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TRL Advancement through the use of Heat Transport Small Scale Testing (HTSST)

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ABBREVIATIONS AND ACRONYMS

Abbreviation or Acronym	Definition
ASME	American Society of Mechanical Engineers
BEA	Battelle Energy Alliance
C	Carbon
CH_4	Methane
CIRC	Circulator
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CTC	Component Test Capability
CTF	Component Test Facility
DDN	Design Data Need
dP	Delta Pressure
ECC	Engineering, Commissioning and Construction
EMB	Electromagnetic Bearing
H_2	Hydrogen
HPAS	Hydrogen Plant Alternative Study
HTGR	High Temperature Gas-Cooled Reactor
HTS	Heat Transport System
HTSST	Heat Transport Small Scale Testing
HX	Heat Exchanger
IHX	Intermediate Heat Exchangers
kg/s	Kilogram per second
kPa	Kilopascal
LAB	Laboratory
m	meter
mm	millimeter
MC	Mixing Chamber
MHTGR	Modular High Temperature Gas-Cooled Reactor
MPa	Megapascal
MW	Megawatt
MWt	Megawatt thermal
N	No
NGNP	Next Generation Nuclear Reactor
OD	Outer Diameter
PCDR	Preconceptual Design Report
PCS	Power Conversion System
PFHE	Plate Fin Heat Exchanger

Abbreviation or Acronym	Definition
PIP	Piping
PHTS	Primary Heat Transport System
Ref.	Reference
ROT	Reactor Outlet Temperature
SG	Steam Generator
SHTS	Secondary Heat Transport System
SOW	Statement of Work
SSCs	Systems, Structures and Components
SSDT	Small-Scale Development Tests
TBD	To Be Determined
TDL	Technology Development Loop
TDRM	Technology Development Roadmapping
TRL	Technology Readiness Level
TS	Test Specification
UUT	Unit Under Test
WEC	Westinghouse Electric Company
Y	Yes

1. SCOPE

1.1 Introduction

The aim of this document is to provide a brief review of the test specifications that were developed as part of both the Reactor Outlet Temperature (ROT) of 950°C [1-1] and the ROT of 750°C-800°C [1-2] Technology Development Roadmapping (TDRM) reports with the focus on applicability thereof in a Heat Transport Small Scale Testing (HTSST) capability. Most of the 950°C TDRM test specifications were originally used as input for the Component Test Facility (CTF – now known as the Component Test Capability (CTC)) Preconceptual design [1-3] and were accordingly allocated to certain envisaged test facilities. However, this document will briefly revisit all specifications (both 950°C and 750°C-800°C Development Paths) to determine which could be included in the scope of an HTSST.

The need for a Heat Transport Small Scale Test (HTSST) surfaced from the CTC Preconceptual Design that addressed the CTC Mission Need. The HTSST loop will be used to facilitate High Temperature Reactor (HTR) heat transfer technology development as a forerunner to larger-scale heat transfer testing loops.

The HTSST can generally be defined as the capability of a conglomerate of test loops and setups that will enable TRL advancement of Next Generation Nuclear Plant (NGNP) heat transfer components. The capability will entail functions that are identified in the test specifications from the TDRM process and are typically NGNP environmentally related such as high temperature and pressure in a helium environment.

The capability would include both static and flow test setups or loops. The static test setups will be similar to materials or metallurgical laboratory configurations in which, for example, a number of material specimens (or coupons) can be tested, including corrosion and fatigue testing.

Different Small-Scale Development Tests (SSDTs) are proposed to operate within the HTSST, i.e. static testing with NGNP representative environments without helium mass flow and testing where helium mass flow is required within the same NGNP representative environments. At writing, static tests will be handled by equipment equivalent to the proposed SSDT1 and SSDT2 whereas loop tests will be handled by equipment equivalent to the proposed SSDT3 [1-3]. All SSDTs make out modularized systems of the HTSST as schematically presented in Figure 1.

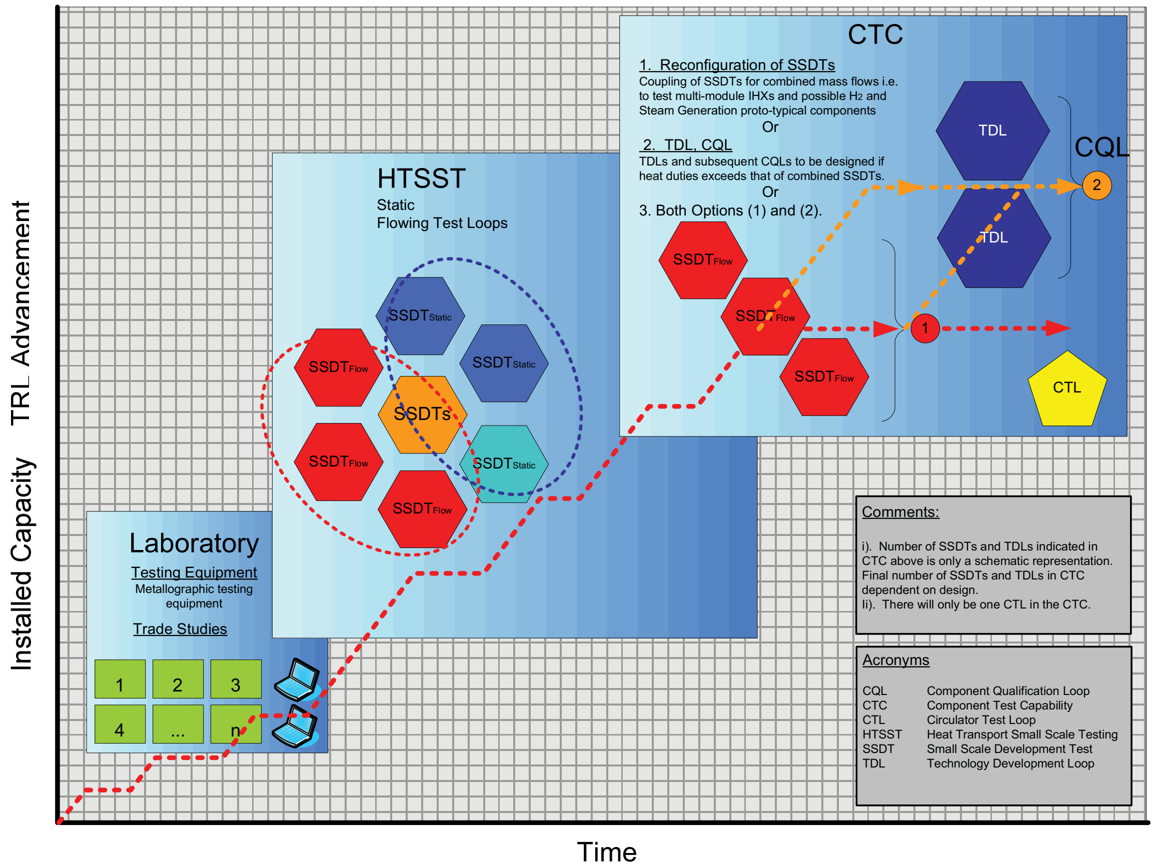

Figure 1: Schematic showing envisaged growth path of HTSST

1.2 Document Overview

The core of this document mainly comprises tables in which both the 950°C [1-1] and the 750°C-800°C [1-2] TDRM test specifications have been evaluated with regards to the applicability thereof in an HTSST. In addition to this review, pie charts are given which illustrate HTSST testability of each of the Systems, Structures and Components (SSCs). A brief overview of the schedule-related issues pertaining to such a testing capability follows, while the final conclusion provides some general advantages and disadvantages associated with such a capability.

2. TEST SPECIFICATIONS REVIEW

2.1 Background

The TDRM process that was conducted by the Westinghouse Electric Company (WEC) NGNP team for a ROT of 950 ºC [1-6] resulted in the identification of numerous critical Systems, Structures and Components (SSCs) and their current Technology Readiness Levels (TRLs). In a follow-up step, similar identification of critical Systems, Structures and Components (SSCs) and their current Technology Readiness Levels (TRLs) regarding the 750°C – 800°C NGNP ROT were determined. The SSCs together with their TRL rating are summarized in Table 1.

Table 1: SCC current TRL rating

SSC	950°C ROT NGNP TRL	750°C – 800°C ROT NGNP TRL
PHTS Circulator	6	6
IHXA Metallic	2	Not Required
IHXA Ceramic	2	Not Required
IHXB (950°C)	3	Not Required
IHX (750°C – 800°C)	Not Required	3
HTS Piping	4	4
SHTS Flow Mixing Chamber	6	Not Required
Hydrogen Production System (Hybrid Sulfur)	2	Not Required
Power Conversion System Steam Generator	6	6
Fuel Elements	6	7
Core Structure Ceramics (Graphite)	6	6
Reserve Shutdown System	6	6
Reactivity Control System	6	6
Core Conditioning System	6	6
Reactor Cavity Cooling System	6	6
Fuel Handling and Storage System	6	5

From these exercises, it was found that the heat transfer components, with specific focus on the Intermediate Heat Exchangers (IHXs) and Heat Transport System (HTS) Piping, had the lowest TRL ratings. These low TRL ratings (2 - 4) were mainly associated with material properties- and behavior-types of tests. These types of tests are generally accepted to be either laboratory scale or very small scale tests, as indicated in Table 3 to Table 12, where applicable. Some of these low TRL advancement tests could still be incorporated into the scope of an HTSST.

Heat exchanging element tests would see the advancement of the TRLs (up to Level 4) with subsequent IHX modules (made up from several HX elements) to be tested thereafter. Testing of the IHX modules in a small scale heat transport test-loop would advance the TRL rating to 6.

2.2 Review of HTS Test Specifications

In order to establish a scope for the high temperature HTSST, a review of all test specifications from both the 750°C – 800°C and 950°C TRL advancement evaluations has been conducted. The results are given in Table 3 to Table 12, which are organized by SSC. For each test, the tables provide an indication of whether it is appropriate to include the test as part of the scope of the proposed HTSST. The columns' headings of these tables are extracted from the Statement of Work (SOW) [1-4] and are defined in Table 2.

Table 2: Description of Headings of Table 3 through Table 12

Table column heading	Description
Component	Critical System, Structure or Component (SSC).
Test Description	Description of the test as identified during the Technology Development Roadmapping (TDRM) exercise.
Test Specification or DDN Number	The specific test number that was assigned to the tests during the TDRM exercise.
TRL Goal	The technology readiness level (TRL) at which the SSC will be after the tests (in the previous column) have been completed.
750ºC / 950ºC	Applicability of the test specifications to the different reactor outlet temperature configurations.
Environment	Indicates whether the test must be performed in a helium, air or other environment.
Static / Flowing	Indicates whether the tests must be performed in a static environment where no flow of process gas is required or otherwise.
Approx. Physical Size	Indicates the approximate physical size of the test setup where possible and applicable.
Approx. Thermal Size	Indicates the approximate thermal size of the test setup where possible and applicable. The thermal heat duty of an HTSST loop is required to be less than 2 MW.
Process Conditions	Indicates what typical temperatures, pressures and flow rates should be for performing the test where applicable and possible.
HTSST	Indicates whether the test is suitable to be performed in the HTSST or not.
LAB	Indicates whether the test is suitable to be performed in a laboratory-type setup within the HTSST or in dedicated laboratories (i.e. metallurgical laboratories) outside of the HTSST environment. These would be typically static type tests.
Comments / Limitations	Comments on the decisions that were taken in determining the contents of the previous table columns.

Table 3: HTSST and Laboratory Scale Testing Applicability of Circulator Test Specifications

Component	Test Description	Test Specification or DDN Number	TRL Goal	750°C/ 950°C	Environment	Static / Flowing	Approx. Physical Size	Approx. Thermal Size	Process Conditions	HTSST	LAB	Comments / Limitations
Circulator	EMBs, Catcher Bearings Tests	WEC-TS-CIRC-001	7	950°C 750°C	Helium, TBD	Static	TBD	< 2 MW	TBD	N	Y	HTSST considered too small for environmental testing of submerged EMB components. Would also not be applicable to rotating tests.
Circulator	Helium Rotating Seals Tests	WEC-TS-CIRC-002	7	950°C 750°C	Helium	Flowing	TBD	< 2 MW	TBD	N	N	Rotating seals (presumably dry gas seals would be considered as an alternate to submerged motors with EMBs. Does not require a loop. Not anticipated for the HTSST.
Circulator	Partial or Full-Scale Circulator Model Tests	WEC-TS-CIRC-003	7	950°C 750°C	Air/Nitrogen and other	Flowing	TBD	> 2 MW	TBD	N	N	Exceeds anticipated capacity of HTSST. Would be tested in upgraded HTSST or CTC.
Circulator	Prototype Circulator Tests	WEC-TS-CIRC-004	8	950°C 750°C	Helium	Flowing	TBD	> 2 MW	TBD	N	N	Exceeds anticipated capacity of HTSST. Would be tested in upgraded HTSST or CTC.

None of the circulator test specifications form part of the testing scope for HTSST.

Table 4: HTSST and Laboratory Scale Testing Applicability of IHXA Metallic Test Specifications

Component	Test Description	Test Specification or DDN Number	TRL Goal	Temp.	Environment	Static / Flowing	Approx. Physical Size	Approx. Thermal Size	Process Conditions	HTSST	LAB	Comments / Limitations
IHXA Metallic	Alloy 617 Material Specification and Procurement	WEC-TS-IHXA-001	3	950°C	N/A	N/A	N/A	N/A	N/A	N	N	No testing.
IHXA Metallic	Alloy 617 Joining Technology and Resultant Properties	WEC-TS-IHXA-002	3	950°C	TBD	Static	TBD	TBD	Temperatures up to 1000°C	N	Y	This specification relates to development of processes for welding, brazing and/or diffusion bonding. Testing can be done at the supplier or in a metallurgical laboratory.
IHXA Metallic	Thermal / Physical and Mechanical Properties of Alloy 617	WEC-TS-IHXA-003	3	950°C	TBD	Static	TBD	TBD	Temperatures up to 1000°C	N	Y	This specification relates to characterization of material properties. Testing can be done in a metallurgical laboratory.
IHXA Metallic	Effects of thermal Aging and Environment on Alloy 617	WEC-TS-IHXA-004	3	950°C	Helium	Static	TBD	TBD	Temperatures 700°C to 1000°C	Y	Y	This specification relates first to aging of materials samples in a controlled chemistry environment and then conducting tests to characterize changes in materials properties. The aging step could be done in the HTSST if an environmental testing capability is included.
IHXA Metallic	Effects of Grain Size and Selection Thickness on Alloy 617 Properties	WEC-TS-IHXA-005	3	950°C	N/A	Static	TBD	TBD	Temperatures up to 1000°C	N	Y	This specification relates to characterization of properties of materials with different grain sizes. Testing can be done in a metallurgical laboratory.
IHXA Metallic	Corrosion Allowances for Alloy 617	WEC-TS-IHXA-006	3	950°C	Helium	Static*	TBD	TBD	Temperatures 700°C to 1000°C at 9MPa with Controlled Impurities	Y	Y	This is basically a long-term environmental test with controlled impurities. In it's most basic form, it can just be thin material samples in a lab environment. Exposure of samples to the helium environment could be done in the HTSST if an environmental testing capability is included. In addition to what is implied in the Test Specification, it may be worthile to expose basic IHX assemblies (e.g., unit cell for PFHE) to the HTGR environment to see if there are any interactions related to joining transitions. In this latter case, the HTSST may be considered. *Also, a procedure is to be established for preserving ALL components used in the test loops, to be available for analysis. All components to be weighed before and after testing to determine mass loss. Corrosion allowance testing could be done in conjunction with other tests.
IHXA Metallic	ASME Selection III Code Case for Alloy 617	WEC-TS-IHXA-007	4	950°C	N/A	N/A	N/A	N/A		N	N	No test facility or equipment is needed.
IHXA Metallic	Thermal / Fluid Modeling Methods for Metallic IHX A	WEC-TS-IHXA-008	4	950°C	Helium	TBD	TBD	TBD	TBD	Y	N	Results of HTSST tests as described below for WEC-TS-IHXA-013 could be used to validate resulting models.
IHXA Metallic	Methods for Stress / Strain Modeling of Metallic IHX A	WEC-TS-IHXA-009	4	950°C	N/A	N/A	N/A	N/A	N/A	N	N	No test facility or equipment is needed.
IHXA Metallic	Criteria for Structural Integrity of IHX A	WEC-TS-IHXA-010	4	950°C	N/A	N/A	N/A	N/A	N/A	N	N	No test facility or equipment is needed.
IHXA Metallic	Performance Modeling Methods for IHX A	WEC-TS-IHXA-011	4	950°C	Helium	TBD	TBD	TBD	TBD	Y	N	Results of HTSST tests as described below for WEC-TS-IHXA-013 could be used to validate resulting models.
IHXA Metallic	Testing of Heat Exchanger Element	WEC-TS-IHXA-012	See breakdown below									"Heat Exchanger Element" is the compact HX functional equivalent of a 1-tube shell & tube heat exchanger with manifolds. For the Plate-Fin HX addressed in the IHX report, the "Unit Cell" would be an example.
IHXA Metallic	Joint Integrity (Diffusion Bonding)	WEC-TS-IHXA-012_1	5	950°C	Helium	Static	TBD	< 2 MW	Temperatures up to 950°C; Pressures up to 9MPa	Y	Y	All components used in test setups to be retained for post-operating analysis.

Table 4: (Continued)

Component	Test Description	Test Specification or DDN Number	TRL Goal	Temp.	Environment	Static / Flowing	Approx. Physical Size	Approx. Thermal Size	Process Conditions	HTSST	LAB	Comments / Limitations
IHXA Metallic	Joint Integrity (Brazing)	WEC-TS-IHXA-012_1	5	950°C	Helium	Static	TBD	< 2 MW	Temperatures up to 950°C; Pressures up to 9MPa	Y	Y	All components used in test setups to be retained for post-operating analysis.
IHXA Metallic	Creep Lifetime Tests	WEC-TS-IHXA-012_2	5	950°C	Helium	Static	TBD	< 2 MW	Temperatures up to 950°C; Pressures up to 9MPa	Y	Y	All components to be tested to be analysed before and after tests to detect creep.
IHXA Metallic	Fatigue Life Test	WEC-TS-IHXA-012_3	5	950°C	Helium	Static	TBD	< 2MW	Temperatures up to 950°C; Pressures up to 9MPa	Y	Y	All components used in test setups to be retained for post-operating analysis.
IHXA Metallic	Testing of Integrated Compact Heat Exchanger Module (~1.2MW). **1. Steady State Tests** Test compact heat exchanger module operating effectiveness and behavior in typical steady state pressure, temperature and temperature / pressure drop environment (Helium). **2. Transient Tests (Normal Operation)** Simulate selected normal operation duty cycle events (e.g., startup / shutdown). **3. Transient Tests (Licensing Basis Events)** Simulate selected off-normal events (e.g., loss of secondary pressure).	WEC-TS-IHXA-013	6	950°C	Helium	Flowing	TBD	< 2MW	Temperatures up to 950°C; Pressures up to 9MPa Temperature delta of ~ 250°C Pressure delta of ~ 500 to 600 kPa sustained (Primary to Secondary) Mass flow of 1.2 kg/s (As per CTF PCDR) He environment with varied composition	Y	N	Similation of transient events limited by characteristics of HTSST, e.g., limited ability to impose high pressure differentials in experiments with helium flow. However, a combination of flowing and static tests can simulate or envelope other events, such as loss of secondary pressure with one side of the IHX test article isolated. Specific tests, other than steady state and corresponding test parameters are TBD.
IHXA Metallic	Establishing ASME III Code Cases for Metallic Compact Heat Exchanger Designs	WEC-TS-IHXA-014	6	950°C	Helium	Flowing	TBD	TBD	Temperatures up to 950°C; Pressures up to 9MPa	TBD	TBD	Specific requirements for testing in support of code case validation are TBD. Tests may help in establishing code requirements, but details are not presently known.
IHXA Metallic	Shell-Side Flow Distribution and Bypass Leakage Testing	WEC-TS-IHXA-015	7	Ambient to 950°C	Air / Helium	Flowing	TBD	< 2MW	Details TBD. Likely to be ambient temperature, pressure	Y	Y	Potential to characterize shell-side bypass at the module level in a test setup without heating. Should be compared with other ambient temperature and pressure testing options (e.g., plexiglas enclosures for improved visualization).
IHXA Metallic	Multi-Module (3 x 1.2 MW) Heat Transfer Testing	WEC-TS-IHXA-016	7	950°C	Helium	Flowing	TBD	> 2MW	Details TBD.	N	N	Exceeds anticipated capacity of HTSST. Would be tested in upgraded HTSST or CTC. Investigate module-to-module interactions on both the tube- and shell-sides of the heat exchanger. Confirm bypass leakage and effects.
IHXA Metallic	Testing of Full Size Compact Heat Exchanger (Full-Scale NGNP IHX A)	WEC-TS-IHXA-017	8	950°C	Helium	Flowing	TBD	> 2MW	Temperature varying up to 950°C; Pressure varying up to 9MPa	N	N	Investigate module-to-module interactions on both the tube- and shell-sides of the heat exchanger.

Table 5: HTSST and Laboratory Scale Testing Applicability of IHXA Ceramic Test Specifications

Component	Test Description	Test Specification or DDN Number	TRL Goal	Temp.	Environment	Static / Flowing	Approx. Physical Size	Approx. Thermal Size	Process Conditions	HTSST	LAB	Comments / Limitations
IHXA Ceramic	Trade Study on Candidate Ceramic Material for IHX A	WEC-TS-IHXA-018	3	950°C	N/A	N/A	N/A	N/A	N/A	N	N	No testing.
IHXA Ceramic	Trade Study on Candidate Ceramic Designs for IHX A	WEC-TS-IHXA-019	3	950°C	N/A	N/A	N/A	N/A	N/A	N	N	No testing.
IHXA Ceramic	Ceramic HX Detailed Design Data Needs (DDNs)	WEC-TS-IHXA-020	4	950°C	N/A	N/A	N/A	N/A	N/A	N	N	No testing.
IHXA Ceramic	Ceramic Materials Specifications and Procurement	WEC-TS-IHXA-021	4	950°C	N/A	N/A	N/A	N/A	N/A	N	N	No testing.
IHXA Ceramic	Thermal Physical Properties of Ceramics	WEC-TS-IHXA-022	4	950°C	TBD	Static	TBD	TBD	Temperatures up to 1000°C	N	Y	This specification relates to characterization of material properties. Testing can be done in a metallurgical laboratory.
IHXA Ceramic	Mechanical Properties of Ceramics	WEC-TS-IHXA-023	4	950°C	TBD	Static	TBD	TBD	Temperatures up to 1000°C	N	Y	This specification relates to characterization of material properties. Testing can be done in a metallurgical laboratory.
IHXA Ceramic	Compatibility of Ceramic Materials to NGNP He Environment	WEC-TS-IHXA-024	4	950°C	Helium	Static	TBD	TBD	Temperatures 700°C to 1000°C at 9MPa with Controlled Impurities	Y	Y	This specification relates first to aging of materials samples in a controlled chemistry environment and then conducting tests to characterize changes in materials properties. The aging step could be done in the HTSST if an environmental testing capability is included.
IHXA Ceramic	Manufacturing Technologies for Ceramic Heat Exchangers	WEC-TS-IHXA-025	4	950°C	N/A	N/A	N/A	N/A	N/A	N	N	Development of manufacturing technologyis typically done by the supplier or in a materials testing laboratory.
IHXA Ceramic	Ceramic Materials Codes and Standards	WEC-TS-IHXA-026	5	950°C	TBD	TBD	TBD	TBD	TBD	TBD	TBD	Specific requirements for testing in support of code case validation are TBD. Tests may help in establishing code requirements, but details are not presently known.
IHXA Ceramic	Methods for Thermal / Fluid and Stress / Strain Modeling	WEC-TS-IHXA-027	5	950°C	TBD	TBD	TBD	TBD	TBD	Y	N	Results of HTSST tests as described below for WEC-TS-IHXA-031 could be used to validate resulting models.
IHXA Ceramic	Structural Integrity Criteria for Ceramic Heat Exchangers	WEC-TS-IHXA-028	5	950°C	N/A	N/A	N/A	N/A	N/A	N	N	No testing.
IHXA Ceramic	Performance Modeling of Ceramic Heat Exchangers	WEC-TS-IHXA-029	5	950°C	Helium	TBD	TBD	TBD	TBD	Y	N	Results of HTSST tests as described below for WEC-TS-IHXA-031 could be used to validate resulting models.
IHXA Ceramic	Testing of Heat Exchanger Element	WEC-TS-IHXA-030	5	950°C	Helium	Static	TBD	< 2 MW	Temperatures up to 950°C; Pressures up to 9MPa	Y	Y	
IHXA Ceramic	Testing of Integrated Compact Heat Exchanger Module (~1.2MW). **1. Steady State Tests** Test compact heat exchanger module operating effectiveness and behavior in typical steady state pressure, temperature and temperature / pressure drop environment (Helium). **2. Transient Tests (Normal Operation)** Simulate selected normal operation duty cycle events (e.g., startup / shutdown). **3. Transient Tests (Licensing Basis Events)** Simulate selected off-normal events (e.g., loss of secondary pressure).	WEC-TS-IHXA-031	6	950°C	Helium	Flowing	TBD	< 2MW	Temperatures up to 950°C; Pressures up to 9MPa Temperature delta of ~ 250°C Pressure delta of ~ 500 to 600 kPa sustained (Primary to Secondary) Mass flow of 1.2 kg/s (As per CTF PCDR) He environment with varied composition	Y	N	Similation of transient events limited by characteristics of HTSST, e.g., limited ability to impose high pressure differentials in experiments with helium flow. However, a combination of flowing and static tests can simulate or envelope other events, such as loss of secondary pressure with one side of the IHX test article isolated. Specific tests, other than steady state and corresponding test parameters are TBD.

Table 5: (Continued)

Component	Test Description	Test Specification or DDN Number	TRL Goal	Temp.	Environment	Static / Flowing	Approx. Physical Size	Approx. Thermal Size	Process Conditions	HTSST	LAB	Comments / Limitations
IHXA Ceramic	ASME III Code Cases for Ceramic Compact Heat Exchanger Designs	WEC-TS-IHXA-032	6	950°C	Helium	Flowing	TBD	TBD	Temperatures up to 950°C; Pressures up to 9MPa	TBD	TBD	Specific requirements for testing in support of code case validation are TBD.
IHXA Ceramic	Shell-Side Flow Distribution and Bypass Leakage Testing	WEC-TS-IHXA-033	7	950°C	Air / Helium	Flowing	TBD	TBD	Details TBD. Likely to be ambient temperature, pressure	Y	Y	Potential to characterize shell-side bypass at the module level in a test setup without heating. Should be compared with other ambient temperature and pressure testing options (e.g., plexiglas enclosures for improved visualization).
IHXA Ceramic	Multi-Module Heat Transfer Testing	WEC-TS-IHXA-034	7	950°C	Helium	Flowing	TBD	> 2 MW	Details TBD.	N	N	Exceeds anticipated capacity of HTSST. Would be tested in upgraded HTSST or CTC.
IHXA Ceramic	Testing of Full Size Compact Heat Exchanger (Full-Scale NGNP IHX A)	WEC-TS-IHXA-035	8	950°C	Helium	Flowing	TBD	< 2MW	Temperature varying up to 950°C; Pressure varying up to 9MPa	N	N	Exceeds anticipated capacity of HTSST. Would be tested in Demo Plant.

Table 6: HTSST and Laboratory Scale Testing Applicability of IHXB (950°C) and IHX (750°C) Metallic Test Specifications

Component	Test Description	Test Specification or DDN Number	TRL Goal	750°C/ 950°C	Environment	Static / Flowing	Approx. Physical Size	Approx. Thermal Size	Process Conditions	HTSST	LAB	Comments / Limitations
IHX B (950°C) IHX (750°C)	Alloy 800H and Hastelloy X Material Specifications and Procurement	WEC-TS-IHXB-001 WEC-TS-IHX-001	4	950°C 750°C	N/A	N/A	N/A	N/A	N/A	N	N	No testing.
IHX B (950°C) IHX (750°C)	Database for Brazed and Diffusion Bonded Alloy 800H and Hastelloy X	WEC-TS-IHXB-002 WEC-TS-IHX-002	4	950°C 750°C	N/A	Static	TBD	TBD	Temperatures up to 950°C	N	Y	Development of joining technology and associated testing can be done by the supplier or in a metallurgical laboratory.
IHX B (950°C) IHX (750°C)	Alloy 800H and Hastelloy X High Temperature Material Properties	WEC-TS-IHXB-003 WEC-TS-IHX-003	4	950°C 750°C	N/A	N/A	N/A	N/A	N/A	N	N	No testing.
IHX B (950°C) IHX (750°C)	Effects of Thermal Aging and Environment on Alloy 800H and Hastelloy X Properties	WEC-TS-IHXB-004 WEC-TS-IHX-004	4	950°C 750°C	N/A	N/A	N/A	N/A	N/A	N	N	No testing.
IHX B (950°C) IHX (750°C)	Effects of Environmental Exposure on Alloy 800H and Hastelloy X Braze and Diffusion Bonded Joints	WEC-TS-IHXB-005 WEC-TS-IHX-005	4	950°C 750°C	N/A	Static	TBD	TBD	Temperatures up to 950°C	Y	Y	Environmental testing capability proposed for HTSST. Testing could also be done in a metallurgical laboratory.
IHX B (950°C) IHX (750°C)	Effects of Grain Size and Section Thickness on Alloy 800H and Hastelloy X Properties	WEC-TS-IHXB-006 WEC-TS-IHX-006	4	950°C 750°C	N/A	Static	TBD	TBD	Temperatures up to 950°C	N	Y	Testing can be done in a metallurgical laboratory
IHX B (950°C) IHX (750°C)	Corrosion Allowances for Alloy 800H and Hastelloy X	WEC-TS-IHXB-007 WEC-TS-IHX-007	4	950°C 750°C	Helium	TBD	TBD	TBD	Temperatures 650°C to 950°C at 9MPa with Controlled Impurities	Y	Y	Environmental testing capability proposed for HTSST. Also, a procedure to be established for preserving ALL components used in the test loops, to be available for analysis. All components to be weighed before and after testing to determine mass loss. Corrosion allowance testing could be done in conjunction with other tests.
IHX B (950°C) IHX (750°C)	Thermal / Fluid Modeling Methods for the IHXB / IHX	WEC-TS-IHXB-008 WEC-TS-IHX-008	4	950°C 750°C	Helium	TBD	TBD	TBD	TBD	Y	N	Results of HTSST tests could be used to validate resulting models.
IHX B (950°C) IHX (750°C)	Methods for Stress / Strain Modeling of the IHXB / IHX	WEC-TS-IHXB-009 WEC-TS-IHX-009	4	950°C 750°C		N/A	N/A	N/A	N/A	N	N	No test facility or equipment is needed.
IHX B (950°C) IHX (750°C)	Criteria for Structural Intergrity of the IHXB / IHX	WEC-TS-IHXB-010 WEC-TS-IHX-010	4	950°C 750°C		N/A	N/A	N/A	N/A	N	N	No test facility or equipment is needed.
IHX B (950°C) IHX (750°C)	Performance Modeling Methods for the IHXB / IHX	WEC-TS-IHXB-011 WEC-TS-IHX-011	4	950°C 750°C	Helium	TBD	TBD	TBD	TBD	Y	N	Results of HTSST tests could be used to validate resulting models.
IHX B (950°C) IHX (750°C)	Testing of Heat Exchanger Element	WEC-TS-IHXB-012 WEC-TS-IHX-012	See breakdown below									
IHX B (950°C) IHX (750°C)	Joint Integrity (Diffusion Bonding)	WEC-TS-IHXB-012_1 WEC-TS-IHX-012_1	5	950°C 750°C	Helium	Static	TBD	< 2 MW	Temperatures up to 950°C; Pressures up to 9MPa	Y	Y	All components used in test loops to be retained for post-operating analysis.
IHX B (950°C) IHX (750°C)	Joint Integrity (Brazing)	WEC-TS-IHXB-012_1 WEC-TS-IHX-012_1	5	950°C 750°C	Helium	Static	TBD	< 2 MW	Temperatures up to 950°C; Pressures up to 9MPa	Y	Y	All components used in test loops to be retained for post-operating analysis.

Table 6: (Continued)

Component	Test Description	Test Specification or DDN Number	TRL Goal	750°C/ 950°C	Environment	Static / Flowing	Approx. Physical Size	Approx. Thermal Size	Process Conditions	HTSST	LAB	Comments / Limitations
IHX B (950°C) IHX (750°C)	Creep Lifetime Tests	WEC-TS-IHXB-012_2 WEC-TS-IHX-012_2	5	950°C 750°C	Helium	Static	TBD	< 2 MW	Temperatures up to 950°C; Pressures up to 9MPa	Y	Y	All components to be tested to be analysed before and after tests to detect creep.
IHX B (950°C) IHX (750°C)	Fatigue Life Test	WEC-TS-IHXB-012_3 WEC-TS-IHX-012_3	5	950°C 750°C	Helium	Static	TBD	< 2 MW	Temperatures up to 950°C; Pressures up to 9MPa	Y	Y	All components used in test loops to be retained for post-operating analysis.
IHX B (950°C) IHX (750°C)	Testing of Integrated Compact Heat Exchanger Module ([TBD] MW Corresponds to 1.2MW IHX A to get Correct Temperatures) **1. Steady State Tests** Test compact heat exchanger module operating effectiveness and behavior in typical steady state pressure, temperature and temperature / pressure drop environment (Helium). **2. Transient Tests (Normal Operation)** Simulate selected normal operation duty cycle events (e.g., startup / shutdown). **3. Transient Tests (Licensing Basis Events)** Simulate selected off-normal events (e.g., loss of secondary pressure).	WEC-TS-IHXB-013 WEC-TS-IHX-013	6	950°C 750°C	Helium	Flowing	TBD	< 2MW	Temperatures up to 760°C; Pressures up to 9MPa Temperature delta of ~ 473°C Pressure delta of ~ 500 to 600 kPa sustained (Primary to Secondary) Mass flow of 1.2 kg/s (As per CTF PCDR) He environment with varied composition	Y	N	Similation of transient events limited by characteristics of HTSST, e.g., limited ability to impose high pressure differentials in experiments with helium flow. However, a combination of flowing and static tests can simulate or envelope other events, such as loss of secondary pressure with one side of the IHX test article isolated. Specific tests, other than steady state and corresponding test parameters are TBD.
IHX B (950°C) IHX (750°C)	Establishing ASME III Code Cases for Metallic Compact Heat Exchanger Designs	WEC-TS-IHXB-014 WEC-TS-IHX-014	6	950°C 750°C	Helium	Flowing	TBD	TBD	Temperatures up to 950°C; Pressures up to 9MPa	TBD	TBD	Specific requirements for testing in support of code case validation are TBD.
IHX B (950°C) IHX (750°C)	Shell-Side Flow Distribution and Bypass Leakage Testing	WEC-TS-IHXB-015 WEC-TS-IHX-015	7	950°C 750°C	Air / Helium	Flowing	TBD	< 2MW	Details TBD. Likely to be ambient temperature, pressure	Y	Y	Potential to characterize shell-side bypass at the module level in a test setup without heating. Should be compared with other ambient temperature and pressure testing options (e.g., plexiglas enclosures for improved visualization).
IHX B (950°C) IHX (750°C)	Multi-Module (3 x 1.2 MW) Heat Transfer Testing	WEC-TS-IHXB-016 WEC-TS-IHX-016	7	950°C 750°C	Helium	Flowing	TBD	> 2MW	Details TBD.	N	N	Exceeds anticipated capacity of HTSST. Would be tested in upgraded HTSST or CTC. Investigate module-to-module interactions on both the tube- and shell-sides of the heat exchanger. Confirm bypass leakage and effects.
IHX B (950°C) IHX (750°C)	Testing of a Full-Scale Compact Heat Exchanger	WEC-TS-IHXB-017 WEC-TS-IHX-017	8	950°C 750°C	Helium	Flowing	TBD	> 2MW	Temperature varying up to 950°C; Pressure varying up to 9MPa	N	N	Exceeds anticipated capacity of HTSST. Would be tested in Demo Plant.

Table 7: HTSST and Laboratory Scale Testing Applicability of HTS Piping Test Specifications

Component	Test Description	Test Specification or DDN Number	TRL Goal	750°C/ 950°C	Environment	Static / Flowing	Approx. Physical Size	Approx. Thermal Size	Process Conditions	HTSST	LAB	Comments / Limitations
Piping	PHTS High-Temperature [760°C and 950°C] Piping Cooling, Liner and Insulation Options Trade Study	WEC-TS-PIP-001 WEC-TS-PIP$_{750}$-001	5	950°C 750°C	N/A	N/A	N/A	N/A	N/A	N	N	Trade study.
Piping	PHTS Low-Temperature [350°C] Piping Liner and Insulation Options Trade Study	WEC-TS-PIP-002 WEC-TS-PIP$_{750}$-002	5	950°C 750°C	N/A	N/A	N/A	N/A	N/A	N	N	Trade study.
Piping	SHTS High-Temperature[840°C and 900°C] Piping Liner and Insulation Study	WEC-TS-PIP-003	5	950°C 750°C	N/A	N/A	N/A	N/A	N/A	N	N	Trade study.
Piping	SHTS Medium-Temperature [659°C and 700°C] Piping Liner and Insulation Trade Study	WEC-TS-PIP-004 WEC-TS-PIP$_{750}$-003	5	950°C 750°C	N/A	N/A	N/A	N/A	N/A	N	N	Trade study.
Piping	SHTS Low-Temperature [<300°C] Piping Liner and Insulation Trade Study	WEC-TS-PIP-005 WEC-TS-PIP$_{750}$-004	5	950°C 750°C	N/A	N/A	N/A	N/A	N/A	N	N	Trade study.
Piping	Effects of Helium Infiltration on Thermal Conductivity of Insulation Material	WEC-TS-PIP-006 WEC-TS-PIP$_{750}$-005	6	950°C 750°C	See breakdown below							
Piping	Effects of He Infiltration on Thermal Conductivity of Insulation Material	WEC-TS-PIP-006_1 WEC-TS-PIP$_{750}$-005_1	6	950°C 750°C	Helium	Static	TBD	< 2MW	Temperature to 950°C/9MPa; Temperature to 800°C/9MPa.	Y	Y	Insulation-only test anticipated to be required. Could be done at lab-scale or as environmental test in HTSST.
Piping	Effect of Sudden Depressurization on Insulation at 9Mpa, 950°C	WEC-TS-PIP-006_2 WEC-TS-PIP$_{750}$-005_2	6	950°C 750°C	Helium	Static	TBD	< 2MW	Temperature: 950°C/Ambient; Pressure → 9MPa; Temperature: 800°C/Ambient; Pressure → 9MPa.	Y	Y	Insulation-only test anticipated to be required. Could be done at lab-scale or as environmental test in HTSST. Post-test examination of insulation required.
Piping	Effects of He Impurities on Thermal Conductivity of Insulation Material	WEC-TS-PIP-006_3 WEC-TS-PIP$_{750}$-005_3	6	950°C 750°C	Helium w/ Controlled Impurities	Static	TBD	< 2MW	Temperature to 950°C/9MPa; Temperature to 800°C/9MPa.	Y	Y	Insulation-only test anticipated to be required. Could be done at lab-scale or as environmental test in HTSST.
Piping	Effect of Fluid Impurities (C) on Insulation Properties	WEC-TS-PIP-007 WEC-TS-PIP$_{750}$-006	6	950°C 750°C	Helium	Static	TBD	< 2MW	Temperature to 950°C/9MPa; Temperature to 800°C/9MPa.	Y	Y	Insulation-only test anticipated to be required. Could be done at lab-scale or as environmental test in HTSST. Post-test analysis in a lab is necessary, may be conducted as a result of other testing.
Piping	Re-Evaluation of Needed Maturation Tasks Based on Trade Studies	WEC-TS-PIP-008 WEC-TS-PIP$_{750}$-007	6	950°C 750°C	N/A	N/A	N/A	N/A	N/A	N	N	Trade study.
Piping	Performance and Environmental Testing of Prototypical High-Temperature and Low-Temperature Piping / Insulation System	WEC-TS-PIP-009 WEC-TS-PIP$_{750}$-008	7	950°C 750°C	Helium	Flowing	TBD	TBD	TBD	N	N	Exceeds anticipated capacity of HTSST. Would be tested in CTC. Specific test size (mass flow, geometry, . . .) and characteristics to be verified to be further evaluated in conjunction with trade studies.
Piping	Testing of Full Size PHTS Piping in NGNP	WEC-TS-PIP-010 WEC-TS-PIP$_{750}$-009	8	950°C 750°C	Helium	Flowing	TBD	>2MW	TBD	N	N	Testing in NGNP

Table 8: HTSST and Laboratory Scale Testing Applicability of Mixing Chamber Test Specifications

Component	Test Description	Test Specification or DDN Number	TRL Goal	750°C/ 950°C	Environment	Static / Flowing	Approx. Physical Size	Approx. Thermal Size	Process Conditions	HTSST	LAB	Comments / Limitations
Mixing Chamber	Specification 1: Enhanced Mixing Devices Test Specification	WEC-TS-MC-001	7	950°C	N/A	N/A	N/A	N/A	N/A	N	N	Exceeds anticipated capacity of HTSST. Would be tested in upgraded HTSST or CTC.
Mixing Chamber	Specification 2: Vibration Damping Devices Test Specification	WEC-TS-MC-002	7	950°C	N/A	N/A	N/A	N/A	N/A	N	N	Exceeds anticipated capacity of HTSST. Would be tested in upgraded HTSST or CTC.
Mixing Chamber	Partial or Full Scale Flow Mixing Chamber Model Test Specification	WEC-TS-MC-003	7	950°C	N/A	N/A	N/A	N/A	N/A	N	N	Exceeds anticipated capacity of HTSST. Would be tested in upgraded HTSST or CTC.
Mixing Chamber	Prototype Flow Mixing Chamber Test Specification	WEC-TS-MC-004	8	950°C	N/A	N/A	N/A	N/A	N/A	N	N	Exceeds anticipated capacity of HTSST. Would be tested in upgraded HTSST or CTC.

Table 9 HTSST and Laboratory Scale Testing Applicability of Hydrogen Production Plant Alternative Study

Component	Test Description	Test Specification or DDN Number	TRL Goal	750°C/ 950°C	Environment	Static / Flowing	Approx. Physical Size	Approx. Thermal Size	Process Conditions	HTSST	LAB	Comments / Limitations
Hydrogen Production	Hydrogen Plant Alternative Study (HPAS)	HPAS	TBD	950°C	TBD	TBD	TBD	TBD	None defined at this stage. Experts to indicate whether suitable scope exists for testing within HTSST boundaries.	TBD	N	

Table 10: HTSST and Laboratory Scale Testing Applicability of Steam Generator DDNs

Component	Test Description	Test Specification or DDN Number	TRL Goal	750°C/ 950°C	Environment	Static / Flowing	Approx. Physical Size	Approx. Thermal Size	Process Conditions	HTSST	LAB	Comments / Limitations
Steam Generator	Acoustic Response of Helical Bundle	DDN:PCS-01-03	7	950°C 750°C	Helium / Steam	Flowing	TBD	TBD	Process conditions TBD.	N	N	Size of HTSST to determine the testing capability and applicability. Likely to be an ambient temperature test in a full cross-section, but axially shortened test article. Note that acoustic response of flow baffles may be an equal or greater issue.
Steam Generator	Inlet Flow Distribution	DDN:PCS-01-06	7	950°C 750°C	Helium / Steam	Flowing	TBD	TBD	Process conditions TBD.	N	N	Size of HTSST to determine the testing capability and applicability. Likely to be an ambient temperature test. Can use plexiglas models here.
Steam Generator	Flow Induced Vibration Testing of Helical Bundle	DDN:PCS-01-12	7	950°C 750°C	Helium / Steam	Flowing	TBD	TBD	Process conditions TBD.	N	N	Size of HTSST to determine the testing capability and applicability. Likely to be an ambient temperature test in a full cross-section, but axially shortened test article.
Steam Generator	Orifice Qualification Test	DDN:PCS-01-13	7	950°C 750°C	Helium / Steam	Flowing	TBD	TBD	Process conditions TBD.	N	N	Size of HTSST to determine the testing capability and applicability. As stated in the DDN, the objectives are to measure dP vs. flow and to indicate erosion/corrosion resistance. This would be typically done in a laboratory.
Steam Generator	Helical Bundle and Transition Region Heat Transfer Test	DDN:PCS-01-16	7	950°C 750°C	Helium / Steam	Flowing	TBD	TBD	Process conditions TBD.	Y	N	The infrastructure provided with the HTSST could possibly be used to characterize the water-side heat transfer coefficient (only) in a 1- or 2-tube test, using electrical heating on the shell side. The size and configuration of the tubes would preclude any realistic characterization of the helium-side. This would be a physically large test. Note that, in the 350 MWt MHTGR-SC, the characteristics of the SG tubes and the overall tube bundle were: Tube bundle OD/Height: 3.8m/8.4m; Number of tubes: 439; Thermal power/tube: 0.8MW; Number of coil layers: 28; Tube OD/Length: 22.2mm/131m
Steam Generator	Bimetallic Welding (800H or other High Temperature Alloys)	Not yet identified	7	950°C 750°C	Helium / Steam	Flowing	TBD	TBD	Process conditions TBD.	N	N	More experience with 800H or other high temperature alloys is necessary for technology development.

Table 11: HTSST and Laboratory Scale Testing Applicability of PHTS Backflow Prevention Valve Test Specifications (Not Identified Yet)

Component	Test Description	Test Specification or DDN Number	TRL Goal	750°C/ 950°C	Environment	Static / Flowing	Approx. Physical Size	Approx. Thermal Size	Process Conditions	HTSST	LAB	Comments / Limitations
PHTS Backflow Prevention Valve	Trade Study to Select Type, Location	Not yet Identified	6	950°C	N/A	N/A	N/A	N/A	N/A	N	N	Trade Study
PHTS Backflow Prevention Valve	Confirmatory Testing	Not yet Identified	8	950°C	Helium	Static (Envir) and/or Flowing	TBD	TBD	TBD	Y	N	HTSST could potentially do environmental tests, but may not be optimum

Table 12: HTSST and Laboratory Scale Testing Applicability of "Other" Test Specifications

Component	Test Description	Test Specification or DDN Number	TRL Goal	750°C/ 950°C	Environment	Static / Flowing	Approx. Physical Size	Approx. Thermal Size	Process Conditions	HTSST	LAB	Comments / Limitations
Other	TDL Blower Development Tests	(Ref. CTF PCDR)		950°C 750°C	Helium	TBD	TBD	TBD	TBD	Y	N	HTSST is suggested as the main platform to develop and mitigate circulator related design risks. This aspect should beconsidered as one of the main drivers behind the HTSST designs
Other	Addition of Chemistry Control of CO, CO_2, CH_4, H_2 and Moisture in the ppm Range	(Ref. SOW: 7342)		950°C 750°C	Helium	TBD	TBD	TBD	TBD	Y	N/A	Can be developed and incorporated in conjunction with other HTSST tests
Other	Loop shall be Used for Long Term Testing (up to 5,000 hours)	(Ref. SOW: 7342)		950°C 750°C						Y	N/A	
Other	Test Loop Design shall Incorporate a Philosophy of Skid-Mounted (Modular & Reconfigurable) Units to Simplify Portability Thereof	(Ref. SOW: 7342)		950°C 750°C						Y	N/A	
Other	Possbile Evaluation of Components for Large Scale Testing. E.g: TDL Hot Gas Duct Development	(Ref. CTF PCDR)		950°C 750°C	TBD	TBD	TBD	TBD	See TDL report for input to test definition	Y	N	To be developed in conjunction with other test facilities' designs

2.3 PIE Charts Representing HTSST Applicability

The PIE charts given below represent Table 3 through to Table 12 in graphical form where applicable. Each graph has the following information, which is deduced from aforementioned tables.

- Number of Test Specifications as per TDRM Reports;
- Number of Test Specifications identified for HTSST Loop Testing;
- Number of Test Specifications identified for Laboratory Testing;
- Number of Test Specifications not suited for both HTSST and Laboratory.
- Number of Test Specifications applicable to both HTSST and Laboratory;

In the case of Circulator- and Mixing Chamber Test Specifications no HTSST is foreseen. Concerning the Hydrogen Production Plant Alternative Study, more information is necessary to determine possible HTSST applicability.

At writing, all the identified "Other" tests (see Table 12) form part of the testing scope for HTSST.

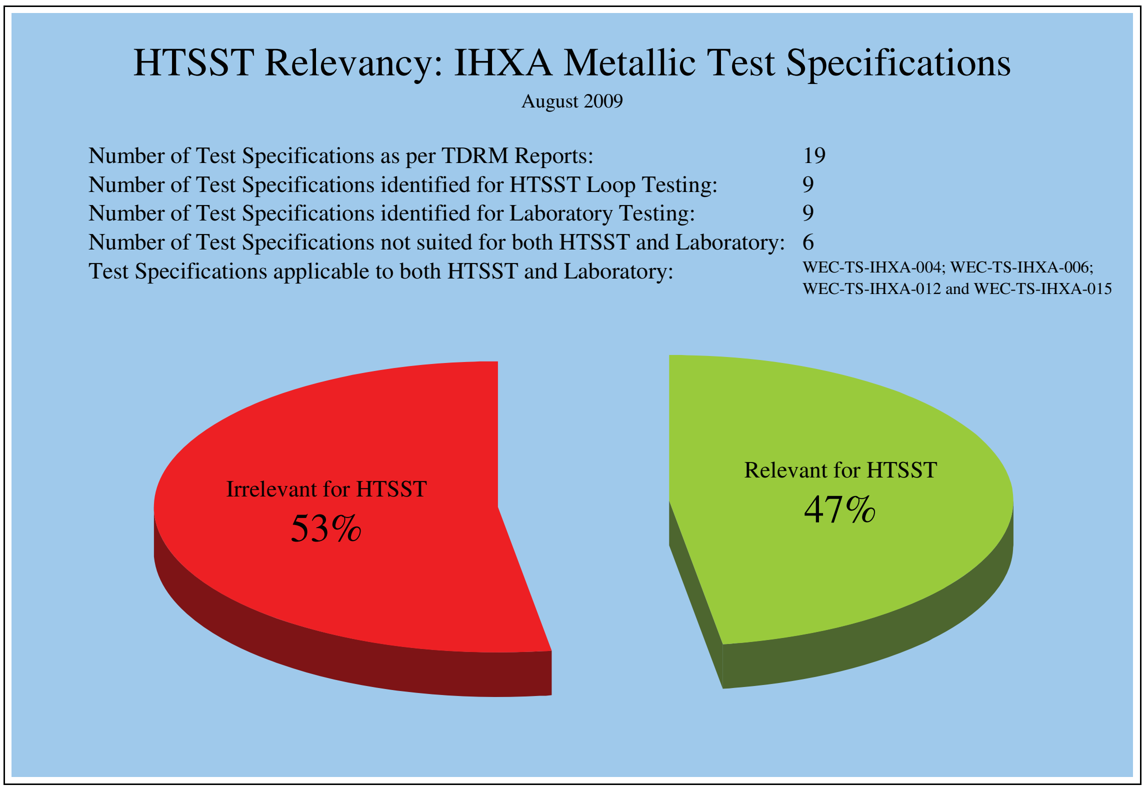

Figure 2: HTSST Relevancy for IHXA Metallic Test Specifications

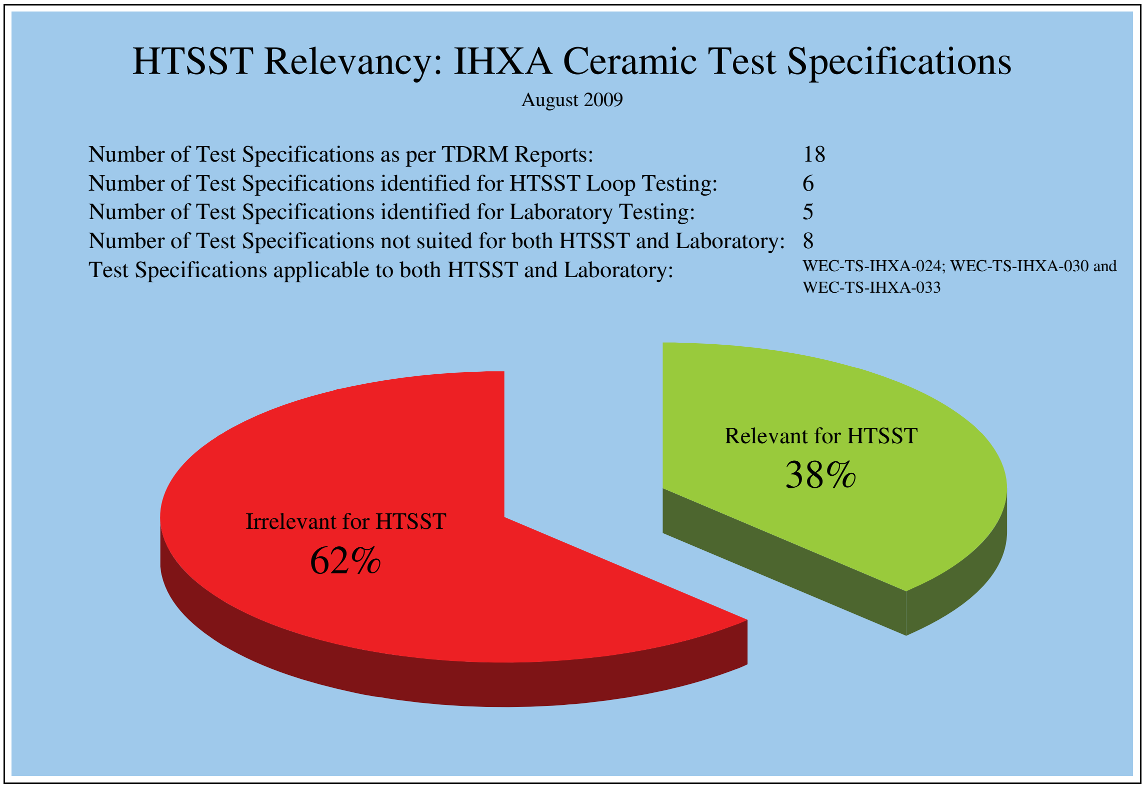

Figure 3: HTSST Relevancy for IHXA Ceramic Test Specifications

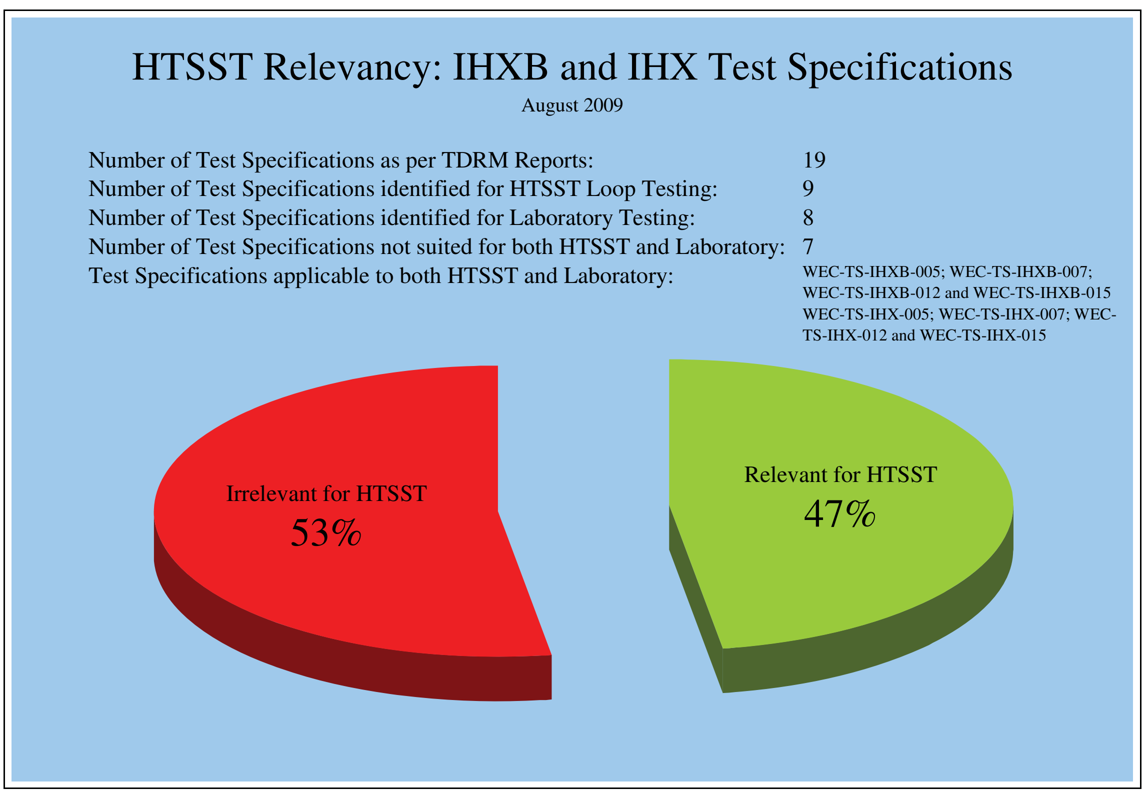

Figure 4: HTSST Relevancy for IHXB (950°C) and IHX (750°C) Test Specifications

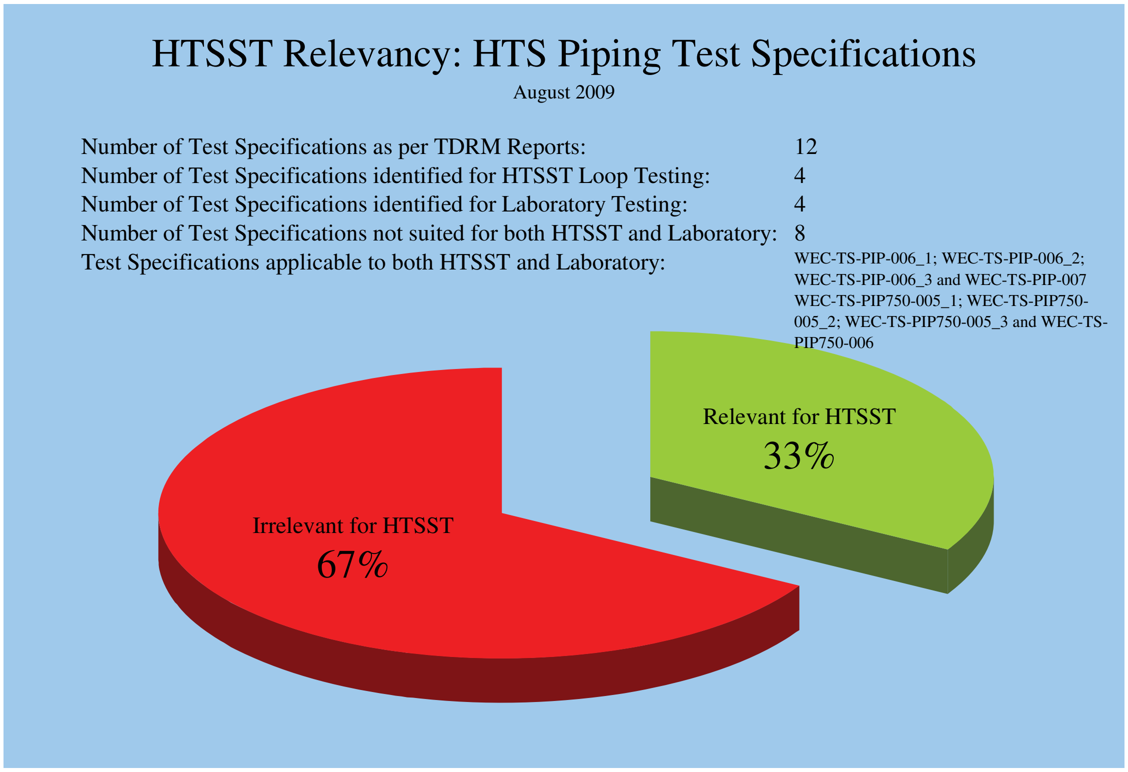

Figure 5: HTSST Relevancy for HTS Piping Test Specifications

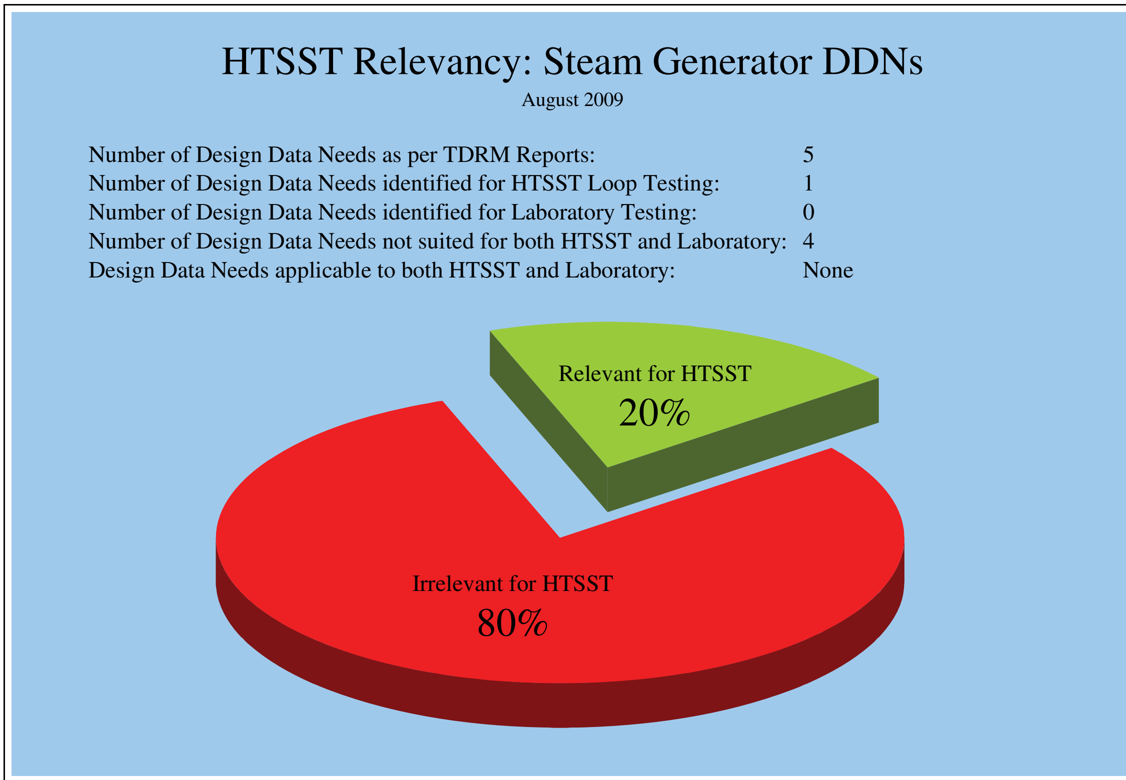

Figure 6: HTSST Relevancy for Steam Generator DDNs

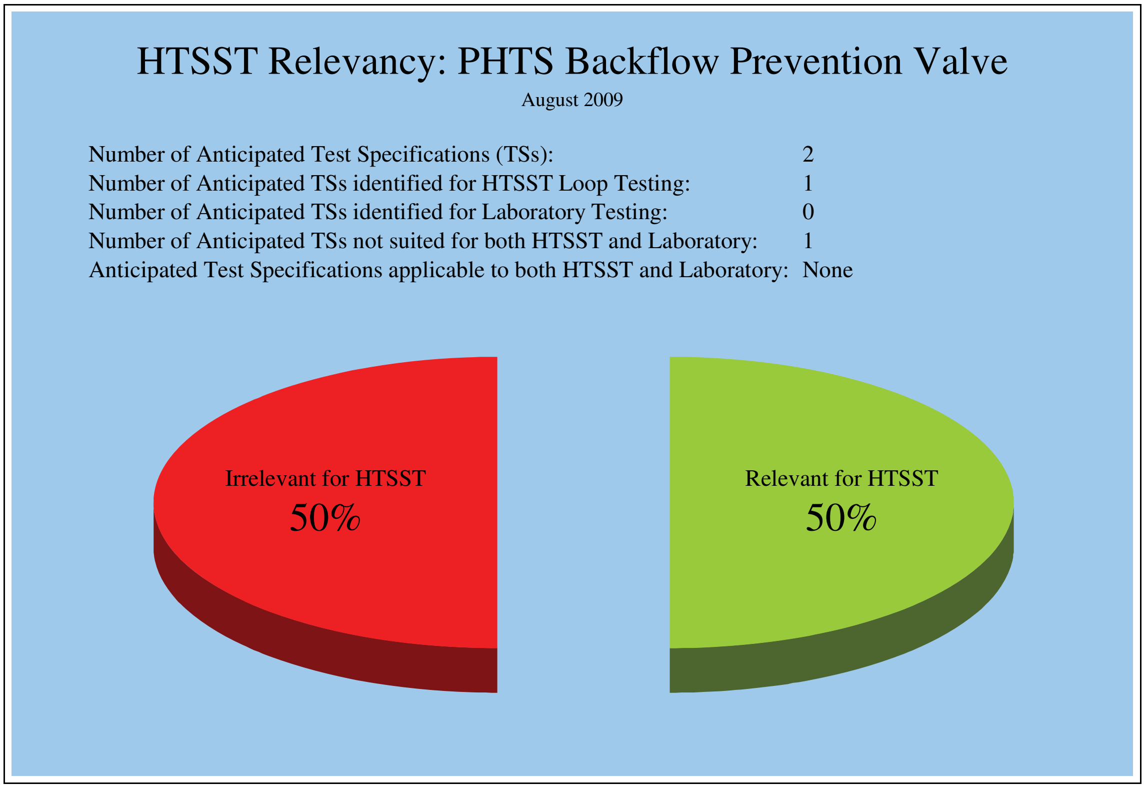

Figure 7: HTSST Relevancy for PHTS Backflow Prevention Valve Test Specifications (TBD)

3. SUMMARY AND CONLCUSION

Test specifications from both the 950°C and 750° - 800°C TDRM reports have been reviewed in order to determine which of these would be suitable for inclusion into the scope of an HTSST facility.

The result of the review of these tests can be summarized as follows:

- No full-scale NGNP circulator tests can be performed within an HTSST facility with the physical specifications as applied.
- A large number of IHX tests are anticipated for HTSST with specific focus on TRL advancement from 4 to 5 with regards to Heat Exchanger Element tests. TRL advancement of IHX tests of levels 2 to 4 within the HTSST capability would also be possible pending design considerations.
- Integrated compact heat exchanger module testing (~ 1.2MW), representing a TRL advancement from 5-6, could also be included for HTSST.
- Multi-module heat transfer is foreseen to be tested within an HTSST capability. Test loops within the HTSST could be reconfigured i.e. combined for larger mass flow.
- A third of all the HTS Piping tests are considered for HTSST.
- No Mixing Chamber tests are anticipated for HTSST.
- The applicability of the HTSST in the development of the Hydrogen Production systems and components could not be determined. This is because no detail test specifications currently exist for this system and components and sizing of representative testable units have yet to be developed.
- Considering the Steam Generator's Design Data Needs, only the "Helical Bundle and Transition Region Heat Transfer Test" is anticipated for HTSST.
- Confirmatory testing on the PHTS Backflow Prevention Valve remains viable for HTSST. The two anticipated test specifications for this aforementioned valve yet needs to be determined.
- Additional aspects that could be included relevant for HTSST are specific tests associated with blower development.

The Engineering, Commissioning and Construction (ECC) phase of an HTSST facility is assumed to approximately span 30 months. It is approximately 60 percent of the period anticipated to complete the proposed larger-sized TDL and has the possibility of being ready for testing at the end of 2012.

This reduction in schedule, together with the fact that such a facility could already assist with major advancements in heat transfer components, seems to dictate the necessity of such a high temperature HTSST facility. A further list of possible advantages as well disadvantages of an HTSST is also presented hereafter:

Advantages

- Such a test loop could be optimized for advancing a maximum number of TRLs at minimum cost. This would, however, be an iterative process between establishing the requirements and determining a feasible, cost effective concept.
- The short development period associated with an HTSST ECC phase could have this test loop completed by end of 2012 assuming an ECC start-up date during the first quarter of 2010. With this being a definite advantage, it should be noted that the Unit Under Test (UUT) would also need to be ready at this point in time.
- Such a facility could perform a vital part in the development and growth path towards a much larger, but necessary, test loop, such as the TDL.

Disadvantages and constraints of such a facility include the following:

- Such a test capability would only provide partial TRL advancement and would not be proficient for performing all required tests.
- The relatively short development time would require that all tests prior to TRL 4 have been completed with the results being made available where it might influence the design of the proposed facility.

4. REFERENCES

[1-1] "NGNP and Hydrogen Conceptual Design Study; NGNP Technology Development Road Mapping Report", NGNP-CTF MTECH-TDRM, Revision 0, December 2008.
[1-2] "NGNP Technology Development Roadmapping Report - Steam Production at 750°C-800°C", NGNP-TDI-TDR-RPT-G-00008 … 00018, August 2009.
[1-3] "NGNP CTF Test Loop Preconceptual Design Report", NGNP-CTF MTECH-TLDR, December 2008.
[1-4] "Statement of Work Westinghouse Electric Company Component Test Facility Conceptual Design Studies", SOW-7342.
[1-5] "INL Engineering Standards" STD-139
[1-6] "HTGR Component Test Facility (CTF) Feasibility and Recommendations", NGNP-CTF, February 2008
[1-7] "NGNP Hydrogen Plant Alternatives Study", NGNP-HPS SHAW-HPA, Rev. 1, Westinghouse Electric Company LLC, March 2009.
[1-8] "Report on Update of Technology Development Roadmaps for NGNP Steam Production at 750 °C – 800 °C", NGNP-TDI-TDR-RPT-G-00003, May 2009.