AREVA NP Inc.,

an AREVA and Siemens company

Technical Data Record

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NGNP Heat Transport Small Scale Testing – Review and Assessment of TDRM Identified Tests

AREVA

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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
Dominique Hittner/ NGNP R&D Coordinator	[signature]	P	1/6/2010	Section 5
James Geschwindt/ Principal Engineer/ HTR Nuclear Island	[signature]	R	1/6/10	All
Lew Lommers/HTR Project Engineering Manager	[signature]	A	1/6/2010	All

Note: P/LP designates Preparer (P), Lead Preparer (LP)
R/LR designates Reviewer (R), Lead Reviewer (LR)
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Revision No.	Pages/Sections/ Paragraphs Changed	Brief Description / Change Authorization
000	All	Initial Issue
001	2.3	Updated wording to reflect INL comments.
001	4.2.1, 5.10.2	Corrected typos.
001	4.4.1, 5.11.2	Clarified text.
001	5.6.1	Updated text to reflect intent that heat exchanger mock-ups could be tested in the loop while other components, including rotating equipment would be tested elsewhere.

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1.0 INTRODUCTION

This report 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 will include evaluation of the Technology Development Roadmaps (TDRMs) and test plans (TPs) generated under previous tasks 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. The development of these Technical and Functional Requirements is detailed in a follow-on report.

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 3) 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, and 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 this report, 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 test systems that could accomplish the required testing, will be detailed within a separate report.

2.2 Reference Design

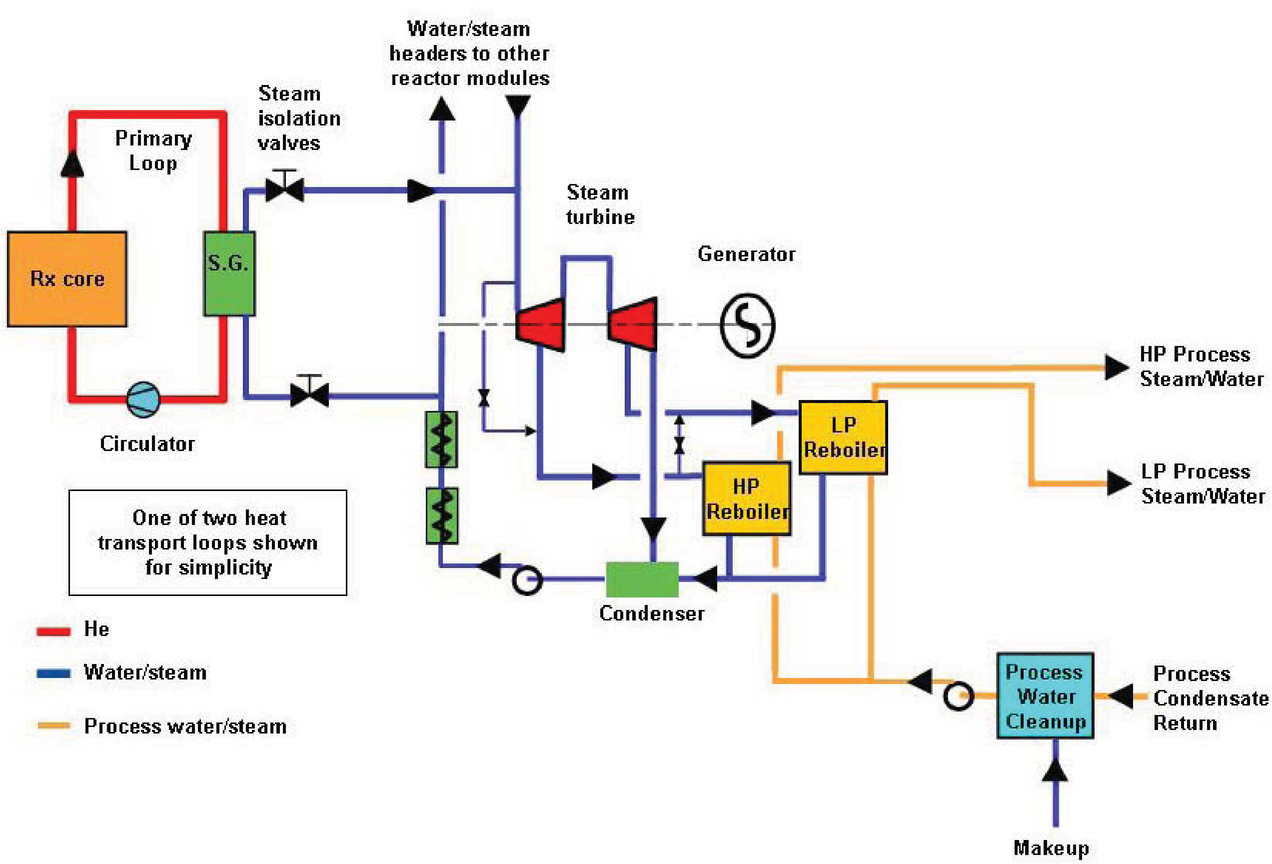
The selected reference design for the AREVA NGNP is consistent with the revised NGNP design requirements presented in the updated Next Generation Nuclear Plant System Requirements Manual (Reference 5). It is a conventional steam cycle commercial First-of-a-Kind (FOAK) concept with a 750 °C reactor outlet temperature as described in Reference 2.

Key parameters of the reference design are summarized below in Table 2-1 and a schematic representation is provided in Figure 2-1.

Table 2-1: Parameters for Selected Reference Design

Reactor Core Configuration	Prismatic Annular, 102 column, 10 blocks/column
Reactor Core Power Level	625 MWt
Reactor Core Outlet Temperature	750 °C
Reactor Core Inlet Temperature	325 °C
Steam Supply Temperature	566 °C
Type of Power Conversion Cycle	Conventional Steam Cycle
Power Conversion System Configuration	Steam Generator (SG) in primary gas loop Steam Turbine uses steam from SG Extraction steam available for process heat applications
Number of Main Loops	2
Number of Side Loops	0
Process Steam Supply	Steam/Steam Reboiler

Figure 2-1: Reference NGNP System Configuration



2.3 Considerations Beyond TDRM Identified Tests

Though the reference scope of work limits required consideration to tests defined within the TDRM document, to assess requirements for future plant designs other tests are assessed in Section 5 of this report in an attempt to support a robust test facility design. These tests are in two primary areas:

- Tests associated with increasing TRL levels above 7. 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.
- Tests associated with activities beyond technology development. 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.

Section 5 of this report is included 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. Consideration will therefore be given to small scale tests which might support future very high temperature concepts (e.g., with reactor outlet temperature of 900-950 °C) and alternative designs (direct cycle), as well as extension of the range of process heat applications beyond mere steam supply.

It is not the intent of Section 5 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.

3.0 BACKGROUND

3.1 TDRM Process and Limits

Reference 3 presents a detailed description of the TDRM process, including identification of the underlying assumptions that have a bearing on the current project, including:

- Only systems with TRLs below 7 were examined
- No tests for TRLs above 7 were developed for any system
- No fabrication or design related tests were identified

These inherent limitations have a direct impact on the nature and types of tests that were identified in the TDRM report and that are reflected in Section 4 of this report. As discussed above, the inclusion of Section 5 of this report is an attempt to provide a broader framework for the development of the small scale test facility.

3.2 Systems Examined

The TDRM report for the 750 °C conventional steam cycle configuration provides test plans for the systems and sub-systems listed in the following sections. Very brief descriptions are provided for each system or component to allow perspective for the test condition discussions to follow. More complete system descriptions and supporting information can be found within the TDRM report (Reference 3). Note that several of the system names have been updated to reflect the nomenclature of the most recent revision of AREVA's NGNP Plant Design Requirements Document (Reference 7), and may not match exactly the names used in Reference 3.

3.2.1 Reactor System - Reactor Internals

Reactor Internals is part of the Reactor System (RS) and includes components that provide the structural interface between the Reactor Core and the Vessel System and also components that route helium between the Reactor Core and the Main Heat Transport and Shutdown Cooling Systems. In addition to providing structural support and directing of the helium flow, other major functions of the Reactor Internals include thermal and radiological shielding of the RPV, conservation of neutrons during power production, and serving as a key link in the conduction cooldown radial heat transport path.

3.2.2 Reactor System - Reactor Core

The Reactor Core design is an annular arrangement of prismatic fuel and reflector elements located within a permanent graphite reflector. The annular core configuration is adopted to achieve a maximum power rating and still permit passive core decay heat removal while maintaining an acceptable fuel temperature distribution.

3.2.3 Reactor System - Control Rod Drives

The Control Rod Drives provide for controlling the reactivity rate within the Reactor Core. This sub-system consists of the control rods, control rod guide tubes, and the control rod drive mechanism (CRDM). The Control Rod Drives include 12 start-up control rods located in the inner ring of fuel blocks and 36 operating control rods located in the inner ring of the outer graphite reflector. The subsystem also includes guide tubes and the CRDM to properly position the control rods in the core. The CRDM includes a cable, drum drive, position indicator, and cable force sensor.

3.2.4 Reactor Cavity Cooling System

The Reactor Cavity Cooling System (RCCS) protects the reactor cavity concrete, including Reactor Pressure Vessel (RPV) supports, from overheating during normal operation and provides an alternate means of heat removal from the reactor system to the environment when neither the Main Heat Transport System nor the Shutdown Cooling System is available. The RCCS includes the cavity cooler panels, which surround the RPV and function as a water-cooled radiative heat exchanger. The tubes are installed vertically and welded into steel panels along the reactor cavity wall. These panels absorb radiative heat load from the vessel as well as convectively cooling the cavity air.

3.2.5 Main Heat Transport System - Main Helium Circulator

The Main Helium Circulator, part of the Main Heat Transport System (MHTS), is an encapsulated 4 MWe motor and vertically mounted centrifugal impeller, which moves helium through the Reactor Internals, the Reactor Core, and through the Main Heat Transport System.

3.2.6 Main Heat Transport System - Circulator Shutoff Valve

Each helium circulator is equipped with a self-actuating flapper butterfly shutoff valve located at the impeller inlet. Its function is to minimize backflow through the primary coolant loop when the circulator is shut down. When the circulator is operating, differential pressure across the valve, created by the flow of helium through the circulator, will open the valve. A gravity-operated counterweight will close the valve.

3.2.7 Main Heat Transport System - Hot Duct

The Hot Duct (HD) is used to transport helium coolant between the reactor and the Steam Generators. It is a multi-layered insulated assembly, located internal and coaxial to the Cross Vessel, which allows for the separation of hot and cold primary coolant within a single pressure vessel.

3.2.8 Main Heat Transport System - Steam Generator

The Steam Generator is a helical tube heat exchanger with an economizer, evaporator, superheater and possibly a reheater. The helium flows on the shell side of the Steam Generator. The secondary, tube side of the Steam Generator contains water and steam.

3.2.9 Plant I&C System - Primary Loop Instrumentation

The Primary Loop Instrumentation, part of the Plant I&C System (ICS), provides input to the Reactor Protection System, including primary system flow rate, reactor cold leg temperature, reactor hot leg temperature, pressure, and moisture.

3.2.10 Fuel Handling and Storage System - Fuel Handling System

The Fuel Handling System is a part of the Fuel Handling and Storage System (FHSS) and consists of a series of machines and devices capable of transferring fuel and reflector blocks between the Reactor Core and the Near Reactor Spent Fuel Storage location. The system is based on previous system designs, with the exception of a Fuel Storage Server (FSS) instead of Fuel Transfer Casks. The FSS reduces the estimated refueling time. The basic technology is similar to that demonstrated at Fort Saint Vrain.

3.3 Tests Defined in TDRM

Table 3.1 provides a summary of all of the tests identified in the TDRM document, including an identification of the system, sub-system, and the title of the test.

Table 3-1: Testing Identified in TDRM Report TDR-3001031-003

System	Sub-System	TRL Change	Test Title
RS	Reactor Internals	4-5	Qualification of Nuclear Grade Graphite
RS	Reactor Internals	4-5	Development and Initial Testing of Composite Materials
RS	Reactor Internals	5-6	Design of Composite/Ceramic Components
RS	Reactor Internals	6-7	Qualification of Composite Materials
RS	Reactor Internals	6-7	Properties Data Collection to Support Conduction Cooldown Analyses
RS	Reactor Core	4-5	Qualification of Nuclear Grade Graphite
RS	Reactor Core	5-6	Design Components
RS	Reactor Core	6-7	Bypass Flow Testing
RS	Reactor Core	6-7	Thermomechanical Testing
RS	Reactor Core	6-7	Structural Integrity Testing
RS	Control Rod Drives	4-5	Design, Development, and Demonstration of Control Rod Elements
RS	Control Rod Drives	4-5	Design, Development, and Demonstration of Guide Tubes
RS	Control Rod Drives	4-5	Selection of CRDM Cable Material
RS	Control Rod Drives	5-6	Design, Development, and Demonstration of Control Rod Elements
RS	Control Rod Drives	6-7	Final Qualification of the Control Rod Drives
RCCS	Reactor Cavity Cooling System	5-6	Emissivity Behavior of RPV and RCCS Materials
RCCS	Reactor Cavity Cooling System	5-6	Effect of Particulates on Radiation Heat Transport
RCCS	Reactor Cavity Cooling System	6-7	Reactor Cavity Heat Transfer Analysis
RCCS	Reactor Cavity Cooling System	6-7	RCCS Natural Circulation Analysis
RCCS	Reactor Cavity Cooling System	6-7	RCCS Thermomechanical Analysis
RCCS	Reactor Cavity Cooling System	6-7	Integrated Test
MHTS	Main Helium Circulator	6-7	Demonstration of the Magnetic Bearings with the Rotating Equipment Assembly
MHTS	Main Helium Circulator	6-7	Electrical Conductors, Connectors, Insulation, and Penetrations in Helium
MHTS	Main Helium Circulator	6-7	Demonstration of Circulator Performance in Air

System	Sub-System	TRL Change	Test Title
MHTS	Main Helium Circulator	6-7	Integrated Test of Gas Circulator with Shutoff Valve
MHTS	Circulator Shutoff Valve	6-7	Performance Tests in Air
MHTS	Hot Duct	5-6	Component Manufacturing Development
MHTS	Hot Duct	5-6	Analytical Performance Assessment
MHTS	Hot Duct	6-7	Engineering Scale Demonstration
MHTS	Steam Generator	6-7	Qualification of Bimetallic Welds
MHTS	Steam Generator	6-7	Characterization and Codification of Alloy 800H
MHTS	Steam Generator	6-7	Component Manufacturability Development
MHTS	Steam Generator	6-7	Testing of Engineering Scale Prototype
ICS	Primary Loop Instrumentation	6-7	Performance Tests in Simulated Plant Conditions
FHSS	Fuel Handling System	6-7	Seal Selection Tests
FHSS	Fuel Handling System	6-7	Bearing Selection Tests
FHSS	Fuel Handling System	6-7	Lubricant Selection Tests
FHSS	Fuel Handling System	6-7	Component Functional and Endurance Tests

4.0 ASSESSMENT OF TDRM TESTS AND IDENTIFICATION OF SMALL-SCALE TESTS BY TDRM SYSTEM

4.1 Definition of Small-Scale Test

Initial guidance provided in Reference 1 suggests that a small scale test might be consistent with the following limits:

- 1 to 2 MW thermal
- Temperatures of 950 °C
- Pressures up to 9 MPa
- Mass flow rates of 0.8 to 1.4 kg He/s
- Chemistry control for CO, CO_2, CH_4, H_2 and moisture in the ppm range.

It is understood that these are approximate limits and that the eventual bounds of the test requirements that provide the basis for the small scale test loop will be dependent on the assessment of TDRM tests and other identified small scale tests. That is, the final configuration of the small scale test loop may incorporate somewhat higher or lower values for these parameters, but is expected that all of the values will be of essentially the same order of magnitude as those listed above.

4.2 Reactor Internals

4.2.1 Identification of TDRM Small-Scale Tests

This section provides the Reactor Internals tests as contained within the various Appendices of Reference 3. After a brief description of each test, an assessment is made as to whether or not the test conforms to, or may conform to, the definition of a Small Scale Test.

<u>TRL 4-5, Test 1, Qualification of Nuclear Grade Graphite</u>

This test includes the activities necessary for qualification of appropriate sources of nuclear grade graphite for use in the NGNP reactor internals. It is currently being addressed in an ongoing program being conducted by INL as part of the overall NGNP program. This program is described in detail in Reference 4.

The scope of the tests that are part of this program, including material irradiations and associated mechanical, thermal, and physical testing, put this test series well beyond the scope of a Small Scale Test, as described in Section 4.1. The small scale helium loop could, nevertheless, be used for some related future corrosion tests in pressurized conditions. This is discussed in Section 5.

<u>TRL 4-5, Test 2, Development and Initial Testing of Composite Materials</u>

The objective of this test series is to develop and initially test a composite material for use in several Reactor Internals subcomponents. The material properties for each composite component will be a strong function of the geometry of the final design of the component. This series of tests and development activities is only conducted to provide a reasonable expectation that the selected material and fiber architecture will eventually be able to successfully meet the material properties requirements when tested as a final component.

The nature of the tests envisioned is primarily composite material development investigations, and they are not amenable to being conducted in a small thermal-hydraulic loop. As such this test is not considered a Small Scale Test as described in Section 4.1. The small scale helium loop could, nevertheless, be used for some related future corrosion tests in pressurized conditions. This is discussed in Section 5.

TRL 5-6, Test 1, Design of Composite/Ceramic Components

This test activity describes the basic design process for the Reactor Internals composite/ceramic components to the point where they are adequate to support qualification testing, including identification of expected bounding component loads and operational environments, followed by development of a detailed component model using appropriate design software.

This test is a design activity, and no supporting tests are envisioned, therefore it is not a Small Scale Test as described in Section 4.1.

TRL 6-7, Test 1, Qualification of Composite Materials

The objective of this test series is to provide sufficient mechanical behavior information about the composite materials selected for reactor internals components to adequately model their behavior in appropriate design calculations and to support codification of the material.

Since these tests focus on mechanical behavior, they are not consistent with Small Scale Tests as described in Section 4.1. The small scale helium loop could, nevertheless, be used for some related future corrosion tests in pressurized conditions. This is discussed in Section 5.

TRL 6-7, Test 2, Properties Data Collection to Support Conduction Cooldown Analysis

The objective of this test series is to provide sufficient thermal hydraulic data on the radial heat path from the core region to the Reactor Pressure Vessel to support the completion of required conduction cooldown analyses. These tests will be conducted in a helium environment at atmospheric pressure conditions. Test temperatures will be varied to provide an assessment of functionality of each variable with temperature over the range from nominal inlet temperature (325 °C) to postulated accident maximum temperatures (1100°C). Graphite thermal properties, including the impacts of neutron irradiation on those properties, are not considered in these tests. They will be covered by the ongoing INL graphite development and qualification program (Reference 4).

The following tests are envisioned to provide the required information:

- Gap loss coefficients – frictional loss coefficients for flow through the gaps between graphite blocks are determined. The proposed test configuration defines a “unit cell” of gaps, i.e., the intersection between three adjacent blocks and neighboring block sides up to half of the block face width. Gap sizes are varied from 0-1.0 cm. Helium flows will be simulated based on Reynolds number. The flow parameters should be based on expected natural circulation in the core under pressurized conduction cooldown conditions.
- Fuel block coolant channel loss coefficients – frictional loss coefficients for flow through a fuel block coolant channel are determined. The proposed test configuration consists of several single fuel block coolant channels, with diameters varying from TBD to TBD cm. Helium flows are varied from TBD-TBD m/s.
- Fuel and reflector block conduction – A heat conduction test is performed using a representative fuel block and reflector block. One side of each block is heated to over a range of conditions up to 1200 °C with an associated heat flux of TBD W/cm2. The temperature of the opposite face of the block is recorded as a function of time.
- Core barrel emissivity – The emissivity of a representative section of core barrel material is determined as a function of temperature between 325 °C and 750 °C.

  These tests will each require a specific test rig and setup to produce the required results. Many of the tests may be amenable to being performed in the Small Scale Test loop and would, therefore, be considered to be Small Scale Tests.

4.2.2 Assessment of Required Test Conditions

Based on the data within Reference 3, the test conditions pertinent to the Reactor Internals small scale tests are described in Table 4.1. Several of the parameters listed in the table were listed as “TBD” in the reference, including flow rate for the tests identified as Small Scale Tests 1 and 2, and power for the test identified as Small Scale Test 3. Test approximate size was not addressed.

The helium flow rate required for Small Scale Tests 1 and 2 is determined based on an overall primary system flow rate of 281.9 kg/s and 102 core columns (Reference 2), which yields a maximum per column flow rate, including some margin, of 3 kg/s.

The required heat flux for Small Scale Test 3 will need to be determined based on additional design work, including establishment of appropriate bounding core designs.

The physical size for the individual test sections are estimated based on the number of core blocks involved on each test configuration described in Reference 3.

- Small Scale Test 1 includes consideration of the intersection of three adjacent blocks, including the block faces to the midpoint of the face. This configuration results in a test section diameter of approximately one block diameter, 415mm based on a flat-to-flat width of 360mm (Reference 6). In order to capture the impacts of block interfaces in the axial direction, a half-core height test section should be considered. Adding clearances for supports, measurement tools, and inlet and outlet flow devices, an overall test section of 0.5m wide and 5 m long would be appropriate.
- Small Scale Test 2 includes consideration of several coolant channels within a fuel or reflector block, each approximately 16mm in diameter (Reference 6), and 800mm long. An estimated test section diameter of 100mm would seem sufficient to accept a reasonable range of coolant flow hole layouts. In order to capture block interface considerations, a half-core height test section is appropriate.
- Small Scale Test 3 considers a complete fuel or reflector block, with dimensions as detailed above.
- Small Scale Test 4 involves testing of a material coupon and should require only a small test section.

Table 4-1: Reactor Internals Small Scale Tests

Small-Scale Test No. 1	**SSC:** Reactor Internals		**TRL Step:** 6-7	**Test ID:** Test 2	**Test Type:** Flow test	
Test Description: Determine gap loss coefficients for flow between graphite blocks						
Temperature °C	**Pressure MPA**	**Environment**	**Flow Rate m/s or kg/s**	**Power MWth**	**Duration**	**Approx Size**
325-1100	Atm.	He	0 -3.0kg/s	N/A	Short Term	0.5m dia. 5m long
Small-Scale Test No. 2	**SSC:** Reactor Internals		**TRL Step:** 6-7	**Test ID:** Test 2	**Test Type:** Flow test	
Test Description: Determine fuel block coolant channel loss coefficients						
Temperature °C	**Pressure MPA**	**Environment**	**Flow Rate m/s or kg/s**	**Power MWth**	**Duration**	**Approx Size**
325-1100	Atm.	He	0 -3.0kg/s	N/A	Short Term	0.5m dia. 5m long

Small-Scale Test No. 3	**SSC:** Reactor Internals		**TRL Step:** 6-7	**Test ID:** Test 2	**Test Type:** Static test	
Test Description: Fuel and reflector block conduction						
Temperature °C	**Pressure MPA**	**Environment**	**Flow Rate m/s or kg/s**	**Power MWth**	**Duration**	**Approx Size**
325-1200	Atm.	He	N/A	TBD W/cm^2	Short Term	0.5m dia. 1m long
Small-Scale Test No. 4	**SSC:** Reactor Internals		**TRL Step:** 6-7	**Test ID:** Test 2	**Test Type:** Static test	
Test Description: Core Barrel emissivity measurement						
Temperature °C	**Pressure MPA**	**Environment**	**Flow Rate m/s or kg/s**	**Power MWth**	**Duration**	**Approx Size**
325-750	Atm.	He	N/A	N/A	Short Term	Small (Test coupon)

4.3 Reactor Core

This section provides the Reactor Core tests as contained within the various Appendices of Reference 3. After a brief description of each test, an assessment is made as to whether or not the test conforms to, or may conform to, the definition of a Small Scale Test.

4.3.1 Identification of TDRM Small-Scale Tests

TRL 4-5, Test 1, Qualification of Nuclear Grade Graphite

This test includes the activities necessary for qualification of appropriate sources of nuclear grade graphite for use in the NGNP reactor core components. It is currently being addressed in an ongoing program being conducted by INL as part of the overall NGNP program. This program is described in detail in Reference 4.

The scope of the tests that are part of this program, including material irradiations and associated mechanical, thermal, and physical testing, put this test series well beyond the scope of a Small Scale Test, as described in Section 4.1. The small scale helium loop could, nevertheless, be used for some related future corrosion tests in pressurized conditions. This is discussed in Section 5.

TRL 5-6, Test 1, Design Components

The activity describes the actions necessary to produce near-final designs of fuel blocks for design and performance acceptability evaluation. The results of these activities will be used to develop detailed test plans for bypass flow testing and demonstrating thermo-mechanical and structural integrity testing of the fuel blocks, which is required before using the graphite in the NGNP core.

This test is a design activity, and no supporting tests are envisioned, therefore it is not a Small Scale Test as described in Section 4.1.

TRL 6-7, Test 1, Bypass Flow Testing

The objective of this test is to determine the bypass flow behavior of the helium coolant within the NGNP core structure. Detailed information is required on specific localized behavior, which can be obtained in a series of separate tests. That data can be used to develop integrated models to predict overall system behavior. The results of the test will be used to validate the thermal hydraulic design codes used to establish the core performance of the initial and subsequent core loadings.

It is envisioned that prismatic core blocks will be assembled on a pitch that allows for an amount of clearance at cold conditions to aid in the core loading. At normal operating conditions thermal expansion of the graphite material would be expected to close these gaps. However, it is conceivable that full closure may not occur on every interface and that an amount of bypass flow will occur through these gaps. Similarly, bypass flow may occur in the axial gap at the interface between blocks within a column. These interface gaps would be unintentional sources of bypass flow and will vary with core temperature and core fluence conditions. For this testing, representative components would be manufactured to simulate both new and irradiated conditions rather than using actual irradiated blocks. The blocks would be manufactured using normal manufacturing tolerances for the top, bottom, and sides.

There are also intentional sources of bypass flow such as the flow that cools the reactivity control channels and the flow that cools the reflector blocks. All of these sources of bypass flow must be characterized in order to validate the analytical predictions of the core cooling.

The bypass testing will cover the full temperature and flow rate ranges of expected NGNP operation during startup, normal, and accident operating conditions as described by:

- Upper Temperature Bound (°C) 1200
- Lower Temperature Bound (°C) 20
- Upper Mass Flow Rate (kg/s) 3.0 [assumes effective test sample diameter of one column width]
- Lower Mass Flow Rate (kg/s) 0.1

It may not be necessary to cover the full range unless the elevated temperatures have a significant impact on the ability of the design codes to predict the hydraulic behavior of the core.

Several combinations of geometry will need to be explored to assess a diverse set of conditions that could occur in the core. For instance, it is conceivable that a gap could run along the entire length of the active core or only exist at a single axial elevation. A synthesis of separate effects tests would be expected to yield the data necessary to generate a reasonable bypass model.

The following parameters are presently considered to be necessary to measure:

- Flow distribution in coolant channels at inlet of each block in column stack
- Flow distribution in coolant channels at outlet of each block in column stack
- Flow through bypass regions
- Pressure drop across core blocks

These tests will require a specific test rig and setup to produce the required results and may be amenable to being performed in the Small Scale Test loop and would, therefore, be considered to be Small Scale Tests as described in Section 4.1.

<u>TRL 6-7, Test 2, Thermo-mechanical Testing</u>

The objective of this test is to determine the thermo-mechanical behavior of the prismatic core blocks to be used in the NGNP. The heat and stress distributions within a core block for both symmetric and asymmetric heating profiles will be investigated. The results of these tests will be used to verify that material property limits of the graphite will not be violated and to validate the thermo-mechanical design codes used to establish the core performance of the initial and subsequent core loadings.

For symmetric conditions the heat distribution is expected to be uniform but a thermal gradient from one side of a block to another or radially from the center may have an impact on the thermo-mechanical stresses within the block. Any variation due to the heat distribution should be characterized in order to validate analytical predictions of the core structural performance.

The expectation for the test would be that a representative graphite prismatic block would be loaded with resistive heaters rather than fuel compacts. These resistive heaters would be used to create the heat distribution within the block. Temperatures within each of the coolant channels and within the block would be measured to establish the temperature distribution in the block. The test shall cover a significant portion of the full temperature and flow rate range of expected NGNP operation during startup and normal operating conditions as described below.

Upper Temperature Bound (°C)	1200	
Lower Temperature Bound (°C)	20	
Upper Mass Flow Rate (kg/s)	3.0	
Lower Mass Flow Rate (kg/s)	0.1	
Average Heat Generation per Block (kW)	500	[~615 kw for 625 MWth reactor]
Radial Peaking Upper Bound	1.5	
Radial Peaking Lower Bound	0.5	

It may not be necessary to cover the full range unless the elevated temperatures have a significant impact on the ability of the design codes to predict the thermal behavior of the core blocks.

The following parameters are presently considered to be necessary to measure:

- Flow and temperature distribution in coolant channels at inlet of block
- Flow and temperature distribution in coolant channels at outlet of block
- Temperature distribution within block
- Stress distribution within the block

These tests will require a specific test rig and setup to produce the required results and may be amenable to being performed in the Small Scale Test loop and would, therefore, be considered to be Small Scale Tests as described in Section 4.1.

<u>TRL 6-7, Test 3, Structural Integrity Testing</u>

The objective of this testing is to determine the structural behavior of the prismatic core blocks to be used in the NGNP. The following are two main concerns:

- Potential block damage during loading and unloading
- Structural integrity of alignment pins during seismic events

The results of these tests will be used to verify the block design is sufficiently robust so damage to the blocks will not occur during routine maneuvers and so the overall core geometry will not be disrupted during a seismic event.

Since these tests focus on mechanical and structural behavior, they are not consistent with Small Scale Tests as described in Section 4.1.

4.3.2 Assessment of Required Test Conditions

Based on the data within Reference 3, the test conditions pertinent to the Reactor Core small scale tests are described in Table 4.2. All of the required test parameters were described in the reference with the exception of test approximate size, which was not addressed. The required test power for Test 6 considers both the block average power and the maximum radial peaking value.

Each of these tests involves evaluating interactions amongst core blocks in both the horizontal and vertical directions. A reasonable maximum test section size might include a set of three columns of blocks, each 360 mm across the flats of the blocks, one half of the core height, 4m (Reference 6). Leaving room for mock-ups of adjacent columns, inlet and outlet flow devices, and instrumentation, this would yield a test section approximately 1m in diameter and 5m high.

Table 4-2: Reactor Core Small Scale Tests

Small-Scale Test No. 5	**SSC:** Reactor Core		**TRL Step:** 6-7	**Test ID:** Test 1	**Test Type:** Flow test	
Test Description: Core bypass flow testing						
Temperature °C	**Pressure MPA**	**Environment**	**Flow Rate m/s or kg/s**	**Power MWth**	**Duration**	**Approx Size**
20-1200	6	He	0.1-3.0 kg/s	N/A	Short Term	1m dia. 5m long
Small-Scale Test No. 6	**SSC:** Reactor Core		**TRL Step:** 6-7	**Test ID:** Test 2	**Test Type:** Flow test	
Test Description: Core block thero-mechanical behavior						
Temperature °C	**Pressure MPA**	**Environment**	**Flow Rate m/s or kg/s**	**Power MWth**	**Duration**	**Approx Size**
20-1200	6	He	0.1-3.0 kg/s	0.95	Short Term	1m dia. 5m long

4.4 Control Rod Drives

This section provides the Control Rod Drive tests as contained within the various Appendices of Reference 3. After a brief description of each test, an assessment is made as to whether or not the test conforms to, or may conform to, the definition of a Small Scale Test.

4.4.1 Identification of TDRM Small-Scale Tests

TRL 4-5, Test 1, Design, Development, and Demonstration of Control Rod Elements

This test activity describes the basic design process for the Control Rod element components to the point where they are adequate to support qualification testing, including identification of expected bounding component loads and operational environments, followed by development of a detailed component model using appropriate design software.

Limited testing must be conducted for C/C and SiC/SiC composites to obtain the data needed to support conceptual design analyses to achieve the objective of developing and demonstrating the control rod canisters and articulating connector for the NGNP Control Rod Drives. Specifically, physical properties, mechanical properties, and environmental stability (helium environment and irradiation) over the range of expected operating conditions will be required.

This test is primarily design activity, coupled with mechanical and irradiation tests. Therefore it is not a Small Scale Test as described in Section 4.1.

TRL 4-5, Test 2, Design, Development, and Demonstration of Guide Tubes

This test activity describes the basic design process for the Control Rod Guide Tubes to the point where they are adequate to support qualification testing, including identification of expected bounding component loads and operational environments, followed by development of a detailed component model using appropriate design software.

Limited testing may be conducted for C/C and SiC/SiC composites should these materials be required to replace the preferred Alloy 800H material. Specifically, physical properties, mechanical properties, and environmental stability (helium environment and irradiation) over the range of expected operating conditions will be required.

This test is primarily design activity, coupled with potential mechanical and irradiation tests. Therefore it is not a Small Scale Test as described in Section 4.1.

TRL 4-5, Test 3, Selection of CRDM Cable Material

This activity describes the actions necessary to evaluate candidate materials and select a cable material for the CRDM cable, including establishing design criteria, selection of candidate cable materials, and testing of candidate materials to determine high temperature strength, creep behavior, and environmental stability. Testing of materials to assess irradiation effects on high temperature strength, creep and environmental stability may also be required.

Since this activity is focused on mechanical strength testing with potential need for irradiation testing, it is not a Small Scale Test as described in Section 4.1.

TRL 5-6, Test 1, Design, Development, and Demonstration of Control Rod Elements

This activity includes the development and demonstration of control rod elements and guide tubes, including design and fabrication of fixtures and the facility for testing individual components of a complete control rod element under reactor operating conditions.

This activity focuses on the development and mechanical testing of control rod components and systems in an operational environment, which likely requires test facilities associated with the control rod fabrication facility. Since this is consistent with the descriptions in Section 4.1, this test is not considered a Small Scale Test.

TRL 6-7, Test 1, Final Qualification of the Control Rod Drives

This activity describes the actions necessary to formally qualify the Control Rod Drives for use in the NGNP reactor, including the following activities and tests:

- Fabricate and test control rod elements to verify design (loads, temperature, and helium atmosphere).
- Fabricate, test, and qualify Control Rod Drives under anticipated normal and off-normal conditions, including the wear and vibration effects of sustained operation.

These activities will require the use of a test facility with a fairly high ceiling but, based on temperature, pressure and flow requirements, could be considered to be Small Scale Tests as described in Section 4.1.

4.4.2 Assessment of Required Test Conditions

Based on the data within Reference 3, the test conditions pertinent to the Control Rod Drives small scale tests are described in Table 4.3. The flow rate for the test is based on the flow in one core column. The actual flow rate required will be established based on the test system design. The required height of the test section will depend on the actual design configuration chosen for the tests (for example, will the entire rod length be needed, or can a shorter length be used). In any case, the test section is anticipated to be 10’s of meters tall.

Table 4-3: Control Rod Drives Small Scale Tests

Small-Scale Test No. 7	**SSC:** Control Rod Drives		**TRL Step:** 6-7	**Test ID:** Test 1	**Test Type:** Flow test	
Test Description: Verify design and qualify control rod drives under anticipated normal and off-normal conditions.						
Temperature °C	**Pressure MPA**	**Environment**	**Flow Rate m/s or kg/s**	**Power MWth**	**Duration**	**Approx Size**
100-900	6	He	0 -3kg/s	N/A	Long Term	~20-30 m

4.5 Reactor Cavity Cooling System

This section provides the Reactor Cavity Cooling System tests as contained within the various Appendices of Reference 3. After a brief description of each test, an assessment is made as to whether or not the test conforms to, or may conform to, the definition of a Small Scale Test.

4.5.1 Identification of TDRM Small-Scale Tests

TRL 5-6, Test 1, Emissivity Behavior of RPV and RCCS Materials

The objective of this test is to determine the long-term emissivity behavior of the NGNP Reactor Pressure Vessel and Reactor Cavity Cooling System materials. The results of these tests will establish guidelines to be used for the analytical design of the RCCS components.

It is envisioned that the RPV material will be manufactured of SA-508/SA-533 steel (consistent with LWR vessel material). The material has not been selected for the RCCS cavity cooler panel, however, it is expected to be manufactured with steel plate and tubing. Test coupons of each material will be tested in air over a range of temperatures for an extended time. The temperature range for each material is as follows:

- SA-508 coupons 20 – 540 °C
- Cavity Cooler Panel material 20 – TBD °C

Long-term testing will be performed at representative NGNP normal operating conditions. Short-term tests will be conducted at representative NGNP accident conditions. The required duration of the long- and short-term tests must be defined during conceptual design.

The following parameters need to be measured:

- Surface temperature and emissivity of the emitting body (reactor vessel) as a function of temperature
- Surface temperature and emissivity of the absorbing body (RCCS panel) as a function of temperature
- Stability of the emissivity values over time and varying environmental conditions

Though these tests are static in nature, that is, there is no requirement for test gas flow, they meet the requirements for a Small Scale Test as defined in Section 4.1 and could be conducted at a Small Scale Test loop.

TRL 5-6, Test 2, Effect of Particulates on Radiation Heat Transport

The objective of this test is to determine the effects of particulate, dust, and steam in the reactor cavity on radiation heat transfer between the Reactor Vessel and the RCCS panels. There are two main concerns with particulates:

- the particulates can scatter radiant energy and act as a participating medium, and

- the particulates may plate out on the cooler surface of the RCCS panels and thus reduce the emissivity of the panels

The testing must establish whether these concerns are justifiable and characterize the overall effect on the heat transfer from the RPV to the RCCS.

A test assembly with a resistance-heated emitter and actively cooled absorber, built from materials with well-established emissivity properties, will be tested in an apparatus capable of controlling environmental conditions and introducing variable levels of particulates, dust, and steam. Ideally the selected materials should be representative of the RPV and RCCS materials, but this may not be strictly necessary. The temperature ranges for the emitter and absorber are as follows:

- Emitter Temperature Range [°C] 20 – 700
- Absorber Temperature Range [°C] 20 – TBD

Baseline measurements will be taken with purified air in a controlled environment. Varying levels of particulates and atmospheric components will be introduced to assess the impact on heat transfer. The types of particulates remain to be determined, but, at a minimum, they should include steam, helium, concrete dust, and graphite dust (from a depressurization).

Longer-term testing to determine the effects of particle plate-out on the RCCS panels must also be completed. The required test duration and level of particulates needed for making these assessments should be based upon the results of testing that varies the level of particulates.

The following parameters need to be measured:

- Change in radiative heat transfer as a function of the amount of particulates and atmospheric condition
- Change in emissivity of RCCS panels as a function of the amount of particulates and atmospheric condition, time, and temperature of the RCCS panels

These tests meet the definition of a Small Scale Test as defined in Section 4.1 and, as such, may be conducted in a Small Scale Test loop.

<u>TRL 6-7, Test 1, Reactor Cavity Heat Transfer Analysis</u>

This activity describes the analyses necessary to characterize heat transport phenomena in the reactor cavity in order to define the coolant path for accident conditions and to assess their impact on normal operations. Phenomena considered will include radiation across the annular gap between the RPV and the RCCS cavity cooler panels, natural convection within the reactor cavity, and conduction across the gap between the RPV and the RCCS cavity cooler panels. Analytical calculation methods, such as computational fluid dynamics and lumped-capacitance models, should be used to characterize the general heat transport phenomena and to perform sensitivity studies on key parameters.

This test is a design activity, and no supporting tests are envisioned, therefore it is not a Small Scale Test as described in Section 4.1.

<u>TRL 6-7, Test 2, RCCS Natural Circulation Analysis</u>

This activity describes the analyses necessary to characterize natural circulation phenomena in the RCCS cavity cooler panels, coolant piping, and water storage tank. Analytical calculation methods, such as computational fluid dynamics and lumped-capacitance models, should be used to characterize the natural circulation phenomena and to perform sensitivity studies on key parameters.

This test is a design activity, and no supporting tests are envisioned, therefore it is not a Small Scale Test as described in Section 4.1.

TRL 6-7, Test 3, RCCS Thermomechanical Analysis

This activity describes the analyses necessary to characterize the thermomechanical behavior of the RCCS cavity cooler panels. Analytical calculation methods, such as finite element analysis, should be used to characterize the thermomechanical behavior of the cavity cooler panels and to perform sensitivity studies on key parameters.

This test is a design activity, and no supporting tests are envisioned, therefore it is not a Small Scale Test as described in Section 4.1.

TRL 6-7, Test 4, Integrated Test

The objective of this test is to validate the overall integrated performance of the RCCS at an engineering scale. While the general phenomena involved in the heat removal path can be calculated analytically piecewise, it is necessary to confirm that the entire system as a whole performs in an acceptable manner. Long-term testing at conditions representative of NGNP normal operating conditions, plus some short-duration tests at conditions representative of accident conditions, will be performed.

This test will require a large test facility, such as the Natural Convection Shutdown Heat Removal Test Facility at Argonne National Laboratory. As such it is not a Small Scale Test as described in Section 4.1.

4.5.2 Assessment of Required Test Conditions

Based on the data within Reference 3, the test conditions pertinent to the Reactor Cavity Cooling System small scale tests are described in Table 4.4.

Table 4-4: Reactor Cavity Cooling System Small Scale Tests

Small-Scale Test No. 8	**SSC:** Reactor Cavity Cooling Syst.		**TRL Step:** 5-6	**Test ID:** Test 1	**Test Type:** Static test	
Test Description: Determine emissivity behavior of RPV and RCCS Materials						
Temperature °C	**Pressure MPA**	**Environment**	**Flow Rate m/s or kg/s**	**Power MWth**	**Duration**	**Approx Size**
20-540	Atm.	Air	N/A	N/A	Short and Long Term	Small (Test coupon)
Small-Scale Test No. 9	**SSC:** Reactor Cavity Cooling Syst.		**TRL Step:** 5-6	**Test ID:** Test 2	**Test Type:** Static test	
Test Description: Determine effect of particulates on radiation heat transfer						
Temperature °C	**Pressure MPA**	**Environment**	**Flow Rate m/s or kg/s**	**Power MWth**	**Duration**	**Approx Size**
20-700	Atm.	Air with particulates	N/A	N/A	Short and Long Term	Small (Test coupon)

4.6 Main Helium Circulator

This section provides the Main Helium Circulator tests as contained within the various Appendices of Reference 3. After a brief description of each test, an assessment is made as to whether or not the test conforms to, or may conform to, the definition of a Small Scale Test.

4.6.1 Identification of TDRM Small-Scale Tests

TRL 6-7, Test 1, Demonstration of the Magnetic Bearings with the Rotating Equipment Assembly

The objective of this test is to demonstrate the performance of the magnetic bearings as part of the integrated rotating equipment assembly (motor, bearings, rotor, and impeller) over the full range of operating conditions. A second objective is to demonstrate that state of the art inverters and input power transformer rectifiers can operate at the frequencies required to control the motor without having an adverse impact on the supply current.

It is anticipated that this test will be conducted in a specialized test facility at the circulator vendor's facility. As such this test is not considered a Small Scale Test as described in Section 4.1.

TRL 6-7, Test 2, Electrical Conductors, Connectors, Insulation, and Penetrations in Helium

The objective of this test is to validate the performance of candidate electrical high voltage motor windings, bearing power conductors and insulation in helium at the most severe combinations of pressure, temperature, and depressurization.

Though this test could be conducted in a small scale facility, it is anticipated that this test will be conducted in a specialized test facility at the circulator vendor's facility. As such this test is not considered a Small Scale Test as described in Section 4.1.

TRL 6-7, Test 3, Demonstration of Circulator Performance in Air

The objective of this test is to demonstrate the behavior of the assembled circulator by examining and characterizing several key aspects of the unit while it is running in air at ambient temperature and pressure, including, satisfactory operation of the complete unit over the complete speed range, fluid dynamics and harmonics of the impeller, efficiency of the impeller and diffuser, and in-duct and housing frequency responses amongst others.

It is anticipated that this test will be conducted in a specialized test facility at the circulator vendor's facility. As such this test is not considered a Small Scale Test as described in Section 4.1.

TRL 6-7, Test 4, Integrated Test of Gas Circulator with Shutoff Valve

The objective of this test is to demonstrate integrated operation of the circulator assembly with the shutoff valve under startup, normal, and transient conditions. The test will demonstrate that the circulator starts without stalling under the load imposed by the shutoff valve. The test will also characterize the impeller and diffuser aerodynamic performance as well as the blower acoustic frequency response of the circulator and shutoff valve in air over the range of operating conditions. The test will confirm the circulator component's performance and design over the range of operating conditions.

It is anticipated that this test will be conducted in a specialized test facility at the circulator vendor's facility. As such this test is not considered a Small Scale Test as described in Section 4.1.

4.6.2 Assessment of Required Test Conditions

Since none of the tests identified within the TDRM document for the Main Helium Circulator are considered to be Small Scale Tests, there are no required test conditions for this component.

4.7 Circulator Shutoff Valve

This section provides the Circulator Shutoff Valve tests as contained within the various Appendices of Reference 3. After a brief description of the test, an assessment is made as to whether or not the test conforms to, or may conform to, the definition of a Small Scale Test.

4.7.1 Identification of TDRM Small-Scale Tests

TRL 6-7, Test 1, Performance Tests in Air

This series of tests will be performed to test the operation of the valve in air at standard temperature and pressure followed by a demonstration of the valve operating under simulated plant conditions. These integrated tasks will cover reactor startup conditions, steady-state conditions, and reactor shutdown. Follow-on testing will demonstrate and validate the performance of the shutoff valve to fully open and close when the gas circulator is turned on and off without stalling the circulator or impacting the gas flow distribution through the impeller and diffuser while operating under simulated plant conditions, startup, normal operation, and shutdown.

It is anticipated that this test will be conducted in a specialized test facility at the circulator vendor's facility. As such this test is not considered a Small Scale Test as described in Section 4.1.

4.7.2 Assessment of Required Test Conditions

Since none of the tests identified within the TDRM document for the Circulator Shutoff Valve are considered to be Small Scale Tests, there are no required test conditions for this component.

4.8 Hot Duct

This section provides the Hot Duct tests as contained within the various Appendices of Reference 3. After a brief description of each test, an assessment is made as to whether or not the test conforms to, or may conform to, the definition of a Small Scale Test.

4.8.1 Identification of TDRM Small-Scale Tests

TRL 5-6, Test 1, Component Manufacturing Development

The test objective is a manufacturing development effort to qualify the manufacturing processes for the composite ceramic liner and the assembly of the Hot Duct. Though the Hot Duct design proposed for the NGNP is based on a design manufactured and tested in Germany in the late 1980s, it may differ in subtle ways and may be somewhat larger than that tested previously. The manufacturing processes necessary to industrially fabricate key components of the HD must be established. The composite ceramic liner provides the largest challenge, but fabrication of the support tube, and possibly the liner from Alloy 800H, and the assembly of the components with the wrapped ceramic insulation must be addressed.

It is anticipated that the required testing will be conducted at the vendor's facility. As such this test is not considered a Small Scale Test as described in Section 4.1.

TRL 5-6, Test 2, Analytical Performance Assessment

The objective of this test is an analysis that assesses the thermal hydraulic and structural performance of the Hot Duct.

This test is a design activity, and no supporting tests are envisioned, therefore it is not a Small Scale Test as described in Section 4.1.

TRL 6-7, Test 1, Engineering Scale Demonstration

The objective of this test is to demonstrate the performance of the Hot Duct under typical operating conditions and to measure the effectiveness and durability of the unit. The thermal hydraulic and thermo-mechanical performance will be determined to support validation of analytical design modeling and predictions. Functional tests will be performed over the full range of expected aerodynamic conditions (mass flow rate, pressure, and temperature) during startup, normal operation, shutdown, and transient conditions. Cycling tests (i.e., ramping between steady state conditions) and steady-state operation tests are required.

This test will require a large test facility, such as the proposed 30 MW Component Test Facility at Idaho National Laboratory. As such it is not a Small Scale Test as described in Section 4.1.

4.8.2 Assessment of Required Test Conditions

Since none of the tests identified within the TDRM document for the Hot Duct are considered to be Small Scale Tests, there are no required test conditions for this component.

4.9 Steam Generator

This section provides the Steam Generator tests as contained within the various Appendices of Reference 3. After a brief description of each test, an assessment is made as to whether or not the test conforms to, or may conform to, the definition of a Small Scale Test.

4.9.1 Identification of TDRM Small-Scale Tests

TRL 6-7, Test 1, Qualification of Bimetallic Welds

The objective of this test is to characterize the properties of the bimetallic welds at the evaporator and superheater tube bundle to qualify the vendor weld process for the NGNP.

Since this test is a standard material process qualification test, it is not considered a Small Scale Test as described in Section 4.1.

TRL 6-7, Test 2, Characterization and Codification of Alloy 800H

The objective of this test is to expand the material data base on Alloy 800H to meet the requirements for NGNP. Long term material tests at higher temperatures are needed to expand creep and fatigue data for 800H up to the NGNP plant design life of 60 years, as data permits.

Since these tests are standard long term material qualification tests, they are not considered a Small Scale Test as described in Section 4.1.

TRL 6-7, Test 3, Component Manufacturability Development

The objective of this test is to demonstrate that the forging process for the ring-shaped hot header for the Steam Generator is adequate. The tests will include evaluation of the forging processes by the forging vendor, as well as alternative manufacturing methods (e.g., bending plates, using pipe fittings). This development testing will be performed on full scale header components.

It is anticipated that the required testing will be conducted at the vendor’s facility. As such this test is not considered a Small Scale Test as described in Section 4.1.

TRL 6-7, Test 4, Testing of Engineering Scale Prototype

The objective of this test is to demonstrate the performance of the Steam Generator under design conditions and to measure its effectiveness and durability. The test will assess thermal hydraulic performance of the SG, flow stability, and test of water and steam system control. It will also support analytical estimation and validation of flow induced vibration behavior of the tube bundle. It is envisioned that power testing at approximately one-tenth scale will be adequate to meet the test objectives.

This test will require a large test facility, such as the proposed 30 MW Component Test Facility at Idaho National Laboratory. As such it is not a Small Scale Test as described in Section 4.1.

4.9.2 Assessment of Required Test Conditions

Since none of the tests identified within the TDRM document for the Steam Generator are considered to be Small Scale Tests, there are no required test conditions for this component.

4.10 Primary Loop Instrumentation

This section provides the Primary Loop Instrumentation tests as contained within the various Appendices of Reference 3. After a brief description of each test, an assessment is made as to whether or not the test conforms to, or may conform to, the definition of a Small Scale Test.

4.10.1 Identification of TDRM Small-Scale Tests

TRL 6-7, Test 1, Performance Tests in Simulated Plant Conditions

This test series is designed to verify that the Primary Loop Instrumentation, which is commercially available but have not been used at NGNP operating pressures and temperatures, demonstrate acceptable accuracy, sensitivity, and lifetime. The tests will include testing candidate designs of the sensor-loop mechanical interface to determine if designs or interfaces impact the accuracy of the measurements and whether the device is leak tight. Tests will be performed at expected reactor startup, normal, shutdown, and off-normal operating conditions and will cover the range from cold startup (ambient pressure and temperature), normal operation (750°C and 6.0 MPa on the hot side), and off-normal conditions.

These tests should be amenable to being performed in the Small Scale Test loop and would, therefore, be considered to be Small Scale Tests as described in Section 4.1.

4.10.2 Assessment of Required Test Conditions

Based on the data within Reference 3, the test conditions pertinent to the Primary Loop Instrumentation small scale tests are described in Table 4.5. Though loop flow rate sensors are part of the Primary Loop Instrumentation system, this parameter is anticipated to be measured via assessment of main circulator speed, thus loop flow is not required and testing of these instruments can be conducted in an essentially static loop.

Table 4-5: Primary Loop Instrumentation Small Scale Tests

Small-Scale Test No. 10	**SSC:** Primary Loop Instr.		**TRL Step:** 6-7	**Test ID:** Test 1	**Test Type:** Static test	
Test Description: Verify Primary Loop Instrumentation at NGNP operating pressures and temperatures, and demonstrate acceptable accuracy, sensitivity, and lifetime.						
Temperature °C	**Pressure MPA**	**Environment**	**Flow Rate m/s or kg/s**	**Power MWth**	**Duration**	**Approx Size**
100-900	6	Moist He (2-1000vpm)	N/A	N/A	Long Term	Small (Sensor)

4.11 Fuel Handling System

This section provides the Fuel Handling System tests as contained within the various Appendices of Reference 3. After a brief description of each test, an assessment is made as to whether or not the test conforms to, or may conform to, the definition of a Small Scale Test.

4.11.1 Identification of TDRM Small-Scale Tests

TRL 6-7, Test 1, Seal Selection Tests

The objective of the first test is to identify a suitable material, or set of materials, for use in the various soft seals within the Fuel Handling Machine and to perform tests that verify the expected performance under both expected operational conditions and accident conditions. The following parameters will be measured:

- Resistance of the seal surface to mechanical abrasion by mating components, both during assembly/disassembly (sliding wear) and during system operation (wear due to vibration)
- Loss of seal elasticity as a function of time at design compression (seal material “creep”)
- Loss of seal elasticity as a function of compression cycles (seal material fatigue)

Seal vendor data will also be used to provide an assessment of uncompressed seal elasticity degradation in ambient air as a function of time

These tests will require a specific test rig and setup to produce the required results and may be amenable to being performed in the Small Scale Test loop and would, therefore, be considered to be Small Scale Tests as described in Section 4.1.

TRL 6-7, Test 2, Bearing Selection Tests

The objective of this activity is to identify a suitable material for use in the various bearings within the Fuel Handling Machine and to perform appropriate tests to verify expected performance under both expected operational conditions and accident conditions. A second objective is to identify bearings that require lubrication.

The following parameters will be measured during the performance tests:

- Bearing performance in excess of the design requirements for the Fuel Handling Machine
- Identification of performance limiting conditions associated with elevated refueling accident temperatures

These tests will require a specific test rig and setup to produce the required results and may be amenable to being performed in the Small Scale Test loop and would, therefore, be considered to be Small Scale Tests as described in Section 4.1.

TRL 6-7, Test 3, Lubricant Selection Tests

The objective of this test is to verify the expected performance of the lubricants, if any, selected for use in the Fuel Handling Machine bearings. Performance parameters include the lubricating function, and the potential for contamination of the primary coolant loop with lubricant.

The parameters to be measured include:

- Lubrication performance in excess of the design requirements for the Fuel Handling Machine
- Identification of performance limiting conditions associated with elevated refueling accident temperatures
- Determination of the material loss rate, and characteristics of the lost material, as a function of temperature

These tests will require a specific test rig and setup to produce the required results and may be amenable to being performed in the Small Scale Test loop and would, therefore, be considered to be Small Scale Tests as described in Section 4.1.

TRL 6-7, Test 4, Component Functional and Endurance Tests

The objective of these tests is to ensure each Fuel Handling System subcomponent operates as designed prior to shipment to the NGNP site and assembly into an integrated system. Specific design requirements for each portion of the Fuel Handling Machine will be developed during the initial phase of the detailed design activities for this system. Operational test plans will be developed based on these design requirements. All functional tests are envisioned as short-duration operability checks. The long-term endurance testing is planned to mimic a refueling outage where the fuel is being handled 24 hours a day for at least 25 days.

This series of tests will require specially designed fixtures that mimic key NGNP system interfaces. It is anticipated that these would be developed and housed at the equipment vendor's facility. As such, these tests do not qualify as Small Scale Tests as described in Section 4.1.

4.11.2 Assessment of Required Test Conditions

Based on the data within Reference 3, the test conditions pertinent to the Fuel Handling System small scale tests are described in Table 4.6. The temperature range identified in the reference is based on assumed operating conditions for the components in question. Once more detailed information is available, including the fuel handling equipment design, the core design, and the required set of fuel handling accidents that must be considered, these temperatures may need to be updated.

Table 4-6: Fuel Handling System Small Scale Tests

<table>
<tr><td>Small-Scale Test No. 11</td><td colspan="2">SSC:
Fuel Handling System</td><td>TRL Step:
6-7</td><td>Test ID:
Test 1,2,3</td><td colspan="2">Test Type:
Static test</td></tr>
<tr><td colspan="7">Test Description: Confirm performance of seals, bearings and lubricants</td></tr>
<tr><td>Temperature °C</td><td>Pressure MPA</td><td>Environment</td><td>Flow Rate m/s or kg/s</td><td>Power MWth</td><td>Duration</td><td>Approx Size</td></tr>
<tr><td>20-100</td><td>~1 Atm.</td><td>He/Air</td><td>N/A</td><td>N/A</td><td>Short Term</td><td>Small (Test Part)</td></tr>
</table>

5.0 OTHER SYSTEMS AND/OR TESTS

5.1 Test Identification

The TDRM approach considers only the tests required for bringing the components and sub-systems to TRL 7. There are other types of heat transport small scale tests that should be considered:

- Even if the technology of components and sub-systems with a TRL 7 or above can be considered as mature, these technologies, components and sub-systems will have to be qualified in a relevant environment for being used in NGNP. This concerns in particular:
  - Some materials for which there is already a large experience, but for which additional data are nevertheless needed for qualification purpose: this is the case for Alloy 800 H and for the insulating material,
  - The helium purification system, its different components and materials used for purification (charcoal, etc.),
  - The shutdown cooling system and its components (pumps, valves, circulator, etc.)
- NGNP should not only demonstrate a frozen technology, but also should be a test bench for the evolution of HTR technology towards an extended scope of applications or/and higher performance capabilities. For allowing preparing such evolution, tests of advanced components and technologies will have to be performed and heat transport small scale facilities will be of great help for screening different technological options and design solutions, for selecting and for validating the most relevant ones:
  - Intermediate Heat Exchanger (IHX) for transferring heat to applications that require temperature above 600 °C,
  - Other advanced reactor components and systems like membrane helium purification system,
  - Advanced materials that could allow higher system performance (in particular in terms of operating temperature): Mod. 9Cr1Mo for the vessel, Nickel Base Alloys or, for longer term applications, ODS or ceramics for the IHX,
  - Direct cycle components: turbo-compressor, recuperator, bypass valve, etc.
  - Innovative components for industrial process heat applications, like integrated heat exchanger steam-methane reformers, innovative membrane steam-methane reformers, water decomposers (either with thermo-chemical processes or high temperature electrolysis), etc.
- Apart from component testing, heat transport small scale test facilities can provide representative operating conditions for feeding code qualification with relevant experimental data. Heat transport small scale facilities could be used for getting data for computer code qualification in the following areas:
  - System transient analysis: most of the thermo-fluid dynamics phenomena at work in the HTR cooling system (pressure losses, heat transfer, natural convection, etc.) are also involved in a helium loop, in a complex circuit with similar components (heat source, pipes, circulator, heat exchangers, valves) than in the reactor cooling system and with a system configuration more or less representative of the reactor one, depending on the loop design. Therefore thermo-fluid experimental data from steady state and transient operation of the loop can be used for enriching the experimental database for qualification of system transient analysis codes.
  - CFD: a Small Scale Helium Loop can provide small component mock-ups with hot helium at a flow rate that might be sufficient for validating CFD codes for calculating the performance of such components.

- Fluid-structure interaction: the helium flow provided by a Small Scale Loop might be sufficiently representative to validate FIV calculation for some components. On the other hand the calculation of loads on components (in particular on the thermal barrier of the hot duct) during a loss of coolant accident can be validated through tests performed on very simple static facilities subject to fast depressurization.
- Thermal stress analysis: if the Small Scale Helium Loop is able to perform multiple thermal transients representative of reactor operational thermal transients, the thermo-mechanical calculation of critical components like the IHX can be validated.
- Tests performed with representative graphite dust of fission product aerosols can provide data for improving modeling of radio-contaminant transport, plate-out and lift-off, as well as for qualifying codes in this area.

5.2 Material testing

5.2.1 Description / Basis for Test

Apart from physical and mechanical property and emissivity measurement for materials mentioned in Section 5.1, which can be performed in standard materials laboratories, corrosion and tribology tests require a helium atmosphere with actual operating temperature and representative impurity content and gas velocity on the sample surface. The screening experiments for material selection are performed in non-pressurized helium loops with controlled impurity content that can possibly, in addition to corrosion testing, allow in situ creep and friction and wear testing. The relevance of results obtained on these loops is based on the assumption that the significant parameters governing materials corrosion is the partial pressure of each impurity, kept at a level representative of actual reactor conditions, while total pressure has no impact. For validating this assumption, some tests will have to be performed with different selected materials in representative conditions for temperature, pressure, gas velocity and impurity content.

5.2.2 Assessment of Required Test Conditions

Depending on the component for which the material is used, the test should be performed at a temperature from 300 to 800 °C or even up to more than 1000°C for advanced very high temperature materials.

Full reactor operating pressure should be provided in the test section (5-9 MPa depending on design).

The velocity at the surface of materials sample should be the same as in the reactor. For usual materials testing conditions, the required flow rate will be at the most in the range of 1g/sec.

The impurities to be considered are O_2, H_2O, H_2, CO, CO_2, CH_4 and N_2, to be monitored and controlled in a range of concentrations from parts per million to percents.

This could be done in a dedicated derivation of a Small Scale Helium Loop, with the test section as close as possible to the helium purification, chemistry and pressure control system of the loop in order to avoid uncontrolled changes in impurity content of the gas flowing over the samples, due to interactions with the loop walls.

Moreover final qualification of components will include an assessment of the impact of corrosion on their lifetime. This will be done on representative component mock-ups, with representative loading conditions. Apart from a much higher flow rate, test conditions for such assessment will be the same as those mentioned above. This will be part of component testing and the relevance of the Small Scale Helium Loop for such tests will be addressed in the following sub-sections.

5.3 IHX

5.3.1 Description / Basis for Test

Whichever design is selected for the IHX (plate or tube), its qualification will require flow rates that cannot be obtained from a Small Scale Loop. If the tubular IHX design is selected, only final qualification tests with a large scale mock-up providing thermo-fluid and stress conditions representative of in-reactor component behavior, will be necessary based on the well proven technology.

But, in order to look for advantages in terms of compactness and fabrication cost, the viability of a plate design IHX in HTR operating conditions might also be investigated. The final qualification will be performed on a full IHX module, in a loop of at least 10 MW, and is out of the scope of small scale facilities. This type of design is very challenging, due to high stresses and corrosion that would drastically limit the component lifetime. Therefore, a more analytical approach is required first, for assessing the comparative performance of different types of plate designs and for identifying separately the effect of each factor on the lifetime and performance of the IHX to optimize the design. In such an analytical approach, the different phenomena impacting the performance and the lifetime will be first investigated separately:

- The thermo-mechanical behavior must be tested at full temperature, with representative thermal transients, in air or in helium,
- The heat exchange performance of the current plate bundle: the possible impact of the nature of the gas and of the channel geometry on the heat transfer coefficient can be assessed separately, in helium in tube geometry and in air with representative plate geometry,
- The homogeneity of flow distribution from the hot collector to the different plate channels can be checked in cold conditions in air, in a facility that provides a full scale flow for a whole IHX module,
- The corrosion is addressed only on material samples in a non-pressurized helium loop with representative impurity content (see 5.2).

The final qualification will allow combining the effects of all reactor operating conditions in the same test, but it will require a large scale helium loop, of at least 10 MW. A very useful intermediate step for selecting the most relevant plate design and for a preliminary validation in HTR conditions would be to bring all effects together, except a representative distribution of flow in the different plate channels of a whole IHX module, in a mockup with a reduced number of full size plates, fed by a Small Scale Helium Loop. Such a test would be possible much earlier and at a much lower cost than with the large scale loop.

5.3.2 Assessment of Required Test Conditions

A helium loop of 1 MW with a flow rate of about 0.5 kg/s should be sufficient for testing an IHX mockup in representative conditions with a few dozen plates. To provide all required conditions except for a large flow rate, it should be able to bring helium at full NGNP operating temperature and pressure, to provide representative thermal transients to the IHX mockup. Also the loop should have not only a helium purification system, but also a system able to add impurities in order to control and maintain impurity content in the range of NGNP conditions (see 5.2.2) because most of these impurities will not be generated naturally, contrary to the case of HTR atmosphere (due to the presence of large quantities of graphite). Moreover the loop should have a secondary system able to release the heat exchanged through the IHX.

5.4 Shutdown Cooling System (SCS)

5.4.1 Description / Basis for Test

The main helium components of the SCS are

- The Shutdown Cooling Helium Circulator
- The Shutdown Cooling Helium Shutoff Valve
- The Shutdown Cooling Heat Exchanger, helium to water.

These components should be qualified for operation in helium representative conditions.

5.4.2 Assessment of Required Test Conditions

Helium flow in the SCS should be at the maximum about 40 kg/s, which is not in the range of performance provided by a Small Scale Helium Loop, even if the circulator and the shutoff valve are tested at a reduced but still significant scale. The circulator should be qualified in air in a manufacturer facility. Test of the heat exchanger with a reduced number of full scale tubes is nevertheless possible in a Small Scale Helium Loop and should be sufficient for qualification of this component. For that purpose, the loop should have a secondary water circuit able to extract several hundred kW of heat.

5.5 Helium Purification System

5.5.1 Description / Basis for Test

The technologies used in the NGNP Helium Purification System will be the same as in the Helium Purification System of the Small Scale Helium Loop. Therefore the operation of the Small Scale Loop will allow qualifying these technologies. But actual components will also have to be qualified at an appropriate scale.

Moreover it should also be possible to test advanced purification technologies for longer term applications, like membrane technology.

5.5.2 Assessment of Required Test Conditions

For satisfying these needs, the Small Scale Loop should be able to provide not only the appropriate helium flow, but also impurities representative of reactor conditions through the combined action of the Helium Purification and Impurity Injection Systems (see 5.3.2).

The flow rate in the purification system is rather low (~ 0.04 kg/s), therefore it can be provided easily by the Small Scale Helium Loop.

5.6 Components of Direct Cycle Power Conversion System

5.6.1 Description / Basis for Test

The main components for a direct cycle PCS are the turbo-compressor and generator, the recuperator heat exchanger, the coolers, and the bypass valves.

Tests of mock-ups of plate type recuperator and coolers with a reduced number of full size plates can be performed in a Small Scale Helium Loop.

Other tests, for example rotating equipment tests of turbo-machines, would be conducted elsewhere.

5.6.2 Assessment of Required Test Conditions

As is the case for the circulator and the shutoff valves, tests of the turbo-machines and of the bypass valves cannot be performed in a small scale facility.

Tests of the recuperator and coolers will be performed with similar conditions to the IHX tests, except for temperature, which will be lower (maximum ~ 500°c for the recuperator) and the significant pressure difference (6 to 9 MPa – full system pressure), which should be maintained between the two sides of the recuperator plates.

5.7 Innovative Components for Industrial Process Heat Applications

5.7.1 Description / Basis for Test

The conditions for heat supply from a nuclear reactor will be, for some applications, quite different from usual conditions in present industrial processes: for many processes, the heat is usually supplied by radiative heat transfer from flame burning at the process reactor boundary or by internal combustion in the process reactor itself. If heat is supplied by a nuclear reactor it will be supplied to the application process by convective heat transfer. The differences in the thermal boundary conditions for the process might be significant and may require a new design of the process reactor that should therefore be qualified. For instance, this was the case in Germany, where an integrated heat exchanger steam-methane reformer has been developed and tested in the KVK loop.

The process itself could even be modified to fit with HTR heat supply conditions. For instance for HTR heat supply, there would be incentives for developing an innovative membrane steam-methane reforming process, in which the reforming reaction, shifted by continuously extracting hydrogen, gets the same efficiency at 650°C as the standard steam-reforming process at 900 °C. The decrease of operating temperature would indeed allow using HTR with its present temperature performance.

The availability of cost effective high temperature heat from the HTR will give incentives for developing completely new processes, like the thermo-chemical or high temperature electrolysis water splitting processes for hydrogen production.

Process heat user industries recommend being very careful in the up-scaling of chemical processes, progressing step by step from laboratory scale to industrial application, avoiding exceeding a factor 10 in each up-scaling step. From this point of view, a step at the level of about 1MW will certainly be relevant after laboratory scale demonstration and a Small Scale Helium Loop can be used for simulating the nuclear heat source at this level.

5.7.2 Assessment of Required Test Conditions

Each process heat application will have its own requirements on the nuclear heat source (temperature, transient performance, etc.) and the test conditions will have to be established on a case-by-case basis.

5.8 System Transient Analysis Code Qualification

5.8.1 Description / Basis for Test

Though transient analysis codes have already been benchmarked towards available measurements from reactor or helium loop operation, a full qualification of such codes would require additional code to experimental data comparisons for representative transient situations not yet covered by calculation to test benchmarks (TBD).

5.8.2 Assessment of Required Test Conditions

A Small Scale Helium Loop can help to provide relevant data for code to experimental data comparisons with some limitations:

- Data will be relevant for situations involving only forced convection (normal operation transients and depressurization), but not natural circulation, if the loop circuit does not have a significant vertical extension. Such a vertical configuration should likely be avoided for a small test facility, in order to limit its cost.
- The components of the reactor cooling circuits should all be simulated by loop components, each of them with representative global thermo-fluid dynamics behavior, at least in forced convection normal and abnormal situations.

5.9 CFD Code Qualification

5.9.1 Description / Basis for Test

Dedicated experiments in cold conditions, with fluids other than helium, can be used for validating CFD code calculations for situations where no significant temperature gradient exist in the fluid (for instance in the IHX inlet collector). But such experiments have a limited value for code qualification as long as thermal exchange between hot and cold regions of the fluid are involved (this is the case in the core outlet plenum). A Small Scale Helium Loop could be used for providing appropriate hot and cold helium flow rates in a mock-up representative of the configuration to be tested.

5.9.2 Assessment of Required Test Conditions

TBD on a case by case basis for each configuration to be tested.

5.10 Fluid-Structure Interaction Code Qualification

5.10.1 Description / Basis for Test

The calculation of FIV behavior and of depressurization loads for NGNP components should be validated in representative flow conditions. The identification of all critical areas for these phenomena can be made only when the design is sufficiently mature. Therefore a comprehensive list of tests to be performed will be defined later. Nevertheless some critical areas are already known and it is worth while examining which kind of tests should be performed in these cases, in order to see if small scale facilities can be of any use at all for validating fluid-structure calculation tools:

- FIV will have to be assessed at least for fuel block columns, control rods, steam generator tubes and IHX tubes or plates,
- Depressurization loads will have to be assessed at least for the hot duct thermal barrier.

Representative flow velocities will be needed for such tests.

5.10.2 Assessment of Required Test Conditions

For FIV tests on a fuel block column, a flow rate of about 3 kg/s, which cannot be provided by a Small Scale Helium Loop, will be needed. For control rod FIV, full height will be required, which cannot be expected from a small scale facility (see 5.8.2). On the contrary, plate IHX mockup tests with a reduced number of full size plates (see 5.3) will be relevant for addressing FIV in the IHX, as long as the mockup is properly instrumented.

For depressurization tests, a static pressurized facility can be used as long as it includes a valve allowing a representative depressurization rate.

5.11 Thermal Stress Analysis Code Qualification

5.11.1 Description / Basis for Test

Structural analysis codes are commonly used by nuclear designers and will not generally require specific qualification for NGNP applications. But at least for assessing the plate IHX lifetime, non-linear calculations will be needed with the use of constitutive laws for visco-plastic behavior. These calculations and constitutive laws will have to be validated by elementary tests of material samples and by tests of an IHX mock-up on a medium-sized helium test loop.

5.11.2 Assessment of Required Test Conditions

The tests described for assessing the IHX lifetime (see 5.3) will be the basis for qualification of the non-linear calculation methods related to determining the mechanical behavior of the IHX components in the high temperature, high stress regime where visco-plastic behavior becomes important.

5.12 Radio-Contaminant Transport Code Qualification

5.12.1 Description / Basis for Test

Before full qualification of the radio-contaminant transport code, elementary models for all relevant phenomena (aerosol and dust transport, plate-out, lift-off, chemical interactions, etc) should be developed and qualified.

5.12.2 Assessment of Required Test Conditions

It is not recommended to use the Small Scale Helium Loop directly for aerosol and dust transport experiments, because the precise instrumentation for measuring temperatures and fluid flow characteristics, as well as the loop wall friction factors and heat transfer coefficients may be affected by aerosol and dust deposition. Nevertheless the Small Scale Loop can be used as a heat source for a dedicated loop for such experiments, through a heat exchanger. The characteristics of this dedicated loop will be defined later.

Table 5-1: Other Small Scale Tests for Current Base Design

<table>
<tr><td>Small-Scale Test No. 12</td><td colspan="4">SSC or Test:
Material Testing</td><td colspan="2">Test Type:
Flow test</td></tr>
<tr><td colspan="7">Test Description: Corrosion and tribology tests of various HTR materials (SA508, Mod. 9Cr1Mo, Alloy 800H, graphite, composites, etc.) under representative conditions to validate screening tests and their assumptions, particularly to control for the absence of helium partial pressure in some tests.</td></tr>
<tr><td>Temperature °C</td><td>Pressure MPA</td><td>Environment</td><td>Flow Rate m/s or kg/s</td><td>Power MWth</td><td>Duration</td><td>Approx Size</td></tr>
<tr><td>250-750</td><td>5-9</td><td>Impure He (O_2, H_2O, H_2, CO, CO_2, CH_4, N_2)</td><td>TBD</td><td>TBD (<<1)</td><td>Long Term</td><td>Sample Coupon</td></tr>
<tr><td>Small-Scale Test No. 13</td><td colspan="4">SSC or Test:
Shutdown Cooling System TRL 7-8</td><td colspan="2">Test Type:
Flow Test</td></tr>
<tr><td colspan="7">Test Description: Shutdown Cooling System heat exchanger qualification</td></tr>
<tr><td>Temperature °C</td><td>Pressure MPA</td><td>Environment</td><td>Flow Rate m/s or kg/s</td><td>Power MWth</td><td>Duration</td><td>Approx Size</td></tr>
<tr><td>TBD</td><td>0.1-9</td><td>He</td><td>0.5kg/s</td><td>1</td><td>Long Term</td><td>Reduced Number of Full Size Tubes</td></tr>
<tr><td>Small-Scale Test No. 14</td><td colspan="4">SSC or Test:
Helium Purification System TRL 8-9</td><td colspan="2">Test Type:
Flow Test</td></tr>
<tr><td colspan="7">Test Description: Qualification of helium purification technologies using the Small Scale Test Loop helium purification system</td></tr>
<tr><td>Temperature °C</td><td>Pressure MPA</td><td>Environment</td><td>Flow Rate m/s or kg/s</td><td>Power MWth</td><td>Duration</td><td>Approx Size</td></tr>
<tr><td>30-450</td><td>0.1-9</td><td>Impure He (O_2, H_2O, H_2, CO, CO_2, CH_4, N_2)</td><td>0.04 kg/s (in HPS)</td><td>N/A</td><td>Long Term</td><td>Full Size HPS</td></tr>
<tr><td>Small-Scale Test No. 15</td><td colspan="4">SSC or Test:
System Transient Analysis Code Qualifications</td><td colspan="2">Test Type:
Flow Test</td></tr>
<tr><td colspan="7">Test Description: Provide basic data to support qualification of system transient analysis codes. Specific tests will be identified as code development progresses.</td></tr>
<tr><td>Temperature °C</td><td>Pressure MPA</td><td>Environment</td><td>Flow Rate m/s or kg/s</td><td>Power MWth</td><td>Duration</td><td>Approx Size</td></tr>
<tr><td>200-900</td><td>0.1-9</td><td>He</td><td><0.5 kg/s</td><td><1 MW</td><td>Short Term</td><td>TBD</td></tr>
</table>

Small-Scale Test No. 16	**SSC or Test:** CFD Code Qualifications				**Test Type:** Flow Test	
Test Description: Provide basic data to support qualification of CFD codes. Specific tests will be identified as code development progresses.						
Temperature °C	**Pressure MPA**	**Environment**	**Flow Rate m/s or kg/s**	**Power MWth**	**Duration**	**Approx Size**
200-900	0.1-9	He	<0.5 kg/s	<1 MW	Short Term	TBD
Small-Scale Test No. 17	**SSC or Test:** Fluid Structure Interaction Code Qualifications				**Test Type:** Flow Tests	
Test Description: Provide basic data to support qualification of fluid structure interaction codes, particularly in the area of IHX flow induced vibration. Specific tests will be identified as code development progresses.						
Temperature °C	**Pressure MPA**	**Environment**	**Flow Rate m/s or kg/s**	**Power MWth**	**Duration**	**Approx Size**
300-775	5-9	He	0.5 kg/s	1	Short Term	IHX Module
Small-Scale Test No. 18	**SSC or Test:** Fluid Structure Interaction Code Qualifications				**Test Type:** Static Test	
Test Description: Provide basic data to support qualification of fluid structure interaction codes, particularly in the area of hot duct insulation depressurization loads. Specific tests will be identified as code development progresses.						
Temperature °C	**Pressure MPA**	**Environment**	**Flow Rate m/s or kg/s**	**Power MWth**	**Duration**	**Approx Size**
750-900	5-9	He	N/A	N/A	Short Term	Hot Duct Sample Section
Small-Scale Test No. 19	**SSC or Test:** Radio-contaminant transport code				**Test Type:** Flow Test	
Test Description: Provide basic data to support qualification of radio-contaminant transport codes. Specific tests will be identified as code development progresses.						
Temperature °C	**Pressure MPA**	**Environment**	**Flow Rate m/s or kg/s**	**Power MWth**	**Duration**	**Approx Size**
20-900	0.1-9	He	TBD	N/A	TBD	TBD

Table 5-2: Other Small Scale Tests for HTGR Design Options

<table>
<tr><td>Small-Scale Test No. 20</td><td colspan="4">SSC or Test:
Material Testing</td><td colspan="2">Test Type:
Flow test</td></tr>
<tr><td colspan="7">Test Description: Corrosion and tribology tests of various HTR materials (Mod. 9Cr1Mo, Ni Based Alloys, ODS, composites, ceramics, etc.) under representative conditions to validate screening tests and their assumptions, particularly to control for the absence of helium partial pressure in some tests.</td></tr>
<tr><td>Temperature °C</td><td>Pressure MPA</td><td>Environment</td><td>Flow Rate m/s or kg/s</td><td>Power MWth</td><td>Duration</td><td>Approx Size</td></tr>
<tr><td>250-1000</td><td>5-9</td><td>Impure He (O_2, H_2O, H_2, CO, CO_2, CH_4, N_2)</td><td>TBD</td><td>TBD (<<1)</td><td>Long Term</td><td>Sample Coupon</td></tr>
<tr><td>Small-Scale Test No. 21</td><td colspan="4">SSC or Test:
Plate IHX</td><td colspan="2">Test Type:
Flow Test</td></tr>
<tr><td colspan="7">Test Description: Plate IHX thermo-mechanical behavior</td></tr>
<tr><td>Temperature °C</td><td>Pressure MPA</td><td>Environment</td><td>Flow Rate m/s or kg/s</td><td>Power MWth</td><td>Duration</td><td>Approx Size</td></tr>
<tr><td>400-1000</td><td>0.6</td><td>Air</td><td>0.04-0.2kg/s</td><td>0.1</td><td>Long Term</td><td>~18 Plates</td></tr>
<tr><td>Small-Scale Test No. 22</td><td colspan="4">SSC or Test:
IHX</td><td colspan="2">Test Type:
Flow Test</td></tr>
<tr><td colspan="7">Test Description: Influence of the gas environment on pressure loss and heat transfer</td></tr>
<tr><td>Temperature °C</td><td>Pressure MPA</td><td>Environment</td><td>Flow Rate m/s or kg/s</td><td>Power MWth</td><td>Duration</td><td>Approx Size</td></tr>
<tr><td>200</td><td>0.2</td><td>Impure He (O_2, H_2O, H_2, CO, CO_2, CH_4, N_2)</td><td>0.07 kg/s</td><td>0.005</td><td>Short Term</td><td>Small Tube</td></tr>
<tr><td>Small-Scale Test No. 23</td><td colspan="4">SSC or Test:
Plate IHX</td><td colspan="2">Test Type:
Flow Test</td></tr>
<tr><td colspan="7">Test Description: Influence of the channel geometry on pressure loss and heat transfer.</td></tr>
<tr><td>Temperature °C</td><td>Pressure MPA</td><td>Environment</td><td>Flow Rate m/s or kg/s</td><td>Power MWth</td><td>Duration</td><td>Approx Size</td></tr>
<tr><td>20-100</td><td>0.1</td><td>Air</td><td><0.005 kg/s</td><td>0.001</td><td>Short Term</td><td>2 Plates</td></tr>
</table>

Small-Scale Test No. 24	**SSC or Test:** Plate IHX				**Test Type:** Flow Test	
Test Description: Influence of flow distribution from the IHX header to the plate bundle.						
Temperature °C	**Pressure MPA**	**Environment**	**Flow Rate m/s or kg/s**	**Power MWth**	**Duration**	**Approx Size**
20	1.5	Air	1.3 kg/s	TBD	Short Term	IHX Module
Small-Scale Test No. 25	**SSC or Test:** Plate IHX				**Test Type:** Flow Test	
Test Description: Validation of IHX performance in representative reactor conditions (except flow distribution) – with appropriate instrumentation, this test can be used for validating FIV and thermal stress calculations in the IHX)						
Temperature °C	**Pressure MPA**	**Environment**	**Flow Rate m/s or kg/s**	**Power MWth**	**Duration**	**Approx Size**
400-1000	5-9	Impure He (O_2, H_2O, H_2, CO, CO_2, CH_4, N_2)	~ 0.5 kg/s	1	Long term	~ 50 full size plates
Small-Scale Test No. 26	**SSC or Test:** Helium Purification System				**Test Type:** Flow Test	
Test Description: Assessing the viability of advanced technologies for helium purification						
Temperature °C	**Pressure MPA**	**Environment**	**Flow Rate m/s or kg/s**	**Power MWth**	**Duration**	**Approx Size**
30-450	0.1-9	Impure He (O_2, H_2O, H_2, CO, CO_2, CH_4, N_2)	0.04 kg/s	TBD (<< 1)	Long term	TBD
Small-Scale Test No. 27	**SSC or Test:** Direct Cycle Recuperator				**Test Type:** Flow Test	
Test Description: Validation of recuperator performance in representative reactor conditions (except flow distribution)						
Temperature °C	**Pressure MPA**	**Environment**	**Flow Rate m/s or kg/s**	**Power MWth**	**Duration**	**Approx Size**
500	7-9 / 3-5	Impure He (O_2, H_2O, H_2, CO, CO_2, CH_4, N_2)	~ 0.5 kg/s	1	Long term	~ 50 full size plates

Small-Scale Test No. 28	**SSC or Test:** Direct Cycle Power Conversion System Components				**Test Type:** Flow Test	
Test Description: Performance tests of plate type recuperators and coolers with a reduced number of full-sized plates						
Temperature °C	**Pressure MPA**	**Environment**	**Flow Rate m/s or kg/s**	**Power MWth**	**Duration**	**Approx Size**
~500	5-9	Impure He (O_2, H_2O, H_2, CO, CO_2, CH_4, N_2)	TBD	TBD	Long Term	Hx Module

Small-Scale Test No. 29	**SSC or Test:** Thermal Stress Analysis Code Qualification				**Test Type:** Flow Test	
Test Description: Provide data to support qualification of codes used to evaluate plate type IHX lifetimes.						
Temperature °C	**Pressure MPA**	**Environment**	**Flow Rate m/s or kg/s**	**Power MWth**	**Duration**	**Approx Size**
300-775	5-9	Impure He (O_2, H_2O, H_2, CO, CO_2, CH_4, N_2)	0.5 kg/s	1	Long Term	IHX Module

6.0 ASSESSMENT OF REQUIRED INDIVIDUAL TEST CONDITIONS

This section will discuss the required test condition ranges for each major controlling test parameter. To facilitate that discussion, the information related to the Small Scale Tests identified in Sections 4 and 5 is summarized in Table 6-1.

Table 6-1: Summary of Small Scale Test Conditions

Small Scale Test No.	SSC or Test	Test Description	Temp. °C	Pressure MPa	Environ.	Flow Rate	Power MWth	Duration	Approx Size
1	Reactor Internals	Determine gap loss coefficients for flow between graphite blocks	325-1100	Atm.	He	0 -3.0kg/s	N/A	Short Term	0.5m dia. 5m long
2	Reactor Internals	Determine fuel block coolant channel loss coefficients	325-1100	Atm.	He	0 -3.0kg/s	N/A	Short Term	0.5m dia. 5m long
3	Reactor Internals	Fuel and reflector block conduction	325-1200	Atm.	He	N/A	TBD W/cm^2	Short Term	0.5m dia. 1m long
4	Reactor Internals	Core Barrel emissivity measurement	325-750	Atm.	He	N/A	N/A	Short Term	Small (Test coupon)
5	Reactor Core	Core bypass flow testing	20-1200	6	He	0.1-3.0 kg/s	N/A	Short Term	1m dia. 5m long
6	Reactor Core	Core block thero-mechanical behavior	20-1200	6	He	0.1-3.0 kg/s	0.95	Short Term	1m dia. 5m long
7	Control Rod Drives	Verify design and qualify control rod drives under anticipated normal and off-normal conditions	100-900	6	He	0 -3kg/s	N/A	Long Term	~20-30m
8	Reactor Cavity Cooling Syst.	Determine emissivity behavior of RPV and RCCS Materials	20-540	Atm.	Air	N/A	N/A	Short and Long Term	Small (Test coupon)
9	Reactor Cavity Cooling Syst.	Determine effect of particulates on radiation heat transfer	20-700	Atm.	Air with particulates	N/A	N/A	Short and Long Term	Small (Test coupon)

Small Scale Test No.	SSC or Test	Test Description	Temp. °C	Pressure MPa	Environ.	Flow Rate	Power MWth	Duration	Approx Size
10	Primary Loop Instr.	Verify Primary Loop Instrumentation at NGNP operating pressures and temperatures, and demonstrate acceptable accuracy, sensitivity, and lifetime.	100-900	6	Moist He (2-1000vpm)	N/A	N/A	Long Term	Small (Sensor)
11	Fuel Handling System	Confirm performance of seals, bearings and lubricants	20-100	~1 Atm.	He/Air	N/A	N/A	Short Term	Small (Test Part)
12	Material Testing	Corrosion and tribology tests of various HTR materials (SA508, Mod. 9Cr1Mo, Alloy 800H, graphite, composites, etc.) under representative conditions to validate screening tests and their assumptions, particularly to control for the absence of helium partial pressure in some tests.	250-750	5-9	Impure He (O_2, H_2O, H_2, CO, CO_2, CH_4, N_2)	TBD	TBD (<<1)	Long Term	Sample Coupon
13	Shutdown Cooling System TRL 7-8	Shutdown Cooling System heat exchanger qualification	TBD	0.1-9	He	0.5kg/s	1	Long Term	Reduced Number of Full Size Tubes
14	Helium Purification System TRL 8-9	Qualification of helium purification technologies using the Small Scale Test Loop helium purification system	30-450	0.1-9	Impure He (O_2, H_2O, H_2, CO, CO_2, CH_4, N_2)	0.04 kg/s (in HPS)	N/A	Long Term	Full Size HPS

Small Scale Test No.	SSC or Test	Test Description	Temp. °C	Pressure MPa	Environ.	Flow Rate	Power MWth	Duration	Approx Size
15	System Transient Analysis Code Qualifications	Provide basic data to support qualification of system transient analysis codes. Specific tests will be identified as code development progresses.	200-900	0.1-9	He	<0.5 kg/s	<1 MW	Short Term	TBD
16	CFD Code Qualifications	Provide basic data to support qualification of CFD codes. Specific tests will be identified as code development progresses.	200-900	0.1-9	He	<0.5 kg/s	<1 MW	Short Term	TBD
17	Fluid Structure Interaction Code Qualifications	Provide basic data to support qualification of fluid structure interaction codes, particularly in the area of IHX flow induced vibration. Specific tests will be identified as code development progresses.	300-775	5-9	He	0.5 kg/s	1	Short Term	IHX Module
18	Fluid Structure Interaction Code Qualifications	Provide basic data to support qualification of fluid structure interaction codes, particularly in the area of hot duct insulation depressurization loads. Specific tests will be identified as code development progresses.	750-900	5-9	He	N/A	N/A	Short Term	Hot Duct Sample Section
19	Radio-contaminant transport code	Provide basic data to support qualification of radio-contaminant transport codes. Specific tests will be identified as code development progresses.	20-900	0.1-9	He	TBD	N/A	TBD	TBD

Small Scale Test No.	SSC or Test	Test Description	Temp. °C	Pressure MPa	Environ.	Flow Rate	Power MWth	Duration	Approx Size
20	Material Testing	Corrosion and tribology tests of various HTR materials (Mod. 9Cr1Mo, Ni Based Alloys, ODS, composites, ceramics, etc.) under representative conditions to validate screening tests and their assumptions, particularly to control for the absence of helium partial pressure in some tests.	250-1000	5-9	Impure He (O_2, H_2O, H_2, CO, CO_2, CH_4, N_2)	TBD	TBD (<<1)	Long Term	Sample Coupon
21	Plate IHX	Plate IHX thermo-mechanical behavior	400-1000	0.6	Air	0.04-0.2kg/s	0.1	Long Term	~18 Plates
22	IHX	Influence of the gas environment on pressure loss and heat transfer	200	0.2	Impure He (O_2, H_2O, H_2, CO, CO_2, CH_4, N_2)	0.07 kg/s	0.005	Short Term	Small Tube
23	Plate IHX	Influence of the channel geometry on pressure loss and heat transfer.	20-100	0.1	Air	<0.005 kg/s	0.001	Short Term	2 Plates
24	Plate IHX	Influence of flow distribution from the IHX header to the plate bundle.	20	1.5	Air	1.3 kg/s	TBD	Short Term	IHX Module
25	Plate IHX	Validation of IHX performance in representative reactor conditions (except flow distribution) – with appropriate instrumentation, this test can be used for validating FIV and thermal stress calculation in the IHX)	400-1000	5-9	Impure He (O_2, H_2O, H_2, CO, CO_2, CH_4, N_2)	~ 0.5 kg/s	1	Long term	~ 50 full size plates

Small Scale Test No.	SSC or Test	Test Description	Temp. °C	Pressure MPa	Environ.	Flow Rate	Power MWth	Duration	Approx Size
26	Helium Purification System	Assessing the viability of advanced technologies for helium purification	30-450	0.1-9	Impure He (O_2, H_2O, H_2, CO, CO_2, CH_4, N_2)	0.04 kg/s	TBD (<< 1)	Long term	TBD
27	Direct Cycle Recuperator	Validation of recuperator performance in representative reactor conditions (except flow distribution)	500	7-9 / 3-5	Impure He (O_2, H_2O, H_2, CO, CO_2, CH_4, N_2)	~ 0.5 kg/s	1	Long term	~ 50 full size plates
28	Direct Cycle Power Conversion System Components	Performance tests of plate type recuperators and coolers with a reduced number of full-sized plates	~500	5-9	Impure He (O_2, H_2O, H_2, CO, CO_2, CH_4, N_2)	TBD	TBD	Long Term	Hx Module
29	Thermal Stress Analysis Code Qualification	Provide data to support qualification of codes used to evaluate plate type IHX lifetimes.	300-775	5-9	Impure He (O_2, H_2O, H_2, CO, CO_2, CH_4, N_2)	0.5 kg/s	1	Long Term	IHX Module

6.1 Temperature

The temperatures in Table 6-1 can be divided into three basic categories: temperatures reflective of normal operation of the primary loop, temperatures reflective of accident conditions, and temperatures outside of the primary loop. It is anticipated that it may be advantageous to use these temperature ranges to define test loop configurations, particularly the highest temperatures, as material performance issues may increase loop complexity or cost.

6.2 Pressure

Test pressures identified in Table 6-1 cover the range from atmospheric pressure to the extremes of primary system pressure anticipated for various HTGR configurations. These pressures are all well within the capabilities of "standard" loop designs and should not present significant design challenges.

6.3 Environment

There are two primary loop environments identified in Table 6-1, a normal low impurity helium operating environment and a controlled impurity "off-normal" helium environment. Though it would be possible to design a loop that allows both environments, it may be advantageous to consider different configurations for the two environments due to potential impacts of some of the anticipated helium impurities on both loop instrument performance and loop materials at high temperatures.

6.4 Flow Rate

Loop flow rates vary from effectively static conditions up to approximately 3 kg/s, which is reflective of the anticipated average core flow for one column of blocks. These flow rates should all well within the capabilities of "standard" loop designs and should not present significant design challenges.

6.5 Thermal Power

The maximum thermal power anticipated for any of the small scale tests is 1 MW, typically applied as a heat load for heat exchanger testing. It is anticipated that these loads will be supplied via electrical resistance heating and will require a like-sized means of loop heat rejection on the secondary side of the test components.

6.6 Approximate Test Size

The test components are typically small material test coupons (~centimeters in size), small component mock-ups or sections (~meters in size), or stacks of core blocks (~meters in size). The latter category will present the most challenge, from a size standpoint, though all of these should be amenable to enclosure within a standard industrial building. The control rod drive functional test, however, will require either a relatively tall building or an outside test stand to accommodate the required height.

6.7 Loop Set-up

Three basic loop set-ups are necessary to address the tests defined in Table 6.1. These are a static test chamber with environment control, a single circuit flow loop, and a two circuit flow loop, with the secondary loop being a water or gas loop. It may be advantageous to combine two or more of these set-ups into a single loop to better utilize test resources. The final set of loop configurations will be determined in the test loop design process.

7.0 ASSESSMENT OF INTEGRATED TEST ENVELOPE

Based on the information presented in Section 6, four small scale test loop configurations that, among them, cover all of the small scale tests are identified in Table 7-1.

Table 7-1: Small Scale Loop Configurations

Small Scale Loop Configuration	Small Scale Tests Covered	Temp. °C	Pressure MPa	Environ.	Flow Rate	Power MWth	Approx Size
1	1, 2, 3, 5, 6	20 - 1200	Atm. – 6 [Atm. – 9]	He	0-3 kg/s	N/A	0.5m dia. 5m long
2	4, 8, 9, 10, 11, 12, 13, 15, 16, 17, 18, 19, 22, 23, 24, 26, 27, 28, 29 [20, 21, 25]	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	7	100 - 900	6 [Atm. – 9]	He	0-3 kg/s	N/A	~20-30m
4	14	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:

Loop Configuration 1 – High Temperature Helium Loop: This loop includes tests requiring the highest helium temperature and the largest test sections (except special loop configuration 3). The test atmosphere required is normal low impurity 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 impurity control to achieve a benign condition with respect to material surfaces) 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.

Loop Configuration 2 – Moderate Temperature Impure Helium Loop: This loop configuration is designed to cover all of the tests which require normal helium, off-normal impure helium, 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.

Loop Configuration 3 – Control Rod Functional Test Loop: 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 Section 6 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.

8.0 REFERENCES

1. AREVA Report PD-3002052-000, “Work Plan for Heat Transport Small Scale Testing for Prismatic Block”, September 2009.
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3. AREVA Report TDR-3001031-003, “NGNP Technology Development Road Mapping Report”, September 2009.
4. INL Report INL/EXT-07-13165 Graphite Technology Development Plan, September 2007.
5. INL Report INL/EXT-07-12999, Rev. 2, “Next Generation Nuclear Plant System Requirements Manual”, March 2009
6. AREVA Report 12-9051191-001, “NGNP with Hydrogen Production Preconceptual Design Studies Report”, June 2007.
7. AREVA Report 51-9106032-001, “NGNP Plant Design Requirements Document”, June 2009.