ASME STANDARDS TECHNOLOGY, LLC

Request for Proposal RFP-ASME ST-15-04

Request for Proposal (RFP) to Develop a Roadmap to Upgrade Nuclear Fatigue Design Criteria in ASME B&PV Code

Solicitation Date: December 24, 2014

Proposal Due Date: January 16, 2015

1. Introduction

ASME Standards Technology, LLC (ASME ST-LLC) is soliciting proposals to develop a Roadmap for upgrading nuclear fatigue design criteria in the ASME Boiler and Pressure Vessel (B&PV) Code.

This project results from a need of the Subgroup on Fatigue Strength (SGFS) for additional support to incorporate newer, less conservative nuclear component fatigue design criteria into the B&PV Code.

All open RFPs are posted on http://stllc.asme.org/Requests_Proposals_RFPs.cfm

2. Background

The fatigue design criteria used in the B&PV Code Section III and Section VIII Division 2 are essentially based on the inherent simplification that stresses and strains through the entire wall thickness are equal to the peak stresses and strains at the surface, including thermal transient peak surface stresses and stress concentration effects at notches. This simplification produces overly conservative fatigue design lives for many limiting locations and loading conditions. Attempts to upgrade the fatigue evaluation methodology for sharp notches and severe thermal transients, suitable for use in a safety code, requires interdisciplinary approaches. Such improvements are needed for the next evolution of the B&PV Code, along with environmental fatigue evaluation methods.

3. Scope of Work

The scope of work is intended to develop a roadmap to update the conservative B&PV Code and NRC fatigue design criteria that are currently used for nuclear components. Fatigue design technology has been rapidly advancing over the past twenty years, and new technical publications are currently being produced at a rate of hundreds per year. The existing fatigue design evaluation rules are conservative, resulting in design and fabrication details that are becoming increasingly expensive and restricting allowable operating conditions to those of reduced efficiency. Furthermore, the NRC's growing requirements for more comprehensive technical support for the use of new fatigue design criteria requires additional attention. This is a particular concern where the proposed new criteria allow more cycling or longer life than the current evaluation criteria.

The proposed scope of work consists of eighteen tasks, which can be divided into three phases, Phase 1 comprised of Tasks I – V, Phase 2 comprised of Tasks VI – X, and Phase 3 comprised of Tasks XI – XVIII, which are described in more details as follows.

Task I – Surface Stresses and Strains

Peak surface stresses and strains exist in very small volumes of material and their fatigue effects depend on the notch sensitivity of the material. Very brittle materials are sensitive to high local stresses and strains even though they exist only in very thin material layers at the surface. Stress and strain values taken from finite element analyses at the surface are meaningful in terms of damage and crack initiation in brittle materials; however, construction materials used in nuclear power plant construction are quite ductile and are not cracked by stresses and strains in very thin layers at the surface of the material. This is the case for most austenitic stainless steels, carbon steels and alloy steels of interest.

Accordingly, the use of the maximum stresses and strains at the surface to quantify fatigue damage does not take advantage of the real properties of these structural materials. Fracture and fatigue tests of these materials have demonstrated their limited notch sensitivity which has not been factored into methods of quantifying their safe fatigue lives in the B&PV Code for nuclear components.

Improved methods to be developed in this scope of work will be capable of using finite element analysis results and accounting for the notch sensitivity of the material, including the consideration of the stress or strain gradient at the surface, and the use of stress or strain values in a known volume of material, at a known distance from the surface. The controlling volume of material or applicable distance below the surface depends on the notch sensitivity of the material that is best obtained using correlations of notched fatigue data.

The scope of work includes systematic correlations of notched fatigue data to quantify and verify the generality of the results for a wide range of geometries and loading conditions. The use of models in these correlations will greatly extend the applicability beyond the limited available data. These improved fatigue evaluation methods shall also be modified to include environmental effects.

Task II – Short Crack Growth

The initiation of short microstructural cracks near the surface of notches and under severe thermal transient conditions is followed by their growth into macrostructural cracks long enough to be treated by continuum mechanics (without consideration of microstructural barriers.) These evaluations can be performed using short crack growth technology accounting for microstructural barriers. Such barriers are often sufficient to prevent the continued growth as microstructural cracks; a fatigue barrier not included in current B&PV Code fatigue design evaluation methods. Accordingly, there are many design details and operating conditions that can be shown to pose no fatigue issues that are nonetheless considered severe fatigue loading using the existing B&PV Code evaluation methods.

Task III – Effects of Stress and Strain Variation Through-Wall

For cases where microstructural crack growth barriers are overcome and macrostructural cracks are developed, the cracks are often propagating into much lower nominal stress fields. The stress intensity values for these cracks are often dropping at a faster rate due to the reduced continuum stresses than the increasing rate due to the increased lengths of the cracks. This would cause the crack growth rate to decrease, a phenomenon not recognized in current B&PV Code fatigue evaluations, which implicitly assume a uniform through-wall

stress. The latter simplification makes the B&PV Code fatigue design criteria overly conservative.

Decreasing crack stress intensities due to crack propagation into lower stress fields can even reduce the crack stress intensities to values below the threshold values for crack propagation, Kth, which results in non-propagating crack conditions such as surface crazing, observed in much operating equipment subjected to cyclic loading. Again, the current B&PV Code fatigue design evaluation methods do not account for this well-known fatigue mitigation phenomenon.

Task IV – Correction of Overly Conservative K_e Factor

One of the most detrimental overly conservative fatigue factors in the B&PV Code is the K_e factor of Paragraph NB-3554 "*Cyclic Stress Calculations*".

This elastic-plastic strain concentration factor, K_e is overly conservative, resulting in limited allowable fatigue loading for thermal transients. The B&PV Code reads:

> "*(c) If $S_{n(max)}$ is greater than $3S_m$ but less than $3mS_m$, the value of S_i /2 to be used for entering the design failure curve is to be found by multiplying S_i by K_e , where*:
>
> $$K_e = 1.0 + \frac{(1-n)}{n\ m-1}\ \ \frac{S_n}{3S_m} - 1$$
>
> *and where the values of the material parameters m and n are as given in Table NB-3228.5(b)-1.*
>
> *(d) If $S_{n(max)}$ is greater than $3mS_m$, use $K_e = 1/n$*."

The value of *n* is 0.2 for carbon steel up to 700º F (370°C) and the value of *n* is 0.3 for austenitic stainless steel up to 800º F (425°C). This means that the K_e factor is 5.0 for carbon steel and 3.33 for austenitic stainless steel at high strain ranges.

This task will develop new K_e factors that will eliminate most of the over-conservatism in the current factors. Because a wide range of thermal and mechanical loading conditions and geometries must be considered, this task is computationally intensive. Some of the overly conservative parts of K_e were removed in Code Case N-779 but even this 2009 Code Case has not been approved by the NRC.

Task V – Potential Use of Technical Advisory Group on Structural Integrity Approved

Potential use of the T.A.G.S.I. (Technical Advisory Group on Structural Integrity) approach for UK regulation includes consideration of the incredibility of fatigue (I.O.F.) failure for nuclear safety cases. This advice is based on the use of four legs of "conceptual arguments", each of which can consist of simplified probabilistic analyses. This technical nuclear safety case basis could be developed as a basis for environmental fatigue acceptance criteria.

Task VI – Resolution of Welding Fatigue Issues

Welding is considered a "special process" in ISO Standards and has a major influence on the quality and cost of nuclear components as well as maintenance and inspection costs. Recent trends in welding process innovations focus on improving weld quality and reducing the dependency on welder/operator skills. Fatigue strength reduction factors for weldments can be reduced by taking credit for the improved quality of welding but must include geometric and metallurgical notch effects.

Task VII – Elastic-Plastic Finite Element Fatigue Analyses

The use of elastic-plastic finite element analyses results to perform Code fatigue evaluations has raised questions regarding how to arrive at the stress intensity amplitude to be used with the fatigue design curves of the Code. Total principal strain ranges have been multiplied by one-half the modulus of elasticity of the material; however, most fatigue problems are at notches where stresses are biaxial and this practice needs to be corrected in order to obtain the correct stress intensity amplitude needed to enter the fatigue design curve. Hoop constraints tend to impose conditions close to plain strain where biaxial effects are important.

Task VIII – Resolution of NRC's Acceptance Problems with Nuclear Code Case: N-792-1, "*Fatigue Evaluations Including Environmental Effects"* Section III, Division 1

Nuclear Code Case N-792-1, "*Fatigue Evaluations Including Environmental Effects Section III, Division 1"*, provides effective environmental correction factors for performing fatigue usage factor evaluations of Class I, light water reactor coolant system and primary pressure boundary components when the effects of light water reactors coolant on fatigue are judged to be significant. This case is limited to carbon and low-alloy steels and stainless steels, and nickel-chrome-iron materials; however, the NRC will not accept this Code Case for licensing purposes, since some of the resulting design evaluations may be less conservative than their NUREG/CR-6909 design evaluations. The work to be done in this task includes making any necessary changes to Code Case N-792-1 and demonstrating that the resulting fatigue design meets acceptable safety margins.

Task IX – Resolution of NRC's Acceptance of Problems with ASME Nuclear Code Case N-761, "*Fatigue Design Curves for Light Water Reactor Environments*" Section III, Division 1

ASME Nuclear Code Case N-761, "*Fatigue Design Curves for Light Water Reactor (LWR) Environments Section III, Division 1*" contains environmental fatigue design curves for the materials of interest, which are very useful to designers.

NRC will not accept this Code Case for licensing purposes and has presented a series of criticisms and questions to the Subgroup on Fatigue Strength, indicating areas where these design curves may be less conservative than their NUREG/CR-6909 design criteria. This task includes making any necessary changes to Code Cases N-761, or demonstrating that the resulting fatigue design lives meet acceptable safety margins.

Task X – Development of Fatigue Evaluation Criteria Using Flaw Tolerance Methods

This task includes the development of fatigue evaluation criteria using flaw tolerance methods and including environmental effects. Material toughness and Section X crack growth rates to be used must be consistent with Appendix L of Section XI, and justification for meeting the intent of Section III fatigue design safety margins is needed.

Task XI – Updated Fatigue Evaluation Methods for Stainless Steels

Current B&PV Code fatigue design curves for stainless steels penalize stainless steels which have better fatigue properties than the lumped material properties, and there is no provision for taking advantage of the better fatigue properties for particular alloys. This can be corrected by more rigorous differentiation of the different alloys of stainless steels.

Task XII – Improved Methods for Mean Stress Fatigue Evaluation

Use of the linear Goodman Diagram tends to exaggerate residual stress and other mean stress effects on fatigue life. Since such stresses are difficult to quantify at notches, the

B&PV Code now uses maximum mean stress effects, limited only by the maximum stress not exceeding the yield strength of the material. Consideration of more accurate technology will help improve the current effects of using over-conservative maximum mean stress effects in B&PV Code fatigue design curves.

Task XIII – Improved Fatigue Design Criteria Based on Mechanism Modeling

The B&PV Code should take advantage of the Mechanism Modeling of Environmental Fatigue being carried out at the Argonne National Laboratory under the DOE/CSRS Program. This includes weldment fatigue testing of similar and dissimilar metal welds, both in-air and in-water, hysteresis behavior, stainless steel stress evaluation during cycling, mechanistic modeling, dynamic crack initiation and propagation modeling, tube cracking stress corrosion cracking, manufacturing residual stresses, and cyclic plasticity. Results can be used to improve overly conservative fatigue evaluation methods in the B&PV Code.

Task XIV – Use of Simple Component Test Results

The use of UK hollow cylindrical fatigue specimens with a temperature varying environment would allow consideration of through wall strain gradients: an internal notch would allow further generalization of the results. This task shall attempt to reduce overly conservative simplifications in current B&PV Code fatigue design criteria using such test results.

Task XV – Use of Strain Range Dependent Environmental Fatigue Reduction Factors

The fact that the environmental fatigue correction factors of NUREG/CR-6909 are the same for all strain ranges conflicts with the dominance of crack growth in the low cycle regime and crack initiation in the high cycle regime. F_{en} factors can be reduced for strain ranges where environmental effects are not as deleterious without reducing the minimum safety margins.

Task XVI – Correction for Higher Compression at Local Elevated Temperatures

Environmental fatigue effects are greater at higher temperatures where corrosion is more active; however, stresses tend to be more compressive at higher temperatures due to the higher local thermal expansion. Credit for differences between compression and tension would correct some current overly-conservative local fatigue evaluation results at higher temperatures.

Task XVII – Use of Operational Experience in Experimental, Commercial, and Naval Plants

Operational Experience has not been quantitatively considered in NUREG/CR-6909 environmental fatigue design criteria. These criteria are based entirely on specimen data. The effects of notches and stress raises are exaggerated when only the surface stresses/strains are used in the fatigue evaluation, because the values drop off through wall. An attempt shall be made to include test reactors, commercial reactors and naval nuclear operational fatigue experience to remove excess conservatism from the B&PV Code fatigue evaluation criteria. This will be accomplished using the Program participants' and plant operating data obtained from literature searches and data obtained from simulated components fatigue data tests.

Task XVIII – Use of European Network Inspection Qualification Methodology to Reduce Inspection Requirements

The European Network for Inspection Qualification (EMQ) has developed a European methodology for independently qualifying that an inspection actually fulfills its intended purpose. The identification of indications which are not meaningful in fatigue is a costly

activity in the nuclear industry. The benefits of inspection qualification are becoming more important as more costly inspections are being performed that have no real safety benefits. This task will evaluate what inspection technologies are useful in fatigue evaluations and which ones are not.

4. Deliverables

The key project deliverables are the following:

i. Draft Roadmap Report to update nuclear fatigue design criteria in the B&PV Code.

ii. Final Roadmap Report incorporating comments from ASME staff and volunteers as applicable.

All written deliverables shall be provided as a Microsoft Word file that is formatted in accordance with the ASME Style Guide. One (1) peer review cycle of the Draft Report is anticipated, and modifications required to the Draft Report as a result of the review cycle are the responsibility of the Consultant awarded the contract.

5. Schedule

The Consultant shall submit a schedule with its proposal that provides major milestones, deliverables, and a reporting schedule. The final deliverable should be completed no later than May 2015.

a. Status Reporting

The Consultant shall provide a brief status report on a monthly basis, via email, to the ASME ST-LLC project manager, who is identified below.

6. Applicant Eligibility Requirements

ASME ST-LLC is seeking proposals from qualified organizations including, but not limited to, engineering firms, independent consultants, academic institutions, and federally-funded research and development centers. In addition to relevant technical qualifications and experience, respondents must possess an understanding of relevant ASME codes and standards.

7. Basis for Selection and Award

ASME ST-LLC will select the winning proposal by evaluating and comparing the merits of each respondent's complete proposal, based on its potential to achieve program objectives rather than solely on evaluated technical merit or cost. Evaluation criteria will include, but not be limited to, the following:

- Respondent's technical capabilities
- Respondent's experience
- Proposal Price
- Project Schedule
- Respondent's Agreement with Terms and Conditions

ASME ST-LLC reserves the right to select, in whole or in part, any, all, or none of the proposals submitted in response to this solicitation.

8. Contract Terms and Conditions

The Project contract shall be fixed-price, including labor and expenses. ASME ST-LLC's standard terms and conditions are located at the following URL: http://files.asme.org/STLLC/13937.pdf. The final contractual terms and conditions will be negotiated between ASME ST-LLC and the Consultant.

ASME ST-LLC will provide access to the required codes, standards, and other technical references applicable to the scope of work and the Project.

9. Submission Requirements

a. Proposal Due Date

Proposals must be submitted by January 16, 2015. Respondents are encouraged to transmit its proposal before this deadline. Requests for an extension to this deadline must be sent by January 10, 2015 to the contact listed in Section 8 herein; ASME ST-LLC reserves the right to deny any and all such requests.

b. Anticipated Selection and Award Date

ASME ST-LLC intends to select the winning proposal within three weeks of the proposal deadline.

c. Proposal Preparation Costs

Proposal costs shall be borne by the respondent. This solicitation does not obligate ASME ST-LLC to pay any costs incurred in the preparation and submission of the respondent's proposal, in making necessary studies or designs for the preparation of the respondent's proposal, or to acquire or contract for any services.

d. Proposal Clarification

ASME ST-LLC reserves the right to request clarification of a proposal or to request supplemental information or both. An award for the scope of work may be made after few or no exchanges, discussions, or negotiations. Therefore, each respondent is advised to submit its most favorable proposal to ASME ST-LLC initially. ASME ST-LLC reserves the right, without qualification, to reject any or all proposals received in response to this solicitation and to select any proposal, in whole or in part, as a basis for negotiation, or award, or both. ASME ST-LLC reserves the right to modify or cancel this solicitation at any time. All questions relating to this solicitation must be submitted to the contact listed in Section 8 herein. Any amendments to this solicitation will be posted on the ASME ST-LLC website (stllc.asme.org).

e. Treatment of Proprietary Information

A proposal may include technical or other data, including trade secrets or privileged and confidential commercial or financial information, that the respondent does not want disclosed to the public or used by ASME ST-LLC for any purpose other than proposal evaluation. To protect such data, the respondent should specifically identify such data or information to be protected.

f. Proposal Preparation and Submittal Instructions

ASME ST-LLC may form a committee of subject matter experts to evaluate the technical qualifications of respondents. To help facilitate this evaluation, responses should be separated into two separate documents: a Technical Proposal and a Financial Proposal.

i. Technical Proposal must include:
   (a) Organization name and contact information.
   (b) Evidence of technical capabilities, including credentials, qualifications, capabilities, and experience of individuals and the organization.
   (c) Description of the approach to accomplish the Scope of Work.
   (d) Demonstration of the agreement with the Scope of Work.

ii. Financial Proposal must include:
   (a) A fixed-price for the entire scope of work, including applicable hourly billing rates.
   (b) An agreement with ASME's standard Terms and Conditions, or state any requested exceptions.

The respondent must submit its Technical Proposal and Financial Proposal electronically via e-mail to the ASME ST-LLC contact below. Responses must be received on or before the deadline.

10. Contact Information

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