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General Comment

See attached file(s)

Attachments

ROLLS-ROYCE COMMENTS ON NUREG-CR-6909 Rev1

COMMENTS ON NUREG/CR-6909 REV.1

EFFECT OF LWR COOLANT ENVIRONMENTS ON THE FATIGUE LIFE OF REACTOR MATERIALS

DOCKET ID: **NRC-2014-0023**

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No.	NUREG/CR-6909 REFERENCE	COMMENT
1	General	Descriptions of *"current"* and *"new"* information need to be reviewed throughout the document to ensure they are clear in the context of the publication date of this Revision 1 to NUREG/CR-6909. For example, Section 3.2.11 discusses *"the current ASME Code Section III fatigue design air curve"* for austenitic stainless steels which, it is found later, means the pre-2009-addenda curve (and therefore not the curve that will be *"current"* when Rev 1 is to be issued). This paragraph is carried over almost unchanged from Rev 0. There are many other examples of this throughout the document, including paragraphs in which it is difficult to distinguish between *"new"* data added to the database prior to analysis reported in Rev 0, and *"new"* data added between the update from Rev 0 to Rev 1. Due to these confusions, it would be easy to misinterpret some of the information in the document.
2	General	There are several figures showing predicted life versus experimental life within the document. It would be useful if run-out (runoff) data were identified in these figures to aid visual assessment of the goodness of fit of the model to the data.
3	General	Some data available in open literature suggest an interdependence of effects considered in the sub-factors and the effect of environment. This leads to possible excessive conservatism when using the approach of applying F_{en} to design curves (which are already adjusted to account for the sub-factors). These interdependencies are not discussed in the document.
4	General	Rev 1 of NUREG/CR-6909 provides no comment on strain gradients within a component, which can account for a significant amount of conservatism with the ASME fatigue method. A basic assumption of the ASME III method is that a small crack (ie 3 mm depth) in a cylindrical test specimen initiates and grows at the same rate as in a pressure vessel component when both are subject to the same cyclic surface strain range. This similitude holds true for some definitions of crack initiation (say, the formation of a 0.25 mm crack), but in many cases, with continued cycling, this equality is not maintained. It depends upon the immediate sub-surface conditions into which the crack grows. If the crack enters a decreasing stress field (typical of that due to thermal shock) it will take more cycles for the crack to grow to a pre-defined length (3 mm) than for a stress field that is uniform across the section, as is the case in a standard strain-controlled ε-N test. This potential conservatism should be discussed in Rev 1.
5	General	The Federal Register Notice for NRC-2014-0023 dated April 17, 2014 (Vol.79, No.74) stated that the NRC was particularly interested in stakeholder feedback on three areas, the third of which was: *"Accuracy check of the technical content of the NUREG, particularly with respect to all of the numerical content of the report."* As a stakeholder, we do not consider that the time allowed for public comment, ie up to June 2, 2014 allows us to give detailed feedback on the numerical content and accuracy of the report.

6	Section 1.2, Page 4	The NUREG needs to be clear with respect to what the factors applied to derive the design fatigue curve are for. This was clear in the past, ie *"not safety margins but rather adjustment factors that are applied to small-specimen data to account for the effects of variables that are known to affect fatigue life but are not accounted for in small-specimen data"*. Page 4 indicates that the fatigue design curves are now defined to estimate an acceptable fatigue life for 95% of the population. Please provide a definition of the purpose of the design factors that clearly identifies whether they are transference factors or are derived to provide an acceptable fatigue life for 95% of the population (or both?). Also provide a reference to the section in NUREG/CR-6909 that provides substantiation to the 95% value.
7	Section 1.2, Page 5	σ_y should be specified as cyclic yield strength for the modified Goodman relationship – eg Jaske and O'Donnell, Journal of Pressure Vessel Technology, November 1977.
8	Figure 16, Page 28,	Figure 16 does not seem to match the text in Section 2.2.1.4 indicating that the figure has not been scanned into the document correctly.
9	Section 2.2.2.4, Page 34	With respect to the cited paper (Reference 44), a more recent paper by Kamaya is available: "Environmental effect on fatigue strength of stainless steel in PWR primary water – Role of crack growth acceleration in fatigue life reduction, Int. Jnl. Fat. 55 (2013) 102- 111". Kamaya's paper concludes that *"reduction in fatigue life due to PWR water environment was brought about not by enhancement of crack initialisation but by the acceleration of crack growth"*. The tests reported in the paper were carried out at relatively high strain amplitude. Therefore there is some evidence to suggest that the predominant effects of environment, with respect to the phases of crack development, may be dependent upon strain amplitude. Rev 1 should recognise more recent research in this topic area.
10	Section 2.2.2.4, Page 35	With respect to referring to Reference 208 *"as existing fatigue crack growth data"*, this data is very old, circa mid-nineties. For PWR it has been superseded by that which forms the basis of the draft ASME Code Case N809. This data is extensive and has been reported via several PVP papers and unlike Reference 208 fully recognises the possible deleterious effects of PWR environment. Reference to the more up to date data should be made.
11	Section 2.2.2.4, Page 37	It is judged that based upon more recent SS fatigue crack growth (FCG) rate data a comparison of Alloy 600 with austenitic SS in PWR environments would show the SS to be significantly higher. The statement *"Fatigue CGR data indicate that enhancement of CGRs of Alloy 600 and austenitic SSs in LWR environments is also comparable"* is therefore open to question. To substantiate the statement made, a comparison of the SS laws of Code Case N809 with those in NUREG/CR-6176 should be provided.
12	Section 3.1.6	The description of the method used by ANL to develop a best-fit line is greatly improved. However, there is no mention of how run-out (runoff) data are considered in the analysis. It would be useful for this to be clarified in the text.

13	Section 3.1.7, Page 49	Why is the dataset for A216-Gr WCC excluded? Is it excluded because it is a casting? It does not appear that inclusion of the value of A of 4.899 for this dataset would significantly change the median value for carbon steels. Does exclusion of this material mean that the best-fit for carbon steels is not considered relevant to this alloy? If so, which best-fit should be used for this alloy?
14	Section 3.2.1, Figure 38, Page 58	For lives > 10^5 cycles, data for Type 304L SS at both 150°C and 300°C show significantly lower lives than suggested by the ANL best-fit. There is no reference to this in the text except a generic statement that *"results...show excellent agreement with the ANL model with respect to the mean data curve"*. Figure 38 suggests that the high cycle fatigue behaviour of Type 304L is quite different to the ANL model; this requires further clarification and discussion. A difference in behaviour of Type 304L compared to other austenitic stainless steels is discussed in Section 4.2.1 (Page 114).
15	Section 3.2.1, Page 59	The quoted *"commonly used"* monotonic yield strength for austenitic stainless steels of 303 MPa is well above the average yield strength for materials in the database, from review of the information provided in Appendix B2. It is suggested that this value is updated or a range of "typical" values quoted. Also, in the context of mean stress correction described here, should a cyclic yield strength be quoted instead of a monotonic value? (see also Comment No. 7)
16	Section 3.2.2, Page 60	The effects of specimen geometry are considered, but only for parallel-sided gauge and hourglass specimens, whereas the database includes tube specimens. Are results from tube specimens also comparable?
17	Section 3.2.3, Page 61	The effect of strain rate on fatigue life of stainless steels in air is concluded to be insignificant. For temperatures less than 400°C, this is based on a single paper. More recently published data suggests that there could be a significant effect in this temperature range, for example: De Baglion and Mendez, "Low cycle fatigue behaviour of a type 304L austenitic stainless steel in air or vacuum, at 20°C or at 300°C: relative effect of strain rate and environment", Procedia Engineering 2 (2010), pp 2171-2179. Similarly, Figure 42 of NUREG/CR-6909 Rev 1, shows a potentially significant effect of strain rate on life at 288°C for Types 316NG and 304 SS.
18	Equation 29, Page 64 and Figure 38, Page 58	Equation 29 is stated to be valid for Types 304, 304L, 316, 316L and 316NG stainless steels. Following the addition of a chart for Type 304L, data for all of these grades are now shown in Figure 38 (Page 58) with the exception of Type 316L. Could a chart for Type 316L also be added to Figure 38?
19	Section 3.2.10, Page 68	The implication here is that the *"surface finish and environment"* sub-factor is sufficient to account for the effects of variations in surface finish in the air environment, but this is based on just two data points for specimens with non-standard surface finish that show an approximate factor of 3 reduction in life. Additional relevant data for the air environment from Le Duff is shown in Figure 109 (Page 136) and should also be discussed here. Further data of relevance is available in open literature and could also be discussed.

20	Section 3.3	The fatigue behaviour of Inconel 718 is discussed. It is stated that *"the fatigue behaviour of Inconel 718 should be represented by a separate fatigue ε-N curve"*, but it is not clear whether the Jaske and O'Donnell model reviewed in the text is being recommended or if development of a new fit is proposed. Further, this statement of a requirement for a separate curve is not consistent with the summary at the end of Section 3.3.2, which suggests that the current model for austenitic stainless steels is acceptable (if conservative) for Inconel 718. Is a separate curve required or not?
21	Section 4.1	The potential non-conservatism of environmental factors for low-sulphur steels is dismissed as *"associated with laboratory test data and not likely to be applicable to LWR operating conditions"*. Presumably this is because the DO content (1ppm) is greater than found in operating LWRs. The reason for the dismissal of this identified non-conservatism should be stated.
22	Section 4.1, Pages 77 and 78	Equations presented on Pages 77 and 78 should be clearly marked as being superseded by the updated equations presented in Sections 4.1.10 and 4.1.11. There is only a brief mention in this section that these equations have been updated, within the text and without a reference to the section containing updated equations. There is a risk that users of this large updated document (Rev 1) could unwittingly use the old equations, believing that they are the current versions.
23	Page 82, First Paragraph, Line 10	Clarify what is meant by *"....slow compressive loading near peak tensile loads."* Is it a reducing strain, but just after reaching the peak tensile condition?
24	Equation 41, Page 98	The new form of F_{en} expression is not consistent with statements elsewhere in the document. For example, Section 4.1.2 (Page 82) states that *"only a moderate decrease in fatigue life was observed in ...PWR water"*; Section 4.1.3 (Page 88) states that *"the equations may consider a threshold strain rate below which environment has no effect on fatigue lives (i.e., F_{en} = 1)"*; Section 7 (p174) states that, for carbon and low-alloy steels, *"expressions were revised so that the value of F_{en} was 1...when any one of the threshold conditions was not satisfied"*. In fact, F_{en} values considerably greater than 1 can result when one or more of the threshold values is not satisfied.
25	Sections 4.1.11 and 4.2.13	Threshold strain amplitudes are not mentioned in these sections (which deal with environmental fatigue correction factors). Reference to these thresholds should be included for clarity; although it is noted that the factors are included in preceding sections – ie Sections 4.1.10 and 4.2.12 – and in Appendix A. It is suggested elsewhere in the document that these thresholds are documented in these sections – eg the final paragraph of Section 4.2.3 (Page 118).
26	Section 4.1.11	There is no mention of whether the revised F_{en} expression is recommended only for fatigue lives up to 10^6 cycles. The previous (Rev 0) expression was recommended only for up to 10^6 (Section 4.1, Page 78), as are the Rev 0 and revised (Rev 1) expressions for stainless steels (Section 4.2, Page 110; Section 4.2.13, Page 129). The figures in Section 4.1.11 suggest that this limitation should apply. Please clarify.
27	Section 4.2, Page 110	As for Section 4.1, equations in this Section should be clearly marked as being superseded by equations in Section 4.2.13 (Page 129).

28	Section 4.2.2	The upper threshold for an effect of strain rate has been increased from 0.4%/s (Rev 0) to 10%/s (Rev 1). It is stated that this change is based on re-analysis of the increased database, yet Figures 85 and 86 show only the same data that were presented in Rev 0 (Figures 44 and 45) which extend to a maximum strain rate of 0.4%/s. What is the basis of the increase to 10%/s?
29	Section 4.3.3, Pages 141 and 144	It is confusing that on Page 141 a set of equations are provided for F_{en} factors for Ni-Cr-Fe Alloys, yet on Page 144 the following statement is made *"Due to significantly less available data for Ni-Cr-Fe materials compared to carbon and low-alloy steels and austenitic SS, the updated austenitic SS F_{en} expression may be used to incorporate environmental effects into ASME Code Section III fatigue evaluations for Ni-Cr-Fe materials"*. The inference is that there is little confidence attached to the equations given on Page 141 and their use is questionable. A clear statement should be provided on whether: (i) the austenitic SS F_{en} expression should be used for Ni-Cr-Fe alloys, or, (ii) the Ni-Cr-Fe F_{en} expression described earlier in the section should be used (which is consistent with Appendix A), or, (iii) the Ni-Cri-Fe F_{en} expression should be used but it is acceptable to use the austenitic SS expression instead.
30	Section 5	This section should clearly state a recommendation for factors that should be used to derive design curves from best fit data. It is implied elsewhere that the continued use of factors of 12 and 2 is proposed. If this is the case, why is it not appropriate to recommend use of the revised factor of 10 on life? A brief explanation is included in the Executive Summary, but not in the Section 5 discussion.
31	Section 5, Pages 148 and 154	It is a concern that significant effort has been made in shifting the factor on cycles from 20 to 12 and now 10, but very little time and effort has been spent in understanding and explaining the factor of 2 on stress.
32	Section 6, Page 158	This section assesses validation of the revised F_{en} expressions against a number of existing component feature tests and claims that they all tie-in with the model in terms of experimental versus predicted cycles to within a factor of x2 that would be expected for material variability/data scatter. However, all of the feature tests are considered to be mainly membrane loading tests. The one key test that is repeatedly discussed by those involved with this environmental fatigue issue, and appears in various PVP papers, is the Bettis Stepped Pipe test. This test did include a strain gradient from severe thermal shocks yet the NUREG/CR-6909 Rev 1 discounts this test due to the claim (Page 158) that the reported estimates of elastic and plastic total strains are not reliable. This is something that is vitally important to resolve. There are reliable elastic and elastic-plastic strain estimates available from several independent sources that could be used to compare numerical predictions with the stepped pipe results. The basis for excluding the stepped pipe tests from the validation study should be further explained, or the results included.
33	Section 6.1, Page 159	Figure 122 is missing.

34	Section 6.2, Page 164	With regard to the data from Le Duff et al, it is stated that the *"behaviour is considered unique to this specific strain loading cycle"*. In fact, the loading rates and waveform are representative of an actual load cycle within plant, unlike the idealised triangular waveforms used in the standard cylindrical test specimen testing. Further explanation is therefore required to explain why the behaviour is considered unique. The same comment applies to discussion of these tests in the summary (Section 7) on Page 176.
35	Section 6.2, Page 164	The summary statement *".....however the predicted values were within the range of data scatter"*, is true, but all the values are consistently at the lower extreme, and this conclusion is misleading in suggesting that the results obtained were due to data scatter. Apart from loading waveform, all other parameters (surface finish, loading, size) are the same between the tests, and a reasonable expectation would be that the complex waveform tests should provide experimental F_{en} values closer to those calculated, not consistently under-predict them. Reasons for the apparent conservative nature of the calculated F_{en} values should be provided. Are the calculated F_{ens} "best estimate", in which case the experimental values would reasonably be expected to be scattered either side, or are they purposefully conservative? In light of the results provided by Le Duff this should be discussed in NUREG/CR-6909 Rev 1.
36	Appendix A	The recommendation that F_{en} expressions should be used only for predicting fatigue lives up to 10^6 cycles is not mentioned in this section. It should be included to avoid inappropriate application of these expressions.
37	Appendix B, Table B2	Please check that the values of YS and UTS are correct for Mat. ID 13 and 14.
38	Appendix B, Table B3	Please check that the values of YS and UTS are correct for Mat. ID 8.
39	Appendix C, Figure C-1	Please show the x, y and z axes on Figure C.1 in order to correlate with the stresses shown in Figures C.3 to C.5.
40	Appendix C, Section C3	The value of Young's Modulus used in the sample problem should be provided.
41	Appendix C, Page C-10, B iv	There is incorrect wording or missing text.
42	Appendix C Table C5	Consideration should be given to presenting this data graphically.