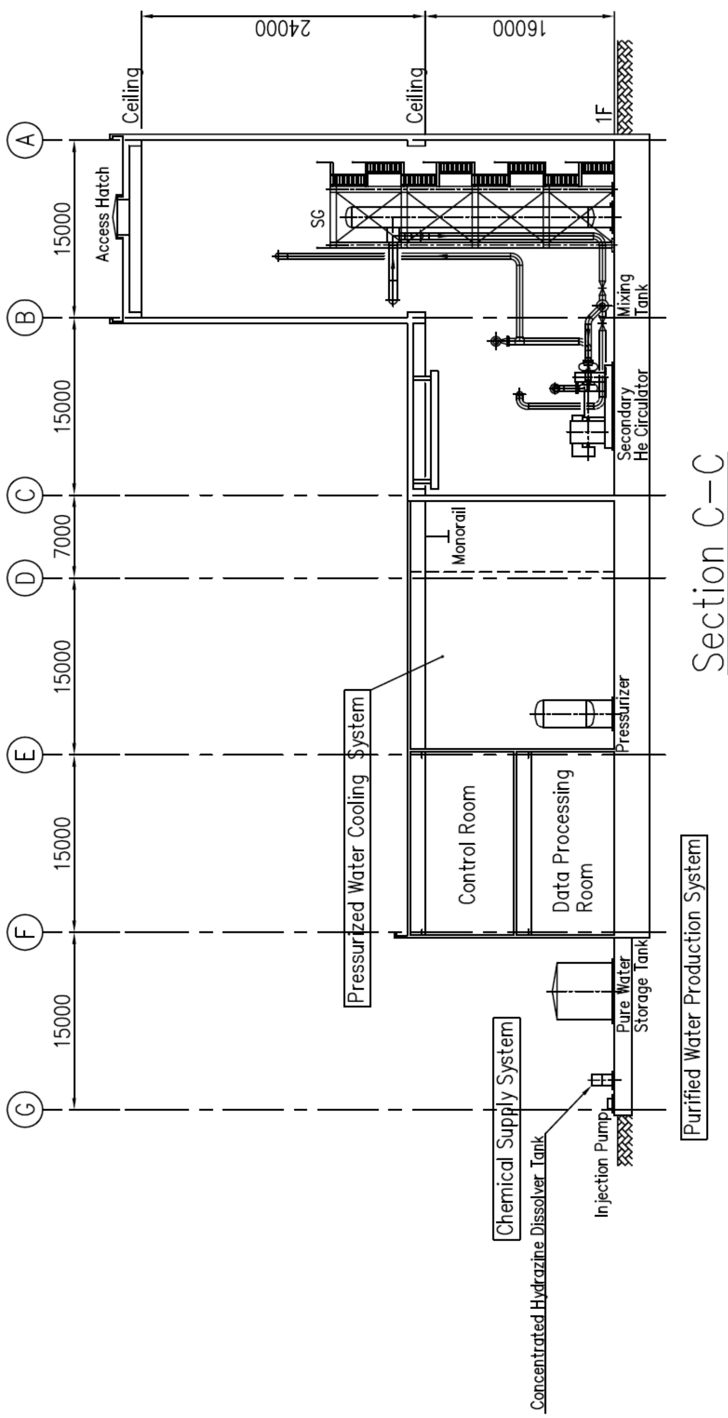
Equipment Layout – Plan View (RF)



Equipment Layout - Sections and Elevations



Equipment Layout - Sections and Elevations



APPENDIX C: DETAIL COMPONENT LIST

C.1 1 MWt Loop Component List

C.1.1 Mechanical Components

Component	Type	Quantity	Size (mm)	Fluid	Flow rate (kg/s)	Capacity (MW)	Design Temp (°C)	Design Press (MPa)	Operating Temp (°C)	Operating Pressure (MPa)	Vendor
Stage 1 Heater	electric	1	∅1400 Height 2130	He	0.4	1.00	950	10	400/850	5	Procured by AREVA NP
Stage 2 Heater	electric	1	∅1400 Height 2130	He	0.4	0.400	1100	10	850/1000	5	Procured by AREVA NP
High Temperature Heat Exchanger	shell-and-tube helical	2	∅ 1500 Height 3000	He/Water	He: 0.4 Water: TBD	0.830	1100	10	He: 1000/600 Water: TBD	5	Standard equipment
Medium Temperature Heat Exchanger	shell-and-tube helical	1	∅ 1500 Height 3000	He/Water	He: 0.4 Water: TBD	0.100	600	10	He: 470/420 Water: TBD	5	Standard equipment
Low Temperature Heat Exchanger	shell-and-tube U-tube	2	∅ 1500 Height 3000	He/Water	He: 0.4 Water: TBD	0.400	300	10	He: 200/50 Water: TBD	5	Standard equipment
Recuperator Heat Exchanger	shell-and-tube helical	2	∅ 1500 Height 3000	He/He	0.4	0.800	500	10	He: 500/150 He: 150/500	5	Standard equipment
High Temp Piping	internal/external insulation single pipe	TBD	DN 500	He	0.4	n/a	1100	10	1000	5	Procured by AREVA NP

Component	Type	Quantity	Size (mm)	Fluid	Flow rate (kg/s)	Capacity (MW)	Design Temp (°C)	Design Press (MPa)	Operating Temp (°C)	Operating Pressure (MPa)	Vendor
Low Temp Piping	external insulation single pipe	TBD	DN100	He	0.4	n/a	600	10	500	5	Standard equipment
Primary Gas Circulator	Centrifugal Immersed motor	1	TBD	He	0.1 to 1.0	TBD	150	10	50	5	Procured by AREVA NP
Secondary Gas Circulator	Centrifugal Immersed motor	1	TBD	He	0.1 to 1.0	TBD	150	10	50	5	Procured by AREVA NP

C.1.2 Valve List

Tag No.	Description	Function	Operator	Type	Design Pressure MPa	Design Temp °C	Fluid	Operating Pressure MPa	Operating Temp °C
V-1	Recuperator Bypass Valve (Primary Loop)	Isolation	Manual	Ball	10	250	Helium	8	200
V-2	Recuperator Isolation Valve (Primary Loop)	Isolation	Manual	Ball	10	250	Helium	8	200
V-3	Recuperator Isolation Valve (Primary Loop)	Isolation	Manual	Ball	10	250	Helium	8	200
V-4	Cold Leg Relief Valve (Primary Loop)	Relief	n/a	Relief	10	200	Helium	8	150
V-5	Temp Control Line Isolation (Primary Loop)	Isolation	n/a	Spring-Check	10	500	Helium	8	150
V-6	Hot Leg Releif Valve (Primary Loop)	Relief	Spring	Relief	10	1100	Helium	8	1000
V-7	Recuperator Bypass Valve (Secondary Loop)	Isolation	Manual	Ball	10	250	Helium	8	200
V-8	Recuperator Isolation Valve (Secondary Loop)	Isolation	Manual	Ball	10	250	Helium	8	200
V-9	Recuperator Isolation Valve (Secondary Loop)	Isolation	Manual	Ball	10	250	Helium	8	200
V-10	Cold Leg Relief Valve (Secondary Loop)	Relief	n/a	Relief	10	200	Helium	8	150
V-11	Hot Leg Releif Valve (Secondary Loop)	Relief	n/a	Relief	10	1100	Helium	8	1000
V-12	High Temp Test Section Temp Control Line Isolation	Isolation	n/a	Spring-Check	10	1100	Helium	8	150
V-13	High Temp Test Section Inlet Isolation	Isolation	Manual	Ball	10	1100	Helium	8	1000
V-14	High Temp Test Section Outlet Isolation	Isolation	Manual	Ball	10	1100	Helium	8	1000
V-15	Med Temp Test Section Temp Control	Isolation	n/a	Spring-	10	500	Helium	8	150

Tag No.	Description	Function	Operator	Type	Design Pressure MPa	Design Temp °C	Fluid	Operating Pressure MPa	Operating Temp °C
	Line Isolation			Check					
V-16	Med Temp Test Section Inlet Isolation	Isolation	Manual	Ball	10	600	Helium	8	500
V-17	Med Temp Test Section Outlet Isolation	Isolation	Manual	Ball	10	600	Helium	8	500
TCV-1	Med Temp Bay Control Valve (Primary Loop)	Control	Air	Globe	10	200	Helium	8	150
TCV-2	High Temp HX Control Valve (Primary Loop)	Control	Air	Globe	10	100	Water	8	50
TCV-3	Low Temp HX Control Valve (Primary Loop)	Control	Air	Globe	10	100	Water	8	50
TCV-4	High Temp HX Control Valve (Secondary Loop)	Control	Air	Globe	10	100	Water	8	50
TCV-5	Med Temp HX Control Valve (Secondary Loop)	Control	Air	Globe	10	100	Water	8	50
TCV-6	Low Temp HX Control Valve (Secondary Loop)	Control	Air	Globe	10	100	Water	8	50
TCV-7	High Temp Test Section Temperature Control Valve	Control	Air	Globe	10	1100	Helium	8	1000
TCV-8	Med Temp Test Section Temperature Control Valve	Control	Air	Globe	10	600	Helium	8	500
PCV-1	Pressure Control Valve (Primary Loop)	Control	Air	Globe	10	100	Helium	8	50
PCV-2	Pressure Control Valve (Secondary Loop)	Control	Air	Globe	10	100	Helium	8	50
PCV-3	High Temp Test Section Pressure Control Valve	Control	Air	Globe	10	1100	Helium	8	1000
PCV-4	Med Temp Test Section Pressure Control Valve	Control	Air	Globe	10	600	Helium	8	500

Tag No.	Description	Function	Operator	Type	Design Pressure MPa	Design Temp °C	Fluid	Operating Pressure MPa	Operating Temp °C
FCV-1	High Temp Test Section Flow Control Valve	Control	Air	Globe	10	1100	Helium	8	1000
FCV-2	Med Temp Test Section Flow Control Valve	Control	Air	Globe	10	600	Helium	8	500

C.1.3 Instrument List

Tag No.	Function	Parameter	Type	Fluid	Design Pressure MPa	Design Temp °C	Operating Pressure MPa	Operating Temp °C
TE-1	Outlet, Heater Stage 2 **and** Inlet, High Temp Test Section	Temperature	Element	Helium	10	1100	8	1000
TE-2	Inlet, High Temp HX **and** Inlet, IHX Primary	Temperature	Element	Helium	10	1100	8	1000
TE-3	Outlet, High Temp HX **or** Outlet, IHX Primary **and** Inlet, High Temp HX	Temperature	Element	Helium	10	600	8	500
TE-4	Outlet, High Temp HX **or** Outlet, IHX Primary **or** Outlet, IHX Secondary	Temperature	Element	Helium	10	600	8	500
TE-5	Inlet, Med Temp Bay	Temperature	Element	Helium	10	600	8	500
TE-6	Inlet, Recuperator HX **and** Outlet, Circulator	Temperature	Element	Helium	10	200	8	150
TE-7	Outlet, Recuperator HX	Temperature	Element	Helium	10	600	8	500
TE-8	Inlet, Recuperator HX **and** Outlet, Med Temp Bay	Temperature	Element	Helium	10	600	8	500
TE-9	Outlet, Recuperator HX **and** Inlet, Low Temp HX	Temperature	Element	Helium	10	250	8	200
TE-10	Outlet, Low Temp HX **and** Inlet, Circulator	Temperature	Element	Helium	10	100	8	50
TE-11	Outlet, High Temp HX **and** Inlet, IHX Secondary	Temperature	Element	Helium	10	600	8	500
TE-12	Outlet, IHX Secondary	Temperature	Element	Helium	10	1100	8	1000
TE-13	Inlet, High Temp HX	Temperature	Element	Helium	10	1100	8	1000
TE-14	Outlet, High Temp HX **and** Inlet, Med Temp Bay	Temperature	Element	Helium	10	600	8	500

Tag No.	Function	Parameter	Type	Fluid	Design Pressure MPa	Design Temp °C	Operating Pressure MPa	Operating Temp °C
TE-15	Inlet, Recuperator HX **and** Outlet, Med Temp Bay	Temperature	Element	Helium	10	600	8	500
TE-16	Outlet, Recuperator HX **and** Inlet, Low Temp HX	Temperature	Element	Helium	10	250	8	200
TE-17	Outlet, Low Temp HX **and** Inlet, Circulator	Temperature	Element	Helium	10	100	8	50
TE-18	Inlet, Recuperator **and** Outlet, Circulator	Temperature	Element	Helium	10	200	8	150
TE-19	Outlet, Recuperator **and** Inlet, Med Temp HX	Temperature	Element	Helium	10	600	8	500
TE-20	Outlet, Heater Stage 1	Temperature	Element	Helium	10	950	8	850
TE-21	Outlet, Med Temp HX **and** Inlet, IHX Secondary	Temperature	Element	Helium	10	600	8	500
TE-22	Inlet, High Temp Test Section	Temperature	Element	Helium	10	1100	8	1000
TE-23	Inlet, Med Temp Test Section	Temperature	Element	Helium	10	600	8	500
PE-1	Outlet, Heater Stage 2 **and** Inlet, High Temp Test Section	Pressure	Element	Helium	10	1100	8	1000
PE-2	Inlet, High Temp HX **and** Inlet, IHX Primary	Pressure	Element	Helium	10	1100	8	1000
PE-3	Outlet, High Temp HX **or** Outlet, IHX Primary / Inlet, High Temp HX	Pressure	Element	Helium	10	600	8	500
PE-4	Outlet, High Temp HX **or** Outlet, IHX Primary **or** Outlet, IHX Secondary	Pressure	Element	Helium	10	600	8	500
PE-5	Inlet, Med Temp Bay	Pressure	Element	Helium	10	600	8	500
PE-6	Inlet, Recuperator HX **and** Outlet, Circulator	Pressure	Element	Helium	10	200	8	150
PE-7	Outlet, Recuperator HX	Pressure	Element	Helium	10	600	8	500

Tag No.	Function	Parameter	Type	Fluid	Design Pressure MPa	Design Temp °C	Operating Pressure MPa	Operating Temp °C
PE-8	Inlet, Recuperator HX **and** Outlet, Med Temp Bay	Pressure	Element	Helium	10	600	8	500
PE-9	Outlet, Recuperator HX **and** Inlet, Low Temp HX	Pressure	Element	Helium	10	250	8	200
PE-10	Outlet, Low Temp HX **and** Inlet, Circulator	Pressure	Element	Helium	10	100	8	50
PE-11	Outlet, High Temp HX **and** Inlet, IHX Secondary	Pressure	Element	Helium	10	600	8	500
PE-12	Outlet, IHX Secondary	Pressure	Element	Helium	10	1100	8	1000
PE-13	Inlet, High Temp HX	Pressure	Element	Helium	10	1100	8	1000
PE-14	Outlet, High Temp HX **and** Inlet, Med Temp Bay	Pressure	Element	Helium	10	600	8	500
PE-15	Inlet, Recuperator HX **and** Outlet, Med Temp Bay	Pressure	Element	Helium	10	600	8	500
PE-16	Outlet, Recuperator HX **and** Inlet, Low Temp HX	Pressure	Element	Helium	10	250	8	200
PE-17	Outlet, Low Temp HX **and** Inlet, Circulator	Pressure	Element	Helium	10	100	8	50
PE-18	Inlet, Recuperator **and** Outlet, Circulator	Pressure	Element	Helium	10	200	8	150
PE-19	Outlet, Recuperator **and** Inlet, Med Temp HX	Pressure	Element	Helium	10	600	8	500
PE-20	Outlet, Heater Stage 1	Pressure	Element	Helium	10	600	8	500
PE-21	Outlet, Med Temp HX **and** Inlet, IHX Secondary	Pressure	Element	Helium	10	600	8	500
PE-22	Inlet, High Temp Test Section	Pressure	Element	Helium	10	1100	8	1000
PE-23	Inlet, Med Temp Test Section	Pressure	Element	Helium	10	600	8	500

Tag No.	Function	Parameter	Type	Fluid	Design Pressure MPa	Design Temp °C	Operating Pressure MPa	Operating Temp °C
FE-1	Outlet, Circulator	Flow	Element	Helium	10	200	8	150
FE-2	Outlet, Circulator	Flow	Element	Helium	10	200	8	150
FE-3	Inlet, High Temp Test Section	Flow	Element	Helium	10	1100	8	1000
FE-4	Inlet, Med Temp Test Section	Flow	Element	Helium	10	600	8	500

C.2 30 MWt Loop Component List

C.2.1 Primary Loop Components

Primary Loop

ID No.	Component	Function	number of Unit	Size D(m)×L(m)	Fluid	Flow rate (kg/s)	Capacity (MWt)	Design Condition of Vessel				Operating Condition of Vessel				Remarks
								Internal Press.		External Press.		Internal Press.		External Press.		
								Temp. ( )	Press. (MPa)	Temp. ( )	Press. (MPa)	Temp. ( )	Press. (MPa)	Temp. ( )	Press. (MPa)	
EH1	Electric Heater 1	Helium heating	2	2.43×12	Helium	10	7.5	350	8.4	40	0.1	100	7.02	40	0.1	
EH2	Electric Heater 2	Helium heating	2	2.43×11	Helium	10	7.5	350	8.4	40	0.1	100	7.01	40	0.1	
WC1	Water Cooler 1	Helium coolimg	1	1.78×5.8	Helium	10	5	350	9	40	0.1	100	7.49	40	0.1	
WC2	Water Cooler 2	Helium coolimg	1	1.98×7	Helium	10	25	350	9	40	0.1	100	7.5	40	0.1	
IHX	Inter mediate Heat Exchanger 'tubular type)	Gas/Gas heat exchanging	1	-	Helium	10	30	350	9	40	0.1	100	7	40	0.1	
PHC	Primary☐Helium Circulator	Helium circulation	1	4.8(W)×8(L)×3.5(H)	Helium	13.8	-	530	8.4	40	0.1	499	5.02	40	0.1	

C.2.2 Secondary Loop Components

Secondary Loop

ID No.	Component	Function	number of Unit	Size D(m)×L(m)	Fluid	Flow rate (kg/s)	Capacity (MWt)	Design Condition of Vessel				Operating Condition of Vessel				Remarks
								Internal Press.		External Press.		Internal Press.		External Press.		
								Temp. ( )	Press. (MPa)	Temp. ( )	Press. (MPa)	Temp. ( )	Press. (MPa)	Temp. ( )	Press. (MPa)	
SG	Steam Generator	Generation of steam	1	-	Helium/Water/ Steam	Helium: 13.8 Water : 11.6	30	350	6.6	40	0.1	100	5.5	40	0.1	
SHC	Secondary Herium Circulator	Helium circulation	1	4.8(W)×8(L)×3.5(H)	Helium	13.8	-	450	9	40	0.1	422	7.7	40	0.1	

C.2.3 Tertiary Loop Components

Tertiary System

ID No.	Component	Function	number of Unit	Fluid	Remarks
-	Condenser	Condensate of steam	1	Steam /Water	
-	Condensed Water Tank	Storage of condensed water	1	Water	
-	Condensed Water Pump	Circulation of condensed water	1	Water	
-	Feed Water Pump	Injection of feed water	1	Water	
-	Recirculation Pump	Recirculation of saturated water	1	Water	
-	Subcooler	Cooling of condensed water	1	Water	
-	Demineralizer	Purificatin of condensed water	1	Water	
-	Dearator	Release of gas	1	Steam /Water	
-	Low Pressure Condensed Water Heater	Heat up of condensed water	1	Water	
-	High Pressure Feed Water Heater	Heat up of feed water	1	Water	
-	Steam-Water Separator	Separation of water and steam	1	Water	

C.2.4 Primary Helium Purification System Components

Location: Primary He Purification System

ID No.	Component	Function	number of Unit	Size D(m)×L(m)	Fluid	Flow rate (g/s)	Capacity (kWt)	Design Condition of Vessel				Operating Condition of Vessel				Remarks
								Internal Press.		External Press.		Internal Press.		External Press.		
								Temp. (℃)	Press. (MPa)	Temp. (℃)	Press. (MPa)	Temp. (℃)	Press. (MPa)	Temp. (℃)	Press. (MPa)	
-	Economizer 1	Heat of charge of inlet and outlet He	1	TBD	Helium	45	53	520	8.4	40	0.1	490	4.9	40	0.1	
-	Heater	Heating He	1	TBD	Helium	45	42	330	8.4	40	0.1	300	4.88	40	0.1	
-	Copper Oxide Reactor	Oxidation of CO and H_2	2	TBD	Helium	45	-	330	8.4	40	0.1	300	4.86	40	0.1	
-	Economizer 2	Heat of charge of inlet and outlet He	1	TBD	Helium	45	70	330	8.4	40	0.1	300	4.84	40	0.1	
-	Cooler	Cooling of He	1	TBD	Helium	45	10	60	8.4	40	0.1	50	4.82	40	0.1	
-	Molecular Shave Trap	Absorption of H_2O and CO_2	2	TBD	Helium	45	-	330	8.4	40	0.1	15	4.8	40	0.1	
-	Economizer 3	Heat of charge of inlet and outlet He	1	TBD	Helium	45	56	60	8.4	40	0.1	15	4.74	40	0.1	
-	Cold Trap	Absorption of CH_4 ,O_2 and N_2	1	TBD	Helium	45	3	60	8.4	40	0.1	-195	4.72	40	0.1	
-	He Circulation Pump	Circulation of He	1	TBD	Helium	45	-	60	8.4	40	0.1	10	4.94	40	0.1	

C.2.5 Secondary Helium Purification System

Location: Secondary He Purification System

ID No.	Component	Function	number of Unit	Size D(m)×L(m)	Fluid	Flow rate (g/s)	Capacity (kWt)	Design Condition of Vessel				Operating Condition of Vessel				Remarks
								Internal Press.		External Press.		Internal Press.		External Press.		
								Temp. (℃)	Press. (MPa)	Temp. (℃)	Press. (MPa)	Temp. (℃)	Press. (MPa)	Temp. (℃)	Press. (MPa)	
-	Economizer 1	Heat of charge of inlet and outlet He	1	TBD	Helium	6.7	4.4	435	9	40	0.1	405	5.4	40	0.1	
-	Heater	Heating He	1	TBD	Helium	6.7	6.3	330	9	40	0.1	300	5.38	40	0.1	
-	Copper Oxide Reactor	Oxidation of CO and H_2	2	TBD	Helium	6.7	-	330	9	40	0.1	300	5.36	40	0.1	
-	Economizer 2	Heat of charge of inlet and outlet He	1	TBD	Helium	6.7	11	330	9	40	0.1	300	5.34	40	0.1	
-	Cooler	Cooling of He	1	TBD	Helium	6.7	1.5	60	9	40	0.1	50	5.32	40	0.1	
-	Molecular Shave Trap	Absorption of H_2O and CO_2	2	TBD	Helium	6.7	-	330	9	40	0.1	15	5.3	40	0.1	
-	Economizer 3	Heat of charge of inlet and outlet He	1	TBD	Helium	6.7	8.3	60	9	40	0.1	15	5.24	40	0.1	
-	Cold Trap	Absorption of CH_4 ,O_2 and N_2	1	TBD	Helium	6.7	0.5	60	9	40	0.1	-195	5.22	40	0.1	
-	He Circulation Pump	Circulation of He	1	TBD	Helium	6.7	-	60	9	40	0.1	10	5.44	40	0.1	

C.2.6 Helium Storage and Supply System Components

Location: He Storage and Supply System

ID No.	Component	Function	number of Unit	Size D(m)×L(m)	Fluid	Flow rate (g/s)	Capacity (m3)	Design Condition of Vessel				Operating Condition of Vessel				Remarks
								Internal Press.		External Press.		Internal Press.		External Press.		
								Temp. (ỹ)	Press. (MPa)	Temp. (ỹ)	Press. (MPa)	Temp. (ỹ)	Press. (MPa)	Temp. (ỹ)	Press. (MPa)	
-	Primary He Supply Tank	Storage of supply He	1	TBD	Helium	9	9	70	16.5	40	0.1	40	15	40	0.1	
-	He Transfer Compressor	He transfer	1	TBD	Helium	12	-	70	16.5	40	0.1	40	15	40	0.1	
-	Secondary He Supply Tank	Storage of supply He	1	TBD	Helium	3	9	70	16.5	40	0.1	40	15	40	0.1	
-	He Storage Tank	Storage of total He inventory	8	TBD	Helium	TBD	72	70	16.5	40	0.1	40	15	40	0.1	

C.2.7 Cooling Water System Components

Location:Pressurized Water Cooling System

ID No.	Component	Function	number of Unit	Size D(m)×L(m)	Fluid	Flow rate (kg/s)	Capacity (MWt)	Design Condition of Vessel				Operating Condition of Vessel				Remarks
								Internal Press.		External Press.		Internal Press.		External Press.		
								Temp. (ỹ)	Press. (MPa)	Temp. (ỹ)	Press. (MPa)	Temp. (ỹ)	Press. (MPa)	Temp. (ỹ)	Press. (MPa)	
-	Pressurized Water Cooler	Cooling of pressurized water	1	TBD	water	118	25	180	9	40	0.1	150	7.2	40	0.1	
-	Rercerculation Pump	Rercerculation of pressurized water	2	TBD	water	118	-	130	9	40	0.1	100	7	40	0.1	
-	Pressurizer	Pressurization of System	1	TBD	water	-	-	130	9	40	0.1	100	7	40	0.1	

Location: Cooling Water System

ID No.	Component	Function	number of Unit	Size D(m)×L(m)	Fluid	Flow rate (kg/s)	Capacity (MWt)	Design Condition of Vessel				Operating Condition of Vessel				Remarks
								Internal Press.		External Press.		Internal Press.		External Press.		
								Temp. (ỹ)	Press. (MPa)	Temp. (ỹ)	Press. (MPa)	Temp. (ỹ)	Press. (MPa)	Temp. (ỹ)	Press. (MPa)	
-	Cooling Tower	Cooling of coolling water	1	TBD	water	952	36.3	70	0.1	40	0.1	40	0.1	40	0.1	
-	Cooling Water Pump	Rercerculation of cooling water	3	TBD	water	952	-	70	1	40	0.1	30	0.45	40	0.1	

C.2.8 Helium Sampling System Components

Helium Sampling System

ID No.	Component	Function	number of Unit	Fluid	Remarks
-	Selector Valve Device	Selection of sampling point	2	Helium	
-	Gas Chromatograph	Analizer of impurity in He	1	Helium	
-	Moisture Detector	Detection of moisture	1	Helium	
-	Sampler	Sampling of He	1	Helium	

C.2.9 Compressed Air, Nitrogen, and Waste Water System Components

Location: Conpressed Air Supply System

ID No.	Component	Function	number of Unit	Fluid	Remarks
-	Compressor Unit A	Compression of air	1	Air	
-	Compressor Unit B	Compression of air	1	Air	
-	Pre-Filter A	Filter of air	1	Air	
-	Pre-Filter B	Filter of air	1	Air	
-	Moisture Separator Unit	Elimination of moisture	1	Air	
-	Supply Tank	Storage of air	1	Air	
-	After-Filter A	Filter of air	1	Air	
-	After-Filter B	Filter of air	1	Air	

Location: Nitrogen Supply System

ID No.	Component	Function	number of Unit	Fluid	Remarks
-	Liquid N_2 Storage Tank Unit	Storage of liquid N_2	1	Liquid Nitrogen	

Location: Waste Water Treatment System

ID No.	Component	Function	number of Unit	Fluid	Remarks
-	Hydrochloric Acid Water Storage Tank	Storage of acid water	1	water	
-	Sodium Hydroxide Water Storage Tank	Storage of hydroxide water	1	water	
-	Blower	Babbling of water	1	air	
-	Neutralized Water Transfer Pump	Transfer of neutralized water	1	water	

C.3 Electrical Components

Component Name	Component function	Operational Parameters	Potential Suppliers	Physical size	Quantity	Location	Cost
Transformer	High voltage to Medium voltage transformer oil filled	55 MVA, Pri 230 KV, Sec 13.KV, Delta-Wye	Siemens, Eaton, Square D	Located outdoors in CTF Substation	1	High voltage to Medium voltage Substation	
Transformer	Medium voltage to low voltage transformer oil filled	2 MVA, Pri 13.8 KV, Sec 480 VAC, 3 ph, Delta-Wye	Siemens, Eaton, Square D	Size dependent on manufacturer and applied options	2	High voltage to Medium voltage Substation	
Transformer	Medium voltage to low voltage transformer oil filled	3 MVA, Pri 13.8 KV, Sec 480 VAC, 3 ph, Delta-Wye	Siemens, Eaton, Square D	Size dependent on manufacturer and applied options	1	High voltage to Medium voltage Substation	
Circuit Breakers	Low voltage overcurrent protection	480 VAC, 3 pole, 3200 AF, 2500 AT, electronic trip	Siemens, Eaton, Square D	Enclosed in low voltage switchgear	3	Low voltage equipment room	
Circuit Breakers	Low voltage overcurrent protection	480 VAC, 3 pole, 800 AF, various trip settings, electronic trip	Siemens, Eaton, Square D	Enclosed in low voltage switchgear	19	Low voltage equipment room	
Circuit Breakers	Low voltage overcurrent protection	480 VAC, 2 pole, 800 AF, various trip settings, electronic trip	Siemens, Eaton, Square D	Enclosed in low voltage switchgear	4	Low voltage equipment room	

Component Name	Component function	Operational Parameters	Potential Suppliers	Physical size	Quantity	Location	Cost
Circuit Breakers, vacuum or SF6 type	Medium voltage overcurrent protection	13.8 KV, 3 pole, 1200 AF, With ac overcurrent time and instantaneous overcurrent protective solid state or microprocessor relays (50/51) with associated current transformers	Siemens, Eaton, Square D	Enclosed in medium voltage switchgear	6	Medium voltage equipment room	
Automatic transfer switch	Low voltage switching between electrical sources.	480 VAC, 3 ph, 400 A rated. Under voltage/under frequency, Over voltage/over frequency	Siemens, Eaton, Square D, GE	46” H x 24” W x 14” D	3	Low voltage equipment room	
Automatic transfer switch	Low voltage switching between electrical source	480 VAC, 3 ph, 200 A rated. Under voltage/under frequency, Over voltage/over frequency	Siemens, Eaton, Square D, GE	46” H x 24” W x 14” D	1	Low voltage equipment room	

Component Name	Component function	Operational Parameters	Potential Suppliers	Physical size	Quantity	Location	Cost
Variable Frequency Drive	Low voltage speed control of induction motors	480 VAC, 3 ph, 300 Hp rated	Siemens, Eaton, Square D	92" H x 60" W x 30" D	2	Near Helium Circulators in 1 MWt loops	
Variable Frequency Drive	Low voltage speed control of induction motors	480 VAC, 3 ph, 20 Hp rated	Siemens, Eaton, Square D	16" W x 24" H x 10" D	2	Near Helium Purification Pumps in 1 MWt loops	
Thyristor controller	Low voltage power delivery control to resistive loads	480 VAC, 3 ph, 0.5 MW rated	Siemens, Eurotherm		2	Near Helium Heaters in 1 MWt loops	
Thyristor controller	Low voltage power delivery control to resistive loads	480 VAC, 3 ph, 0.2 MW rated	Siemens, Eurotherm		2	Near Helium Heaters in 1 MWt loops	
Motor starters	Medium voltage fused disconnects with motor overload protection.	15 KV, 3 ph, 3 MW rated	Siemens, Eaton, Square D	92" H x 60" W x 30" D	2	Near Helium circulators in 30 MWt loops	
Thyristor controllers (May be made up from modified VFDs)	Medium voltage power delivery control to resistive loads.	13.8 KV, 3 ph, 7.5 MW rated	Siemens, Eaton, Square D	92" H x 60" W x 36" D	4	Near Helium Heaters in 30 MWt loops	
Power distribution panel	Low voltage panel containing circuit breakers.	480 VAC, 3 ph, 400 A rated.	Siemens, Eaton, Square D	Wall mounted	2	Distributed throughout the facility	

Component Name	Component function	Operational Parameters	Potential Suppliers	Physical size	Quantity	Location	Cost
Power distribution panel	Low voltage panel containing circuit breakers.	480 VAC, 3 ph, 200 A rated.	Siemens, Eaton, Square D	Wall mounted	1	Distributed throughout the facility	
Power distribution panel	Low voltage panel containing circuit breakers.	480 VAC, 1 ph, 200 A rated.	Siemens, Eaton, Square D	Wall mounted	2	Distributed throughout the facility	
Motor controller	Low voltage disconnect with motor overload protection.	480 VAC, 3 ph, 200 Hp rated	Siemens, Eaton, Square D	20" W x 78" H x 16" D	1	Near Helium loop fill compressor	
Motor controller	Low voltage disconnect with motor overload protection.	480 VAC, 3 ph, 75 Hp rated	Siemens, Eaton, Square D	16" W x 53" H x 12" D	1	Near facility air compressor	
Transformer	Medium voltage to low voltage transformer oil filled	Pri 13.8 KV, Sec 480 VAC, 3 ph, Delta-Y. 500 KVA rated	Siemens, Eaton, Square D	Size dependent on manufacturer and applied options	1	Medium voltage equipment room	
Transformer	Low voltage dry type stepdown transformer	Pri 480 VAC, Sec 120/208 VAC, 3 ph, 50 KVA rated	Siemens, Eaton, Square D	37" H x 30" W x 24" D	1	Facility- near lighting and appliance distribution panels	

Component Name	Component function	Operational Parameters	Potential Suppliers	Physical size	Quantity	Location	Cost
Transformer	Low voltage dry type stepdown transformer	Pri 480 VAC, Sec 120/208 VAC, 3 ph, 25 KVA rated	Siemens, Eaton, Square D	30" H x 20" W x 20" D	1	Facility- near lighting and appliance distribution panels	
Transformer	Low voltage dry type stepdown transformer	Pri 480 VAC, Sec 120/208 VAC, 3 ph, 15 KVA rated	Siemens, Eaton, Square D	27" H x 20" W x 16" D	2	Facility- near lighting and appliance distribution panels	
Transformer	Low voltage dry type stepdown transformer	Pri 480 VAC, Sec 120/208 VAC, 3 ph, 10 KVA rated	Siemens, Eaton, Square D	27" H x 20" W x 16" D	3	Facility- near lighting and appliance distribution panels	
Low Voltage Switchgear Housing	Metal Clad enclosures to house main circuit breaker and distribution circuit breakers.	480 VAC, 3200 A bus, 3 ph, 4 wire, to house drawout circuit breakers	Siemens, Eaton, Square D	22" wide x 91" high x 60" depth per segment for 5 segments with one segment being 36" wide.	2	1 MWth Low voltage equipment room	

Component Name	Component function	Operational Parameters	Potential Suppliers	Physical size	Quantity	Location	Cost
Low Voltage Switchgear Housing	Metal Clad enclosures to house main circuit breaker and distribution circuit breakers.	480 VAC, 3200 A bus, 3 ph, 4 wire, to house drawout circuit breakers	Siemens, Eaton, Square D	22” wide x 91” high x 60” depth per segment for 8 segments with one segment being 36” wide.	1	Facility Low voltage equipment room	
Motor Control Center	Metal Clad enclosures to house motor controllers, VFDs, and miscellaneous circuit breakers for facility overhead cranes	480 VAC, 800 A bus, 3 ph, 4 wire	Siemens, Eaton, Square D	22” wide x 91” high x 60” depth per segment for 5 segments with one segment being 36” wide.	1	Near Overhead Cranes	
Medium Voltage Switchgear Housing	Metal Enclosed indoor switchgear to house medium voltage main circuit breaker and distribution circuit breakers.	13.8 KV, 3200 A bus, 3 Ph, 4 wire	Siemens, Eaton, Square D	22” wide x 91” high x 90” depth per segment for 12 segments with two segments being 36” wide.	1	Medium voltage equipment room	

C.4 Computer and Data Acquisition System

S. No.	Component Name	Component Function	Quantity	Size	Remarks
1	Input Out Cabinets	Data Acquisition	3	30"x24"x90"	
2	AP Cabinets	Data processing	2	30"x24"x90"	
3	Network Cabinet	Networking	1	30"x24"x90"	
4	FT Server	Displays, alarms, etc.	1	NA	Installed in Network cabinet
5	Workstations	Display, controls	3	NA	Mounted on operator desk
6	Color Printer	Printing	1	NA	Mounted on desk
7	Alarm Printer	Alarm printing	1	NA	Mounted on desk
8	PI System	Data storage & retrieval	1	NA	See attached data sheet

C.4.1 SPPA-T3000 System Information

The Benchmark
in Nuclear Power Plant Controls –
Technical Highlights

Siemens Power Plant Automation™ – SPPA-T3000

Answers for energy.

SIEMENS

The benchmark for Distributed Control Systems

Developed to meet the demands of power plant owners and operators for operational I&C in nuclear power plants

SPPA-T3000 combines the real-time processing power of Siemens controls technology with a state-of-the-art system architecture for plant I&C.

Benefits for owners

SPPA-T3000 provides a competitive advantage by helping to minimize costs.

Tailored for nuclear power plants	Safe and reliable NPP operation
Simplification of system architecture	Reduced total cost of ownership
Unique solution for Operational and Safety I&C (AREVA's TELEPERM XS)	Comprehensive I&C which addresses diversity and defense-in-depth

2

Benefits for users

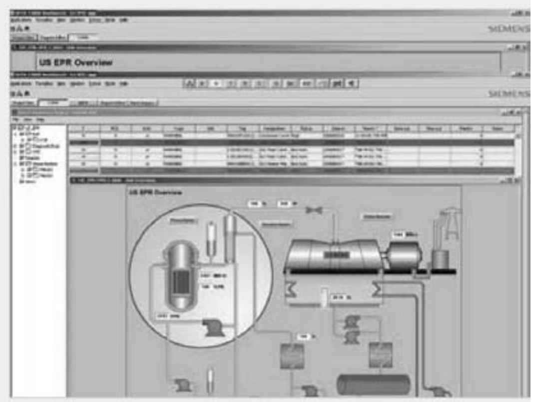
SPPA-T3000 is a reliable and easy-to-use Distributed Control System that can noticeably simplify daily work.

Easy to operate	The power plant at your fingertips
Easy to engineer	Fully supports the engineering and commissioning process for nuclear power plants
Easy to diagnose	A perfect solution for reliable production

3

Alarm Management

Troubleshooting at your fingertips with plant situation management and electronic alarm procedures



Archive

Archiving for plant analysis and optimization

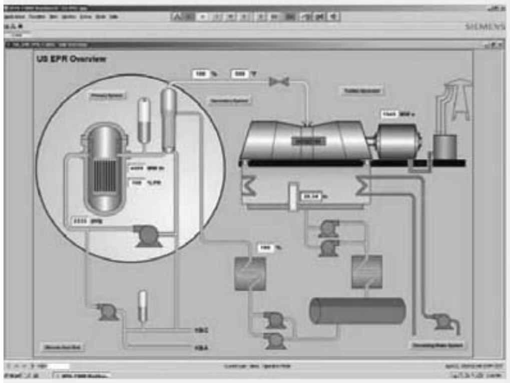
Field

Integrated process interface for field device communication

9

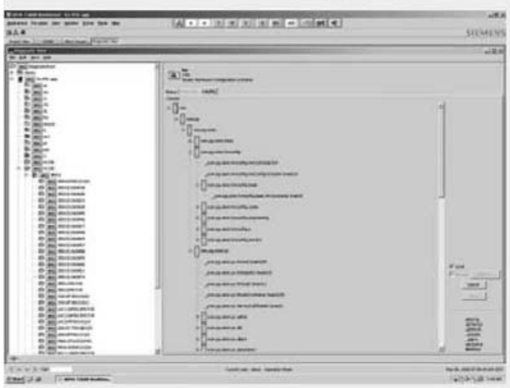
SPPA-T3000

Views at a glance



Operation
All information available at a glance for reliable plant operation

Engineering
Integrated engineering for easy configuration and modification



I&C Diagnostics
Built-in I&C Diagnostics without additional equipment for optimized maintenance strategies

4

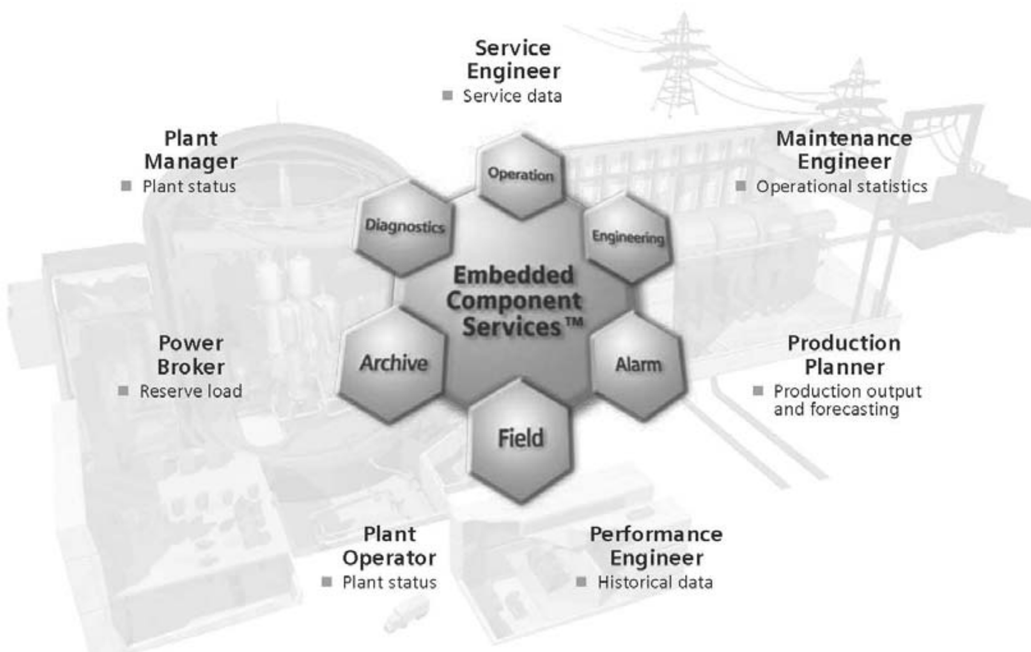
Beyond DCS

One platform for integrated Plant Control, Monitoring and Management

The Siemens Power Platform is designed not only for I&C, but also as the basis for a fleet wide Plant Control, Monitoring and Management System. Its Embedded Component Services™ based system architecture takes advantage of the web's current and future capabilities. The platform easily allows integration of additional process data based third party applications or expert systems while protecting the intellectual property.

In addition to SPPA-T3000, the following components are part of the Siemens Power Platform:

- SPPA-D3000 Diagnostic Suite
- SPPA-M3000 Energy Management Suite
- SPPA-E3000 Integration of Electrical Systems based on IEC61850
- SPPA-R3000 Turbine Controls and Protection



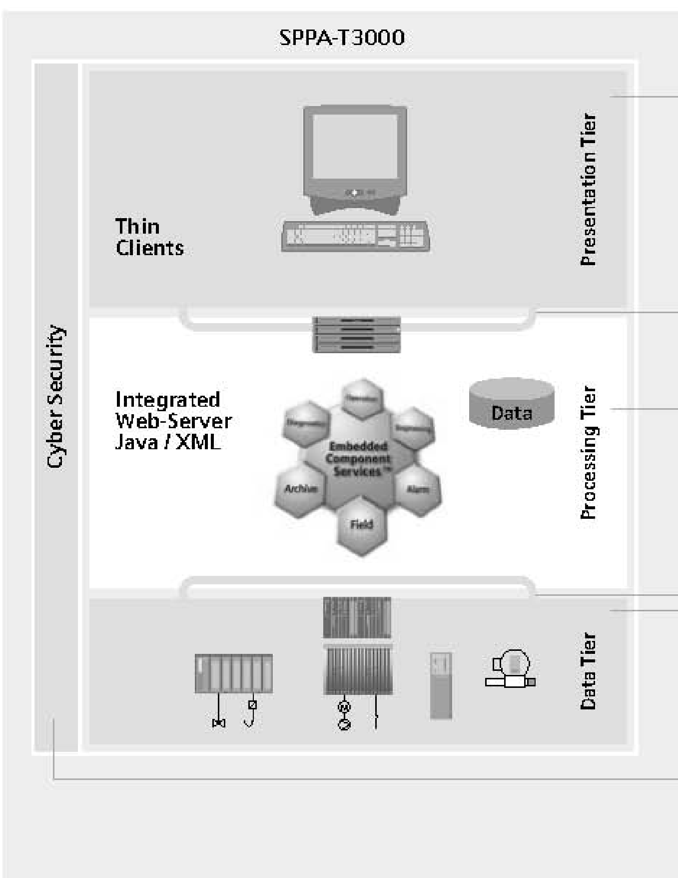
For further information: sppa-t3000.pg@siemens.com, www.siemens.com/sppa-t3000

5

SPPA-T3000 system architecture

Simplified system architecture eliminates sub-systems

SPPA-T3000 combines the reliability of proven, real-time process controllers with new technologies to establish a simple and robust platform. The system is designed to provide real-time data – at the right place, at the right time – to give power plant owners and operators the information they need to make the right decisions, thus improving their ability to be competitive. The SPPA-T3000 process control system has been developed based on the needs of today's power plants with an integrated system architecture for all automation tasks, from engineering and commissioning to operation and diagnostics. This approach simplifies the system structure and eliminates the need for the required sub-systems as used in traditional control systems.



User Interfaces
Thin Clients are the window to the process and present information regarding engineering, operation and diagnostics.

Communication
The highly available interconnection between all components is implemented by a redundant Ethernet network with TCP/IP. The access to the process and connection to the Power Services, are provided by PROFIBUS DP field bus.

Power Server
Application Servers and Automation Servers are used for processing data and real-time execution of the control algorithms. Redundancy A and B of the application server can be located in separate equipment rooms.

Process Interfaces
The interface to the process provides signal conditioning and command output via I/O modules or intelligent PROFIBUS DP field devices.

Cyber Security
SPPA-T3000 provides effective built in cyber security features. The relevant rules and guidelines from NERC (North American Electric Reliability Council) and VGB (Verband der Großkraftwerks Betreiber) are considered.

6

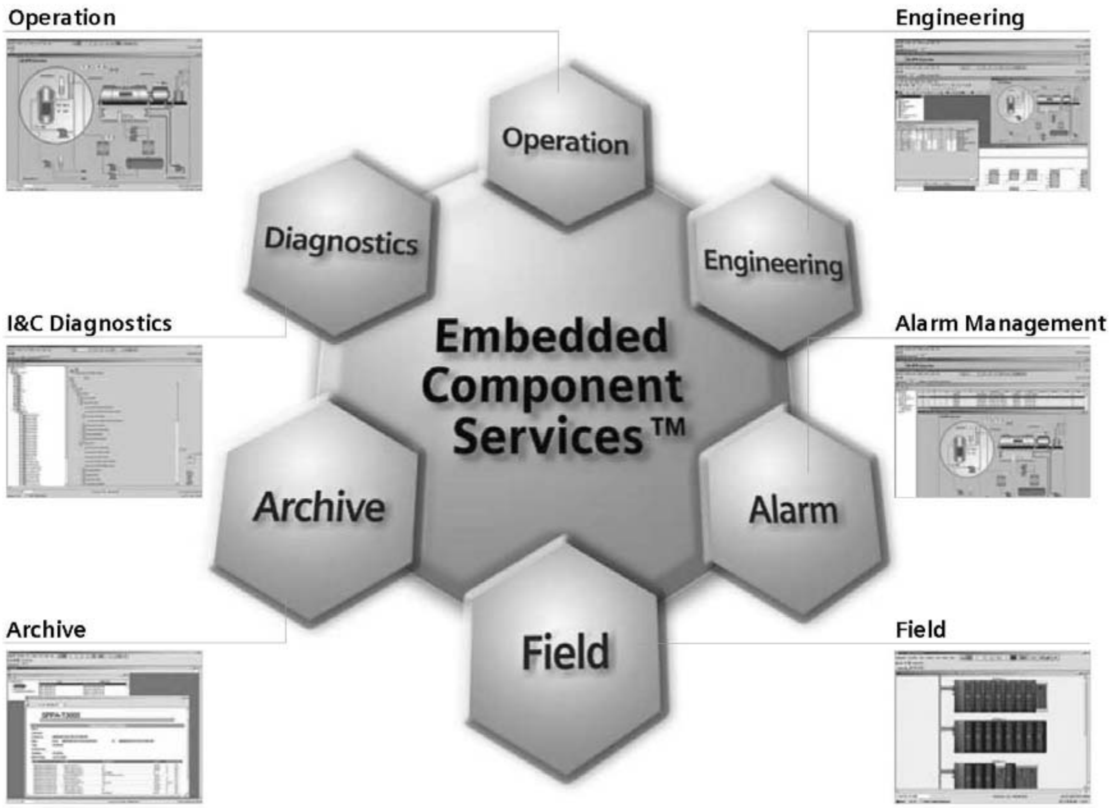
Embedded Component Services™

The software heart of SPPA-T3000

Embedded Component Services™, the heart of the SPPA-T3000 system, gives you what you have been looking for: a single user interface for all tasks via intuitive links throughout the entire system.

The Embedded Component Services™ software ...

- Intrinsically embeds data into every object
- Enables different views for different user roles
- Makes the information available, at a glance



7

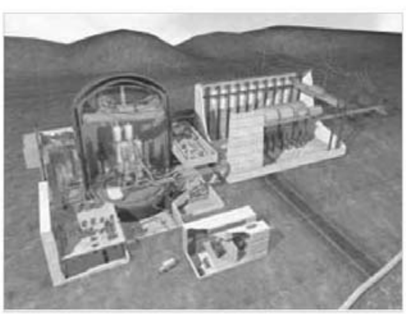
SPPA-T3000 – designed for nuclear power plants

Comprehensive functionality compliant with nuclear codes and standards

SPPA-T3000 cooperates perfectly with AREVA's TELEPERM XS safety I&C system. Therefore SPPA-T3000 provides an integrated screen-based Human Machine Interface (HMI) allowing the operator to control operational and safety process systems. For effective operator training, SPPA-T3000 supports training simulators.

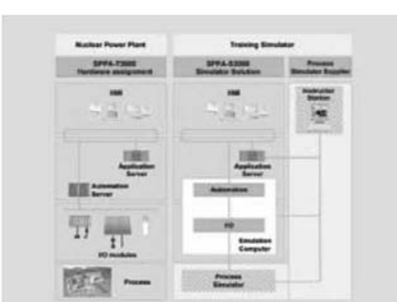
Integrated operational and safety I&C

- SPPA-T3000 and AREVA's TELEPERM XS constitute a comprehensive I&C for nuclear power plants
- Common Human-Machine Interface (HMI) for the entire plant
- Common process data archiving and retrieval



Complies with nuclear codes and standards

- Meets nuclear specific human factor engineering requirements
- Seismic and Electromagnetic Interference/Radio Frequency Interference (EMI / RFI) qualification
- Designed to perform safety related functions according to IEC 61226, category B and C or similar



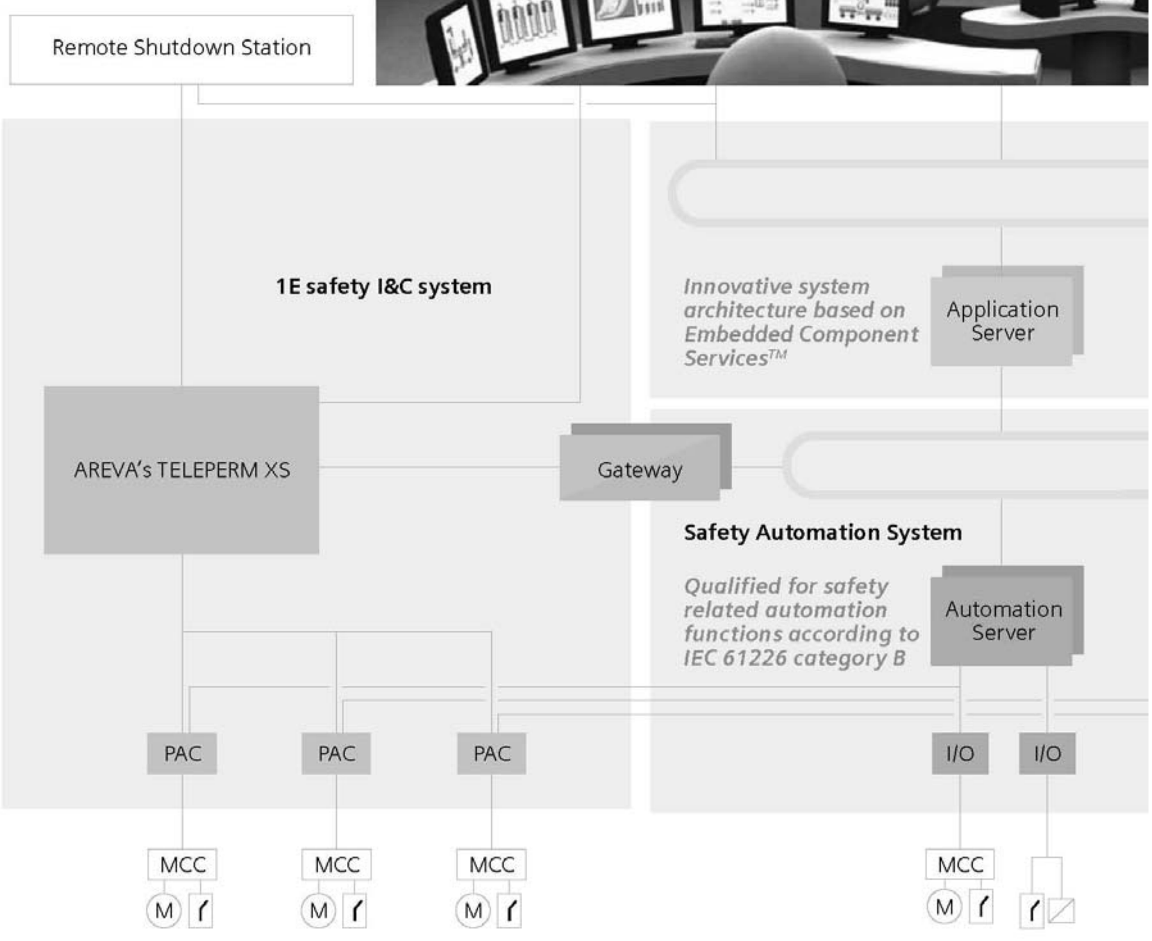
Simulator ready

- Exact emulation of automation functions, simulator capable HMI
- Direct utilization of original SPPA-T3000 engineering data
- Standard interface to process simulator and instructor station
- Fully supports simulator functions (freeze, initial conditions, ...)

Comprehensive I&C for the entire nuclear power

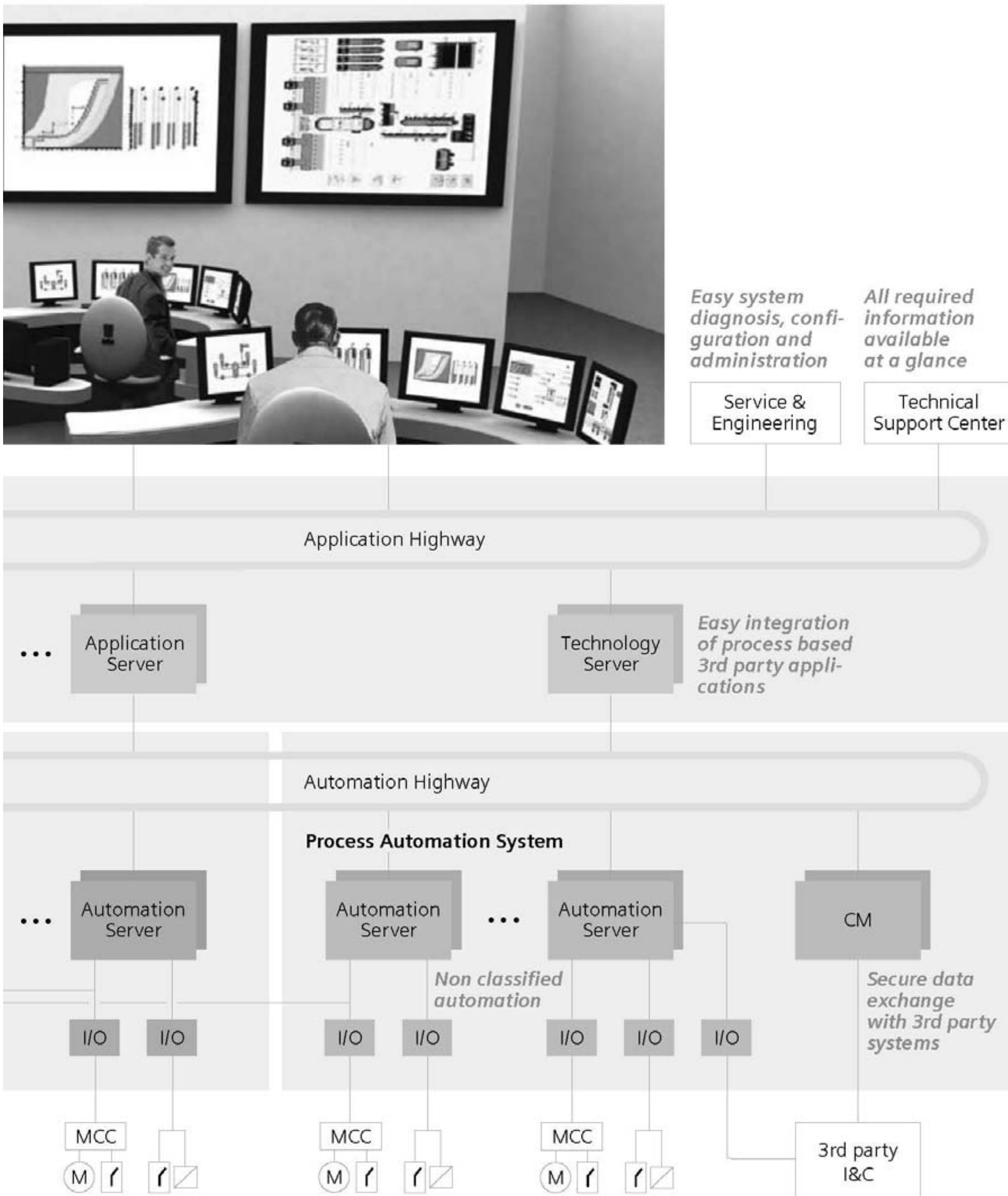
SPPA-T3000 and AREVA's TELEPERM XS

- Ensures safe and reliable nucelar power plant operation
- Provides the complete functionality for nuclear I&C
- Improves the ability to be competitive in the energy market



10 PAC: Priority Actuator Control MCC: Motor Control Center I/O: Input / Output Module CM: Communication Module

plant considering diversity and defense-in-depth



11

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Siemens AG
Power Generation
Freyeslebenstrasse 1
91058 Erlangen, Germany

Siemens Power Generation, Inc.
Instrumentation & Controls
1345 Ridgeland Parkway, Suite 116
Alpharetta, GA 30004, USA
Phone: +1 678 256 1500

For more information, contact our
Customer Support Center.
Phone: +49 180/524 70 00
Fax: +49 180/524 24 71
(Charges depending on provider)
e-mail: support.energy@siemens.com

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C.4.2 PI System Information

D A T A S H E E T

VALUE NOW, VALUE OVER TIME
PI SYSTEM
POWERING THE REAL-TIME ENTERPRISE

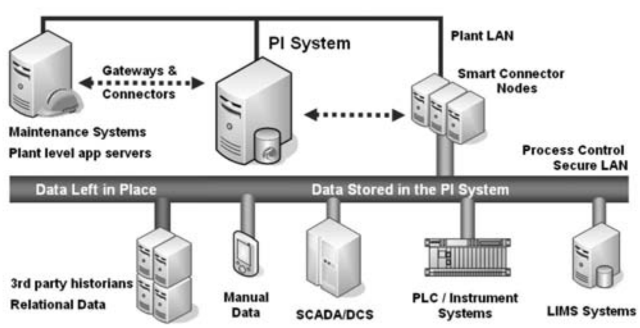
PI System

Business Challenge

Process-focused manufacturing companies produce extremely large amounts of data from a wide variety of sources throughout their operations, front office and back office. Plant managers and business executives need access to this information in a meaningful and practical format, so they can direct operations toward increased profitability and productivity, and additionally conduct effective business planning. Information aggregation from a multitude of sources manually or through custom programming can be costly and slow to deliver business value. Companies need to find a way to unify the streams of information from many sources into a single, comprehensive system that lets them accomplish their business goals as they manage their operation to achieve the highest levels of performance and productivity. The OSIsoft® PI System™ provides this unification at over 14,000 mission-critical installations worldwide.

PI System Overview

The PI System provides real-time event management, retrieval, and deep archiving of volumes of data for scalable management of relevant variables and events enterprise-wide. The PI System brings all operational data into a single system that can deliver it to users at all levels of the company - from the plant floor to the enterprise level. The PI System keeps all critical operating data online and available in a specialized time-series database so it is always available. With the help of the PI System's reporting and analytical tools, the wealth of data in your operation can drive meaningful, empowered and informed action. The PI System, now enhanced for very high data volumes and new technologies like 64-bit computing, gives you the power to practice comprehensive performance management on as wide or narrow scope as necessary, all in real-time. From process areas anywhere in your organization to enterprise information systems, the PI System integrates all information systems into a streamlined management infrastructure. Because the PI System is built to be an off-the-shelf set of products, implementation is fast and yields tangible results rapidly, often in just days after commissioning.



Typical site architecture: OSIsoft has over 425 interfaces to DCS/PLCs, LIMS, OPC, SCADA Systems, IT, and other equipment and business systems.

TECHNICAL COMPONENTS

PI System. Collects real-time data throughout the entire information infrastructure and connects all information sources to make a complete, set of relevant data available to everybody who needs to see it and work with it.

PI Notifications. Provides access to the configuration, management, delivery, acknowledgement, and visualization of notifications.

AF. AF enables an organization to define a consistent representation of its assets and use these assets in simple to complex analyses that yield critical and actionable information.

PI Interfaces. OSIsoft offers more than 400 standard connectors that link the PI System with Programmable Logic Controllers (PLCs), Distributed Control Systems (DCS), Laboratory Information Systems (LIMS), Supervisory Control and Data Acquisition systems (SCADA), IT Infrastructure (routers, switches, gateways) and other equipment and business systems.

PI Server Applications. Users can get more out of their real-time data with PI Server Applications such as PI Alarm, PI Batch, PI Real-time SQC, PI SQC Alarms, PI Steam Tables and PI Totalizer. These processing tools automate processes and allow users to leverage their real-time data using server-based calculations and modules.

PI System

DATASHEET

VALUE NOW, VALUE OVER TIME
PI SYSTEM
POWERING THE REAL-TIME ENTERPRISE

TECHNICAL COMPONENTS

PI Advanced Computing Engine (ACE). Supports the design and schedule of complex process calculations with minimal code-writing and eases the process of applying these calculations to multiple units and processes.

PI System Thin Clients: RtWebParts and RtPortal iViews. Interactive displays can be created that provide visibility into real-time production data and provide them to users in their Web browsers.

PI System Smart Clients: ProcessBook, AlarmView, DataLink, RtReports and BatchView are used to bring process data to individual Windows desktops to support effective process management and efficient data analysis and reporting.

RLINK. RLINK connects the PI System to a company's ERP or EAM system, such as SAP R/3, JD Edwards One World, MRO Software Maximo or Indus International Passport/ EMPAC. This enables sound business management based on comprehensive, real-time information.

Sigmafine. Sigmafine reconciles raw process data and generates a consistent set of unified operating data for all stakeholders and information workers.

PN OS4404

Benefits

Fast return on investment now and continued returns over time.
Realize positive results immediately upon implementation of the PI System, and generate returns on your investments in data, infrastructures, processes, and personnel.

Empowered managers and workers.
Deliver real-time and historical data from your processes quickly and securely to the right people and business roles, so they can practice sound management and make informed business decisions.

Real-time performance management.
As the data collection and distribution engine for the manufacturing plant and its processes, the PI System supports efficient, responsive, real-time performance management. The PI System serves as the time-series repository for all the events on the operations floor.

Features

High Availability
Meets the demands of organizations that depend on the availability of operational data and introduces a significant boost in protecting data by providing fault tolerant software that delivers interface failover, buffering, PI Server replication, and SDK services.

Consistent, high performance
Gives managers and workers direct access to vast data volumes, accommodating more users, more data storage, and more overall data throughput.

Server consolidation
Creates a large central PI System in your corporate data center with millions of data streams so that your manufacturing data is readily available in a centralized location.

Platform scalability
Implements the PI System in a Windows environment using either 32-bit or 64-bit processors.

PI System security
Protects critical data by determining the appropriate permissions for all user accounts, and integrate the PI System into your existing security infra- structure and policies.

About OSIsoft

OSIsoft (www.osisoft.com) delivers the PI System, the industry standard in enterprise infrastructure, for management of time series data and events. A global base of more than 14,000 installations across manufacturing, energy, utilities, life sciences, data centers and process industries relies upon the OSIsoft PI System to safeguard data and deliver enterprise-wide visibility into operational and business data in order to manage assets, mitigate risks, improve processes, drive innovation, make business decisions in real time, as well as identify competitive business and market opportunities.

Founded in 1980, OSIsoft, Inc. is headquartered in San Leandro, California, with operations worldwide and is privately held.

For additional information about the PI System and other products from OSIsoft, please visit our web site at www.osisoft.com or call us at (01) 510-297-5800, option 2.

OSIsoft. www.osisoft.com

OSIsoft, Inc. 777 Davis Street, Suite 250 • San Leandro, CA 94577

APPENDIX D: HTR COMPONENT TEST FACILITY 1MW LOOP HEAT BALANCE CALCULATION (32-9097953-000)

0402-01-F01 (20697) (Rev. 012, 04/04/2008)

AREVA

CALCULATION SUMMARY SHEET (CSS)

Document No. 32 - 9097953 - 000

Safety Related: ☐ Yes ☒ No

Title HTR Component Test Facility 1MW Heat Balance Design Calculation

PURPOSE AND SUMMARY OF RESULTS:

Purpose

The purpose of this calculation is to estimate the preliminary heat balance for the High Temperature Reactor (HTR) Component Test Facility (CTF). See Section 1.0 for a more detailed introduction and purpose.

Summary of Results

The results of this balancing calculation are summarized in the Node Value and Process Change Tables as shown in Appendices B, C, D and E.

THE FOLLOWING COMPUTER CODES HAVE BEEN USED IN THIS DOCUMENT:

CODE/VERSION/REV	CODE/VERSION/REV

THE DOCUMENT CONTAINS ASSUMPTIONS THAT MUST BE VERIFIED PRIOR TO USE ON SAFETY-RELATED WORK

☒ YES
☐ NO

AREVA
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an AREVA and Siemens company

0402-01-F01 (20697) (Rev. 012, 04/04/2008)

Document No. 32-9097953-000

HTR Component Test Facility 1MW Heat Balance Design Calculation

Signature Block

Name (printed or typed) and Title	Signature	P/R/A and LP/LR	Date	Pages/Sections Prepared/Reviewed/Approved and Comments/Review Method
James Bakke	[signature]	LP	11-25-08	All
Matt Touna	[signature]	LR	11-25-08	All
F. Shahrokhi	[signature]	A	12/1/08	All

Note: P/R/A designates Preparer (P), Reviewer (R), Approver (A);
LP/LR designates Lead Preparer (LP), Lead Reviewer (LR)

Page 2

Record of Revision

Revision No.	Date	Pages/Sections/ Paragraphs Changed	Brief Description / Change Authorization
000		All	Initial Issue

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(continued)

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1.0 INTRODUCTION / PURPOSE

The Next Generation Nuclear Plant (NGNP) project involves research, development, design, construction, and operation of a prototype nuclear plant intended for both high-efficiency electricity production and high-temperature industrial applications, such as hydrogen production. During various life cycle stages of the NGNP project, a number of systems, subsystems, assemblies, parts, and components need to be developed. To mitigate the technical risk associated with these systems, a large-scale test facility is required for the purposes of supporting the development of high-temperatures gas thermal hydraulic technologies, as applied in heat transport and heat transfer application in High-Temperature Gas-Cooled Reactors.

A helium test facility is necessary to provide prototype testing and qualification of heat transfer system components (e.g., IHX, valves, hot gas duct), reactor internals, and hydrogen generation processing to mitigate the associated technical risks and to increase the technology readiness levels (TRLs) for these components. Since such a facility does not exist at the capacity needed for NGNP, it must be built. Failure to complete the facility in time to perform prototype testing could delay NGNP startup or could result in incomplete risk mitigation with potential adverse impact on plant performance if the NGNP was started up without prototype component testing and qualification.

The purpose of this calculation is to estimate steady state values for system components and provide a calculated basis for the heat balance and pressure drop of the 1 MW test loop test facility.

2.0 ACRONYMS AND ABBREVIATIONS

CTF	Component Test Facility
He	Helium
HX	Heat Exchanger
HTR	High Temperature Reactor
IHX	Intermediate Heat Exchanger
Kg/s	kilograms per second
MPa	mega Pascals
kW	kilowatt
MW	megawatt
NGNP	Next Generation Nuclear Plant
SG	Steam Generator
TBD	To be determined
A	Area, m^2

C_p	Specific Heat Coefficient, $\frac{J}{kg^{\circ}K}$
D	Pipe Diameter, m
ε	Relative Roughness, m
f	Friction Factor
G	Constant Mass Flow Rate per Unit Area $\frac{kJ}{m^2 s}$
h	Enthalpy, $\frac{kJ}{kg}$
L	Piping Length, m
$\dot{m}$	Mass Flow Rate, $\frac{kg}{s}$
p	Pressure, Pa
R	Helium Gas Constant $\frac{J}{kg^{\circ}K}$
R*	Universal Gas Constant $\frac{J}{kmol^{\circ}K}$
Re	Reynolds Number
T	Temperature °K
v	Fluid Velocity, $\frac{m}{s}$
ρ	Fluid Density, $\frac{kg}{m^3}$
μ	Dynamic Viscosity, $\frac{Ns}{m^2}$

3.0 ANALYTICAL METHODOLOGY

The calculations performed in this document have been performed with assistance from commercially available computer software (e.g. Microsoft Excel). In accordance with AREVA Procedure 0402-01, the commercial software package itself is not required to be verified; however, the calculations or data manipulation performed by the software shall be verified by the reviewer.

4.0 DESIGN INPUT

Reference 3 (Component Test Facility Initial System Requirements Manual) is the main input for design requirements for this calculation. The proposed component test facility has a great deal of flexibility in its possible configurations as well as temperature and pressure ranges. This calculation evaluates the three configurations as defined in Reference 3. The process flow diagrams for each configuration can be seen in Appendix A. A single operating case was chosen for each configuration. It is assumed that the high temperature test section will not be used while the IHX is being tested. Therefore the high temperature test section was not included in the evaluation of the primary loop of configurations 2 and 3. The remaining corresponding single case values that were chosen for evaluation can be seen in Section 5.0.

5.0 ASSUMPTIONS

Assumptions are required to develop this preliminary calculation. As more information is available this calculation may be revised.

The He Purification and Pressure Control System is assumed to maintain system pressure at an average of 5.0 to 5.5 MPa.

The He Purification and Gas composition system are assumed to have a negligible effect on the primary and secondary loop average pressure and fluid flow rate.

Pipe lengths and diameters are assumed. The low temperature piping is assumed to be a standard schedule 40 DN 100 pipe. This equates to a inside diameter of 102.26 mm (Ref 4: 5).

The high temperature piping will be assumed to be DN 500 pipe that will have internal insulation installed with a metal liner. Therefore, the inside diameter will be something smaller than the standard pipe. The inside diameter for DN 500, standard schedule 20, is 488.94 mm (Ref 4: 9). A 50 mm thickness is assumed for the internal insulation and metal liner so the inside diameter would then be an assumed 388.94 mm.

This length and diameters used are shown in the tables in Appendices F through I.

The heat loss to the atmosphere of the piping is assumed to be approximately 100 kw each for each primary and secondary loop. This loss is assumed to be in the high temperature piping only. This equates to roughly a 7°C loss in each high temperature piping section. No heat loss is included in the low temperature piping.

Tables 5-1 and 5-2 detail the assumptions made for the major components in the primary and secondary loops for each configuration.

PRIMARY LOOP – All Configurations						
System / Component	Configuration	Inlet Temp (°C)	Outlet Temp (°C)	Estimated Efficiency / Effectiveness	Estimated Heat Loss to Atmoshpere (kW)	Estimated Pressure Differential (MPa)
Primary Loop First Stage Heater	1	403	850	TBD	TBD	0.033
	2	403	850	TBD	TBD	0.033
	3	403	850	TBD	TBD	0.033
Primary Loop Second Stage Heater	1	850	1007	TBD	TBD	0.033
	2	850	921	TBD	TBD	0.033
	3	850	921	TBD	TBD	0.033
Primary Loop High Temperature Test Section	1	1000	993	TBD	14.5	0.100
	2	N/A	N/A	N/A	14.5	N/A
	3	N/A	N/A	N/A	14.5	N/A
Primary Loop Intermediate Heat Exchanger	2 - Primary	900	866	0.95	4.2	0.033
	2 - Secondary	475	507	N/A	N/A	0.033
	3	900	507	0.95	41.5	0.033
Primary Loop High Temperature Heat Exchanger	1	986	500	TBD	TBD	0.033
	2	859	482	TBD	TBD	0.033
	3	N/A	N/A	N/A	N/A	N/A
Primary Loop Medium Temperature Test Section	1	500	493	N/A	14.5	0.100
	2	500	493	N/A	14.5	0.100
	3	500	493	N/A	14.5	0.100
Primary Loop Recuperator	1 – Cold	150	410	0.91	-	0.033
	1 – Hot	486	193	0.91	68.5	0.033
	2 - Cold	150	410	0.91	-	0.033
	2 - Hot	486	200	0.91	68.5	0.033
	3 – Cold	150	410	0.91	-	0.033
	3 – Hot	486	193	0.91	68.5	0.033
Primary Loop Low Temperature Heat Exchanger	1	193	50	TBD	TBD	0.033
	2	200	50	TBD	TBD	0.033
	3	193	50	TBD	TBD	0.033
Primary Loop Gas Circulator	1	50	150	TBD	TBD	0.400
	2	50	150	TBD	TBD	0.400
	3	50	150	TBD	TBD	0.400

Table 5-1: Primary Loop Component Assumptions

SECONDARY LOOP – Configuration 3					
System / Component	Inlet Temp (°C)	Outlet Temp (°C)	Estimated Efficiency / Effectiveness	Estimated Heat Loss to Atmosphere (kW)	Estimated Pressure Differential (MPa)
Secondary Loop Medium Temperature Heat Exchanger	488	475	TBD	TBD	0.033
Secondary Loop Intermediate Heat Exchanger (Interface with Primary Loop)	475	875	TBD	TBD	0.033
Secondary Loop High Temperature Test Section	868	861	TBD	14.5	0.100
Secondary Loop High Temperature Heat Exchanger	854	500	TBD	TBD	0.033
Secondary Loop Medium Temperature Test Section	493	486	TBD	14.5	0.100
Secondary Loop Recuperator (Cold Side Inlet)	150	495	0.91	-	0.033
Secondary Loop Recuperator (Hot Side Inlet)	479	100	0.91	67.1	0.033
Secondary Loop Low Temperature Heat Exchanger	100	50	TBD	TBD	0.033
Secondary Loop Gas Circulator	50	150	TBD	TBD	0.400

Table 5-2: Secondary Loop Component Assumptions

6.0 CALCULATION

The primary and secondary helium loops are closed systems. For the purpose of this calculation, node points have been established for each loop. The flow diagrams with node points for reference can be seen in Appendix A. The basis formulas that were used are shown in the following sections along with an example calculation. The example calculation shows the method used for a specific node. The remaining results are shown in Appendices B through I.

6.1 Heat Balance

The node with the lowest anticipated temperature will be chosen as the datum for determining the change in enthalpy. This is node 1 for the primary and secondary loops. The specific heat is assumed to be constant over all temperatures and pressures that will be experienced in both loops. The change in enthalpy can be calculated as follows:

$$\Delta h = c_p(\Delta T) \qquad \text{(Ref 2: 701)}$$

The example for this section is configuration 3 - primary loop nodes 6 to 7.

The specific heat is a reference value:

$$c_p = 5192\frac{J}{kg^{\circ}K} \qquad \text{(Ref 1: 24-15)}$$

The temperature scale for Celsius and Kelvin are equal therefore the differential temperature in °K is calculated as follows:

$$\Delta T = 921 - 850 = 71^{\circ}K$$

The change in enthalpy from node 6 to 7 in the primary loop can be calculated as follows:

$$\Delta h = 5192 \bullet 71 = 368632\frac{J}{kg}$$

Converting to kJ:

$$368632\frac{J}{kg} \bullet \frac{1kJ}{1000J} = 368.6\frac{kJ}{kg}$$

The time dependent change in energy can be calculated as follows:

$$\Delta kW = \dot{m}\Delta h$$

In this case, it is the high temperature heater. The mass flow rate is a required parameter for the primary loop and is given as 0.4 kg/s. The amount of energy required to raise the temperature the given fluid can be calculated as follows:

$$\Delta kW = 0.4\frac{kg}{s} \bullet 368.6\frac{kJ}{kg} = 147.5kW$$

Using this methodology for calculating the change in enthalpy and energy, the remaining values were calculated. Those results can be seen in Appendices B through E.

6.2 Pressure Losses

Pressure loss is calculated

The example for this section is configuration 3 - primary loop nodes 7 to 8.

The ideal gas density, by definition, can be calculated as follows:

$$\rho = \frac{p}{RT} \qquad \text{(Ref 1: 24-15)}$$

For all of the nodes, the overall average pressure will be used. These values are as follows:

$$p = 5.0MPa \quad \text{Primary Loop (Ref 3)}$$

$$p = 5.5MPa \quad \text{Secondary Loop (Ref 3)}$$

The Gas Constant for Helium is a reference value:

$$R = 2.077 \bullet 10^3 \frac{J}{kg^\circ K} \quad \text{(Ref 1: 24-15)}$$

The highest temperature for this section is:

$$T = 1194^\circ K$$

The ideal gas density can be calculated as follows:

$$\rho = \frac{5.0 \bullet 10^6}{2.077 \bullet 10^3 \bullet 1194} = 2.02 \frac{kg}{m^3}$$

The pipe interior cross sectional area can be calculated as follows:

$$A = \pi \frac{D^2}{4} \qquad \text{(Ref 1: A-7)}$$

The pipe interior diameter is assumed to be:

$$D = 388.94mm = 0.39m$$

$$A = \pi \frac{0.39^2}{4} = 0.1188m^2$$

The gas velocity (based on pipe diameter) can be calculated as follows:

$$v = \frac{\dot{m}}{\rho A} \qquad \text{(Ref 1: 17-9)}$$

Based in the given mass flow rate for the Primary Loop as 0.4 kg/s, the gas velocity (based on pipe diameter) can be calculated as follows:

$$v = \frac{0.4}{2.02 \bullet 0.1188} = 1.67 \frac{m}{s}$$

The constant mass flow rate per unit area can be calculated as follows:

$$G = v_{ave} \rho_{ave} \qquad \text{(Ref 1: 17-9)}$$

$$G = 1.67 \bullet 2.02 = 3.368 \frac{kg}{m^2 s} \qquad \text{(Ref 1: 17-9)}$$

The Reynolds number can be calculated as follows:

$$\text{Re} = \frac{DG}{\mu} \qquad \text{(Ref 1: 17-9)}$$

The dynamic viscosity is a reference value:

$$\mu = 1.94 \bullet 10^{-5} \frac{N \bullet s}{m^2} \qquad \text{(Ref 2: Table 1.8)}$$

$$\text{Re} = \frac{0.39 \bullet 3.368}{1.94 \bullet 10^{-5}} = 67531$$

The friction factor can be calculated as follows:

$$f = \frac{0.25}{\left(\log_{10} \left(\frac{\frac{\varepsilon}{D}}{3.7} + \frac{5.74}{\text{Re}^{0.9}} \right) \right)^2} \qquad \text{(Ref 1: 17-5)}$$

The pipe interior will be assumed to be smooth pipe. This will reduce the equation to:

$$f = \frac{0.25}{\left(\log_{10} \left(\frac{5.74}{\text{Re}^{0.9}} \right) \right)^2}$$

$$f = \frac{0.25}{\left(\log_{10}\left(\frac{5.74}{67531^{0.9}}\right)\right)^2} = 0.0194$$

The downstream pressure can be calculated as follows:

$$p_1^2 - p_2^2 = \frac{fLG^2R*T}{D(MW)} \qquad \text{(Ref 1: 17-9)}$$

Rearranging and solving for ΔP:

$$\Delta p = p_1 - \sqrt{p_1^2 - \frac{fLG^2R^*T}{D(MW)}}$$

The Universal Gas Constant is a reference value:

$$R^* = 8314\frac{J}{kmol^\circ K} \qquad \text{(Ref 1: 24-14)}$$

Base on the assumed pipe length of 6 meters:

$$\Delta p = 5.0 \bullet 10^6 - \sqrt{\left(5.0 \bullet 10^6\right)^2 - \frac{0.0194 \bullet 6 \bullet 3.368^2 \bullet 8314 \bullet 1194}{0.39(4.0)}} = 0.8437 \text{ Pa}$$

Using this methodology for calculating the change in pressure, the remaining values were calculated. Those results can be seen in Appendices F through I.

7.0 RESULTS

This calculation shows the proof on concept for the HTR Component Test Facility. The results show that the facility will perform its required function at steady state based on the assumed values detailed in Section 5.

8.0 REFERENCES

8.1 Lindeburg, M.R., Mechanical Engineering Reference Manual, Twelth Edition, 2006

8.2 Munson, B.R., Fundamental of Fluid Dynamics, Third Edition, 1998

8.3 51-9096878-000 HTGR CTF Preconceptual System Requirements Manual

8.4 ASME B36.10M-2004, Welded and Seamless Wrought Steel Pipe, 2004

APPENDIX A: PROCESS FLOW DIAGRAM

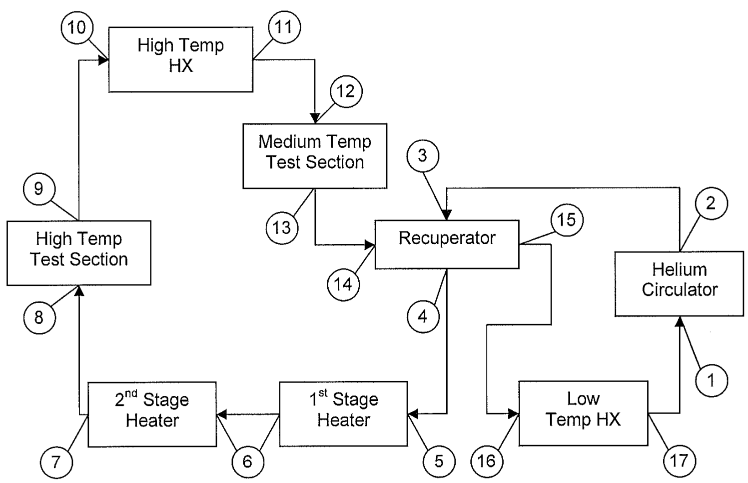

Figure A-1: Primary Loop Process Flow Diagram Configuration 1

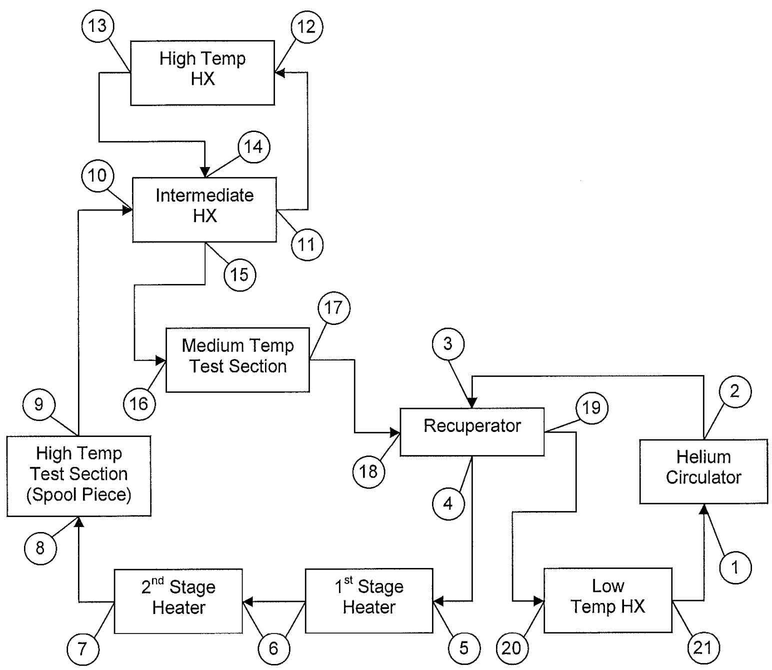

Figure A-2: Primary Loop Process Flow Diagram Configuration 2

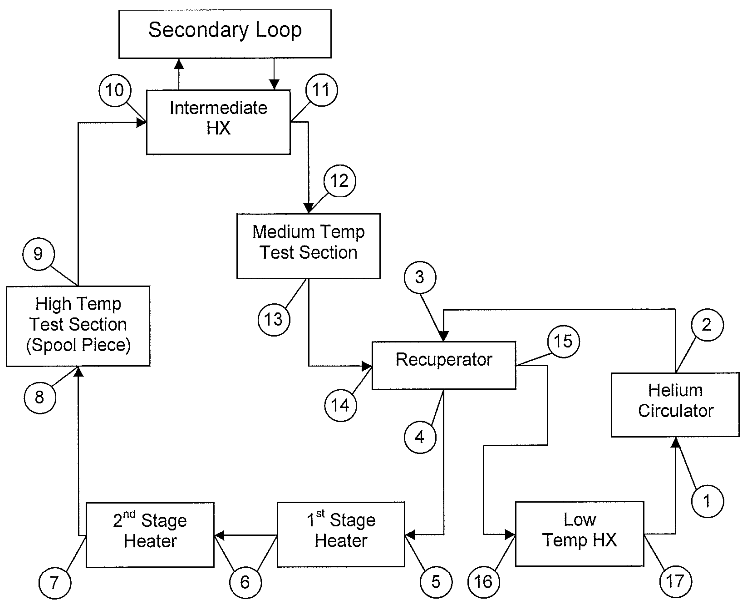

Figure A-3: Primary Loop Process Flow Diagram Configuration 3

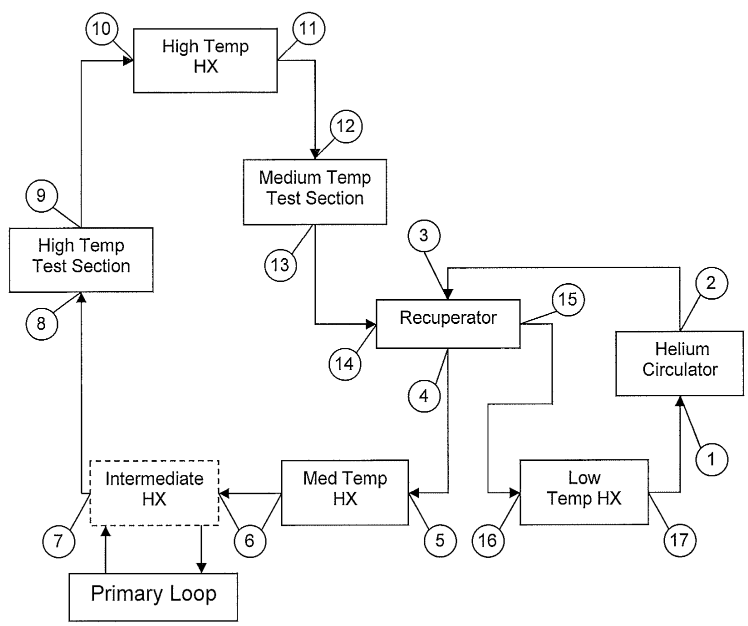

Figure A-4: Secondary Loop Process Flow Diagram Configuration 3

APPENDIX B: CONFIGURATION 1 - PRIMARY LOOP CALCULATED NODE VALUES / PROCESS CHANGE CALCULATION

Primary Loop - Node Values Configuration 1					
Node	Fluid	Temp (°C)	Nominal Pressure (Mpa)	Enthalpy (kJ/kg)	Mass Flow Rate (kg/s)
Node 1	Helium	50	5.00	0.0	0.4
Node 2	Helium	150	5.00	519.2	0.4
Node 3	Helium	150	5.00	519.2	0.4
Node 4	Helium	410	5.00	1869.1	0.4
Node 5	Helium	403	5.00	1832.8	0.4
Node 6	Helium	850	5.00	4153.6	0.4
Node 7	Helium	1007	5.00	4968.7	0.4
Node 8	Helium	1000	5.00	4932.4	0.4
Node 9	Helium	993	5.00	4896.1	0.4
Node 10	Helium	986	5.00	4859.7	0.4
Node 11	Helium	507	5.00	2372.7	0.4
Node 12	Helium	500	5.00	2336.4	0.4
Node 13	Helium	493	5.00	2300.1	0.4
Node 14	Helium	486	5.00	2263.7	0.4
Node 15	Helium	193	5.00	742.5	0.4
Node 16	Helium	193	5.00	742.5	0.4
Node 17	Helium	50	5.00	0.0	0.4

Table B-1: Configuration 1 - Primary Loop Node Values

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Document No. 32-9097953-000

HTR Component Test Facility 1MW Heat Balance Design Calculation

Primary Loop - Process Change Configuration 1						
Section	Component	Δ P (Pa)	Δ T (K)	Δ H (kJ/kg)	Δ kW	Heat Loss to Atmosphere (kW)
Node 1 to 2	Gas Circulator	399034.01	100.00	519.2	-	-
Node 2 to 3	LT Piping	-181.30	-	-	-	-
Node 3 to 4	Recuperator	-33000.00	260.00	1349.9	540.0	-
Node 4 to 5	HT Piping	-0.24	7.00	36.3	-	14.5
Node 5 to 6	First Stage Heater	-33000.00	447.00	2320.8	928.3	-
Node 6 to 7	High Temp Heater	-33000.00	157.00	815.1	326.1	-
Node 7 to 8	HT Piping	-0.90	7.0	36.3	-	14.5
Node 8 to 9	HT Test Section	-100000.00	7.0	36.3	-	14.5
Node 9 to 10	HT Piping	-4.47	7.0	36.3	-	14.5
Node 10 to 11	High Temp HX	-33000.00	479.0	2487.0	994.8	-
Node 11 to 12	HT Piping	-1.38	7.0	36.3	-	14.5
Node 12 to 13	MT Test Section	-100000.00	7.0	36.3	-	14.5
Node 13 to 14	HT Piping	-0.27	7.0	36.3	-	14.5
Node 14 to 15	Recuperator	-33000.00	293.0	1521.3	608.5	68.5
Node 15 to 16	LT Piping	-499.34	-	-	-	-
Node 16 to 17	Low Temp HX	-33000.00	143.0	742.5	297.0	-
Node 17 to 1	LT Piping	-346.11	-	-	-	-

Table B-2: Configuration 1 - Primary Loop Process Change

APPENDIX C: CONFIGURATION 2 - PRIMARY LOOP CALCULATED NODE VALUES / PROCESS CHANGE CALCULATION

Primary Loop - Node Values Configuration 2					
Node	Fluid	Temp (°C)	Nominal Pressure (Mpa)	Enthalpy (kJ/kg)	Mass Flow Rate (kg/s)
Node 1	Helium	50	5.00	0.0	0.4
Node 2	Helium	150	5.00	519.2	0.4
Node 3	Helium	150	5.00	519.2	0.4
Node 4	Helium	410	5.00	1869.1	0.4
Node 5	Helium	403	5.00	1832.8	0.4
Node 6	Helium	850	5.00	4153.6	0.4
Node 7	Helium	921	5.00	4522.2	0.4
Node 8	Helium	914	5.00	4485.9	0.4
Node 9	Helium	907	5.00	4449.5	0.4
Node 10	Helium	900	5.00	4413.2	0.4
Node 11	Helium	866	5.00	4236.7	0.4
Node 12	Helium	859	5.00	4200.3	0.4
Node 13	Helium	482	5.00	2242.9	0.4
Node 14	Helium	475	5.00	2206.6	0.4
Node 15	Helium	507	5.00	2372.7	0.4
Node 16	Helium	500	5.00	2336.4	0.4
Node 17	Helium	493	5.00	2300.1	0.4
Node 18	Helium	486	5.00	2263.7	0.4
Node 19	Helium	200	5.00	778.8	0.4
Node 20	Helium	200	5.00	778.8	0.4
Node 21	Helium	50	5.00	0.0	0.4

Table C-1: Configuration 2 - Primary Loop Node Values

Primary Loop - Process Change Configuration 2						
Section	Component	Δ P (Pa)	Δ T (K)	Δ H (kJ/kg)	Δ kW	Heat Loss to Atmosphere (kW)
Node 1 to 2	Gas Circulator	365044.10	100.00	519.2	-	-
Node 2 to 3	LT Piping	-181.30	-	-	-	-
Node 3 to 4	Recuperator	-33000.00	260.00	1349.9	540.0	-
Node 4 to 5	HT Piping	-0.24	7.00	36.3	-	14.5
Node 5 to 6	First Stage Heater	-33000.00	447.00	2320.8	928.3	-
Node 6 to 7	High Temp Heater	-33000.00	71.00	368.6	147.5	-
Node 7 to 8	HT Piping	-0.84	7.0	36.3	-	14.5
Node 8 to 9	HT Spool Piece	-1.00	7.0	36.3	-	14.5
Node 9 to 10	HT Piping	-0.83	7.0	36.3	-	14.5
Node 10 to 11	Intermediate HX	-33000.00	34.0	176.5	70.6	-
Node 11 to 12	HT Piping	-4.00	7.0	36.3	-	14.5
Node 12 to 13	High Temp HX	-33000.00	377.0	1957.4	783.0	-
Node 13 to 14	HT Piping	-1.32	7.0	36.3	-	14.5
Node 14 to 15	Intermediate HX	-33000.00	32.0	166.1	66.5	4.2
Node 15 to 16	HT Piping	-0.27	7.0	36.3	-	14.5
Node 16 to 17	MT Test Section	-100000.00	7.0	36.3	-	14.5
Node 17 to 18	HT Piping	-1.34	7.0	36.3	-	14.5
Node 18 to 19	Recuperator	-33000.00	286.0	1484.9	594.0	54.0
Node 19 to 20	LT Piping	-506.84	-	-	-	-
Node 20 to 21	Low Temp HX	-33000.00	150.0	778.8	311.5	-
Node 21 to 1	LT Piping	-346.11	-	-	-	-

Table C-2: Configuration 2 - Primary Loop Process Change

APPENDIX D: CONFIGURATION 3 - PRIMARY LOOP CALCULATED NODE VALUES / PROCESS CHANGE CALCULATION

Primary Loop - Node Values Configuration 3					
Node	Fluid	Temp (°C)	Nominal Pressure (Mpa)	Enthalpy (kJ/kg)	Mass Flow Rate (kg/s)
Node 1	Helium	50	5.00	0.0	0.4
Node 2	Helium	150	5.00	519.2	0.4
Node 3	Helium	150	5.00	519.2	0.4
Node 4	Helium	410	5.00	1869.1	0.4
Node 5	Helium	403	5.00	1832.8	0.4
Node 6	Helium	850	5.00	4153.6	0.4
Node 7	Helium	921	5.00	4522.2	0.4
Node 8	Helium	914	5.00	4485.9	0.4
Node 9	Helium	907	5.00	4449.5	0.4
Node 10	Helium	900	5.00	4413.2	0.4
Node 11	Helium	507	5.00	2372.7	0.4
Node 12	Helium	500	5.00	2336.4	0.4
Node 13	Helium	493	5.00	2300.1	0.4
Node 14	Helium	486	5.00	2263.7	0.4
Node 15	Helium	193	5.00	742.5	0.4
Node 16	Helium	193	5.00	742.5	0.4
Node 17	Helium	50	5.00	0.0	0.4

Table D-1: Configuration 3 - Primary Loop Node Values

Primary Loop - Process Change Configuration 3						
Section	Component	Δ P (Pa)	Δ T (K)	Δ H (kJ/kg)	Δ kW	Heat Loss to Atmosphere (kW)
Node 1 to 2	Gas Circulator	299034.65	100.00	519.2	-	-
Node 2 to 3	LT Piping	-181.30	-	-	-	-
Node 3 to 4	Recuperator	-33000.00	260.00	1349.9	540.0	-
Node 4 to 5	HT Piping	-0.24	7.00	36.3	-	14.5
Node 5 to 6	First Stage Heater	-33000.00	447.00	2320.8	928.3	-
Node 6 to 7	High Temp Heater	-33000.00	71.00	368.6	147.5	-
Node 7 to 8	HT Piping	-0.84	7.0	36.3	-	14.5
Node 8 to 9	HT Spool Piece	-1.00	7.0	36.3	-	14.5
Node 9 to 10	HT Piping	-4.17	7.0	36.3	-	14.5
Node 10 to 11	Intermediate HX	-33000.00	393.0	2040.5	816.2	-
Node 11 to 12	HT Piping	-1.38	7.0	36.3	-	14.5
Node 12 to 13	MT Test Section	-100000.00	7.0	36.3	-	14.5
Node 13 to 14	HT Piping	-0.27	7.0	36.3	-	14.5
Node 14 to 15	Recuperator	-33000.00	293.0	1521.3	608.5	68.5
Node 15 to 16	LT Piping	-499.34	-	-	-	-
Node 16 to 17	Low Temp HX	-33000.00	143.0	742.5	297.0	-
Node 17 to 1	LT Piping	-346.11	-	-	-	-

Table D-2: Configuration 3 - Primary Loop Process Change

APPENDIX E: CONFIGURATION 3 - SECONDARY LOOP CALCULATED NODE VALUES / PROCESS CHANGE CALCULATION

Secondary Loop - Node Values Configuration 3					
Node	Fluid	Temp (°C)	Nominal Pressure (Mpa)	Enthalpy (kJ/kg)	Mass Flow Rate (kg/s)
Node 1	Helium	50	5.50	0.0	0.38
Node 2	Helium	150	5.50	519.2	0.38
Node 3	Helium	150	5.50	519.2	0.38
Node 4	Helium	495	5.50	2310.4	0.38
Node 5	Helium	488	5.50	2274.1	0.38
Node 6	Helium	475	5.50	2206.6	0.38
Node 7	Helium	875	5.50	4283.4	0.38
Node 8	Helium	868	5.50	4247.1	0.38
Node 9	Helium	861	5.50	4210.7	0.38
Node 10	Helium	854	5.50	4174.4	0.38
Node 11	Helium	500	5.50	2336.4	0.38
Node 12	Helium	493	5.50	2300.1	0.38
Node 13	Helium	486	5.50	2263.7	0.38
Node 14	Helium	479	5.50	2227.4	0.38
Node 15	Helium	100	5.50	259.6	0.38
Node 16	Helium	100	5.50	259.6	0.38
Node 17	Helium	50	5.5	0.0	0.38

Table E-1: Configuration 3 - Secondary Loop Node Values

Secondary Loop - Process Change Configuration 3						
Section	Component	Δ P (Pa)	Δ T (K)	Δ H (kJ/kg)	Δ kW	Heat Loss to Atmosphere (kW)
Node 1 to 2	Gas Circulator	398848.91	100.00	519.2	-	-
Node 2 to 3	LT Piping	-164.82	-	-	-	-
Node 3 to 4	Recuperator	-33000.00	345.00	1791.2	680.7	-
Node 4 to 5	HT Piping	-0.25	7.00	36.3	-	13.8
Node 5 to 6	Medium Temp HX	-33000.00	13.00	67.5	25.6	-
Node 6 to 7	Intermediate HX	-33000.00	400.00	2076.8	789.2	-
Node 7 to 8	HT Piping	-0.74	7.0	36.3	-	13.8
Node 8 to 9	HT Test Section	-100000.00	7.0	36.3	-	13.8
Node 9 to 10	HT Piping	-3.64	7.0	36.3	-	13.8
Node 10 to 11	High Temp HX	-33000.00	354.0	1838.0	698.4	-
Node 11 to 12	HT Piping	-1.24	7.0	36.3	-	13.8
Node 12 to 13	MT Test Section	-100000.00	7.0	36.3	-	13.8
Node 13 to 14	HT Piping	-0.24	7.0	36.3	-	13.8
Node 14 to 15	Recuperator	-33000.00	379.0	1967.8	747.8	67.1
Node 15 to 16	LT Piping	-363.35	-	-	-	-
Node 16 to 17	Low Temp HX	-33000.00	50.0	259.6	98.6	-
Node 17 to 1	LT Piping	-314.64	-	-	-	-

Table E-2: Configuration 3 - Secondary Loop Process Change

APPENDIX F: CONFIGURATION 1 - PRIMARY LOOP PRESSURE DROP CALCULATION

Primary Loop Low Temperature Piping - Pressure Drop (Node 2 to 3) (Configuration 1)								
Process Conditions			Reference Values				Assumed Values	
Temp (°K)	Average Pressure (Pa)	Mass Flow Rate (kg/s)	MW (kg/kmol)	Helium Gas Constant (J/kg*K)	Universal Gas Constant (J/kmol*K)	Viscosity (N*s/m2)	Pipe ID (mm)	Length (m)
423	5.00E+06	0.4	4.00	2.077E+03	8314	1.94E-05	102.26	6
Calculated Values								
Density (kg/m3)	Pipe ID (m)	Inside Area (m2)	Velocity (m/s)	G (kg/m2*s)	Re (Reynolds number)	f (friction factor)	Downstream Pressure (Pa)	Pressure Loss (Pa)
5.69	0.10	0.0082	8.56	4.873E+01	256852	0.014801239	5.00E+06	1.813E+02

Table F-1: Configuration 1 - Primary Loop Pressure Drop (Node 2 to 3)

Primary Loop High Temperature Piping - Pressure Drop (Node 4 to 5) (Configuration 1)								
Process Conditions			Reference Values				Assumed Values	
Temp (°K)	Average Pressure (Pa)	Mass Flow Rate (kg/s)	MW (kg/kmol)	Helium Gas Constant (J/kg*K)	Universal Gas Constant (J/kmol*K)	Viscosity (N*s/m2)	Pipe ID (mm)	Length (m)
683	5.00E+06	0.4	4.00	2.077E+03	8314	1.94E-05	388.94	3
Calculated Values								
Density (kg/m3)	Pipe ID (m)	Inside Area (m2)	Velocity (m/s)	G (kg/m2*s)	Re (Reynolds number)	f (friction factor)	Downstream Pressure (Pa)	Pressure Loss (Pa)
3.52	0.39	0.1188	0.96	3.368E+00	67531	0.01942323	5.00E+06	2.413E-01

Table F-2: Configuration 1 - Primary Loop Pressure Drop (Node 4 to 5)

Primary Loop High Temperature Piping - Pressure Drop (Node 7 to 8) (Configuration 1)								
Process Conditions			Reference Values				Assumed Values	
Temp (°K)	Average Pressure (Pa)	Mass Flow Rate (kg/s)	MW (kg/kmol)	Helium Gas Constant (J/kg*K)	Universal Gas Constant (J/kmol*K)	Viscosity (N*s/m2)	Pipe ID (mm)	Length (m)
1280	5.00E+06	0.4	4.00	2.077E+03	8314	1.94E-05	388.94	6
Calculated Values								
Density (kg/m3)	Pipe ID (m)	Inside Area (m2)	Velocity (m/s)	G (kg/m2*s)	Re (Reynolds number)	f (friction factor)	Downstream Pressure (Pa)	Pressure Loss (Pa)
1.88	0.39	0.1188	1.79	3.368E+00	67531	0.01942323	5.00E+06	9.045E-01

Table F-3: Configuration 1 - Primary Loop Pressure Drop (Node 7 to 8)

Primary Loop High Temperature Piping - Pressure Drop (Node 9 to 10) (Configuration 1)								
Process Conditions			Reference Values				Assumed Values	
Temp (°K)	Average Pressure (Pa)	Mass Flow Rate (kg/s)	MW (kg/kmol)	Helium Gas Constant (J/kg*K)	Universal Gas Constant (J/kmol*K)	Viscosity (N*s/m2)	Pipe ID (mm)	Length (m)
1266	5.00E+06	0.4	4.00	2.077E+03	8314	1.94E-05	388.94	30
Calculated Values								
Density (kg/m3)	Pipe ID (m)	Inside Area (m2)	Velocity (m/s)	G (kg/m2*s)	Re (Reynolds number)	f (friction factor)	Downstream Pressure (Pa)	Pressure Loss (Pa)
1.90	0.39	0.1188	1.77	3.368E+00	67531	0.01942323	5.00E+06	4.473E+00

Table F-4: Configuration 1 - Primary Loop Pressure Drop (Node 9 to 10)

Primary Loop High Temperature Piping - Pressure Drop (Node 11 to 12) (Configuration 1)									
Process Conditions			Reference Values				Assumed Values		
Temp (°K)	Average Pressure (Pa)	Mass Flow Rate (kg/s)	MW (kg/kmol)	Helium Gas Constant (J/kg*K)	Universal Gas Constant (J/kmol*K)	Viscosity (N*s/m2)	Pipe ID (mm)	Length (m)	
780	5.00E+06	0.4	4.00	2.077E+03	8314	1.94E-05	388.94	15	
Calculated Values									
Density (kg/m3)	Pipe ID (m)	Inside Area (m2)	Velocity (m/s)	G (kg/m2*s)	Re (Reynolds number)	f (friction factor)	Downstream Pressure (Pa)	Pressure Loss (Pa)	
3.09	0.39	0.1188	1.09	3.368E+00	67531	0.01942323	5.00E+06	1.378E+00	

Table F-5: Configuration 1 - Primary Loop Pressure Drop (Node 11 to 12)

Primary Loop High Temperature Piping - Pressure Drop (Node 13 to 14) (Configuration 1)									
Process Conditions			Reference Values				Assumed Values		
Temp (°K)	Average Pressure (Pa)	Mass Flow Rate (kg/s)	MW (kg/kmol)	Helium Gas Constant (J/kg*K)	Universal Gas Constant (J/kmol*K)	Viscosity (N*s/m2)	Pipe ID (mm)	Length (m)	
759	5.00E+06	0.4	4.00	2.077E+03	8314	1.94E-05	388.94	3	
Calculated Values									
Density (kg/m3)	Pipe ID (m)	Inside Area (m2)	Velocity (m/s)	G (kg/m2*s)	Re (Reynolds number)	f (friction factor)	Downstream Pressure (Pa)	Pressure Loss (Pa)	
3.17	0.39	0.1188	1.06	3.368E+00	67531	0.01942323	5.00E+06	2.682E-01	

Table F-6: Configuration 1 - Primary Loop Pressure Drop (Node 13 to 14)

Primary Loop Low Temperature Piping - Pressure Drop (Node 15 to 16) (Configuration 1)								
Process Conditions			Reference Values				Assumed Values	
Temp (°K)	Average Pressure (Pa)	Mass Flow Rate (kg/s)	MW (kg/kmol)	Helium Gas Constant (J/kg*K)	Universal Gas Constant (J/kmol*K)	Viscosity (N*s/m2)	Pipe ID (mm)	Length (m)
466	5.00E+06	0.4	4.00	2.077E+03	8314	1.94E-05	102.26	15
Calculated Values								
Density (kg/m3)	Pipe ID (m)	Inside Area (m2)	Velocity (m/s)	G (kg/m2*s)	Re (Reynolds number)	f (friction factor)	Downstream Pressure (Pa)	Pressure Loss (Pa)
5.17	0.10	0.0082	9.43	4.873E+01	256852	0.014801239	5.00E+06	4.993E+02

Table F-7: Configuration 1 - Primary Loop Pressure Drop (Node 15 to 16)

Primary Loop Low Temperature Piping - Pressure Drop (Node 17 to 1) (Configuration 1)								
Process Conditions			Reference Values				Assumed Values	
Temp (°K)	Average Pressure (Pa)	Mass Flow Rate (kg/s)	MW (kg/kmol)	Helium Gas Constant (J/kg*K)	Universal Gas Constant (J/kmol*K)	Viscosity (N*s/m2)	Pipe ID (mm)	Length (m)
323	5.00E+06	0.4	4.00	2.077E+03	8314	1.94E-05	102.26	15
Calculated Values								
Density (kg/m3)	Pipe ID (m)	Inside Area (m2)	Velocity (m/s)	G (kg/m2*s)	Re (Reynolds number)	f (friction factor)	Downstream Pressure (Pa)	Pressure Loss (Pa)
7.45	0.10	0.0082	6.54	4.873E+01	256852	0.014801239	5.00E+06	3.461E+02

Table F-8: Configuration 1 - Primary Loop Pressure Drop (Node 17 to 1)

APPENDIX G: CONFIGURATION 2 - PRIMARY LOOP PRESSURE DROP CALCULATION

Primary Loop Low Temperature Piping - Pressure Drop (Node 2 to 3) (Configuration 2)									
Process Conditions			Reference Values				Assumed Values		
Temp (°K)	Average Pressure (Pa)	Mass Flow Rate (kg/s)	MW (kg/kmol)	Helium Gas Constant (J/kg*K)	Universal Gas Constant (J/kmol*K)	Viscosity (N*s/m2)	Pipe ID (mm)	Length (m)	
423	5.00E+06	0.4	4.00	2.077E+03	8314	1.94E-05	102.26	6	
Calculated Values									
Density (kg/m3)	Pipe ID (m)	Inside Area (m2)	Velocity (m/s)	G (kg/m2*s)	Re (Reynolds number)	f (friction factor)	Downstream Pressure (Pa)	Pressure Loss (Pa)	
5.69	0.10	0.0082	8.56	4.873E+01	256852	0.014801239	5.00E+06	1.813E+02	

Table G-1: Configuration 2 - Primary Loop Pressure Drop (Node 2 to 3)

Primary Loop High Temperature Piping - Pressure Drop (Node 4 to 5) (Configuration 2)									
Process Conditions			Reference Values				Assumed Values		
Temp (°K)	Average Pressure (Pa)	Mass Flow Rate (kg/s)	MW (kg/kmol)	Helium Gas Constant (J/kg*K)	Universal Gas Constant (J/kmol*K)	Viscosity (N*s/m2)	Pipe ID (mm)	Length (m)	
683	5.00E+06	0.4	4.00	2.077E+03	8314	1.94E-05	388.94	3	
Calculated Values									
Density (kg/m3)	Pipe ID (m)	Inside Area (m2)	Velocity (m/s)	G (kg/m2*s)	Re (Reynolds number)	f (friction factor)	Downstream Pressure (Pa)	Pressure Loss (Pa)	
3.52	0.39	0.1188	0.96	3.368E+00	67531	0.01942323	5.00E+06	2.413E-01	

Table G-2: Configuration 2 - Primary Loop Pressure Drop (Node 4 to 5)

Primary Loop High Temperature Piping - Pressure Drop (Node 7 to 8) (Configuration 2)								
Process Conditions			Reference Values				Assumed Values	
Temp (°K)	Average Pressure (Pa)	Mass Flow Rate (kg/s)	MW (kg/kmol)	Helium Gas Constant (J/kg*K)	Universal Gas Constant (J/kmol*K)	Viscosity (N*s/m2)	Pipe ID (mm)	Length (m)
1194	5.00E+06	0.4	4.00	2.077E+03	8314	1.94E-05	388.94	6
Calculated Values								
Density (kg/m3)	Pipe ID (m)	Inside Area (m2)	Velocity (m/s)	G (kg/m2*s)	Re (Reynolds number)	f (friction factor)	Downstream Pressure (Pa)	Pressure Loss (Pa)
2.02	0.39	0.1188	1.67	3.368E+00	67531	0.01942323	5.00E+06	8.437E-01

Table G-3: Configuration 2 - Primary Loop Pressure Drop (Node 7 to 8)

Primary Loop High Temperature Piping - Pressure Drop (Node 9 to 10) (Configuration 2)								
Process Conditions			Reference Values				Assumed Values	
Temp (°K)	Average Pressure (Pa)	Mass Flow Rate (kg/s)	MW (kg/kmol)	Helium Gas Constant (J/kg*K)	Universal Gas Constant (J/kmol*K)	Viscosity (N*s/m2)	Pipe ID (mm)	Length (m)
1173	5.00E+06	0.4	4.00	2.077E+03	8314	1.94E-05	388.94	6
Calculated Values								
Density (kg/m3)	Pipe ID (m)	Inside Area (m2)	Velocity (m/s)	G (kg/m2*s)	Re (Reynolds number)	f (friction factor)	Downstream Pressure (Pa)	Pressure Loss (Pa)
2.05	0.39	0.1188	1.64	3.368E+00	67531	0.01942323	5.00E+06	8.289E-01

Table G-4: Configuration 2 - Primary Loop Pressure Drop (Node 9 to 10)

Primary Loop High Temperature Piping - Pressure Drop (Node 11 to 12) (Configuration 2)									
Process Conditions			Reference Values					Assumed Values	
Temp (°K)	Average Pressure (Pa)	Mass Flow Rate (kg/s)	MW (kg/kmol)	Helium Gas Constant (J/kg*K)	Universal Gas Constant (J/kmol*K)	Viscosity (N*s/m2)		Pipe ID (mm)	Length (m)
1132	5.00E+06	0.4	4.00	2.077E+03	8314	1.94E-05		388.94	30
Calculated Values									
Density (kg/m3)	Pipe ID (m)	Inside Area (m2)	Velocity (m/s)	G (kg/m2*s)	Re (Reynolds number)	f (friction factor)	Downstream Pressure (Pa)		Pressure Loss (Pa)
2.13	0.39	0.1188	1.58	3.368E+00	67531	0.01942323	5.00E+06		4.000E+00

Table G-5: Configuration 2 - Primary Loop Pressure Drop (Node 11 to 12)

Primary Loop High Temperature Piping - Pressure Drop (Node 13 to 14) (Configuration 2)									
Process Conditions			Reference Values					Assumed Values	
Temp (°K)	Average Pressure (Pa)	Mass Flow Rate (kg/s)	MW (kg/kmol)	Helium Gas Constant (J/kg*K)	Universal Gas Constant (J/kmol*K)	Viscosity (N*s/m2)		Pipe ID (mm)	Length (m)
748	5.00E+06	0.4	4.00	2.077E+03	8314	1.94E-05		388.94	15
Calculated Values									
Density (kg/m3)	Pipe ID (m)	Inside Area (m2)	Velocity (m/s)	G (kg/m2*s)	Re (Reynolds number)	f (friction factor)	Downstream Pressure (Pa)		Pressure Loss (Pa)
3.22	0.39	0.1188	1.05	3.368E+00	67531	0.01942323	5.00E+06		1.321E+00

Table G-6: Configuration 2 - Primary Loop Pressure Drop (Node 13 to 14)

Primary Loop High Temperature Piping - Pressure Drop (Node 15 to 16) (Configuration 2)									
Process Conditions			Reference Values				Assumed Values		
Temp (°K)	Average Pressure (Pa)	Mass Flow Rate (kg/s)	MW (kg/kmol)	Helium Gas Constant (J/kg*K)	Universal Gas Constant (J/kmol*K)	Viscosity (N*s/m2)	Pipe ID (mm)	Length (m)	
773	5.00E+06	0.4	4.00	2.077E+03	8314	1.94E-05	388.94	3	
Calculated Values									
Density (kg/m3)	Pipe ID (m)	Inside Area (m2)	Velocity (m/s)	G (kg/m2*s)	Re (Reynolds number)	f (friction factor)	Downstream Pressure (Pa)	Pressure Loss (Pa)	
3.11	0.39	0.1188	1.08	3.368E+00	67531	0.01942323	5.00E+06	2.731E-01	

Table G-7: Configuration 2 - Primary Loop Pressure Drop (Node 15 to 16)

Primary Loop High Temperature Piping - Pressure Drop (Node 17 to 18) (Configuration 2)									
Process Conditions			Reference Values				Assumed Values		
Temp (°K)	Average Pressure (Pa)	Mass Flow Rate (kg/s)	MW (kg/kmol)	Helium Gas Constant (J/kg*K)	Universal Gas Constant (J/kmol*K)	Viscosity (N*s/m2)	Pipe ID (mm)	Length (m)	
759	5.00E+06	0.4	4.00	2.077E+03	8314	1.94E-05	388.94	15	
Calculated Values									
Density (kg/m3)	Pipe ID (m)	Inside Area (m2)	Velocity (m/s)	G (kg/m2*s)	Re (Reynolds number)	f (friction factor)	Downstream Pressure (Pa)	Pressure Loss (Pa)	
3.17	0.39	0.1188	1.06	3.368E+00	67531	0.01942323	5.00E+06	1.341E+00	

Table G-8: Configuration 2 - Primary Loop Pressure Drop (Node 17 to 18)

Primary Loop Low Temperature Piping - Pressure Drop (Node 19 to 20) (Configuration 2)									
Process Conditions			Reference Values					Assumed Values	
Temp (°K)	Average Pressure (Pa)	Mass Flow Rate (kg/s)	MW (kg/kmol)	Helium Gas Constant (J/kg*K)	Universal Gas Constant (J/kmol*K)	Viscosity (N*s/m2)		Pipe ID (mm)	Length (m)
473	5.00E+06	0.4	4.00	2.077E+03	8314	1.94E-05		102.26	15
Calculated Values									
Density (kg/m3)	Pipe ID (m)	Inside Area (m2)	Velocity (m/s)	G (kg/m2*s)	Re (Reynolds number)	f (friction factor)		Downstream Pressure (Pa)	Pressure Loss (Pa)
5.09	0.10	0.0082	9.57	4.873E+01	256852	0.014801239		5.00E+06	5.068E+02

Table G-9: Configuration 2 - Primary Loop Pressure Drop (Node 19 to 20)

Primary Loop Low Temperature Piping - Pressure Drop (Node 21 to 1) (Configuration 2)									
Process Conditions			Reference Values					Assumed Values	
Temp (°K)	Average Pressure (Pa)	Mass Flow Rate (kg/s)	MW (kg/kmol)	Helium Gas Constant (J/kg*K)	Universal Gas Constant (J/kmol*K)	Viscosity (N*s/m2)		Pipe ID (mm)	Length (m)
323	5.00E+06	0.4	4.00	2.077E+03	8314	1.94E-05		102.26	15
Calculated Values									
Density (kg/m3)	Pipe ID (m)	Inside Area (m2)	Velocity (m/s)	G (kg/m2*s)	Re (Reynolds number)	f (friction factor)		Downstream Pressure (Pa)	Pressure Loss (Pa)
7.45	0.10	0.0082	6.54	4.873E+01	256852	0.014801239		5.00E+06	3.461E+02

Table G-10: Configuration 2 - Primary Loop Pressure Drop (Node 21 to 1)

APPENDIX H: CONFIGURATION 3 - PRIMARY LOOP PRESSURE DROP CALCULATION

Primary Loop Low Temperature Piping - Pressure Drop (Node 2 to 3) (Configuration 3)								
Process Conditions			Reference Values				Assumed Values	
Temp (°K)	Average Pressure (Pa)	Mass Flow Rate (kg/s)	MW (kg/kmol)	Helium Gas Constant (J/kg*K)	Universal Gas Constant (J/kmol*K)	Viscosity (N*s/m2)	Pipe ID (mm)	Length (m)
423	5.00E+06	0.4	4.00	2.077E+03	8314	1.94E-05	102.26	6
Calculated Values								
Density (kg/m3)	Pipe ID (m)	Inside Area (m2)	Velocity (m/s)	G (kg/m2*s)	Re (Reynolds number)	f (friction factor)	Downstream Pressure (Pa)	Pressure Loss (Pa)
5.69	0.10	0.0082	8.56	4.873E+01	256852	0.014801239	5.00E+06	1.813E+02

Table H-1: Configuration 3 - Primary Loop Pressure Drop (Node 2 to 3)

Primary Loop High Temperature Piping - Pressure Drop (Node 4 to 5) (Configuration 3)								
Process Conditions			Reference Values				Assumed Values	
Temp (°K)	Average Pressure (Pa)	Mass Flow Rate (kg/s)	MW (kg/kmol)	Helium Gas Constant (J/kg*K)	Universal Gas Constant (J/kmol*K)	Viscosity (N*s/m2)	Pipe ID (mm)	Length (m)
683	5.00E+06	0.4	4.00	2.077E+03	8314	1.94E-05	388.94	3
Calculated Values								
Density (kg/m3)	Pipe ID (m)	Inside Area (m2)	Velocity (m/s)	G (kg/m2*s)	Re (Reynolds number)	f (friction factor)	Downstream Pressure (Pa)	Pressure Loss (Pa)
3.52	0.39	0.1188	0.96	3.368E+00	67531	0.01942323	5.00E+06	2.413E-01

Table H-2: Configuration 3 - Primary Loop Pressure Drop (Node 4 to 5)

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Primary Loop High Temperature Piping - Pressure Drop (Node 7 to 8) (Configuration 3)								
Process Conditions			Reference Values				Assumed Values	
Temp (°K)	Average Pressure (Pa)	Mass Flow Rate (kg/s)	MW (kg/kmol)	Helium Gas Constant (J/kg*K)	Universal Gas Constant (J/kmol*K)	Viscosity (N*s/m2)	Pipe ID (mm)	Length (m)
1194	5.00E+06	0.4	4.00	2.077E+03	8314	1.94E-05	388.94	6
Calculated Values								
Density (kg/m3)	Pipe ID (m)	Inside Area (m2)	Velocity (m/s)	G (kg/m2*s)	Re (Reynolds number)	f (friction factor)	Downstream Pressure (Pa)	Pressure Loss (Pa)
2.02	0.39	0.1188	1.67	3.368E+00	67531	0.01942323	5.00E+06	8.437E-01

Table H-3: Configuration 3 - Primary Loop Pressure Drop (Node 7 to 8)

Primary Loop High Temperature Piping - Pressure Drop (Node 9 to 10) (Configuration 3)								
Process Conditions			Reference Values				Assumed Values	
Temp (°K)	Average Pressure (Pa)	Mass Flow Rate (kg/s)	MW (kg/kmol)	Helium Gas Constant (J/kg*K)	Universal Gas Constant (J/kmol*K)	Viscosity (N*s/m2)	Pipe ID (mm)	Length (m)
1180	5.00E+06	0.4	4.00	2.077E+03	8314	1.94E-05	388.94	30
Calculated Values								
Density (kg/m3)	Pipe ID (m)	Inside Area (m2)	Velocity (m/s)	G (kg/m2*s)	Re (Reynolds number)	f (friction factor)	Downstream Pressure (Pa)	Pressure Loss (Pa)
2.04	0.39	0.1188	1.65	3.368E+00	67531	0.01942323	5.00E+06	4.169E+00

Table H-4: Configuration 3 - Primary Loop Pressure Drop (Node 9 to 10)

Primary Loop High Temperature Piping - Pressure Drop (Node 11 to 12) (Configuration 3)									
Process Conditions			Reference Values				Assumed Values		
Temp (°K)	Average Pressure (Pa)	Mass Flow Rate (kg/s)	MW (kg/kmol)	Helium Gas Constant (J/kg*K)	Universal Gas Constant (J/kmol*K)	Viscosity (N*s/m2)	Pipe ID (mm)	Length (m)	
780	5.00E+06	0.4	4.00	2.077E+03	8314	1.94E-05	388.94	15	
Calculated Values									
Density (kg/m3)	Pipe ID (m)	Inside Area (m2)	Velocity (m/s)	G (kg/m2*s)	Re (Reynolds number)	f (friction factor)	Downstream Pressure (Pa)	Pressure Loss (Pa)	
3.09	0.39	0.1188	1.09	3.368E+00	67531	0.01942323	5.00E+06	1.378E+00	

Table H-5: Configuration 3 - Primary Loop Pressure Drop (Node 11 to 12)

Primary Loop High Temperature Piping - Pressure Drop (Node 13 to 14) (Configuration 3)									
Process Conditions			Reference Values				Assumed Values		
Temp (°K)	Average Pressure (Pa)	Mass Flow Rate (kg/s)	MW (kg/kmol)	Helium Gas Constant (J/kg*K)	Universal Gas Constant (J/kmol*K)	Viscosity (N*s/m2)	Pipe ID (mm)	Length (m)	
759	5.00E+06	0.4	4.00	2.077E+03	8314	1.94E-05	388.94	3	
Calculated Values									
Density (kg/m3)	Pipe ID (m)	Inside Area (m2)	Velocity (m/s)	G (kg/m2*s)	Re (Reynolds number)	f (friction factor)	Downstream Pressure (Pa)	Pressure Loss (Pa)	
3.17	0.39	0.1188	1.06	3.368E+00	67531	0.01942323	5.00E+06	2.682E-01	

Table H-6: Configuration 3 - Primary Loop Pressure Drop (Node 13 to 14)

Primary Loop Low Temperature Piping - Pressure Drop (Node 15 to 16) (Configuration 3)								
Process Conditions			Reference Values				Assumed Values	
Temp (°K)	Average Pressure (Pa)	Mass Flow Rate (kg/s)	MW (kg/kmol)	Helium Gas Constant (J/kg*K)	Universal Gas Constant (J/kmol*K)	Viscosity (N*s/m2)	Pipe ID (mm)	Length (m)
466	5.00E+06	0.4	4.00	2.077E+03	8314	1.94E-05	102.26	15
Calculated Values								
Density (kg/m3)	Pipe ID (m)	Inside Area (m2)	Velocity (m/s)	G (kg/m2*s)	Re (Reynolds number)	f (friction factor)	Downstream Pressure (Pa)	Pressure Loss (Pa)
5.17	0.10	0.0082	9.43	4.873E+01	256852	0.014801239	5.00E+06	4.993E+02

Table H-7: Configuration 3 - Primary Loop Pressure Drop (Node 15 to 16)

Primary Loop Low Temperature Piping - Pressure Drop (Node 17 to 1) (Configuration 3)								
Process Conditions			Reference Values				Assumed Values	
Temp (°K)	Average Pressure (Pa)	Mass Flow Rate (kg/s)	MW (kg/kmol)	Helium Gas Constant (J/kg*K)	Universal Gas Constant (J/kmol*K)	Viscosity (N*s/m2)	Pipe ID (mm)	Length (m)
323	5.00E+06	0.4	4.00	2.077E+03	8314	1.94E-05	102.26	15
Calculated Values								
Density (kg/m3)	Pipe ID (m)	Inside Area (m2)	Velocity (m/s)	G (kg/m2*s)	Re (Reynolds number)	f (friction factor)	Downstream Pressure (Pa)	Pressure Loss (Pa)
7.45	0.10	0.0082	6.54	4.873E+01	256852	0.014801239	5.00E+06	3.461E+02

Table H-8: Configuration 3 - Primary Loop Pressure Drop (Node 17 to 1)

APPENDIX I: CONFIGURATION 3 - SECONDARY LOOP PRESSURE DROP CALCULATION

Secondary Loop Low Temperature Piping - Pressure Drop (Node 2 to 3) (Configuration 3)								
Process Conditions			Reference Values				Assumed Values	
Temp (°K)	Average Pressure (Pa)	Mass Flow Rate (kg/s)	MW (kg/kmol)	Helium Gas Constant (J/kg*K)	Universal Gas Constant (J/kmol*K)	Viscosity (N*s/m2)	Pipe ID (mm)	Length (m)
423	5.50E+06	0.4	4.00	2.077E+03	8314	1.94E-05	102.26	6
Calculated Values								
Density (kg/m3)	Pipe ID (m)	Inside Area (m2)	Velocity (m/s)	G (kg/m2*s)	Re (Reynolds number)	f (friction factor)	Downstream Pressure (Pa)	Pressure Loss (Pa)
6.26	0.10	0.0082	7.78	4.873E+01	256852	0.014801239	5.50E+06	1.648E+02

Table I-1: Configuration 3 - Secondary Loop Pressure Drop (Node 2 to 3)

Secondary Loop High Temperature Piping - Pressure Drop (Node 4 to 5) (Configuration 3)								
Process Conditions			Reference Values				Assumed Values	
Temp (°K)	Average Pressure (Pa)	Mass Flow Rate (kg/s)	MW (kg/kmol)	Helium Gas Constant (J/kg*K)	Universal Gas Constant (J/kmol*K)	Viscosity (N*s/m2)	Pipe ID (mm)	Length (m)
768	5.50E+06	0.4	4.00	2.077E+03	8314	1.94E-05	388.94	3
Calculated Values								
Density (kg/m3)	Pipe ID (m)	Inside Area (m2)	Velocity (m/s)	G (kg/m2*s)	Re (Reynolds number)	f (friction factor)	Downstream Pressure (Pa)	Pressure Loss (Pa)
3.45	0.39	0.1188	0.98	3.368E+00	67531	0.01942323	5.50E+06	2.467E-01

Table I-2: Configuration 3 - Secondary Loop Pressure Drop (Node 4 to 5)

Secondary Loop High Temperature Piping - Pressure Drop (Node 7 to 8) (Configuration 3)								
Process Conditions			Reference Values				Assumed Values	
Temp (°K)	Average Pressure (Pa)	Mass Flow Rate (kg/s)	MW (kg/kmol)	Helium Gas Constant (J/kg*K)	Universal Gas Constant (J/kmol*K)	Viscosity (N*s/m2)	Pipe ID (mm)	Length (m)
1148	5.50E+06	0.4	4.00	2.077E+03	8314	1.94E-05	388.94	6
Calculated Values								
Density (kg/m3)	Pipe ID (m)	Inside Area (m2)	Velocity (m/s)	G (kg/m2*s)	Re (Reynolds number)	f (friction factor)	Downstream Pressure (Pa)	Pressure Loss (Pa)
2.31	0.39	0.1188	1.46	3.368E+00	67531	0.01942323	5.50E+06	7.375E-01

Table I-3: Configuration 3 - Secondary Loop Pressure Drop (Node 7 to 8)

Secondary Loop High Temperature Piping - Pressure Drop (Node 9 to 10) (Configuration 3)								
Process Conditions			Reference Values				Assumed Values	
Temp (°K)	Average Pressure (Pa)	Mass Flow Rate (kg/s)	MW (kg/kmol)	Helium Gas Constant (J/kg*K)	Universal Gas Constant (J/kmol*K)	Viscosity (N*s/m2)	Pipe ID (mm)	Length (m)
1134	5.50E+06	0.4	4.00	2.077E+03	8314	1.94E-05	388.94	30
Calculated Values								
Density (kg/m3)	Pipe ID (m)	Inside Area (m2)	Velocity (m/s)	G (kg/m2*s)	Re (Reynolds number)	f (friction factor)	Downstream Pressure (Pa)	Pressure Loss (Pa)
2.34	0.39	0.1188	1.44	3.368E+00	67531	0.01942323	5.50E+06	3.642E+00

Table I-4: Configuration 3 - Secondary Loop Pressure Drop (Node 9 to 10)

Secondary Loop High Temperature Piping - Pressure Drop (Node 11 to 12) (Configuration 3)								
Process Conditions			Reference Values				Assumed Values	
Temp (°K)	Average Pressure (Pa)	Mass Flow Rate (kg/s)	MW (kg/kmol)	Helium Gas Constant (J/kg*K)	Universal Gas Constant (J/kmol*K)	Viscosity (N*s/m2)	Pipe ID (mm)	Length (m)
773	5.50E+06	0.4	4.00	2.077E+03	8314	1.94E-05	388.94	15
Calculated Values								
Density (kg/m3)	Pipe ID (m)	Inside Area (m2)	Velocity (m/s)	G (kg/m2*s)	Re (Reynolds number)	f (friction factor)	Downstream Pressure (Pa)	Pressure Loss (Pa)
3.43	0.39	0.1188	0.98	3.368E+00	67531	0.01942323	5.50E+06	1.241E+00

Table I-5: Configuration 3 - Secondary Loop Pressure Drop (Node 11 to 12)

Secondary Loop High Temperature Piping - Pressure Drop (Node 13 to 14) (Configuration 3)								
Process Conditions			Reference Values				Assumed Values	
Temp (°K)	Average Pressure (Pa)	Mass Flow Rate (kg/s)	MW (kg/kmol)	Helium Gas Constant (J/kg*K)	Universal Gas Constant (J/kmol*K)	Viscosity (N*s/m2)	Pipe ID (mm)	Length (m)
752	5.50E+06	0.4	4.00	2.077E+03	8314	1.94E-05	388.94	3
Calculated Values								
Density (kg/m3)	Pipe ID (m)	Inside Area (m2)	Velocity (m/s)	G (kg/m2*s)	Re (Reynolds number)	f (friction factor)	Downstream Pressure (Pa)	Pressure Loss (Pa)
3.52	0.39	0.1188	0.96	3.368E+00	67531	0.01942323	5.50E+06	2.415E-01

Table I-6: Configuration 3 - Secondary Loop Pressure Drop (Node 13 to 14)

Secondary Loop Low Temperature Piping - Pressure Drop (Node 15 to 16) (Configuration 3)								
Process Conditions			Reference Values				Assumed Values	
Temp (°K)	Average Pressure (Pa)	Mass Flow Rate (kg/s)	MW (kg/kmol)	Helium Gas Constant (J/kg*K)	Universal Gas Constant (J/kmol*K)	Viscosity (N*s/m2)	Pipe ID (mm)	Length (m)
373	5.50E+06	0.4	4.00	2.077E+03	8314	1.94E-05	102.26	15
Calculated Values								
Density (kg/m3)	Pipe ID (m)	Inside Area (m2)	Velocity (m/s)	G (kg/m2*s)	Re (Reynolds number)	f (friction factor)	Downstream Pressure (Pa)	Pressure Loss (Pa)
7.10	0.10	0.0082	6.86	4.873E+01	256852	0.014801239	5.50E+06	3.633E+02

Table I-7: Configuration 3 - Secondary Loop Pressure Drop (Node 15 to 16)

Secondary Loop Low Temperature Piping - Pressure Drop (Node 17 to 1) (Configuration 3)								
Process Conditions			Reference Values				Assumed Values	
Temp (°K)	Average Pressure (Pa)	Mass Flow Rate (kg/s)	MW (kg/kmol)	Helium Gas Constant (J/kg*K)	Universal Gas Constant (J/kmol*K)	Viscosity (N*s/m2)	Pipe ID (mm)	Length (m)
323	5.50E+06	0.4	4.00	2.077E+03	8314	1.94E-05	102.26	15
Calculated Values								
Density (kg/m3)	Pipe ID (m)	Inside Area (m2)	Velocity (m/s)	G (kg/m2*s)	Re (Reynolds number)	f (friction factor)	Downstream Pressure (Pa)	Pressure Loss (Pa)
8.20	0.10	0.0082	5.94	4.873E+01	256852	0.014801239	5.50E+06	3.146E+02

Table I-8: Configuration 3 - Secondary Loop Pressure Drop (Node 17 to 1)