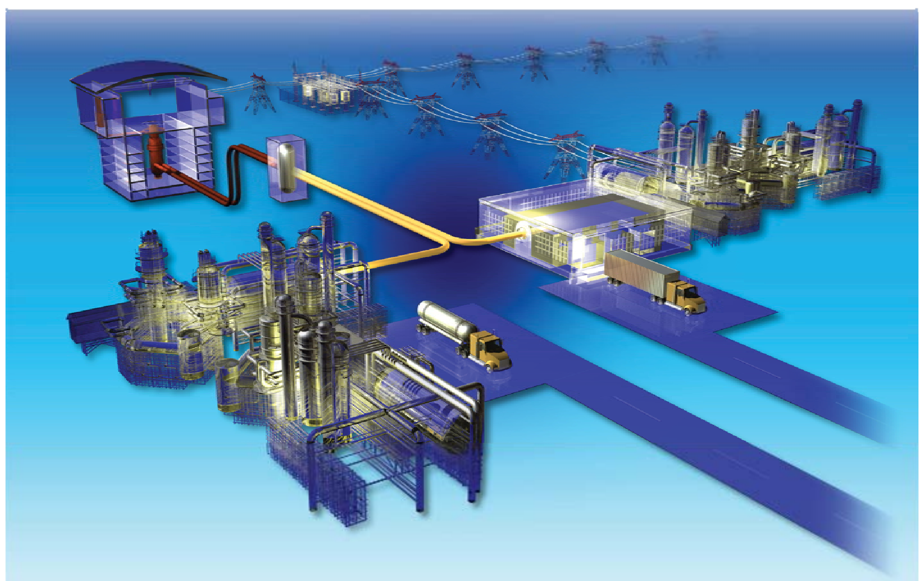
Document ID: TEV-573
Revision ID: 0
Effective Date: 08/12/2009

Technical Evaluation Study

Project No. 29147

NGNP Component Test Capability Test Loop Configuration Study



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NGNP COMPONENT TEST CAPABILITY TEST LOOP CONFIGURATION STUDY	Identifier: TEV-573 Revision: 0 Effective Date: 08/12/2009	Page: 1 of 32

NGNP Project	Technical Evaluation Study (TEV)	eCR Number: 570785

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Note: Applicable QLD: ALL-000473

REVISION LOG

Rev.	Date	Affected Pages	Revision Description
0	08/12/2009	All	New document.

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1. INTRODUCTION

1.1 Description of the Proposed Issue or System

Testing will be required to develop the technologies needed for the NGNP Project and to move the components, subsystems, and systems from their current Technology Readiness Levels (TRLs)[a] to the levels needed to deploy the NGNP reactor and related systems. The types of tests range from determining material properties of exotic alloys to transient testing of complete systems to simulate off-normal operations. A wide variety of research and test equipment will therefore be needed to accomplish this testing. A specific test facility has not yet been identified for this testing, so reference will be made in this report to a generic Component Test Capability (CTC), which could be provided by test facilities distributed across the country at various vendors' shops, foreign test facilities, or a new Department of Energy (DOE) test facility.

The issue to be addressed in this evaluation is the initial concept development for the circulation loops that will be needed to advance the TRLs of some of the components and subsystems of the NGNP. These loops will provide flowing helium to test articles at pressures of up to 9.0 MPa and temperatures up to 950°C. Power (heat) inputs to the test articles will be in the range of 1 MW to 30 MW. This study identifies and discusses various solutions to provide the necessary flow configurations and capacities over the range of flow rates and power inputs.

1.2 Problem Statement

Identify and discuss flow configurations for component and subsystem testing that will effectively support the technology development needs for the current NGNP Project reference designs, potential future NGNP reference designs that may extend the reactor outlet temperatures to 950°C and employ alternative power conversion systems, and other applications.

The requirements for the technology development testing are still being defined and in some cases cannot be defined until further design has been completed. The preconceptual designs of the pebble bed and prismatic block core NGNP (Reference NGNP_WEC, NGNP_AREVA, and NGNP_GA) and the preconceptual designs of the Component Test Facility developed by AREVA and Westinghouse (CTF_AREVA 2008; and CTF_WEC 2009) have been used to establish the requirements for this study. These designs, along with the options developed in this study, will be evaluated in a facilitated Value Engineering study during subsequent evaluation or design efforts.

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a. The TRL is a way to measure the maturity of a technology, that is, the extent to which the technology has been proven by analysis, demonstration, or deployment. See Reference 1 for additional description of TRLs.

1.3 Definitions/Glossary

For the purposes of this report, the size of the test loops will be designated by the power input of the main heater(s). In other words, a loop with a 30 MW main heater would be designated the 30 MW loop, even though the actual power demand of the loop would be much higher.

2. BACKGROUND

2.1 Facility, Structure, System, Component Functions

The technology development needs for the 950°C reactor configuration, as of January 2009 [Collins], were grouped into the 18 systems, subsystems, and components (SSCs) listed in Table 1. These SSCs were designated as the critical SSCs. There are many other SSCs not addressed in Table 1 that may also require technology development. Table 1 also lists some anticipated requirements for testing of the critical SSCs, but it is not an exhaustive listing. Rather, the intent of this table is to present the range and types of tests that will require flow loops of some sort.. These SSCs have been organized by test type as low flow, low heat input tests, high flow, low heat input tests, and high flow, high heat input tests. Note that low heat input does not necessarily imply low test temperatures. Low heat input only means that the test article does not require substantial heat transfer from a primary to a secondary fluid. For example, a test of the cross vessel piping to determine temperature distributions and heat loss to the environment would have relatively low heat losses, hence a low heat input.

Table 1. Critical subsystems or components.

System	Subsystem/Component	Tests Required	Test Type	Test Requirements
Nuclear Heat Supply System	Reactor Pressure Vessel	Materials testing	low flow, low heat	Size <1 MW Fluid Helium Pressure 9 MPa Inlet Temp 950°C
Nuclear Heat Supply System	Reactor Vessel Internals	Materials testing Form/fit Warping at high temp	low flow, low heat	Size <1 MW Fluid Helium Pressure 9 MPa Inlet Temp 950°C
Nuclear Heat Supply System	Reactor Core and Core Structure	Materials testing Form/fit Warping at high temp	low flow, low heat	Size <1 MW Fluid Helium Pressure 9 MPa Inlet Temp 950°C
Nuclear Heat Supply System	Fuel Elements	Possibly graphite testing at temp	low flow, low heat	Size <1 MW Fluid Helium Pressure 9 MPa Inlet Temp 950°C

System	Subsystem/Component	Tests Required	Test Type	Test Requirements
Nuclear Heat Supply System	Reactivity Control System	Control rod insertion (form /fit/warping)	low flow, low heat	Size <1 MW Fluid Helium Pressure 9 MPa Inlet Temp 950°C Probably full height
BOP	Instrumentation and Control	Instrumentation performance	low flow, low heat	Size <1 MW Fluid Helium Pressure 9 MPa Inlet Temp 950°C
Nuclear Heat Supply System	Reserve Shutdown System	Materials testing Form/fit	high flow, low heat	Size <1 MW Fluid Helium Pressure 9 MPa Inlet Temp 950°C Possibly full height
Heat Transport System	High Temperature Valves (Isolation, Flapper, and Relief)	High temp, helium environment	high flow, low heat	Size <1 MW Fluid Helium Pressure 9 MPa Inlet Temp 950°C
Heat Transport System	Cross Vessel Piping	Insulation testing Hot spot testing Temp distributions	high flow, low heat	Size <1 MW Fluid Helium Pressure 9 MPa Inlet Temp 950°C
Nuclear Heat Supply System	Core Conditioning System (Shutdown Cooling)	Circulator performance at temperature Valves at temperature	high flow, low heat also lower temp	Size <1 MW Fluid Helium Pressure 9 MPa Inlet Temp 400°C Flow rate full flow?
Heat Transport System	Circulators (main)	Circulator performance at temperature	high flow, low heat also lower temp	Size <1 MW Fluid Helium Pressure 9 MPa Inlet Temp 400°C Flow rate full flow? 5 MW electrical power for circ
Heat Transport System	Intermediate Heat Exchangers	Plate thermal performance, module thermal performance, Stress, fatigue at temp, other	high flow, high heat	Size 1.5 MW up to 30MW Fluid Helium Pressure 9 MPa Inlet Temp 950°C Outlet Temp 450°C
Power Conversion System	Steam Generator	Heat transfer structural issues Dissimilar metal weld	high flow, high heat	Size 1.5 MW up to 30MW Fluid Helium steam Pressure 9 MPa Inlet Temp 900°C

System	Subsystem/Component	Tests Required	Test Type	Test Requirements
Nuclear Heat Supply System	Reactor Cavity Cooling System	Possibly verification testing but would not require high temp or helium flow		No requirement for flowing helium
Balance Of Plant (BOP)	Fuel Handling System			No requirement for flowing helium
Heat Transport System	Mixing Chamber			TBD
Hydrogen Production System	Hydrogen Production System Components	Production demonstration		TBD
Power Conversion System	PCS Equipment for Direct Combined Cycle (Brayton cycle compressors, turbines,…)	Would require very high He flow, very high heat input but not currently considered for NGNP		TBD

2.2 Previous Studies

The design of loops for testing high temperature components have been the subject of a number of previous studies (CTF_AREVA 2008; CTF_WEC 2009; 2MW_BEA 2006) and the concepts described therein have been used to the extent practical.

All these studies have concluded that the most cost effective and reliable approach is to use off-the-shelf components wherever practical. In particular, use of commercially available circulators and valves should be accommodated by designing the loops such that these components are not subjected to the extreme temperatures of the test sections of the loops. The loop configurations described in this document use that approach to the extent practical.

2.3 Facility, Structure, System, Component Classification

The CTC test loops will be Quality Level (QL) QL-2. This study will be used as a supporting document in a future procurement and is QL-3

2.4 Operational Overview

Not applicable

3. LIMITATIONS AND ASSUMPTIONS

3.1 Limitations

The heat allowed for the largest single component or system will be limited to the maximum power input of the primary heater(s) of a 30 MW test loop.

There is insufficient data available at this time to select the optimum solution. An effort is currently underway to determine the number and sizes of test loops needed to support the technology development for NGNP, but that information will not be available in time for this report.

3.2 Assumptions

The size of the test loop needed for the largest single component or system will be 30 MW.

For concepts that employ multiple identical small loops to provide additional testing capability, a total of two small loops will be provided.

Intermediate heat exchanger (IHX) testing requirements shall be based on a compact heat exchanger concept that will require unit cell testing (approximately 1.5 MW) and testing of a number of combined unit cells (modules).

4. PROPOSED SOLUTION(s)

4.1 Elements/Functions of Proposed Solution(s)

This section describes four options, in addition to the Westinghouse and AREVA concepts previously referenced, for providing hot helium to test articles over a range of flow rates and heat inputs. These possible solutions are intended to be used to explore requirements, capabilities, and limitations of the loops and serve as a basis for future design efforts. It is not the purpose of this report to select the optimum solution. Rather, as noted previously, the solutions discussed here (and possibly others) will be the subject of a facilitated Value Engineering effort to more fully develop functions and evaluate solutions.

This section also goes on to provide a discussion on another circulating loop, the circulator test loop, and a sixth discussion that is related to the acquisition strategy for any of the loops rather than a specific option to be considered. These latter two are included in this report for future consideration.

4.1.1 Design Specific Capability Now (Small and Large Thermal Loops)

This proposed solution provides the nominal capability in the form of two small (nominally 1.5 MW heater capacity) loops and one large 30 MW heater capacity loop and builds all of the loops as a single project. The flow sheets for this solution are similar to the concept developed in the “NGNP Component Test Facility Loop Pre-Conceptual Design” (CTF_AREVA 2008). The small loops are intended for early testing of materials, helium purification system qualification, and IHX preliminary testing. The 30 MW test loop is intended for large-scale testing, code validation, and qualification of reactor components that are subjected to high temperatures (IHXs, steam generators, hot gas duct, coaxial pipes, high temperature valves, etc.).

4.1.1.1 Small Loop Capability

Each small loop is made up of a primary test loop that can be coupled to a secondary test loop as shown in Figure 1.

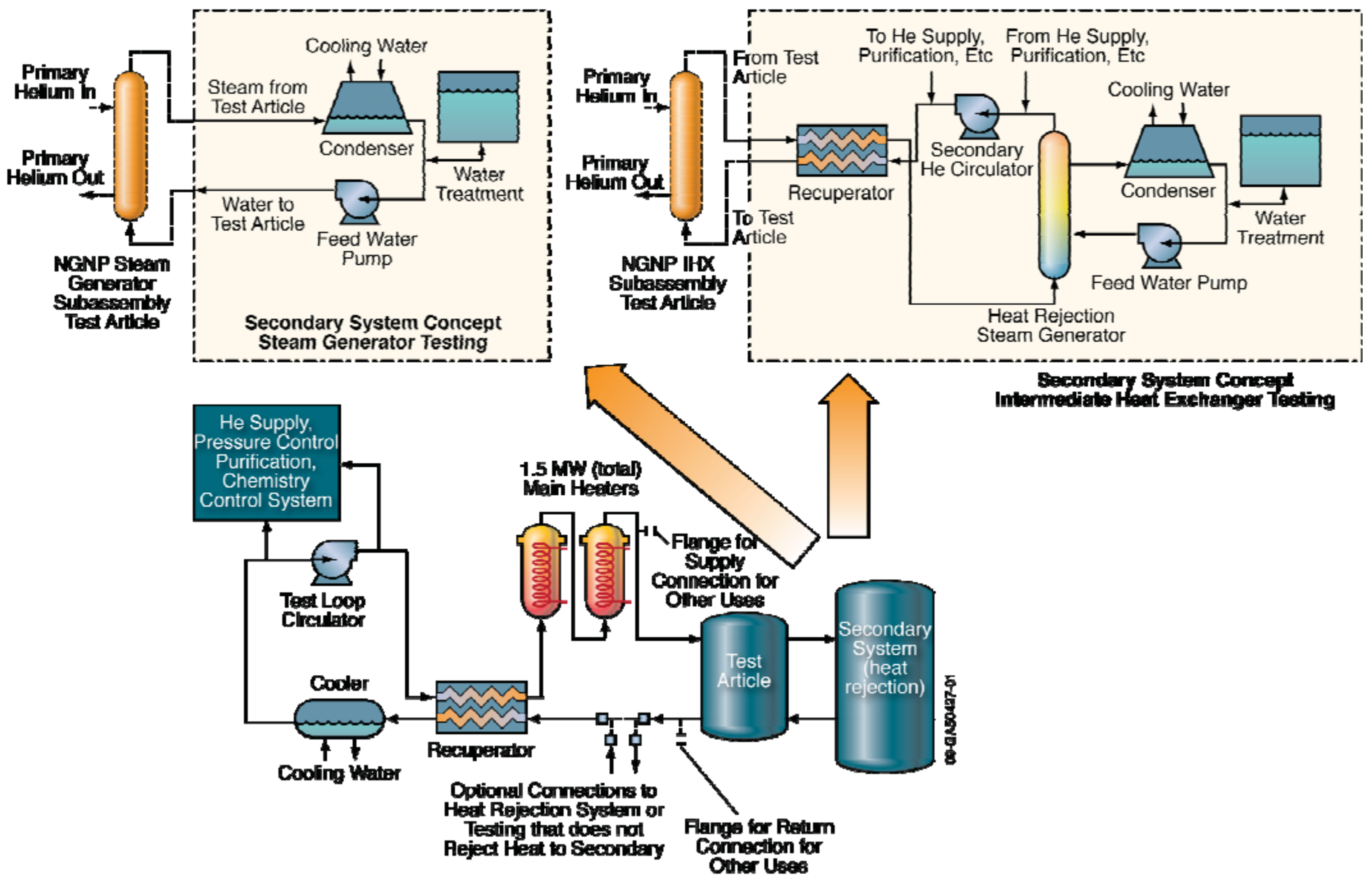

Figure 1. Process flow diagram of small loop.

Heat input to the primary fluid for the 1.5 MW primary test loop is provided by main heaters (probably a two-stage heater set) in the primary test loop hot leg, where the helium can be heated up to 950°C. The hot helium then enters the test article. To minimize loop heating requirements, the helium leaving the test article passes through a recuperative heat exchanger where a portion of the heat is recovered (transferred to the helium entering the two-stage heaters) before entering the cold leg of the primary loop. Depending on the component and the test objectives, some of the heat in the primary fluid may be transferred to the secondary test loop, resulting in temperatures at the outlet of the test article that are typical of the reactor inlet temperature. In other cases, however, the test objective may not require significant (or any) heat rejection to the secondary side (e.g., hot duct testing) so the temperature of the fluid leaving the test article may be almost as high as the inlet temperature. Design of a single recuperator to function with this wide range of test article outlet temperatures may not be feasible. For the purposes of this study, connections are provided to another heat rejection system that will reduce the recuperator inlet temperature to a value that the recuperator design can accommodate. Other options should be evaluated as the conceptual design of the CTC continues.

In the cold leg of the primary loop, the helium passes through a low temperature heat exchanger where it is cooled to a temperature that will allow use of a helium loop circulator made of more conventional moderate temperature materials. The helium leaving the circulator then passes back through the recuperative heat exchanger where the heat from the fluid leaving the test article is transferred to the cooler circulator outlet stream prior to entering the main heaters.

The purpose of the 1.5 MW secondary test loop is to remove heat from the test article. As currently envisioned, the secondary loop must be able to accommodate test articles representing a steam generator or test articles representing an IHX. Thus, two different secondary loop configurations must be provided, as depicted in Figure 1. The design for the steam generator configuration for NGNP provides feed water to a steam generator test article. The steam exits the test article, is condensed in a condenser, and returned to the feed-water pump. This system also contains the associated utility systems such as water chemistry control, deaeration, and the like.

The other secondary heat rejection design is intended to represent an IHX, which will have helium on the secondary side of the heat exchanger. This design includes a secondary helium circulation system and an ultimate heat rejection system. The secondary helium circulation system is similar to the primary system in that it is designed so that components such as circulators and valves are operated at lower temperatures, allowing use of more conventional materials. Flow from the circulator is routed to the cool side of the recuperator, where it picks up heat to meet the specified test article inlet temperature. The helium picks up heat in the test article and will exit the test article at temperatures up to 900°C. This high temperature helium flows through the hot side of the recuperator where its temperature is reduced, and then through a heat rejection heat exchanger (depicted in Figure 1 as the heat rejection steam generator) where it transfers its heat to a third heat transfer fluid. For the purposes of this study, the tertiary fluid is assumed to be steam, although other options, including pressurized water or air could also be used. The final selection of the fluid will be performed in the next phase of this project.

The design conditions for the 1.5 MWt test loop are:

- Fluid Helium
- Temperature range 300–950°C
- Operating pressure 4–8 MPa
- Design pressure 10 MPa
- Flow range 0.04–0.4 kg/s
- Power range 1–1.5 MWt

When certain components have the proper design and specification (most notably the loop circulators), the primary and secondary loops of the two 1.5 MW systems could be connected to a header and used in parallel to supply a single larger component.

The connections for the helium purification and inventory control system are located near the inlet to the helium circulator.

4.1.1.2 Large Loop Capability

For this study, the large loop is sized to provide 30 MW of heat to the helium, heating 10 kg/s of helium to a maximum of 950°C.

The flow diagram for this test loop, shown in Figure 2, is very similar to that of the 1.5 MW loop and consists of a primary loop and two secondary loops, one for testing steam generator components and another for testing IHX components. The primary helium loop includes the primary helium circulator, electric heaters capable of delivering 30 MWt power to the primary helium fluid, the test article, a recuperator, and a cooler.

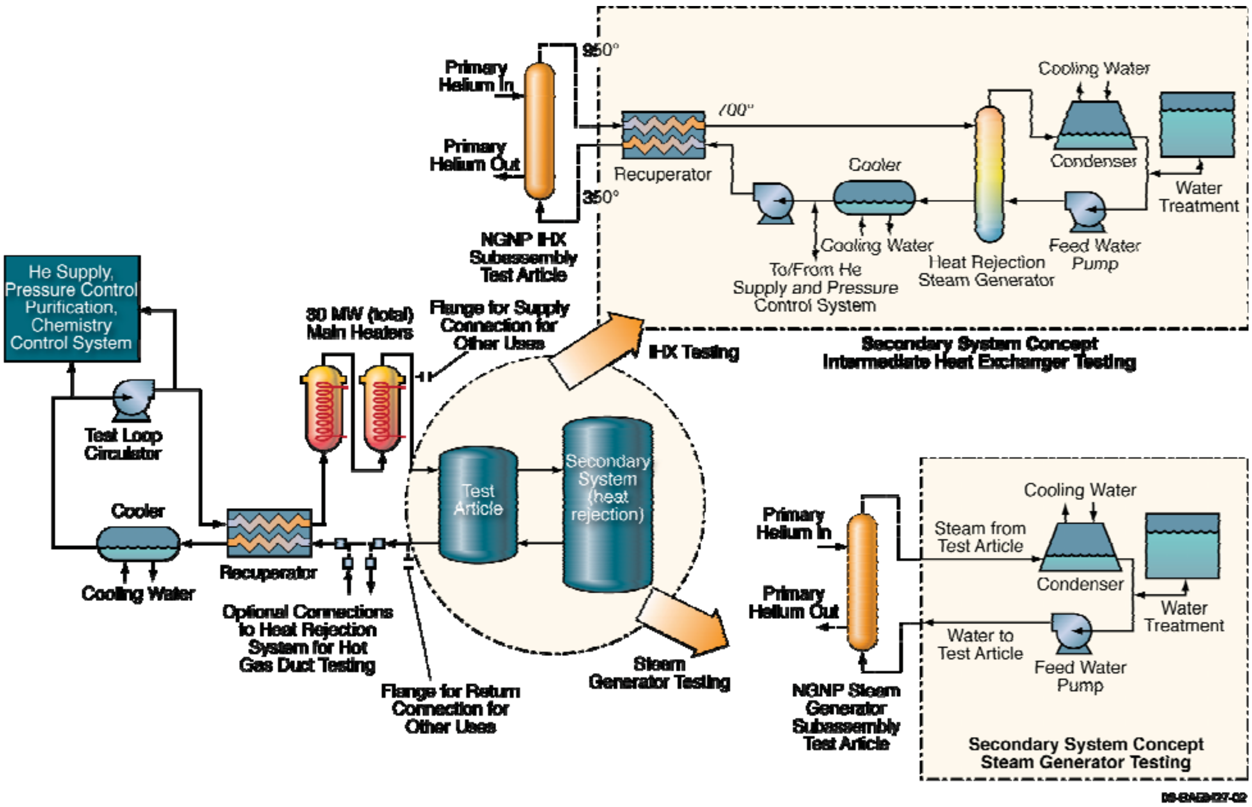

Figure 2. Process flow diagram of 30 MW test loop.

The main heaters provide up to 30 MW to the helium flow of nominally 10 kg/s to provide an outlet temperature from the second heater of up to 950°C. Figure 2 shows two main heaters but physical constraints may require four or more heaters in a series/parallel arrangement. This design will be updated as details are obtained from suppliers.

The hot helium passes through the test article and enters the recuperator where some of the energy is conserved by transferring it to the cold stream from the circulator outlet. The helium is then routed to the cooler where the temperature is reduced to the allowable conditions for the circulator inlet. Similar to the 1.5 MW loop shown in Figure 1 above, the inlet temperature of the circulator is maintained at a temperature that permits use of common materials of construction.

The system on the secondary side of the test article again depends on the type of component to be tested. Steam generator testing will be supported by a water/steam system consisting of a feed-water pump, feed-water heaters if required (not shown in Figure 2), a condenser, and the associated utilities. For IHX testing, the secondary side consists of a helium loop similar to the primary loop, but without heaters, and a tertiary steam loop consisting of a heat rejection steam generator and the associated feed water, condenser, and utilities.

Optional connections to a heat rejection system that can reject the 30 MW to the environment are provided for testing of the hot gas duct, valves, and other large components that will not result in a significant temperature loss through the test article.

The design conditions for the 30 MWt test loop are shown in Table 2.

Finally, although not developed in detail, the 30 MWt loop design also provides supply and return taps that could be used by another user of high temperature helium.

Table 2. Design conditions for the 30 MWt test loop.

1. Primary Loop:	
• Fluid	Helium
• Maximum Temperature	950°C
• Flow rate	10 kg/s
• Pressure	7 MPa
• Temperature Transients	not specified at this time
• Power	30 MWt
2. Secondary Loop (IHX component testing):	
• Fluid	Helium
• Maximum temperature	950°C
• Flow rate	10 kg/s
• Pressure	7.5 MPa
3. Secondary Loop (Steam Generator component testing):	
• Fluid	Water/steam
• Maximum temperature	TBD°C
• Flow rate	TBD kg/s
• Pressure	7.5 MPa

4.1.2 Design Specific Capability Now (Large with Turn Down)

This concept provides for a single conditioning loop that operates within the conditions of commercial-off-the-shelf (COTS) technology. As such, high pressure and low temperature will be supplied by the conditioning loop. With only the conditioning loop in operation, the circulators and preheaters can go through start-up and continually run as tests are taken on and off line as shown in Figure 3.

Independent inner branch loops are provided for fractional flow and turn down, high pressure and high temperature SSDT3, and technology development loop testing. As such, piping and valving are not COTS and, as an option, may be provided by the vendors. The branch loops contain control and isolation valves, heater section, cooler, test vessel, and purge/relief lines as shown in Figure 4.

An outer branch loop is provided for fractional to full flow high temperature and high pressure IHX, HYTEST, and CQL1 testing. As such, piping and valving are not COTS, and, as an option, may be provided by the vendors. The branch loops contain control and isolation valves, heater section, cooler, IHX (once established), and purge/relief lines as shown in Figure 5.

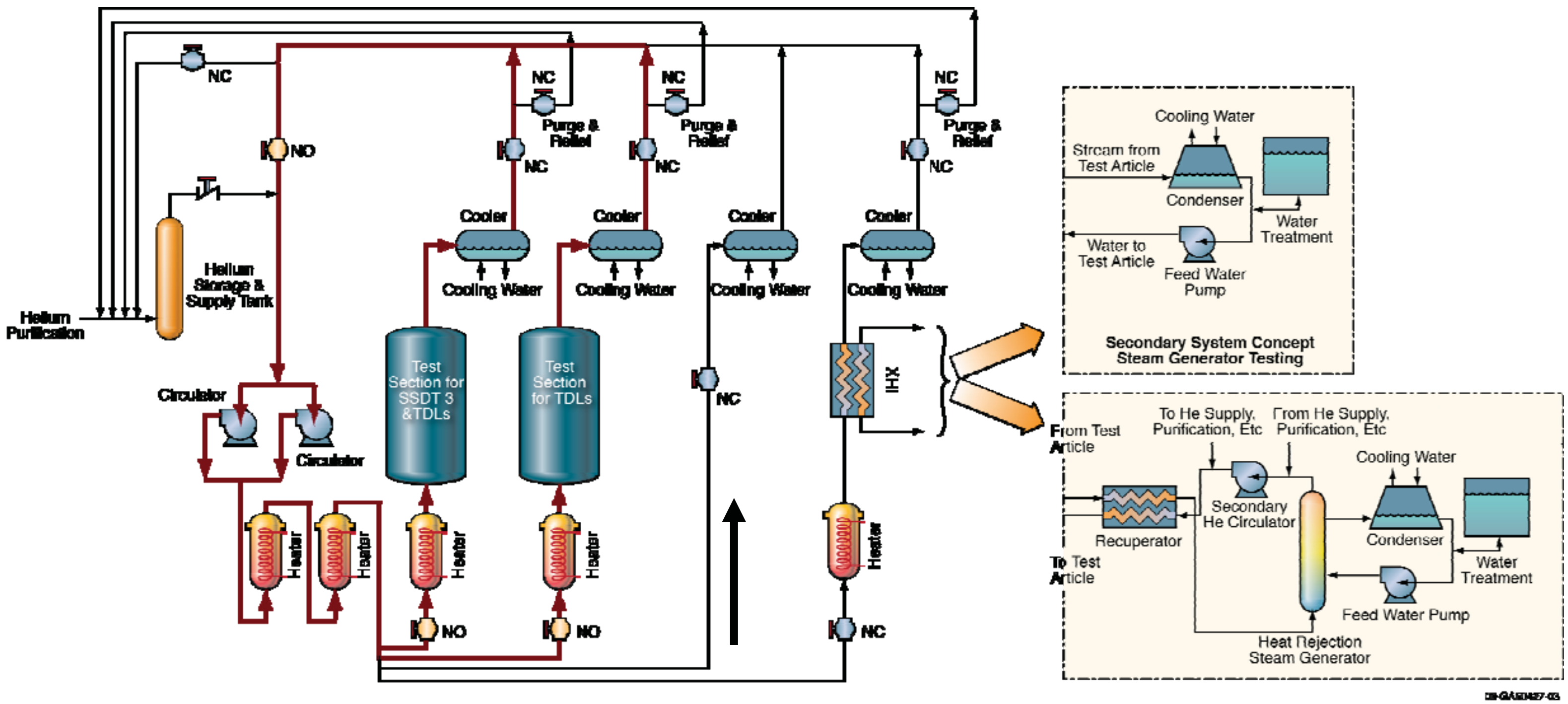

Figure 3. Conditioning/Control Loop Diagram

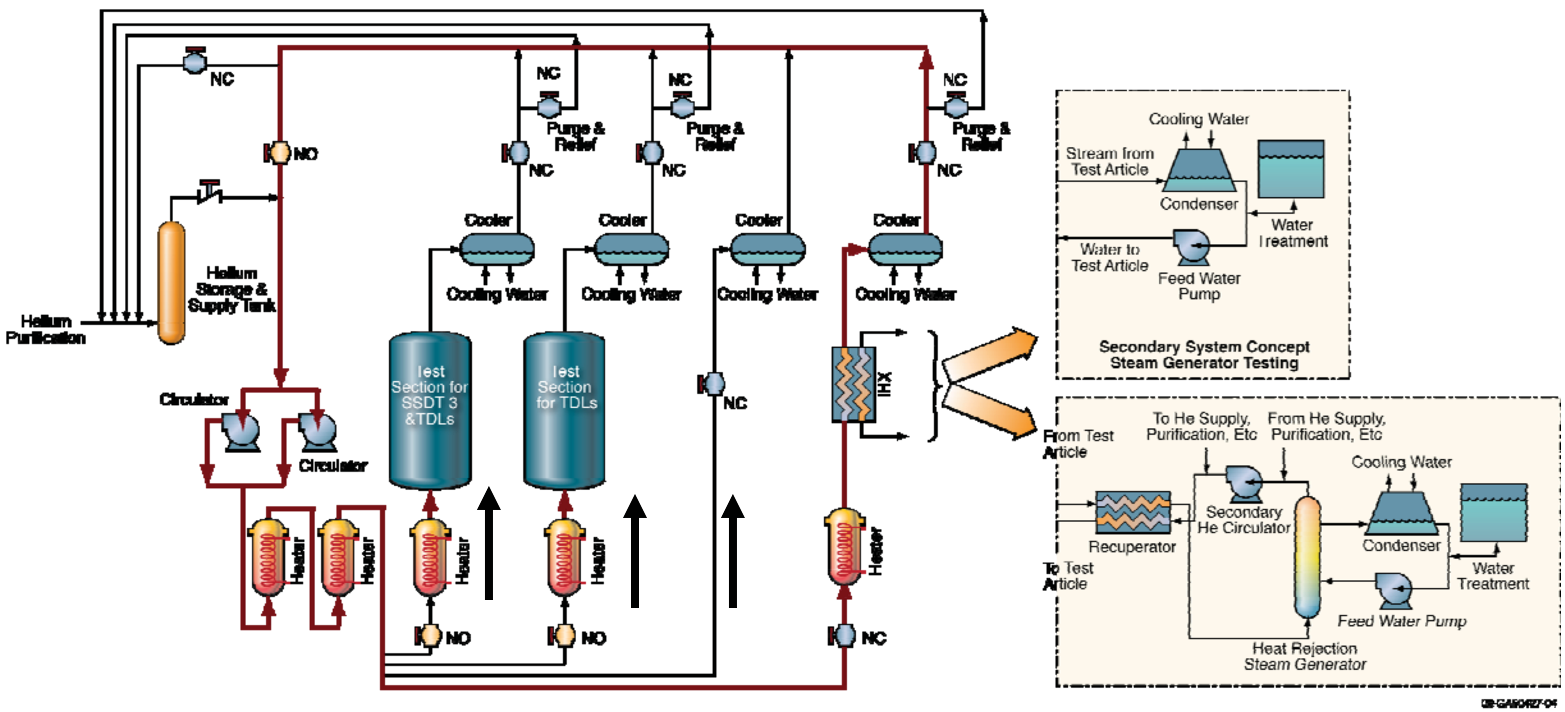

Figure 4. Branch Loop Flow Diagram

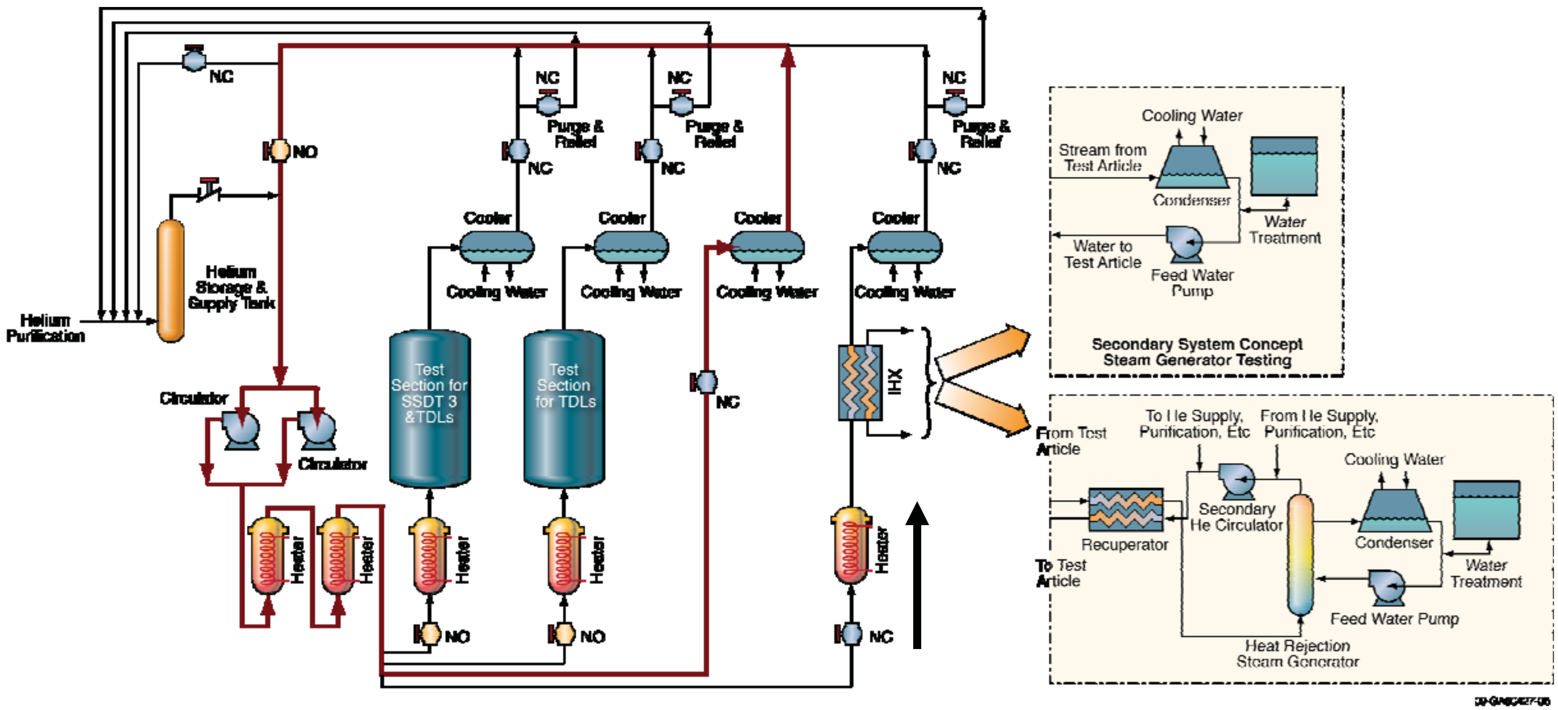

Figure 5. IHX Loop Flow Diagram

4.1.3 Build Multiple Small (2MW) Loops Now and Gang Together

As noted previously, an independent effort is underway to determine the testing schedule and number of test loops that will be required to support it. If the results of that effort indicate that several small loops are required, it may be that the need for the smaller loops will diminish at about the same time as the need for larger loop testing increases. If that is so, combining the smaller loops to provide a larger capacity may be cost effective.

The “large capacity with turn down” solution described previously is one way of providing this capability. Another, which will be the basis for this solution, is to design and build completely independent loops as depicted in Figure 6 combined.

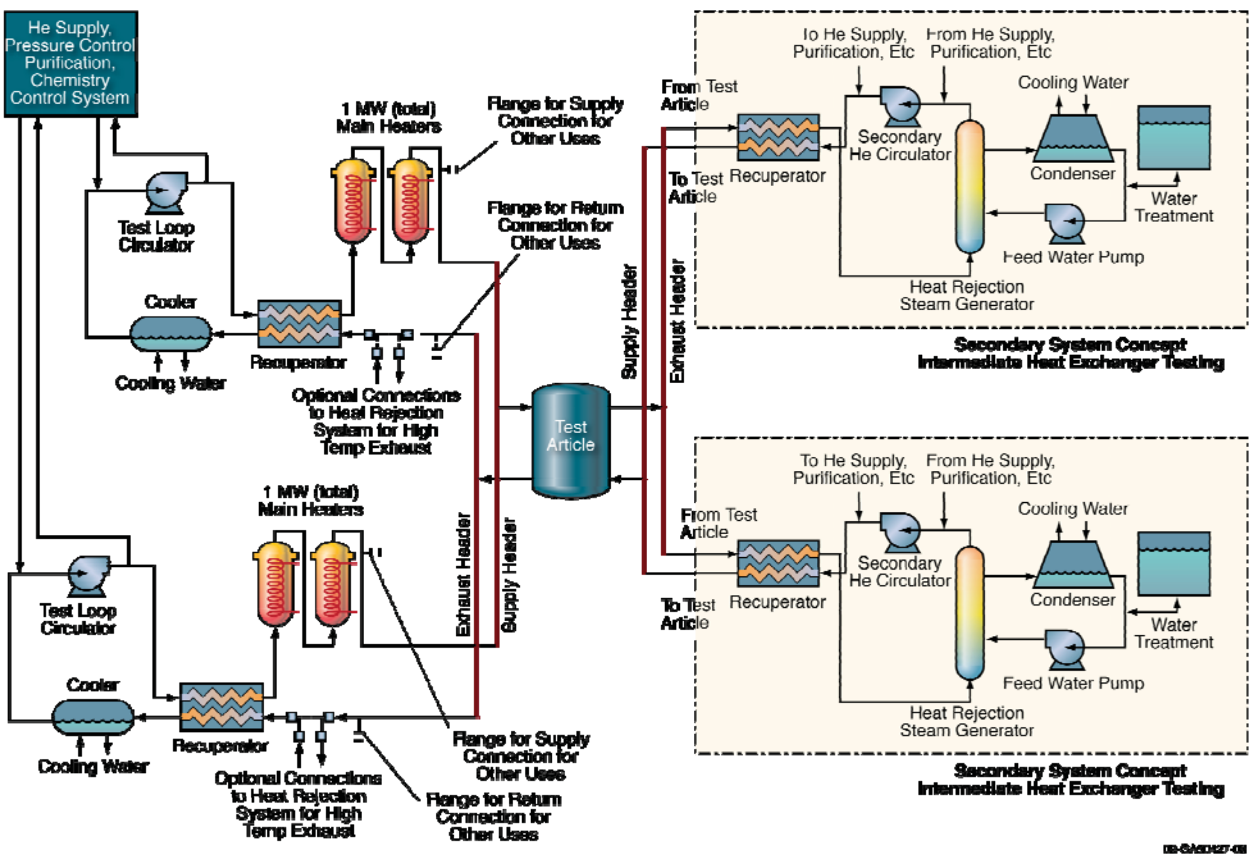

Figure 6. Multiple small loops combined to provide higher heat input.

In this solution, the high temperature helium from the individual loop heaters is combined in a header that can supply a test article that requires a larger helium flow than would be possible from any single loop. Flow returning from the test article would be routed to an exhaust header, which is in turn connected to the multiple primary loops. Flow in each primary loop is controlled by the circulator speed.

The secondary side for the IHX test component is also fairly straightforward, connecting to a secondary exhaust header, which is in turn connected to the secondary circulation loops. The secondary side for the steam generator test component may present more of a problem. Depending on the ultimate heat sink, it may be more difficult to control the flow splits between multiple steam/feed water loops and the multiple secondary loops may have to be replaced with a single larger loop.

4.1.4 Design range of capabilities

The proposed concept shown in Figure 7 is intended to provide NGNP with a component testing capability that starts with an initial 1 MWt helium test loop that can be expanded as needed to provide increased power and flow testing options. The expansion can be for any power and flow increase desired, but the configuration depicted in Figure 7 begins with a primary helium flow loop with a 1-MWt test loop (shown within the dashed box). Each additional test loop progressing from left to right in the figure increases the total power and flow capability of the facility by a factor of approximately two. The total expanded power capability of the facility shown in Figure 7, consisting of the initial 1 MWt test loop and four expansion test loops, is therefore 31 MWt.

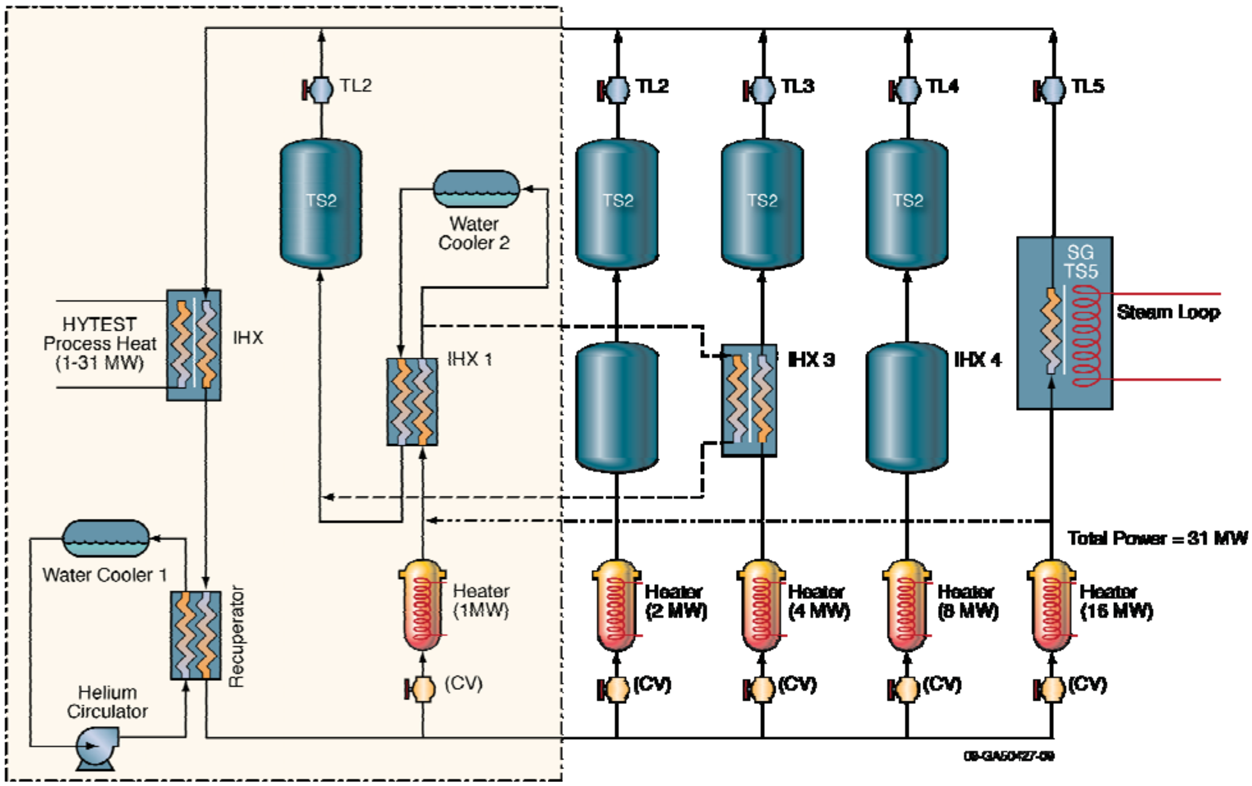

Figure 7. Option for an expandable (1 to 31 MWt) CTC.

The cold side of the loop includes Water Cooler 1, the helium circulator, and the piping feeding the heaters for the 1-MWt loop and each subsequent expansion loop. To minimize material costs and labor associated with subsequent expansions of the loop, the cold side components should probably be sized to accommodate the maximum anticipated power and flow capability of the expanded facility. For the configuration shown in Figure 1, this means that Water Cooler 1, the helium recuperator, the helium circulator, and the piping leading to the individual test loops would be sized for the maximum anticipated power and flow of the expanded system. While the initial cost of the facility will be higher, the overall life-cycle cost of the facility should be lower because this portion of the system will not be replaced during the life of the facility.

The initial 1-MWt test loop (in dashed box) includes a flow control valve, a 1-MWt heater, a test station for testing a helium-to-helium IHX, a high-temperature component test station, and the process heat interface for the HYTEST facility. The flow control valve is used to adjust the helium flow rate to the test loop. Flow from the control valve then passes through the 1-MWt heater that raises the helium temperature to the desired IHX primary side inlet temperature (950°C max.). Heat is transferred from the primary to secondary side of the IHX, resulting in lower temperature helium exiting the IHX primary side. The helium exiting the IHX primary side then passes through Water Cooler 2, where it is further cooled, and then recirculated back to the secondary side inlet of the IHX. This helium passes through the secondary side, where heat from the primary side raises its temperature to the desired secondary side outlet temperature (925°C max.). This configuration eliminates the need for a secondary helium loop, since the same helium is passed through the primary and secondary sides of the IHX.

After exiting the IHX, the helium enters Test Station (TS) TS1, which allows testing of components, structures, and/or materials in a helium environment up to 900°C. Since this test station is not intended for the testing of heat exchanger components, no cooling system or secondary heat removal system is provided. After leaving TS1, the helium is then delivered to the HYTEST interface where process heat at temperatures comparable to those expected in NGNP is provided to processes being tested in the HYTEST facility. Helium exiting the HYTEST facility then passes through a recuperative heat exchanger to recover a portion of the residual heat before the helium passes through Water Cooler 1, which cools the helium to the desired helium circulator inlet temperature. The helium circulator then delivers the helium back through the recuperative heat exchanger, where the recovered heat increases helium temperature before it is returned to the test loop (completing the flow circuit).

As indicated earlier, to expand the basic 1 MWt test loop configuration to allow testing at higher power levels and flows, additional loops can be added as shown in Figure 7. Each additional loop (proceeding from left to right) would approximately double the power capability of the facility. Flow control valves would be provided for each additional loop so that all, or a portion of the total flow, could be delivered to the new loop(s). Figure 7 shows how the loop might be configured when the 4 MWt test loop (TL3) containing IHX3 and Test Station TS3 is added. In this case, the primary side helium flow is delivered to the IHX3 test station at a maximum temperature of 950°C. As indicated by the dashed lines, secondary helium flow to the IHX3 test station is provided by flow from TL1 and/or TL2 in a countercurrent fashion. As indicated in Figure 7, each additional test loop has the same testing capability as the previous loops, but with higher power and flow capability. Test stations in each of the loops could also potentially be operated in parallel, depending on the particular test conditions and flow rates desired at each test station.

The final test loop (TL5) is intended to provide relatively large helium flow and power capabilities for testing of large-scale, full-length steam generators and/or a more traditional helium-to-helium tube and shell IHX design. The loop contains a 16 MWt heater, but by valving five loops together it can provide a total heater power of 31 MWt with corresponding helium flow capabilities. Figure 7 shows TL5 with a water/steam secondary loop for testing of a steam generator. However, this secondary loop could be replaced with a secondary helium loop for large-scale testing of helium-to-helium heat exchangers. A 31 MWt test loop capability should be sufficient for large-scale testing of steam generators and/or helium-to-helium heat exchangers since it will allow testing of 5–10% of the tubes in the steam generator or IHX bundle at full length.

Although detailed analyses of this proposed expandable CTC option have not been performed, Table 1 below approximates the expected operating conditions around the system. Future analyses to determine component heat loads and operating conditions, piping heat losses, and system pressure losses will help to more accurately quantify the values in the table.

As noted earlier, as additional loops are added, the option exists to “gang” heaters and flow loops together for larger component testing and/or to operate loops in parallel for long-term testing of components and/or materials. As the system expands, the HYTEST process heat interface is maintained so that capability will exist for the life of the facility and grows as the number of helium flow loops and heater power is increased.

Table 3. Estimate of expected fluid conditions in expandable Component Test Capability option.

Operating Conditions	1 MWt TL (TL1)	2 MWt TL (TL2)	4 MWt TL (TL3)	8 MWt TL (TL4)	16 MWt TL (TL5)
Heater Power in MW	1	2	4	8	16
Test Loop max. pressure in MPa	7.0	7.0	7.0	7.0	7.0
Helium flow, (primary) in kg/s	0.5	1.0	2.0	4.0	8.0
Helium flow (secondary) in kg/s	0.5	0.5	1.5	3.5	7.5
IHX max. inlet temperature in °C	950	950	950	950	950
Test Station max. Inlet temperature in °C	900	900	900	900	N/A
HYTEST max. inlet temperature in °C	850	850	850	850	850
Circulator max. inlet temperature in °C	150	150	150	150	150
Circulator inlet pressure in MPa	2.6	2.6	2.6	2.6	2.6

4.1.5 Circulator Test Loop

A capability to provide a full size test loop(s) for the primary reactor coolant circulators, shut down system circulators, and other helium circulators will also be required to verify hydraulic designs and test bearings, seals, and other components. This loop(s) is simpler than the thermal loops discussed previously in that these circulators are located in the cooler portions of the primary coolant system, operating at temperatures in the range of 400°C. The proposed circulator test loop could be designed without a heater because the gas compression heat can be used to bring the entire loop to the circulator operating temperature. However, operating conditions could be reached more quickly with the addition of a heater. The loop, as shown in Figure 8, is adequate for relatively steady-state testing conditions. If rapid thermal transients at the circulator inlet are required, additional piping and control systems will be required (dashed lines). A high temperature source (possibly a large mass of high temperature sintered metal), control valves, and a mixing chamber would be one way of providing temperature transients. As the test requirement matures, the capability can be added to the circulator test loop.

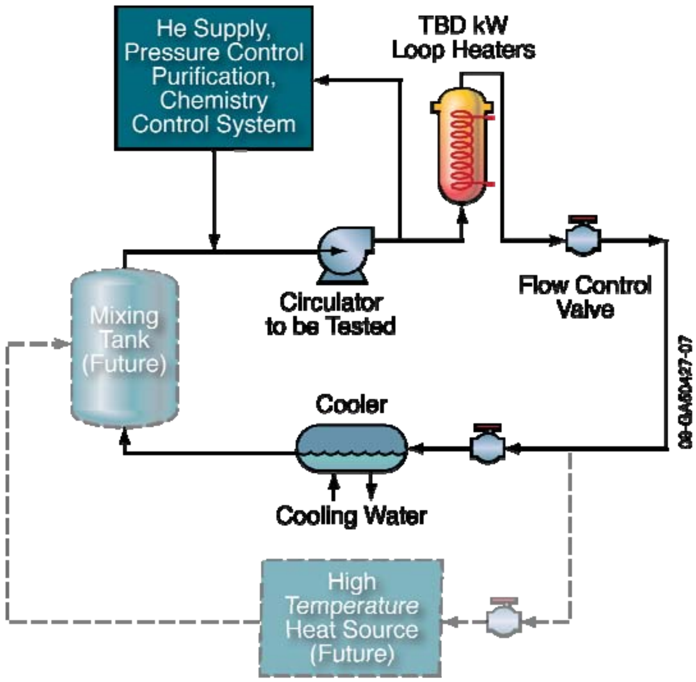

Figure 8. Circulator test loop concept.

4.1.6 Build Near-Term Capability Now, Add More or Larger Capability Later

This solution addresses acquisition strategy for multiple loops rather than technical capabilities of those loops and could be applied to several of the options discussed above. Simply put, deferring costs of test loops that are not needed immediately until a later time provides a “time value of money” advantage. The flow sheets for this solution are the same as discussed previously. The acquisition strategy, however, involves designing the building and infrastructure (building envelope, cranes, electrical power and other utilities) for the future capacities but only procuring and installing the “high dollar” test equipment and piping as needed to support the technology development schedule. This approach could defer the cost of the large, expensive systems for some time and allow requirements to be developed in more detail as the design progresses.

4.2 Detailed Evaluation

4.2.1 Advantages

4.2.1.1 Design Specific Capability Now (Small and Large)

- Large and small components can be tested in parallel.
- The large loop is built at the earliest possible time and will be available to support testing as needed.

4.2.1.2 Design Specific Capability Now (Large with Turn Down)

- Since the majority of the piping is COTS design, construction can occur when required.
- Cost estimates for piping, valves, circulators, coolers, and heaters are known.
- Although the pipe diameter is larger for the low temperature/high pressure piping, less total piping, valving, and controls are used relative to multiple loops making them less expensive.
- Less control algorithms relative to multiple loops.
- Maintenance and failure rates are better understood and known to help with downtime and risk analysis.

4.2.1.3 Build Multiple Small (2 MW) Loops Now and Gang Together

If multiple smaller loops are required to support the testing schedule, it may be cost effective to utilizing several of the smaller loops to provide larger capacity testing as smaller capacity testing is completed.

4.2.1.4 Design Range of Capabilities (1, 3, 10, and 30 MW)

- Basic design employs a relatively simple single-loop design for testing both IHX and non heat-exchanger-component and materials.
- A building block approach is used to allow the testing capability to be expanded as needed.
- Each building block approximately doubles the testing capability (IHX and Test Station) of the preceding loops.

- Basic loop design, including circulator, coolers, and recuperative heat exchangers, are sized for maximum expected power and flow requirements so that expansion (addition of loops) is relatively straightforward.

- The design incorporates an interface to provide HYTEST process heat that can be expanded over time.

- As loops are added, individual loops can be ganged together to maximize test loop flow and power capability, or operated separately in parallel for smaller long-term testing needs.

- High-temperature heaters at increased power levels can be added over time to allow development of heater technology.

4.2.1.5 Build Near-Term Capability Now, Add More or Larger Capability Later

The advantages of this solution (more properly, this acquisition strategy) are:

- The small test loops can be deployed earlier

- Design of the large loop can be delayed until additional requirements can be defined

- The cost of the large loop designs and construction can be delayed to some extent.

4.2.2 Disadvantages

4.2.2.1 Design Specific Capability Now (Small and Large)

- The design of the loops must be fixed before all the test requirements can be defined. The design of the CTC will have to be performed in parallel with (if not ahead of) the design of the reactor.

- Relative to the time value of money, the large loop will be a large capital investment that may not be utilized immediately, depending on the schedule for preliminary smaller-scale testing and development of the larger components. Money spent on a large idle system cannot be used to support other tasks needed now.

- The selection of small and large loops somewhat limits the ability to test intermediate conditions (e.g., 10 MW) with the available turn-down of the 30 MW test loop.

4.2.2.2 Design Specific Capability Now (Large With Turn Down)

- Larger pipe diameters will be required as opposed to multiple loops. This low temperature/high pressure pipe has existing dimensional and material standards.

4.2.2.3 Build Multiple Small (2 MW) Loops Now and Gang Together

- This is an inefficient way to provide large loop test capability because it will require more space and more equipment than one single dedicated loop.
- Even if the economics are viable, the control issues associated with balancing a number of loops in parallel may be significant, especially on the secondary side of the steam generator tests.
- Multiple small loops may be somewhat more expensive than a single larger circulator.

4.2.2.4 Design Range of Capabilities (1, 3, 10, and 30 MW)

- Initial design will be more expensive because major components are sized for maximum expected power and flow requirements.
- The design includes a number of control valves and associated piping that must be designed for high temperatures (950°C) downstream of the heaters.
- The number of control valves and complexity of the control systems will increase as the design expands.

4.2.2.5 Build Near-Term Capability Now, Add More or Larger Capability Later

The project schedule may be so compressed that procurement of the expensive long lead items (e.g., the heaters) may have to start essentially immediately, which means that the costs of these components cannot be delayed.

5. RECOMMENDATION

As noted previously, it is not the intent of this report to select a one of the solutions discussed above as the optimum one. Rather, this study is intended to serve to evaluate possible concepts, identify issues and concerns to be addressed in subsequent design efforts, and stimulate development of requirements.

Nonetheless, a summary of the advantages and disadvantages of the flow loop concepts is provided below in Table 4. The criteria were mainly selected to evaluate technical performance because the solutions have not been developed to the point that meaningful cost estimates could be performed, although a very qualitative cost criterion is included. Overall ratings were also qualitatively assigned but it should be understood that much more work is needed before selecting the optimum solution.

As this study proceeded, it became clear that the complete set of requirements for testing of the NGNP SSCs is not yet defined and it is certain that additional needs for component test capability will be identified as the designs of the reactors and heat transport systems are developed. The design of the CTC should emphasize flexibility and provide ample space and utilities to allow expansion and modification of the capability to accommodate emerging testing needs.

Table 4. Summary of evaluation of test loop solutions.

Criteria	Design Specific Capability (1, 30 MW) Now	Design Specific Capability (Large with Turn Down)	Build Multiple Small Loops and Gang Together	Design Range of Capabilities
Capacity: The ability of the proposed solution to provide a wide range of flow and temperature capacities to meet the testing needs	Medium. Provides 1 and 30 MW, but limited capacity between	High. Provides range between 1 and 30 MW	Low. Large test capability (~30 MW) is not feasible	High. Provides a range of flowrates between 1 and 31 MW
Flexibility: The ability of the proposed solution to test a number of different test articles at one time	High. Given the optimized number of 1 MW loops, this concept should provide the necessary flexibility	High. Combination of turn down and bypass will allow several loops to be operated in parallel.	High. The number of small loops can be selected based on test program requirements.	Low. Does not provide capability for multiple tests at the same or similar power levels.
Feasibility: The ability of the proposed concept to perform as intended.	High. Control concepts are relatively simple, high temperature components are minimized	Medium. Combination of turn-down and bypass should be easier to control that multiple circulators. However, it will require a valve operating in the high temperature flow.	High for individual tests. Control concepts simple, high temperature components minimized. Low for ganged configuration. Large number of parallel loops will lead to complexity in piping and controls	Low. A single circulator may not be able to support the wide range of flow rates. Interconnecting a number of different size loops will lead to complexity in piping and controls
Adaptability: The ability of the proposed solution to accommodate new or changed testing requirements	Low. The flow capacity for this concept is essentially either small or large.	Medium. Circulator and some other components will have to be procured early and maximum capability will be set.	Medium. Small loops could be combined or replaced with less cost impact.	Medium. The various loops can be combined to provide a single test capability but the piping re-configuration may be complex.
Cost Effectiveness: The ability of the proposed concept to provide the needed capability with the minimum cost over time	Low. Essentially all capital outlays are incurred early and high heat input test capability is not needed until later.	Low. Operating costs will be more expensive because of high flows. Initial capital cost will be higher because circulator and some other components have to be sized for maximum flow.	Medium. Initial Capital outlays can be low.	Low. Capital costs will be high because the wide range of capabilities also requires a lot of equipment. Piping arrangements to provide combined flows will be complex, in the high temperature sections.
Overall Assessment	**Medium**	**High**	**Medium-low**	**Low**

6. FUTURE WORK

Addition requirements are needed to define the maximum heat input and flow capacity that will be required for any test.

Areas needing additional design development include:

- Investigation of heat rejection from the secondary side. Options in addition to those shown could include once-through air or helium to pressurized water.
- Design of the heat rejection system for hot gas ducting or other test articles that have high outlet temperatures. Options may include designing the recuperator for a wider range of inlet temperatures or, given a fixed recuperator inlet temperature, pressurized water coolers or additional steam generators to remove some of the heat.
- A concept for testing intermediate heat exchangers that uses the primary coolant on both sides of the heat exchanger as discussed in small scale development Test 3 for the IHX concept (CTF_WEC 2009) should be investigated.
- For the multiple loops and gang together solution, perform more detailed analysis to assure that the primary loops and secondary loops can be operated in parallel.
- Late in the development of this study, the concept of grouping tests as low flow, low heat input, high flow, low heat input, and high flow, high heat input, was identified. The loop designs in the next phase should address the design of a high flow, low heat input loop in more detail.

A number of value engineering efforts could be performed to address items like multiple small loops vs. one large loop. Things to be considered in this study would be capital costs of several smaller loops vs. one larger circulator with a number of outlet branches, optimization of number of loops with testing schedule, etc. The eventual large loop capacity will also impact these studies. It may be more effective to design the “small” loops with somewhat larger capacity (say 5 MW) even though only a 1 to 2 MW capacity is needed initially so that the number of combined loops is minimized. Combining four 5 MW loops in parallel to provide a 20 MW capacity would be more feasible than combining ten 2 MW loops.

7. IMPLEMENTATION, SCHEDULE, AND COST

Not applicable.

8. CONCLUSIONS

The selection of the optimum solution from the options discussed in this report cannot be made until more information is available. However, it does seem reasonable to conclude that the strategy for providing the CTC should be one allows for starting small to gain these insights early and to use or capitalize on the knowledge gained to take the next bigger step. Each bigger step has to have the benefit of the flexibility to adapt to the insights gained in the previous steps.

In addition, this study has been valuable in that items for additional study have been identified.

9. REFERENCES

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10. APPENDIXES

None