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an AREVA and Siemens company

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NGNP Heat Transport Small Scale Testing – Loop Technical and Functional Requirements

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Name and Title/Discipline	Signature	P/LP, R/LR, A/A-CRF, A/A-CRI	Date	Pages/Sections Prepared/Reviewed/ Approved or Comments
John Mayer/ Advisory Engineer/ HTR Nuclear Island	[signature]	LP	1/6/2010	All
Farshid Shahrokhi/ Advisory Engineer/ NT Technical Integration	[signature]	P	1/6/2010	Sections 1, 6
James Geschwindt/ Principal Engineer/ HTR Nuclear Island	[signature]	R	1/6/10	All
Lew Lommers/HTR Project Engineering Manager	[signature]	A	1/7/2010	All

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Record of Revision

Revision No.	Pages/Sections/ Paragraphs Changed	Brief Description / Change Authorization
000	All	Initial Issue
001	4.1.1.8	Revised requirement per INL comments.
001	4.2.1.6	Revised requirement per INL comments.
001	4.2.3.9	Deleted requirement (covered in 4.2.8.3).
001	Figures 5-2, 5-3, 5-4	Added these Figures.
001	Section 5.0	Minor changes to Section to reflect addition of Figures 5-2, 5-3, and 5-4..
001	Table 6-1	Deleted row containing Test Section Pressure Loss

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1.0 INTRODUCTION

The technical and functional requirements for a small scale helium heat transport test loop are provided in this document. These requirements are developed for the design of a test loop facility to perform selected NGNP technology development road map test sets identified in Reference 3.

Four basic loop configurations, and their associated design parameters, are presented in Section 6 of this report. It is not the intent that these loop configurations be treated as separate, stand-alone facilities, but rather that they be combined into a single, reconfigurable loop concept. This will allow many of the components (for example the circulators, helium purification systems, heaters, etc) to be used for many or all of the configurations, while allowing the more specialized components to be added as necessary. Such an approach will facilitate early development of a useable test loop facility, making the best use of available resources, while maintaining the ability to evolve with the NGNP design as subsequent design phases are accomplished.

Section 2 of this report defines the work scope. Section 3 identifies four sets of test loop thermodynamic conditions that are necessary to perform tests identified in Reference 3. Section 4 provided the technical and functional requirements for a small scale test loop. Section 5 provides a basic description of a test loop previously designed by AREVA for INL that can be modified to accommodate the four test configurations. Section 6 provides a listing of the proposed test loop estimated design parameters.

2.0 SCOPE OF WORK

The work plan that describes this task is contained within Reference 1. This plan is formulated to provide for development of a listing of all systems, structures, and components (SSCs) that will require static or small scale tests prior to use in the NGNP. This is to be accomplished through evaluation of the Technology Development Roadmaps (TDRMs) and test plans (TPs), generated under previous tasks (Reference 2) for the NGNP reactor outlet temperature of 750 to 800 °C, to identify small scale test requirements at elevated temperature and pressures. The results of this evaluation will be used to identify Technical and Functional Requirements of a small-scale, high-temperature, high pressure helium test loop.

2.1 Major Tasks

There are three major tasks that are necessary to accomplish the above described scope of work. The first two tasks are covered within Reference 3, including:

- Review and assessment of the TDRMs and TPs and identification of testing that can be performed in static tests or small-scale, low flowing test loops.
- Identification of small-scale test conditions by SSC at elevated temperature and pressure

The third task, definition of test facility technical and functional requirements for a set of tests identified in Reference 3, will be detailed within this report.

2.2 Reference Design

The small scale test loop described within this report is designed to fulfill a subset of the test requirements of AREVA's current baseline NGNP design, a 750 °C Conventional Steam Cycle Prismatic High Temperature Gas-Cooled Reactor more fully described in Reference 4.

2.3 Considerations Beyond Reference Design Limits

Though the reference scope of work limits required consideration to tests defined within the TDRM document, for completeness, other tests are assessed in Reference 3 in an attempt to support a robust and forward looking test facility design. These tests are in two primary areas:

- <u>Tests associated with increasing TRL levels above 7</u>. The process used to generate the TDRM report contained an initial screening that identified SSCs that had TRL scores of 7 and above. These SSCs were not included in the subsequent development of the TDRM report and associated test plans.
- <u>Tests associated with activities beyond technology development</u>. Tests required for support of other areas beyond technology development, for example tests supportive of methods development, are not included in the development of the TDRM report and associated test plans.

Reference 3 also included other tests as an attempt to capture many of these required tests and reflect their requirements within the development of the requirements for the small scale test loop. It is not the intent of Reference 3 to try to capture all of the tests which might fall under the above headings, but rather to develop an understanding of the needs of the more readily identified tests.

Consideration was also given to small scale tests which might be required to support future higher temperature HTGR concepts (e.g., with reactor outlet temperature of 900-950 °C).

3.0 SUMMARY OF REQUIRED SMALL-SCALE TEST CONDITIONS

Based on the information presented in Reference 3, four small scale test loop configurations that, between them, cover all of the small scale tests are identified in Table 3-1.

Table 3-1: Summary of Required Small Scale Test Configurations

Small Scale Loop Configuration	Temp. °C	Pressure MPa	Environ.	Flow Rate	Power MWth	Approx Size
1	20 - 1200	Atm. – 6 [Atm. – 9]	He	0-3 kg/s	N/A	0.5m dia. 5m long
2	20 – 900 [1000]	0.1 - 9	Impure He or Air	0-0.5 kg/s	0-1 MW	Test Coupon or Hx Module/ Component
3	100 - 900	6 [Atm. – 9]	He	0-3 kg/s	N/A	~20-30m
4	30 - 450	0.1 - 9	Impure He	0.04 kg/s	N/A	HPS

These four loop configurations were chosen based on the following logic:

<u>Loop Configuration 1 – High Temperature Helium Loop:</u> This loop includes tests requiring the highest helium temperature and the largest test sections (except special loop configuration 3). The test atmosphere required is simply helium, that is, there are no requirements for addition of impurities to the test fluid. At these high temperatures, loop materials performance issues will likely require more costly material selections. Limitation of the atmosphere to low impurity helium (with sufficient impurities to create a benign atmosphere with respect to material performance) may alleviate some material performance concerns. The small scale tests covered by this configuration are all specified to have a maximum pressure of 6 MPa, reflective of the current NGNP reference design proposed by the AREVA design team. It might be advantageous to consider an increase in this value to 9 MPa to provide both design flexibility for the ongoing NGNP design process, and to allow testing of components for other HTGR designs.

<u>Loop Configuration 2 – Moderate Temperature Impure Helium Loop:</u> This loop configuration is designed to cover all of the tests which require normal, off-normal helium impurity, or air environments. In addition, all of the tests covered are either small in scale, primarily sample coupons, or consist of a stand-alone small component which is to be tested, for example compact heat exchanger modules. The majority of these tests require temperatures below 900 °C, which should make loop materials performance issues easier to address, even in light of the variety of environmental constituents. Three of the tests require temperatures up to 1000 °C, which may increase these issues, though the tests are supportive of designs beyond the NGNP base design. Such tests may be deferred should material performance issues become too costly.

<u>Loop Configuration 3 – Control Rod Functional Test Loop:</u> This loop configuration is designed specifically to support functional testing of the Control Rod Drives and associated components. Though the test conditions are bound by those of Loop 2, the need for a comparatively very large test section warrants its consideration as a unique test loop configuration. The test covered by this configuration is specified to have a maximum pressure of 6 MPa, reflective of the current NGNP reference design. It might be advantageous to consider an increase in this value to 9 MPa to provide both design flexibility for the ongoing NGNP design process, and to allow testing of components for other HTGR designs.

Loop Configuration 4 – Helium Purification System: This loop configuration is not a separate test loop per se, but rather an engineering scale representation of the helium purification system that will be used for the NGNP reactor. It is proposed that such a system be used as the purification system for the helium test loop, thus doing double duty, as both a qualification test and as an integral operational part of the loop.

Presentation of four separate loop configurations does not imply that it is necessary to construct four independent test loops. It may be possible, and advantageous, to consider a modular and/or reconfigurable approach to the loops design whereby common equipment can be used for multiple configurations. The final number of loops and their configuration will be decided in the loop detailed design phase.

It is also important to note that the tests described in Reference 3 have not been ordered or prioritized with respect to an integrated test schedule in support of the NGNP prototype plant design and deployment schedule. Completion of an integrated schedule would be expected to provide additional insight regarding the appropriate strategy for determining final test facility loop configurations and the construction order for those loops.

4.0 TECHNICAL AND FUNCTIONAL REQUIREMENTS

4.1 Functional Requirements

The following Functional Requirements are defined for the Small Scale Test Loop, which shall:

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

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

4.1.1.3 Provide helium at the representative or scaled pressures, temperatures (including temperature transient rate), mass flow rates, energies, and purity (impurity addition and controls) anticipated for the tests to be conducted.

4.1.1.4 Provide high-temperature working fluids- simulating the conditions of potential future prototype reactor secondary loop configurations – at the representative or scaled pressures, temperatures and temperature transients, mass flow rates, energies, and purity (impurity control) necessary to support the range and scales of tests identified for development of possible future HTGR prototype reactor components (particularly heat exchangers) and subsequent HTGR user-facility component tests.

4.1.1.5 Provide secondary heat transfer fluid capability needed to support heat exchanger testing.

4.1.1.6 Provide off-line trouble-shooting of component and system problems.

4.1.1.7 Enable coolant and heat transfer fluid tests.

4.1.1.8 Enable testing of certain direct-cycle power conversion components.

4.1.1.9 Provide equipment areas for conducting instrumentation testing, qualification, and calibration.

4.1.1.10 Enable high quality test data collection, processing, recording, storage, transmission, and archiving capability.

4.1.1.11 Enable materials testing capability – HT fluid conditions.

4.1.1.12 Enable development and qualification capabilities including various test scales, types, scenarios, components, and HT fluid conditions.

4.2 Technical Requirements

4.2.1 System Requirements

4.2.1.1 The Small Scale Test Loop shall provide an in-service reliability greater than TBD. The in-service reliability plan shall be developed during design.

4.2.1.2 The Small Scale Test Loop shall provide a level of maintainability that minimizes the need for maintenance personnel and costs.

4.2.1.3 The Small Scale Test Loop shall have a design life of 40 years, the standard for DOE capital assets.

4.2.1.4 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.

4.2.1.5 The design, procurement, and construction of the facility shall adhere to applicable Idaho National Laboratory site local, state, and federal building codes.

4.2.1.6 The Small Scale Test Loop test loop shall be designed to provide the configurations listed in Table 3-1.

4.2.2 Civil and Structural Design Requirements

4.2.2.1 The loop shall be designed to maintain its structural integrity for the maximum acceleration caused by International Building Code (IBC) 2006, Occupancy Category II.

4.2.3 Control and Instrumentation Requirements

4.2.3.1 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. The loop operation and control shall be conducted from a central control room area away from any potential loop hazards.

4.2.3.2 The data logging computer system shall provide sufficient number of data points for the loop test sections.

4.2.3.3 Software Verification and Validation (V&V) shall be performed.

4.2.3.4 The Small Scale Test Loop shall provide equipment to enable test data collection, processing, recording, transmission, storage and archiving capability.

4.2.3.5 The Small Scale Test Loop shall provide instrumentation to measure and record pressures, temperatures, temperature transients, impurity content, and mass flow rates.

4.2.3.6 Temperatures shall be measured at the inlet and outlet of each major component such as cooler, heat exchanger and recuperator.

4.2.3.7 Circulator speed control shall be used to control helium flow rate in the loop. The circulator speed shall be measured and recorded.

4.2.3.8 The control loops shall provide automatic detection and shutdown protection for off-normal and onset of dangerous pressures, temperatures, atmospheric chemical compositions, and flows.

4.2.3.9 The Small Scale Test Loop shall meet appropriate Control and Instrumentation Codes and Standards

4.2.4 Electrical Requirements

4.2.4.1 The Small Scale Test Loop external power source shall be from the local electric utility.

4.2.4.2 Backup power for emergency shutdown and cool-down of the loop, emergency facility lighting and the test facility computer and data logging system shall be provided by an uninterruptible battery backed power supply.

4.2.4.3 The Small Scale Test Loop shall meet appropriate Electrical Codes and Standards

4.2.5 Mechanical Requirements

4.2.5.1 The Small Scale Test Loop pressure boundary shall be designed for the loop maximum pressure, temperature, and flow rate.

4.2.5.2 The Small Scale Test Loop shall meet appropriate Mechanical Codes and Standards

4.2.6 Loop Heat Sink Requirements

4.2.6.1 The Small Scale Test Loop shall reject excess heat into a site circulating cooling water (CCW) system with a supply temperature of ≤ 40 °C.

4.2.7 Dimensional Requirements

4.2.7.1 The Small Scale Test Loop shall be flexible and have provision for a variety of test pieces. Provisions for test loop alteration and adjustment shall be provided.

4.2.8 Safety and Operability Requirements

4.2.8.1 The Small Scale Test Loop Design shall ensure protection of the operating and maintenance personnel, equipment, components, and materials safety (test-adjacent areas) in the event of an operations, component, or integrated test failure.

4.2.8.2 The Small Scale Test Loop Design shall provide preventative and/or mitigative safety measures for the test loop.

4.2.8.3 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 measures included in the design, including Environmental Hazards (heat), Electromagnetic Hazards, and Physical/Chemical Hazards.

5.0 TEST LOOP BASIC CONCEPT DESCRIPTION

The test loop described here is based on the low power (1 MWth) loop developed in References 5 and 6, based on the AREVA HELITE design. The primary circuit of this test loop has a “figure-8” configuration with a recuperator heat exchanger. This allows operating the circulator at low temperature. The functional schematic of the phase 1 loop is illustrated in Figure 5-1.

The helium flow leaving the circulator is heated in the recuperator heat exchanger, then in the electric resistance heater allowing test temperature up to the loop maximum temperature. Helium flows at this temperature into the high temperature test section and then, at the outlet of this test section the helium is cooled in a cooler to a lower temperature. At this temperature, helium enters into a medium temperature test section. After going through this test section, the helium is cooled by entering into the recuperator heat exchanger and then into a cooler, in order to get back to the circulator.

In later loop test phases, an additional heater can be added in the primary loop for increasing its operating temperature to 1000 °C or even 1200 °C depending on the flow rate and loop materials used.

Another option would be to construct the initial test loop consistent with operation at 800 – 900 °C, then add a second, parallel test section capable of supporting tests at 1000 – 1200 °C, as depicted in Figure 5-2. This parallel section would contain an additional heater section to increase the temperature to the required value, a very high temperature test section, and a high temperature heat exchanger to cool the gas exiting the test section to temperatures low enough to re-enter the initial test loop.

The high temperature test section can be used to test IHX and other component mock-ups in conditions representative of normal operation. The test section can be operated:

- With a secondary circuit very similar to the primary circuit, in an “8” configuration, including a representative secondary atmosphere. This is shown in Figure 5-3.
- With the primary helium re-circulated in the secondary side of the mock-up, allowing testing of a higher power mock-up, but only for isobar behavior. This is shown in Figure 5-4.

Figure 5-1: Basic Helium Test Loop

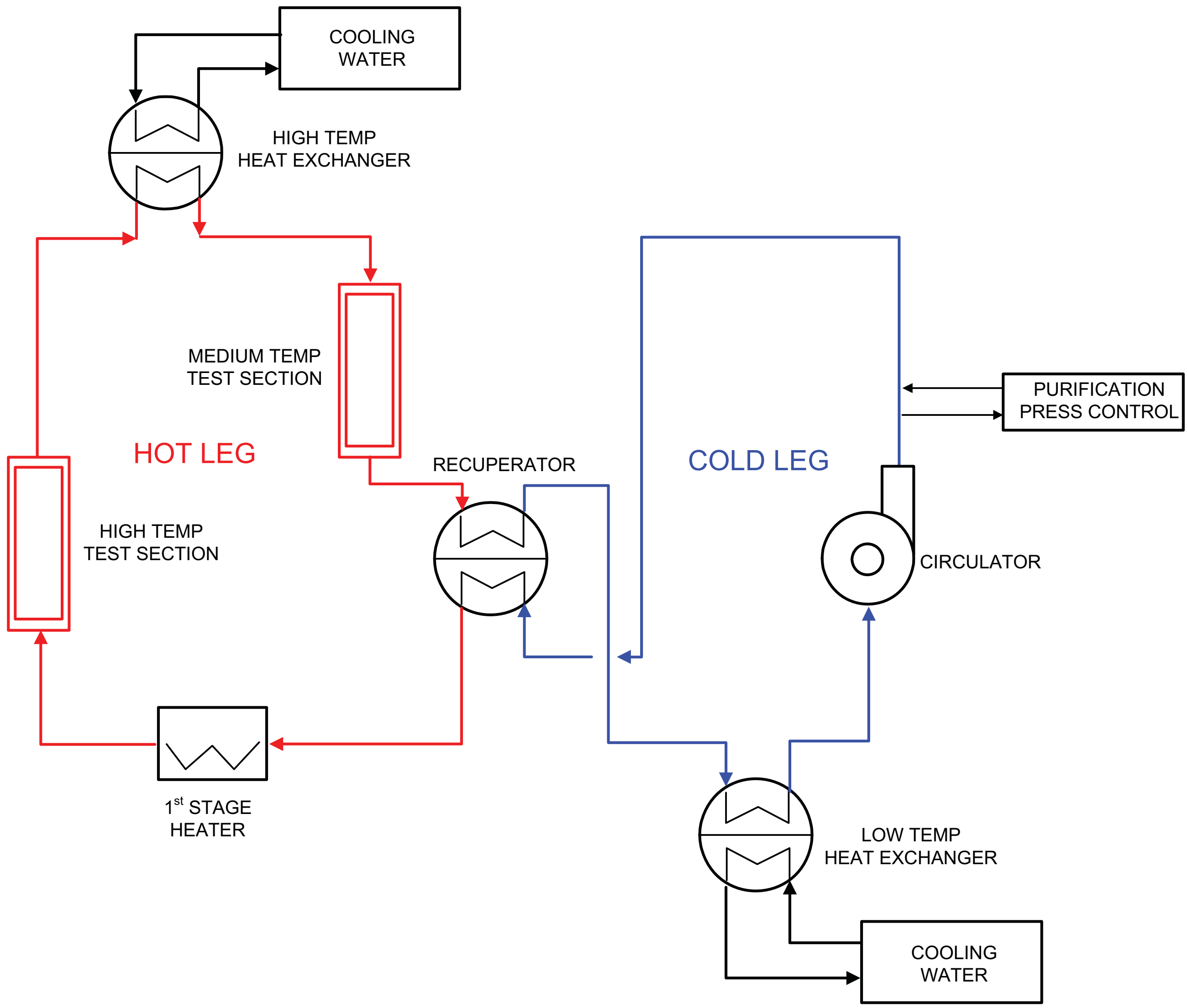


Figure 5-2: Helium Test Loop with Very High Temperature Test Section

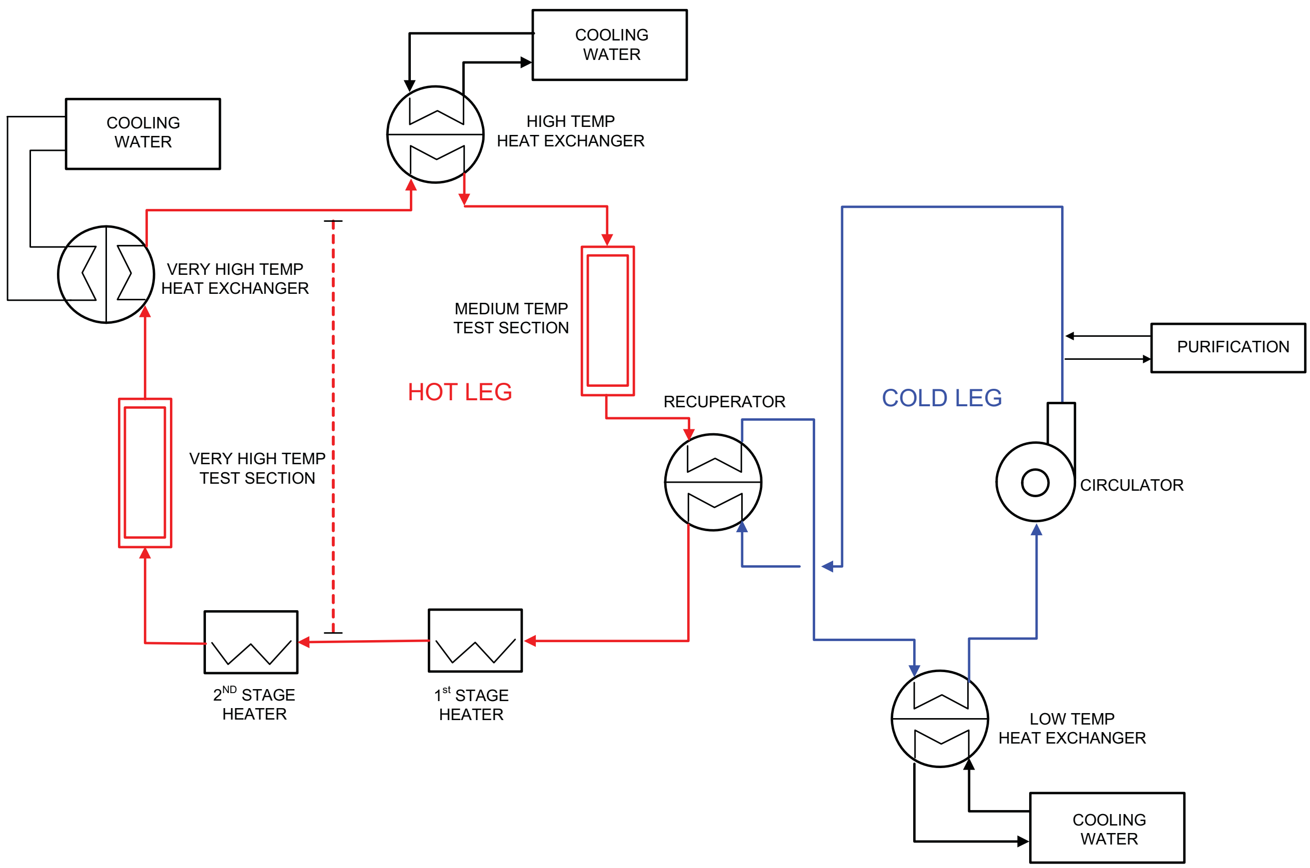


Figure 5-3: Helium Test Loop with IHX Testing via. Secondary Loop

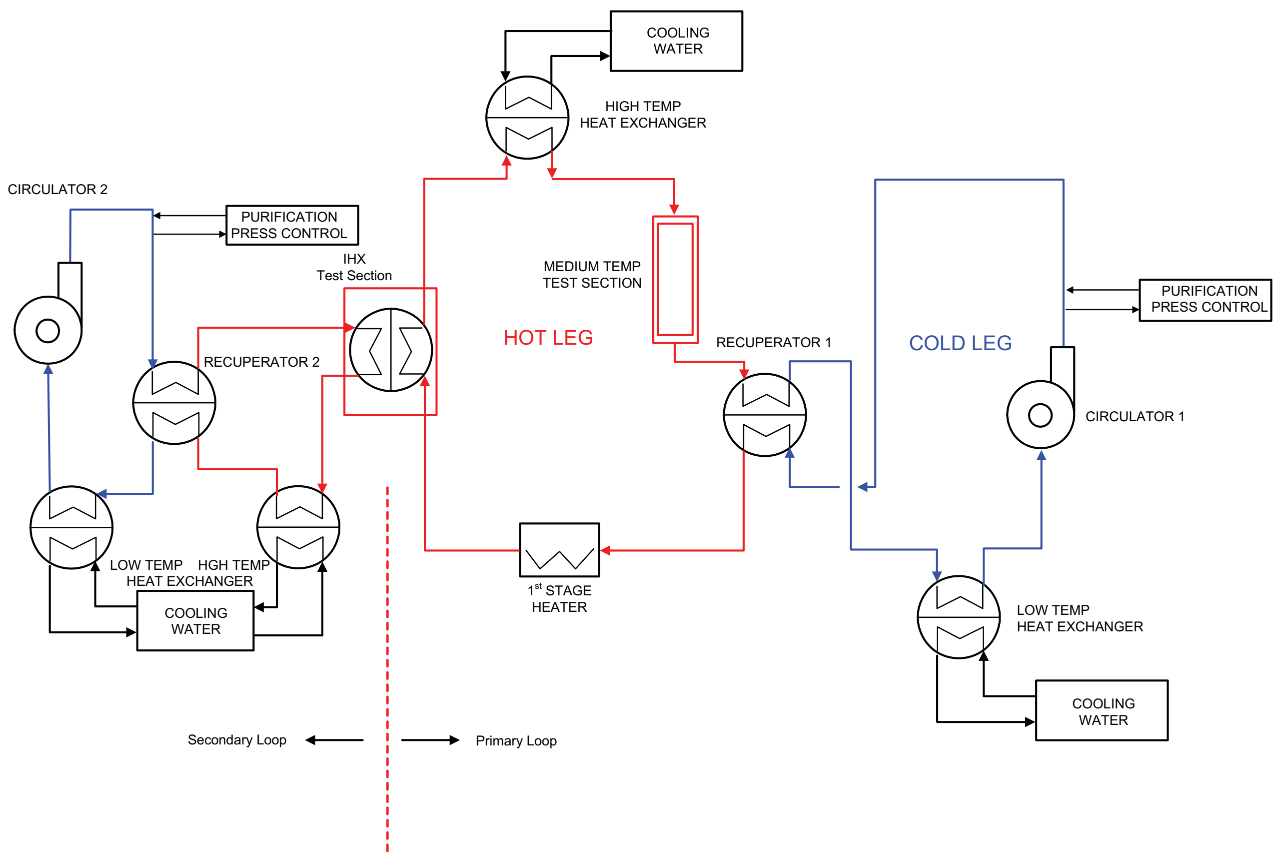
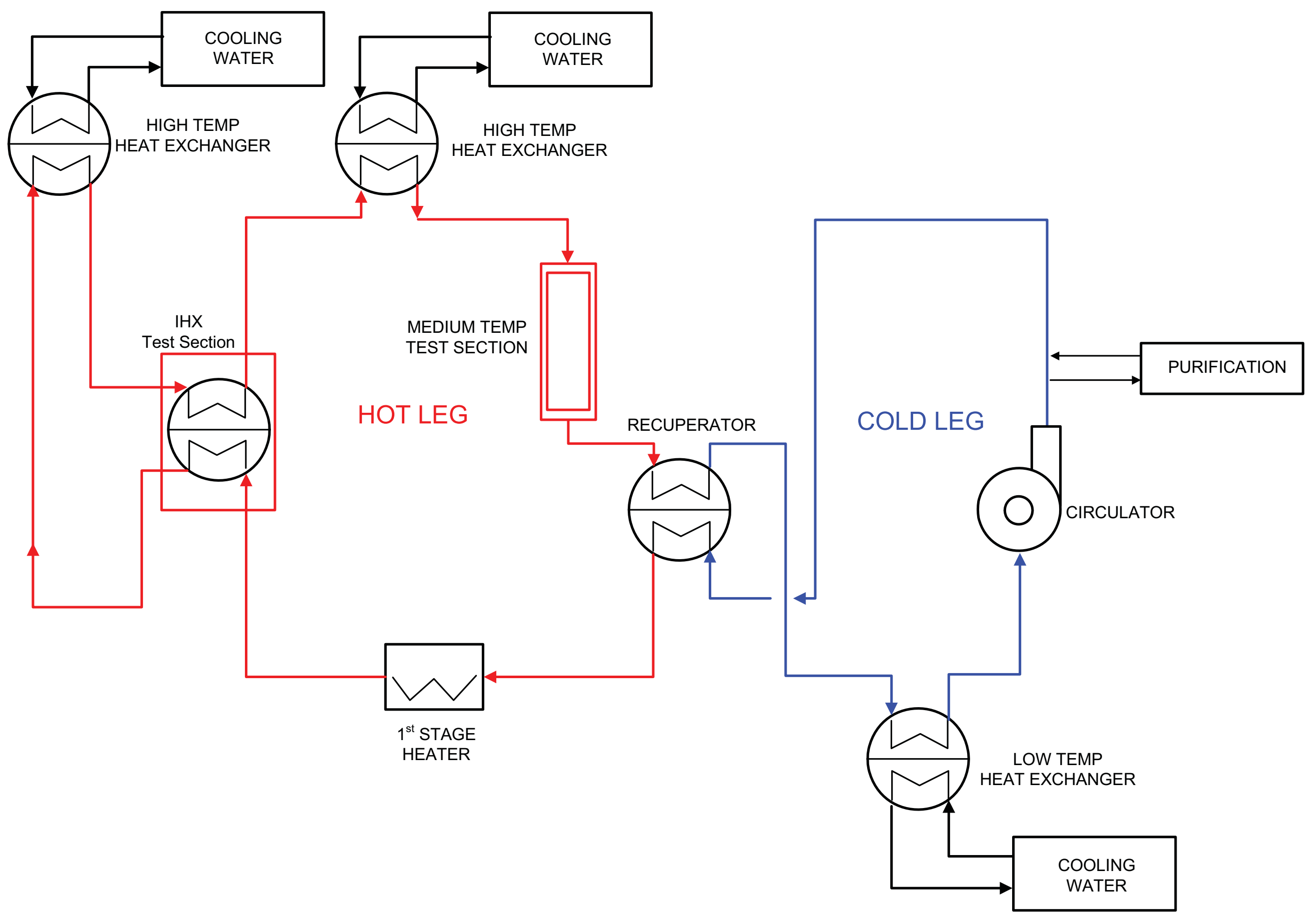


Figure 5-4: Helium Test Loop with Alternate IHX Test Configuration



6.0 DESIGN PARAMETERS

Utilizing the loop configurations discussed in Section 3 and the basic loop design from Section 5, the following summary of loop design parameters has been developed. It should be noted that these parameters are representative of a composite of individual tests. Actual loop parameters must be developed during the detailed test loop design phase. The four basic loop configurations are presented not with the intent that they be treated as separate, stand-alone facilities, but rather combined into a single, reconfigurable loop concept. This will allow many of the components (for example the circulators, helium purification systems, heaters, etc) to be used for many or all of the configurations, while allowing the more specialized components to be added as necessary. Such an approach will facilitate early development of a useable test loop facility, making the best use of available resources, while remaining able to evolve with the NGNP design as subsequent design phases are accomplished.

Table 6-1: Summary of Estimated Loop Design Parameters

Description	**Loop Configuration**			
	1	**2**	**3**	**4**
Gas	Helium	Controlled Impurity Helium	Helium	Controlled Impurity Helium
Design Power (Test Section)	N/A	1.0 MWt	N/A	N/A
Loop Design –	Recuperated figure eight design			
Pressure	0 to 9 MPa	0 to 9 MPa	0 to 9 MPa	0 to 9 MPa
Loop Pressure Loss (depressurization event)	8 MPa	8 MPa	8 MPa	8 MPa
Circulator Compression Ratio	1.3	1.3	1.3	1.3
Primary Loop First stage heater (Electric)				
Power	0.9 - TBD MW	0.9 MW	0.9 - TBD MW	0.9 MW
Flow	0.04 to 3 kg/s	0.04 to 0.5 kg/s	0.04 to 3 kg/s	0.04 kg/s
Temperature rise	400 to 850 °C	400 to 850 °C	400 to 850 °C	400 to 850 °C
Primary Loop High temperature heater (Electric)				
Power	0.7 - TBD MW	0.5 MW	0.5 - TBD MW	N/A
Flow	0.04 to 3 kg/s	0.04 to 0.5 kg/s	0.04 to 3 kg/s	N/A
Temperature rise	850 to 1200 °C	850 to 1000 °C	850 to 900 °C	N/A
Primary Loop Recuperator				
Number of units	1	1	1	1

Description	**Loop Configuration**			
	1	**2**	**3**	**4**
High Temperature Side (highest/lowest)	TBD °C	500 to 120 °C	TBD °C	TBD °C
Low Temperature Side (highest/lowest)	TBD °C	70 to 420 °C	TBD °C	TBD °C
Number of Water Cooled Heat Exchangers	1	1	1	1
Primary Loop Low Temperature Heat Exchanger				
Tin (maximum) – Tout	200 to 50 °C	200 to 50 °C	200 to 50 °C	200 to 50 °C
High Temperature Heat Exchanger (used as part of the primary loop test configuration when an IHX is not being tested)				
Tin – Tout	1200 to 500 °C	850 to 500 °C	850 to 500 °C	N/A
Primary Test Loop Gas Circulator				
Number of units	1	1	1	1
Fluid	Helium	Helium	Helium	Helium
Flow	0.04 to 3 kg/s	0.04 to 0.5 kg/s	0.04 to 3 kg/s	0.04 kg/s

7.0 REFERENCES

1. AREVA Report PD-3002052-000, “Work Plan for Heat Transport Small Scale Testing for Prismatic Block”, September 2009.
2. AREVA Report TDR-3001031-003, “NGNP Technology Development Road Mapping Report”, September 2009.
3. AREVA Report 12-9127825-000, “NGNP Heat Transport Small Scale Testing - Review and Assessment of TDRM Identified Tests”, December 2009.
4. AREVA Report 51-9103803-002, “NGNP Conceptual Design Baseline Document for Conventional Steam Cycle for Process Heat and Cogeneration”, April 2009.
5. AREVA Report 12-9076931-000, “NGNP Component Test Facility – Conceptual Configuration, Cost, and Schedule Estimate”, March 2008.
6. AREVA Report 51-9096878-001, “HTGR CTF Preconceptual System Requirements Manual”, September 2008.