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18MAY09

Discussion of changes in the TRL ratings from the first TRL report not due to ROT

The TRL process has proceeded through four steps. With each step the design of the NGNP has evolved and advanced in parallel, and during this time period additional system engineers with expertise in their respective technical areas have participated in the ranking task. The four steps are as follows:

- The first TRL rankings in 2007 [1] based on the Preconceptual Design [2]
- The first TDRM task in 2008 [3], which included revised TRL rankings based on and expanded from the first TRL report.
- The updated TRL report in 2009 [4], for which the task was interpreted to be:
  - Update the first report
  - Incorporate the changes to TRLs in the first TDRM report
  - Revise the TRLs in light of the change in ROT from 950°C to 750-800°C.
  - Review the TRLs in general and revise as appropriate
- Update the TDRM report [5]. The TRLs in that report agree with those in the updated TRL report [4].

From the first TRL report [1] to the updated report [4] there have been 11 SSCs for which the TRL rating has been increased and 6 SSCs for which the TRL rating has been reduced. Of those SSCs having reduced rankings, none were related to the change in ROT from 950°C to 750-800°C.

Of these six SSCs with lower TRLs:

- One is the Fuel Handling and Storage System (FHSS), and another is the Intermediate Heat Exchanger (IHX) Core. These two are discussed below.
- Two of the SSCs with lower TRL are SSCs whose rating changed only because the lowest TRL rating of a lower level SSC's was reduced. Theses are the PHTS Piping (ID in the TRL report, #024) and the SHTS Piping (ID in the TRL report, #029). These are not discussed further.
- Two SSCs have been combined into one in the Rating Sheets in the TRL report [1], and these are the PHTS Piping Internal Ducts, Supports and Insulation and the SHTS Piping Internal Ducts, Supports and Insulation. These are discussed together as the HTS Piping Internal Ducts, Supports and Insulation.

Therefore, there are three cases of lower TRL ratings to discuss, none of which was changed due to the change in ROT from 950°C to 750-800°C.

<u>FHSS</u>
(ID in the TRL report, #011)

In the period of time since the preparation of the first TDRM Report [3], the conceptual design phase has progressed to the point of including additional system engineers with expertise in their respective technical areas. In their review of updated report [4], changes were made to some TRLs. In that review, one SSC – the FHSS – has been given lower TRL assessment.

The primary purpose of the FHSS is to circulate the spherical fuel elements through the reactor core while the reactor is operating at power. When the selected burn-up is reached, spent fuel is removed from the circulation loop and stored in intermediate storage tanks. The spent fuel is then replaced by fresh fuel, which is introduced into the circulation loop. The NGNP WEC-team envisages utilizing a FHSS similar to that of the PBMR DPP.

Operating experience exists on fuel handling and storage systems similar to that of the FHSS on other Gas Cooled Reactors. The FHSS development for the PBMR DPP is nearing basic design completion, with a number of development tests being performed, resulting in a rating of TRL-6, except the Burn-up Measurement System (BUMS) which has been demonstrated at experimental scale, resulting in a rating of TRL-5.

A number of development and qualification tests will be performed on the Helium Test Facility (HTF) in South Africa before the FHSS can be commissioned in the PBMR DPP. Upon the completion of pre-fuel commissioning tests, the FHSS will have a rating of TRL-7, although the testing excludes a neutronic environment. A rating of TRL-8 will be achieved after DPP commissioning tests with fuel. The BUMS will only be tested in an integrated FHSS system at the DPP after fuel load.

A Technology Development Roadmap (TDRM) has been compiled to outline the process that needs to be followed for the FHSS to obtain a rating of TRL-8. The TDRM indicates that the experience obtained in the development of the FHSS for the PBMR DPP can be used for application in the NGNP.

<u>IHX Core</u>
(ID in the TRL report, #017)

The rating for the IHX - Compact, Metallic Core was TRL-4 in the first TRL report [1] and was changed in the first TDRM report [3] to TRL-3.

The initial rating [1] of TRL-4 in 2007 was based on the preconceptual design of a generalized plate-fin design and a specific definition saying essentially that heat exchangers of similar materials and design have operated in other applications and/or environments and that one or more materials were identified with potentially acceptable characteristics. An underlying assumption in this initial TRL rating was that the relatively inert helium environment of the PBMR PHTS would be less demanding on the proposed materials than the typical environments in which similar heat exchangers had already been operated (*e.g.*- the exhaust stream of gas turbine engines in the case of plate-fin recuperators).

It was subsequently concluded from the 2008 IHX and HTS Conceptual Design Study [6] that the adequacy of materials was not a valid assumption for the thin cross sections required for the heat transfer surfaces of compact heat exchangers. A review of prior corrosion studies revealed that the slightly reducing environment of the PHTS led to deterioration of the protective oxide scale and, consequently, to internal corrosion and depletion of chromium from the bulk material at the temperatures of interest to the IHX. On this basis, high-priority DDNs were identified to obtain corrosion data for both I-617 (IHX A) and 800H (IHX B) (See Ref. [6], Section 4, Table 4-1, DDNs HTS-01-20,21 and 26-29). In addition, a DDN (HTS-01-31) was specified to undertake a readiness assessment of Hastelloy XR, which was viewed as having greater corrosion resistance than I-617 or 800H.

In the 2008 TDRM report [3], the TRL rating of IHX-B, which is the analogous SSC for the 750-800°C ROT case, was reduced to TRL-3. The basis for this reduction was the materials assessment of Reference [6], as summarized above. It was concluded that the TRL-4 criterion to ". . . demonstrate technical feasibility . . ." had not been met in the absence of materials data that confirms the adequacy of the material for the thin heat transfer sections in the PHTS environment. The need to provide materials data sufficient to characterize the corrosion of thin sections and to support a statement of full-life functionality for the IHX core design was accordingly addressed in the Technology Maturation Plans.

The basis for the TRL rating of Reference [3] is unchanged in going from the 950°C to 750-800°C ROT case, since the operating temperatures of IHX B and the present IHX are comparable. The TRL-3 rating has, thus, been carried forth into the present TRL update (Ref. [4]).[1]

<u>HTS Piping Internal Ducts, Supports and Insulation</u>
(ID in the TRL report, #026 & #031)

The rating for the Heat Transport System (HTS) Piping Internal Ducts, Supports and Insulation was TRL-6 in the first TRL report [1]. The initial TRL-6 rating was based on prior experience with similar ductwork and insulation for gas-cooled reactors. Of particular relevance was the design and testing of hot gas piping in support of the Process Heat Nuclear Plant (PNP) in Germany. As part of that program, hot gas pipe sections were fabricated and tested at engineering scale in a helium environment for periods up to 15,000 hours at temperatures in the range of 900-950°C. The German design is the basis for the DPP piping design. At the time of the PBMR NGNP preconceptual design, an engineering judgment was made that the PHTS Piping would be similar to the DPP design, which was further advanced in the design process, and that the DPP design was sufficiently similar to ductwork and insulation of gas-cooled reactors that had been previously built and operated. Passive insulation was identified as a desirable basis for the SHTS circuit (to reduce complexity and cost); however, that tentative selection was to be confirmed during conceptual design.

In the course of the subsequent IHX and HTS Conceptual Design Study [6], it was realized that certain transients (*e.g.*- loss of SHTS heat removal, combined with failure of the PHP circulator to trip) might lead to overheating of the PHTS piping outer helium pressure

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[1] Subsequent to the development of Ref. 2, a further assessment of materials options for the IHX at 750-800°C has been undertaken as part of an ongoing priority task, "IHX Development and Trade Studies". A conclusion of this in-process task is that Hastelloy X should be identified as the reference material for the lower-temperature IHX, based on superior corrosion resistance and adequate structural properties in the intermediate temperature range. This does not change the TRL rating, which is still based on the need to confirm the corrosion resistance of the thin-section material in the relevant PHTS environment.

boundary (potentially in both the cold and hot legs).[2] If such transients were confirmed to be an issue, potential design solutions might include features to assure continued cooling of the helium pressure boundary during transients, internal insulation of the helium pressure boundary and/or a change in the helium pressure boundary material to one that has higher temperature capability. A trade study was recommended to confirm the selection of internal insulation for the SHTS and to evaluate passive internal insulation for potential use in the PHTS.

The applicability of passive internal insulation was further evaluated as part of the Composites R&D Technical Issues Conceptual Design Study [7]. Extrapolation of helium data to 9MPa by Microtherm suggested that microporous insulation (*e.g.*- Microtherm's product) is potentially suitable. However, the uncertainty range associated with the Microtherm extrapolation is relatively large and testing is required to confirm both the insulation values and the long-term stability of the insulation in high temperature, high-pressure helium and during duty cycle events.

The reduction in rating to TRL-4 in the 2008 TDRM report [3] was based on the transient issues identified as a result of the IHX and HTS Conceptual Design Study, the corresponding uncertainty with respect to the preferred PHTS piping design and the lack of data for passive insulation in high-pressure helium. If it were assumed that the PHTS pressure boundary is replaced with a material that has higher temperature capability and/or that additional active features (*e.g.*- an alternate source of cooled helium) are provided to ensure cooling of the helium pressure boundary during transients (these options must be considered for both the hot and cold legs), the actively cooled design of the DPP could be applied and a higher TRL level would be justified. However, both approaches involve significant trade-offs and it was concluded that passive insulation should also be considered. Further passive insulation is the reference basis for the SHTS.

Given that both active and passive insulation/cooling options are to be considered for the PHTS piping, the TRL level assigned to the PHTS internal structures and insulation corresponds to the lower of the two options. For the passive insulation option, the TRL-4 rating is based on the judgment that prior tests in helium at low pressure, along with industrial experience in conventional applications, establish technical feasibility; however, they do not constitute demonstration in the relevant environment (high-pressure helium). The Technology Maturation Plans call for both trade-off studies and material qualification to advance the insulation from TRL-4 to TRL-5. This included Technology Maturation Tasks that applied to all temperature ranges, although for the change from 950°C to 750-800°C, the number of tasks is reduced from 6 to 4. To advance "back" to TRL-6 and to meet the test of a similar SSC tested in relevant environment, three additional Technology Maturation Tasks are called for in the TDRM: Tests to determine the effects of helium infiltration on thermal conductivity of insulation materials, testing the effect of impurities on the insulation properties and reevaluation of the maturation tasks based on trade study results.

[2] Transients leading to overheating of the helium pressure boundary are not associated with the DPP, in which helium flow and cooling are intrinsically coupled by the characteristics of the Brayton cycle.

References

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[3] "NGNP and Hydrogen Production, Conceptual Design Study, NGNP Technology Development Road Mapping Report", NGNP-CTF MTECH-TDRM, Rev. 0, Westinghouse Electric Company LLC, December 2008.

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[7] "NGNP Conceptual Design Study: Composites R&D Technical Issues", NGNP-NHS TI-COMP, Rev. 0, Westinghouse Electric Company LLC, October 2008.