OAK RIDGE NATIONAL LABORATORY
MANAGED BY UT-BATTELLE FOR THE DEPARTMENT OF ENERGY

ORNL-GEN4/LTR-06-005

STATUS OF ASME SUBSECTION NH

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GEN IV Nuclear Energy Systems

March 30, 2006

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U.S. DEPARTMENT OF ENERGY
under contract DE-AC05-00OR22725

EXECUTIVE SUMMARY

The American Society of Mechanical Engineers (ASME) Boiler & Pressure Vessel Code (B&PVC) rules for construction of elevated temperature Class 1 components for nuclear service are specified in the Section III, Subsection NH – also known as SG-ETD (Subgroup on Elevated Temperature Design). The purpose of this report is to summarize the status of ASME Subsection NH (ASME-NH or NH hereafter) to date, specifically related to the needs of the Department of Energy's (DOE's) Generation IV (Gen IV) nuclear reactor concepts such as the Next Generation Nuclear Plant (NGNP), also referred to as the Very High Temperature Reactor (VHTR).

The DOE-ASME collaboration plan to support development of nuclear codes and standards for Gen IV was established in September 2005. This 3-year agreement outlines twelve (12) specific tasks identified by DOE, ASME, Idaho National Laboratory (INL) and Oak Ridge National Laboratory (ORNL) staff, and industrial stakeholders for Gen IV needs. DOE has awarded funding to ASME for the first five (5) activities. ASME released a Request for Proposals (RFP) to support these tasks in December 2005, with expectations that the period of performance of tasks range from 1-3 years depending upon the task. ASME has successfully selected a list of Technical Advisors and Technical Investigators and remains on track within the timeline of the DOE-ASME Collaboration Plan. ASME is expected to award subcontracts to Technical Advisors and Investigators by the time this report is published to initiate efforts in the first five tasks of the DOE-ASME Collaboration Plan.

Activity and discussion of several action items already within ASME Section III Subsection NH are directly relevant to several of the tasks identified in the DOE-ASME Collaboration Plan. These tasks include: Verification of Code Allowables, Regulatory Safety Issues (NRC), Negligible Creep & Creep-Fatigue of Gr91 Steel, and Simplified Methods. Progress in these areas varies. No modification or additions to NH have taken place as a result of progress in these areas. Outside of Subsection NH, a Project Team on Graphite Core Components in Section III has begun developing a draft code for use of graphite as a structural material, also one of the tasks identified in the DOE-ASME agreement. Additional progress in the first five tasks is expected in the next 6-12 months once ASME awards the subcontracts; as such, interaction and discussion of such activities is expected to occur within Subsection NH.

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ACKNOWLEDGEMENTS

The author is grateful to William Corwin and George Hayner for their support. Further, the assistance and mentoring provided by Robert Jetter, Chair of ASME Subsection NH is very much appreciated. Finally, thanks to Richard Williamson and Weiju Ren for reviewing this report.

This work is sponsored by the U.S. Department of Energy, Office of Nuclear Energy Science and Technology under contract DE-AC05-00OR22725 with Oak Ridge National Laboratory, managed by UT-Battelle, LLC.

ABBREVIATED TERMS & SYMBOLS

ACRS	Advisory Committee on Reactor Safeguards
ASME	American Society of Mechanical Engineers
B&PVC	Boiler & Pressure Vessel Code
CRBRP	Clinch River Breeder Reactor Project
DOE	Department of Energy
Gen IV	Generation IV
GIF	Generation IV International Forum
HCF	high cycle fatigue
HTR	High Temperature Reactor
INL	Idaho National Laboratory
LMFBR	Liquid Metal Fast Breeder Reactor
NGNP	Next Generation Nuclear Plant
NH	Subsection NH of ASME Section III B&PVC
NRC	Nuclear Regulatory Commission
ORNL	Oak Ridge National Laboratory
PBMR	Pebble Bed Modular Reactor
PVP	Pressure Vessels & Piping
RCC-MR	French Nuclear Design Code
RFP	Request for Proposal
SG-ETD	Subgroup Elevated Temperature Design
S_m	time independent stress allowable
TA	Technical Advisor
TI	Technical Investigator
VHTR	Very High Temperature Reactor

1. INTRODUCTION

The American Society of Mechanical Engineers (ASME) Boiler & Pressure Vessel Code (B&PVC) rules for construction of elevated temperature Class 1 components for nuclear service are specified in the Section III, Subsection NH – also known as SG-ETD (Subgroup on Elevated Temperature Design). The purpose of this letter report is to summarize the status of ASME Subsection NH (ASME-NH or NH hereafter) to date, specifically related to the needs of the Department of Energy's (DOE's) Generation IV (Gen IV) nuclear reactor concepts such as the Next Generation Nuclear Plant (NGNP), also referred to as the Very High Temperature Reactor (VHTR).

While this report does not address the status of rules for Class 2 and 3 Components and Core Support Structures, such rules are contained in a series of Code Cases [1]. The rules address materials, design, fabrication, inspection, overpressure protection, testing, and marking. Section III defines "elevated temperature" as 371^{o}C (700F) for ferritic steels and 427^{o}C (800F) for austenitic stainless steels and nickel based alloys. For service temperatures below these limits, Subsections NB, NC, ND, and NG apply. These rules are mentioned because the basis for many of these rules are similar to those of Subsection NH, and Subsection NH may be the forum by which activities and effort relevant to the Code Cases or Subsections listed above may transpire within the ASME B&PVC organization.

2. DOE-ASME COLLABORATION PLAN

The DOE-ASME collaboration plan to support development of nuclear codes and standards for Gen IV was established in September 2005. This 3-year agreement outlines twelve (12) specific tasks identified by DOE, ASME, Idaho National Laboratory (INL) and Oak Ridge National Laboratory (ORNL) staff, and industry stakeholders for Gen IV needs. DOE has awarded funding to ASME for the first five (5) activities. ASME released a Request for Proposals (RFP) to support these tasks in December 2005, with expectations that the period of performance of tasks range from 1-3 years depending upon the task. The deadline for the RFP's was extended to January 31, 2006. Two specific types of RFP's were solicited: Technical Advisors (TA's) and Technical Investigators (TI's). The roles of Technical Advisors are to assist ASME's Project Manager in further refinement of the work scope within the specified framework for the tasks and assess the work performed by the Task Investigators. Task Investigators are individuals who will perform the work on individual tasks identified in the DOE-ASME Collaboration Plan and the ASME RFP. ASME has successfully selected a list of Technical Advisors and Technical Investigators and remains on track within the timeline of the DOE-ASME Collaboration Plan.

The twelve tasks identified within the DOE-ASME Collaboration Plan are listed below. They are listed for easy reference, of which several are relevant to recent activities within ASME-NH.

TASK 1: Verification of Allowable Stresses
TASK 2: Regulatory Safety Issues in Structural Design Criteria for ASME Section III Subsection NH
TASK 3: Improvement of ASME Section III Subsection NH Rules for Negligible Creep & Creep-Fatigue of Grade 91 Steel
TASK 4: Updating of ASME Nuclear Code Case N-201
TASK 5: Creep-Fatigue Procedures for Grade 91 Steel and Hastelloy XR
TASK 6: Graphite and Ceramic Code Development
TASK 7: NH Evaluation and Simplified Methods
TASK 8: Identification of Testing Needed to Validate Elevated Temperature Design Procedures for the VHTR
TASK 9: Environmental and Neutron Fluence Effects
TASK 10: ASME Code Rules for Intermediate Heat Exchangers (IHX)
TASK 11: Flaw Assessment and Leak Before Break (LBB)
TASK 12: Improved NDE Methods for Metals

3. ASME-NH STATUS

The ASME B&PVC meetings are held quarterly; two meetings have taken place in FY2006, one in Greensboro, NC from October 31-Nov 4th, 2005 and another in Portland, OR from February 12-17th, 2006. Many of the Gen IV related discussions and activities are naturally aligned with the tasks identified in the DOE-ASME Collaboration Plan; as such, the status and related activities are summarized within the specific task unless such activity is unrelated. The reader should realize that activities/discussions on these activities to date are not a result of the DOE-ASME agreement, but rather from action items already existing within NH. The DOE-ASME collaboration plan and the relevant RFP's were already summarized in section 2. Elevated temperature materials and design issues have drawn considerable interest, and will remain a key topic for discussion within ASME Section III, particularly Subsection NH.

<u>Task 1: Verification of Allowable Stresses:</u>

Activity and discussion has taken place addressing verification of allowable stresses. In summary, most of the effort and progress stems from Dr. Swindeman (retired from ORNL). Dr. Swindeman currently provides consulting services to ORNL, which includes collection, review, and assembly of materials test data on numerous code materials. His progress and leadership will be invaluable to the Technical Investigator selected by ASME for this task. Below is a summary of related activities.

> A summary of the overall status of Alloy 617, 230, 800H, 316FR or equivalent was made by Dr. Swindeman at the February meeting. Identification of data sources used to set current allowables for NH is underway. Verification of the consistency of NH allowables with Section II-D for Alloy 800H is also underway, as well as determining

if sufficient data exist to extend coverage to 850^{O}C. Design life for Alloy 800H at 850^{O}C will likely be limited to 100,000 hours. Weld material properties, including creep rupture strength, are much lower than base metal. Filler material and cross weld data are both needed. Strength reduction factors were likely assumed to be equal to those obtained from testing of austenitic stainless steels by Dr. Corum of ORNL during the Liquid Metal Fast Breeder Reactor (LMFBR) program. Review of creep and stress rupture, fatigue, creep-fatigue, aging effects, environmental effects, and weld metal behavior will all be needed.

The issue of removing one or more materials from ASME-NH was discussed. The members decided not to remove any of the existing materials from NH, as these materials may be needed for other nuclear applications in the future, and the material allowables in NH are often used in non-nuclear applications as well.

Dr. Kimura of Japan delivered a presentation at the November meeting summarizing Japanese efforts of analyzing long term creep data and performance of Gr92 and 122 steels. These are ferritic creep resistant steels with higher chromium content than Gr91 (also referred to as Mod9Cr1Mo). Recommendations on revisions of tensile strength for long term use, and extrapolation methods for prediction of 60 year life were made. The presentation is identical to the information contained within Dr. Kimura's 2005 Pressure Vessel & Piping (PVP) conference paper [2]. This topic is of relevance to extrapolation of allowable stresses of current NH materials to meet Gen IV plant lives of 60 years.

TASK 2: Regulatory Safety Issues in Structural Design Criteria for ASME Section III Subsection NH:

Dr. O'Donnell and Dr. Griffin are currently NH members who were deeply involved in the LMFBR program. Both have extensive knowledge of the issues and history of the Advisory Committee on Reactor Safeguards (ACRS) and the Nuclear Regulatory Commission (NRC) review of the Clinch River Breeder Reactor Project (CRBRP). No specific activity has taken place in this area other than recognition of these individuals experience and knowledge with this topic, and the identification of this topic as one of the top priorities within the DOE-ASME agreement. A summary paper on the technical issues related to the CRBRP is an excellent reference [3]. A recent NRC report summaries material concerns for High Temperature Reactors (HTR) [4].

In a related matter, the South African Pebble Bed Modular Reactor company, PBMR (Pty) Ltd, has met three (3) times with the United States NRC to date. No other information is available.

TASK 3: Improvement of ASME Section III Subsection NH Rules for Negligible Creep & Creep-Fatigue of Grade 91 Steel:

Considerable discussion has taken place regarding Gr91 steel, as it is one of the primary candidate reactor pressure vessel materials for AREVA's gas-cooled VHTR. Dr. Riou of AREVA has led much of the discussion and related activity, and collaboration with ORNL staff has begun, including sharing of data and reports. Japan has also provided publication materials and data. A summary of analysis of ORNL and French data on Gr91 related to insignificant creep is expected to be published in the 2006 Pressure Vessel & Piping Conference in Vancouver, Canada. Similarly, recent creep-fatigue test results and data analysis is expected to be published at the same conference. Below are summaries of some of the technical details related to these topics.

Negligible creep of Grade 91 Steel (Gr91 or Mod9Cr1Mo):

There are differences between definitions of negligible creep in RCC-MR (French Code) and ASME Code: RCC-MR is based upon a reference stress and strain while ASME-NH is based upon a time duration factor. Application of negligible creep definition to austenitic stainless steel 316L(N) and ferritic Gr91 steel may require modification on a per material basis. An attempt to base negligible creep on $3S_m$ (S_m is the time independent stress allowable) for both ASME and RCC-MR methods generated significant differences between ASME and RCC-MR allowables, with RCC-MR permitting use only to 375^{O}C and ASME permitting limited use as high as 500^{O}C. Review of creep strain laws and creep stress to rupture below 500^{O}C are required. Consideration of metallurgical studies for long term creep conditions in addition to mechanical properties should be given. Initial analysis indicates that 425^{O}C may be near the negligible creep temperature for Gr91 steel.

Creep-Fatigue of Grade 91 Steel (Gr91 or Mod9Cr1Mo):

In summary, information provided by Dr. Asayama of Japan and Dr. Riou of France have lead to quarterly discussion of the creep-fatigue of Gr91 steel. The issue requires significantly more time and effort; as such, no changes within NH have been proposed. Below are brief technical summaries related to creep-fatigue of Gr91 steel.

> Dr. Asayama of Japan has provided publications and summary data in August 2005 for Gr91 (Mod9Cr1Mo). Availability of actual stress-strain-time numerical data is uncertain; data are unavailable as negotiations within the Generation IV International Forum (GIF) take place.
>
> Dr. Riou of AREVA has made several presentations on creep-fatigue analysis of Gr91 steel. In summary, the work is in progress, but the following have been noted. 1) The effect of hold-time on creep-fatigue is not obvious. 2) Shorter lives were observed with compressive hold times, especially at lower strain ranges; it remains uncertain if the reduction is an oxidation phenomena or a mean stress effect. Dr. Asayama's experience in Japan (sodium vs. air tests) indicated that effects may be oxidation related; Asayama is obtaining reference on this work for discussion. 3) The high cycle fatigue (HCF) regime of ASME Code was

questioned. 4) The Japanese testing was mostly conducted in air, with limited testing in vacuum. 5) The French code, RCC-MR, takes into account cyclic softening and hysteresis symmetry. 6) Attempts to implement ASME safety factors for Gr91 resulted in calculated stresses that were higher than the creep rupture stress; the background of the K' factor from 0.9 to 0.67 needs review to determine applicability to Gr91. 7) The procedure for estimating creep-fatigue damage for various loading histories remains unclear. 8) The French creep-fatigue results and analysis of Gr91 steel will be published in the 2006 PVP Conference in Vancouver.

TASK 4: Updating of ASME Nuclear Code Case N-201:

An old draft revision of Code Case 201 has been located and will be made available for the Technical Investigator(s) for this task with the DOE-ASME agreement. PBMR has no specific need or request for revision of Code Case 201; AREVA on the other hand, does have an interest in its revision, including the addition of Gr91 steel.

TASK 5: Creep-Fatigue Procedures for Grade 91 Steel and Hastelloy XR

Hast X / XR:

Several publications available in the literature on Hast X / XR were provided by Dr. Asayama of Japan. The availability of non-published data remains to be determined, as the negotiations within the GIF continue. No further activity has taken place.

Gr91 Steel:

This DOE-ASME task has an intentional parallel activity related to Task 3 for creep-fatigue of Gr91 steel. See Task 3 above for a summary of activity within NH.

TASK 6: Graphite and Ceramic Code Development

ASME related activity on this task does not take place in NH. Ongoing efforts in this area are underway within ASME Section III as a Project Team on Graphite Core Components chaired by Dr. Burchell of ORNL. The project team is currently developing a new draft code for use of graphite as a structural material. Because of the inherent variability of graphite properties, a probabilistic approach has been adopted. Interaction with other groups (starting in 2nd quarter of 2006) is required to achieve the target date of the 1st quarter of 2007 for a partial first draft; a full first draft is targeted for 3rd quarter 2007.

TASK 7: NH Evaluation and Simplified Methods

Considerable discussion and activity has transpired related to this task, generated as a result of efforts supported by DOE at ORNL in FY2005 and FY2006. The discussions center about two major aspects of NH: 1) primary load criteria (stress based design criteria), and 2) deformation based criteria (strain limits). Note, the deformation based criteria are in the Non-Mandatory Appendix, Appendix T.

The use of the reference stress approach for primary load limits was presented on numerous occasions, summarizing results in [5]. The method, which is not new and currently is used extensively in the British R5 standard, is an attractive means of classifying stresses (primary vs. secondary). Also, the method may be implemented with the use of personal computers as an advanced technological tool, especially in circumstances where geometry and/or loading may be complex. Efforts to date are significant, but have not yet reached a stage for direct implementation into NH.

Similarly, the use of a cyclic reference stress approach for deformation based criteria has also been discussed, summarizing results obtained in [5]. In particular, there are three types of references stresses: limit load, shakedown, and ratcheting. The method is not new, but is an advanced application of reference stress techniques to cyclic applications. Similarly, development of an analytical solution to the classical Bree Problem for the case of unequal yield strengths has also been presented by Dr. McGreevy of ORNL; consequently, consideration of modifying the existing NH B-1 test was introduced and discussed. The cyclic reference stress approach and similar methods are in the early stages in their application and development into NH.

Tasks 8-12:

No mentionable activity or discussions related to these tasks have taken place.

4. SUMMARY

The DOE-ASME Collaboration Plan that addresses numerous tasks identified as priorities to codification needs for Gen IV is official. ASME has released Requests for Proposal for Technical Advisors and Technical Investigators for the first five (5) tasks. Selection of Technical Advisors and Technical Investigators has been completed, and the announcement of such results released by the time this document is published.

Many of the action items within NH are included in the tasks identified in the DOE-ASME Collaboration Plan. Consequently, various levels of discussion and activity in several of the tasks have taken place prior to any official efforts resulting directly from the DOE-ASME agreement and the RFP's. Considerable progress is expected within the next 6-12 months in the first five tasks as subcontracts should be awarded to the Technical Investigators and Advisors prior to the publication of this document. Additional ongoing work sponsored by DOE at National Laboratories such as INL and ORNL will also be included in discussions relevant to codification issues for Gen IV within ASME, particularly elevated temperature design in Subsection NH.

5. REFERENCES

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