STP-NU-019-1

# VERIFICATION OF ALLOWABLE STRESSES IN ASME SECTION III SUBSECTION NH FOR GRADE 91 STEEL



ASME STANDARDS TECHNOLOGY, LLC

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Date of Issuance: March 19, 2009

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Three Park Avenue, New York, NY 10016-5990

ISBN No. 978-0-7918-3221-9

# Summary of Changes
## March 19, 2009

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The following changes have been made to the first revision of STP-NU-019.

| *Rev. 1 Page* | *Location* | *Change* |
|---|---|---|
| *v-vi* | Table of Contents | Updated to reflect changes |
| 6 | paragraph 2, line 1 | Corrected from reference [15] to [14] |
| 6 | figure 2 | Replaced with correct figure |
| 7 | figure 3 | Replaced with correct figure |
| 8 | paragraph 2, line 2 | Corrected "if" to "of" |
| 8 | paragraph 4, line 3 | Corrected "Fave" to "$F_{ave}$" |
| 9 | equation (3) | Improved formatting |
| 9 | equation (4) | Improved formatting |
| 9 | equation (5) | Improved formatting |
| 9 | equation (6) | Improved formatting |
| 10 | paragraph 1, line 4 | Correct "Cave" to "$C_{ave}$" |
| 11 | paragraph 1, line 4 | Corrected from reference [13] to [14] |
| 11 | figure 7 | Replaced with correct figure |
| 12 | figure 9 | Replaced with correct figure |
| 13 | figure 12 | Replaced with correct figure |
| 14 | paragraph 1, line 7 | Corrected figure number from 4 to 14. |

| *Rev. 1 Page* | *Location* | *Change* |
|---|---|---|
| 19 | figure 20 | Replaced with correct figure |
| 20 | figure 22 | Replaced with correct figure |
| 24 | figure 24 | Replaced with correct figure |
| 31 | title | Deleted "**FISH**" and "**B**" from title. |
| 45 | title | Deleted "**FISH**" and "**B**" from title. |
| 76 | figure 26 | Replaced with correct figure |
| 77 | equation (11) | Improved formatting |
| 77 | equation (12) | Improved formatting |
| 79 | figure 30 | Replaced with correct figure |
| 81 | paragraph 3, line 6 | Replaced "105" with "100,000" |
| 81 | paragraph 3, line 8 | Replaced "104" with "10,000" |
| 82 | equation (13) | Improved formatting |
| 83 | figure 31 | Replaced with correct figure |
| 96 | figure 41 | Replaced with correct figure |

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# FOREWORD

This document is the result of work resulting from Cooperative Agreement DE-FC07-05ID14712 between the U.S. Department of Energy (DOE) and ASME Standards Technology, LLC (ASME ST-LLC) for the Generation IV (Gen IV) Reactor Materials Project. The objective of the project is to provide technical information necessary to update and expand appropriate ASME materials, construction and design codes for application in future Gen IV nuclear reactor systems that operate at elevated temperatures. The scope of work is divided into specific areas that are tied to the Generation IV Reactors Integrated Materials Technology Program Plan. This report is the result of work performed under Task 1 titled "Verification of Allowable Stresses in ASME Section III, Subsection NH with Emphasis on Alloy 800H and Grade 91 Steel (a.k.a., 9Cr-1Mo-V or 'Modified 9Cr-1Mo')."

ASME ST-LLC has introduced the results of the project into the ASME volunteer standards committees developing new code rules for Generation IV nuclear reactors. The project deliverables are expected to become vital references for the committees and serve as important technical bases for new rules. These new rules will be developed under ASME's voluntary consensus process, which requires balance of interest, openness, consensus and due process. Through the course of the project ASME ST-LLC has involved key stakeholders from industry and government to help ensure that the technical direction of the research supports the anticipated codes and standards needs. This directed approach and early stakeholder involvement is expected to result in consensus building that will ultimately expedite the standards development process as well as commercialization of the technology.

ASME has been involved in nuclear codes and standards since 1956. The Society created Section III of the Boiler and Pressure Vessel Code, which addresses nuclear reactor technology, in 1963. ASME Standards promote safety, reliability and component interchangeability in mechanical systems.

The American Society of Mechanical Engineers (ASME) is a not-for-profit professional organization promoting the art, science and practice of mechanical and multidisciplinary engineering and allied sciences. ASME develops codes and standards that enhance public safety and provides lifelong learning and technical exchange opportunities benefiting the engineering and technology community. Visit www.asme.org.

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## ABSTRACT

Part I Base Metal - The database for the creep-rupture of 9Cr-1Mo-V (Grade 91) steel was collected and reviewed to determine if it met the needs for recommending time-dependent strength values, St, for coverage in ASME Section III Subsection NH (ASME III-NH) to 650˚C (1200˚F) and 600,000 hours. The accumulated database included over 300 tests for 1% total strain, nearly 400 tests for tertiary creep and nearly 1700 tests to rupture. Procedures for analyzing creep and rupture data for ASME III-NH were reviewed and compared to the procedures used to develop the current allowable stress values for Gr 91 for ASME II-D. The criteria in ASME III-NH for estimating St included the average strength for 1% total strain for times to 600,000 hours, 80% of the minimum strength for tertiary creep for times to 600,000 hours and 67% of the minimum rupture strength values for times to 600,000 hours. Time-temperature-stress parametric formulations were selected to correlate the data and make predictions of the long-time strength. It was found that the stress corresponding to 1% total strain and the initiation of tertiary creep were not the controlling criteria over the temperature-time range of concern. It was found that small adjustments to the current values in III-NH could be introduced but that the existing values were conservative and could be retained. The existing database was found to be adequate to extend the coverage to 600,000 hours for temperatures below 650˚C (1200˚F).

Part II Weldments - A creep-rupture database that was used to develop stress rupture factors (SRFs) in ASME Section III Subsection NH (ASME III-NH) for weldments of 9Cr-1Mo-V (Gr 91) steel was reassembled. The intent was to review the original work, supplement the database with newer data and validate the applicability of the SRFs to longer time service to meet the needs for the Generation IV nuclear reactor materials program. After a review of the augmented database, approximately 85 of 200 data on weld metal and weldments were selected for the re-evaluation of SRFs. Data were processed using a lot-centered Larson Miller parametric analysis similar to the model used to correlate stress-rupture data for base metal. It was found that the weldments did not follow the same stress dependency in stress-rupture as base metal. As a result, the SRF values depended on both time and temperature. Some SRF values were estimated, but the long-time, low-stress SRF values were found to be lower than those values which formed a basis for the SRFs in 2007 ASME III-NH. Moreover, the lack of long-time data above 540˚C (1000˚F) made the database unsuitable for the estimation of SRFs for application to all the St values covered in ASME III-NH. The coverage needed for the Generation IV nuclear pressure vessels, however, was expected to be for temperatures below 540˚C (1000˚F). A review of European and Asian work on Gr 91 weldments provided helpful information in this respect. Although significant differences in behavior were reported from one research effort to another, special notice was taken of recent work in Japan to develop weld strength reduction factors (WSRFs) for use in the fossil and petrochemical industries. Here, the WSRFs were based on stress-rupture models applicable to welded components for long-time service to at least 600˚C (1110˚F). Further testing of Gr 91 weldments for long times and low stresses was recommended.