4.3 METAL FATIGUE

Review Responsibilities

Primary- Branch responsible for mechanical engineering
Secondary- None

4.3.I Areas of Review

A metal component subjected to cyclic loading at loads less than the static design load may fail because of fatigue. Metal fatigue of components may have been evaluated based on an assumed number of transients or cycles for the current operating term. The validity of such metal fatigue analysis is reviewed for the period of extended operation.

4.3.1.1 Time-Limited Aging Analysis

Metal components may be designed or analyzed based on guidance in the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code or the American National Standards Institute (ANSI) requirements. These codes contain explicit metal fatigue or cyclic considerations based on time-limited aging analyses.

4.3.1.1.1 ASME Section III, Class 1

ASME Class 1 components, which include core support structures, are analyzed for metal fatigue. ASME Section III (Ref. 1) requires a fatigue analysis for Class 1 components considering all transient loads based on the anticipated number of transients. A Section III Class 1 fatigue analysis requires the calculation of the "cumulative usage factor" (CUF) based on the fatigue properties of the materials and the expected fatigue service of the component. The ASME Code limits the CUF to a value of less than unity for acceptable fatigue design. The fatigue resistance of these components during the period of extended operation is an area of review.

4.3.1.1.2 ANSI B31.1

ANSI B31.1 (Ref. 2) does not require an explicit fatigue analysis. It specifies allowable stress levels based on the number of anticipated thermal cycles. ANSI B31.1 applies only to piping. The specific allowable stress reductions due to thermal cycles are listed in Table 4.3-1. For example, the allowable stress would be reduced by a factor of 1.0, that is, no reduction, for piping that is not expected to experience more than 7,000 thermal cycles during plant service but would be reduced to half of the maximum allowable static stress for 100,000 or more thermal cycles. The fatigue resistance of these components during the period of extended operation is an area of review.

4.3.1.1.3 Other Evaluations Based on CUF

The codes also contain metal fatigue analysis requirements based on a CUF calculation [the 1969 edition of ANSI B31.7 (Ref. 3) for Class 1 piping, ASME NC-3200 vessels, ASME NE-3200 Class MC components, and metal bellows designed to ASME NC-3649.4(e)(3), ND-3649.4(e)(3), or NE-3366.2(e)(3)]. For these components, the discussion relating to ASME Section III, Class 1 in Subsection 4.3.1.1.1 of this review plan section applies.

4.3.1.1.4 ASME Section III, Class 2 and 3

ASME Section III, Class 2 and 3 piping cyclic design requirements are similar to those for ANSI B31.1. The discussion relating to B31.1 in Subsection 4.3.1.1.2 of this review plan section applies.

4.3.1.2 Generic Safety Issue

The fatigue design criteria for nuclear power plant components has changed as the industry consensus codes and standards have evolved. The fatigue design criteria for a specific component depend on the version of the design code that applied to that component, that is, the code of record. There is a concern that the effects of the reactor coolant environment on the fatigue life of component was not adequately addressed by the code of record.

The Commission has decided that the adequacy of the code of record relating to metal fatigue is a potential safety issue to be addressed by the current regulatory process for operating reactors (Refs. 4 and 5). The effects of fatigue for the initial 40-year initial reactor license period were studied and resolved under Generic Safety Issue (GSI)-78, “Monitoring of Fatigue Transient Limits for Reactor Coolant System,” and GSI-166, "Adequacy of Fatigue Life of Metal Components" (Ref. 6). GSI-78 addressed whether fatigue monitoring was necessary at operating plants. As part of the resolution of GSI-166, an assessment was made of the significance of the more recent fatigue test data on the fatigue life of a sample of components in plants were Code fatigue design analysis had been performed. The efforts on fatigue life estimation and ongoing issues under GSI-78 and GSI-166 for 40-year plant life were addressed separately under a staff generic task action plan (Refs. 7 and 8). The staff documented its completion of the fatigue action plan in SECY-95-245 (Ref. 9).

SECY-95-245 was based on a study described in NUREG/CR-6260, "Application of NUREG/CR-5999 Interim Fatigue Curves to Selected Nuclear Power Plant Components" (Ref. 10). In NUREG/CR-6260, sample locations in the plant with high fatigue usage were evaluated. Conservatisms in the original fatigue calculations, such as actual cycles versus assumed cycles, were removed and the fatigue usage was recalculated using a fatigue curve considering the effects of the environment. The staff found that most of the locations would have a CUF of less than the ASME Code limit of 1.0 for 40 years. On the basis of the component assessments, supplemented by a 40-year risk study, the staff concluded that a backfit of the environmental fatigue data to operating plants could not be justified. However, because the staff was less certain that sufficient excessive conservatisms in the original fatigue calculations could be removed to account for an additional 20 years of operation for renewal, the staff recommended in SECY-95-245 that the samples in NUREG/CR-6260 should be evaluated considering environmental effects for license renewal. GSI-190, “Fatigue Evaluation of Metal Components for 60-year Plant Life,” was established to address the residual concerns of GSI-78 and GSI-166 regarding the environmental effects on fatigue on pressure boundary components for 60-years of plant operation.

The scope of GSI-190 included design basis fatigue transients, studying the probability of fatigue failure and its effect on core damage frequency (CDF) of selected metal components for 60-year plant life. The study showed that some components have cumulative probabilities of crack initiation and through-wall growth that approach unity within the 40- and 60-year period. The maximum failure rate (through-wall cracks per year) was in the range of 10^{-2} per year, and those failures were generally associated with high cumulative usage factor locations and components with thinner walls, i.e., pipes more vulnerable to through-wall cracks. In most cases, the leakage from these through-wall cracks is small and not likely to lead to core damage. Based on the results of probabilistic analyses, along with the sensitivity studies performed, the interactions with the industry (NEI and EPRI), and different approaches available to the licensees to manage the effects of aging, it was concluded that no generic regulatory action is required, and that GSI-190 is resolved (Ref. 11). However, the calculations supporting resolution of this issue, which included consideration of environmental effects, and the nature of age-related degradation indicate the potential for an increase in the frequency of pipe leaks as plants continue to operate. Thus, the staff concluded that licensees must address the effects of coolant environment on component fatigue life as aging management programs are formulated in support of license renewal.

An applicant's consideration of the effects of coolant environment on component fatigue life for license renewal is an area of review.

4.3.1.3 FSAR Supplement

Detailed information on the evaluation of time-limited aging analyses is contained in the renewal application. A summary description of the evaluation of time-limited aging analyses for the period of extended operation is contained in the applicant's final safety analysis report (FSAR) supplement. The FSAR supplement is an area of review.

4.3.2 Acceptance Criteria

The acceptance criteria for the areas of review described in Subsection 4.3.1 of this review plan section define acceptable methods for meeting the requirements of the Commission's regulations in 10 CFR 54.21(c)(1).

4.3.2.1 Time-Limited Aging Analysis

Pursuant to 10 CFR 54.21(c)(1)(i) through (iii), an applicant must demonstrate one of the following:

(i) the analyses remain valid for the period of extended operation,

(ii) the analyses have been projected to the end of the extended period of operation, or

(iii) the effects of aging on the intended function(s) will be adequately managed for the period of extended operation.

Specific acceptance criteria for metal fatigue are:

4.3.2.1.1 ASME Section III, Class 1

For components designed or analyzed to ASME Class 1 requirements, the acceptance criteria, depending on the applicant's choice, that is, 10 CFR 54.21(c)(1)(i), (ii), or (iii), are:

4.3.2.1.1.1 10 CFR 54.21(c)(1)(i)

The existing CUF calculations remain valid because the number of assumed transients would not be exceeded during the period of extended operation.

4.3.2.1.1.2 10 CFR 54.21(c)(1)(ii)

The CUF calculations have been re-evaluated based on an increased number of assumed transients to bound the period of extended operation. The resulting CUF remains less than unity as required by the code during the period of extended operation.

4.3.2.1.1.3 10 CFR 54.21(c)(1)(iii)

The effects of aging on the intended function(s) will be adequately managed for the period of extended operation. The component could be replaced and the CUF for the replacement will be less than unity during the period of extended operation.

Alternative acceptance criteria under 10 CFR 54.21(c)(1)(iii) have yet to be developed and will be evaluated on a case-by-case basis to ensure that the aging effects will be managed such that the intended functions(s) will be maintained during the period of extended operation.

4.3.2.1.2 ANSI B31.1

For piping designed or analyzed to B31.1 requirements, the acceptance criteria, depending on the applicant's choice, that is, 10 CFR 54.21(c)(1)(i), (ii), or (iii), are:

4.3.2.1.2.1 10 CFR 54.21(c)(1)(i)

The existing allowable stresses remain valid because the number of assumed thermal cycles would not be exceeded during the period of extended operation.

4.3.2.1.2.2 10 CFR 54.21(c)(1)(ii)

The allowable stresses have been re-evaluated based on an increased number of assumed thermal cycles and Table 4.3-1 to bound the period of extended operation. The resulting allowable stresses remain sufficient as required by the code during the period of extended operation.

4.3.2.1.2.3 10 CFR 54.21(c)(1)(iii)

The effects of aging on the intended function(s) will be adequately managed for the period of extended operation. The component could be replaced and the allowable stresses for the replacement will be sufficient as required by the code during the period of extended operation.

Alternative acceptance criteria under 10 CFR 54.21(c)(1)(iii) have yet to be developed and will be evaluated on a case-by-case basis to ensure that the aging effects will be managed such that the intended functions(s) will be maintained during the period of extended operation.

4.3.2.1.3 Other Evaluations Based on CUF

The acceptance criteria in Subsection 4.3.2.1.1 of this review plan section apply.

4.3.2.1.4 ASME Section III, Class 2 and 3

The acceptance criteria in Subsection 4.3.2.1.2 of this review plan section apply.

4.3.2.2 Generic Safety Issue

The staff recommendation for the closure of GSI–190 is contained in a December 26, 1999, memorandum from Ashok Thadani to William Travers (Ref. 11). The staff recommended that licensees address the effects of the coolant environment on component fatigue life as aging management programs are formulated in support of license renewal. One method acceptable to the staff of satisfying this recommendation is to assess the impact of the reactor coolant environment on a sample of critical components. These critical components should include, as a minimum, those components selected in NUREG/CR–6260 (Ref. 10). The sample of critical components can be evaluated by applying environmental correction factors to the existing ASME Code fatigue analyses. Formulas for calculating the environmental life correction factors for carbon and low–alloy steels are contained in NUREG/CR–6583 (Ref. 12) and those for austenitic stainless steels are contained in NUREG/CR–5704 (Ref. 13).

4.3.2.3 FSAR Supplement

The specific criterion for meeting 10 CFR 54.21(d) is:

The summary description of the evaluation of time-limited aging analyses for the period of extended operation in the FSAR supplement provides appropriate description such that later changes can be controlled by 10 CFR 50.59. The description should contain information associated with the time-limited aging analysis regarding the basis for determining that aging effects are managed in the period of extended operation.

4.3.3 Review Procedures

For each area of review described in Subsection 4.3.1 of this review plan section, the following review procedures are followed:

4.3.3.1 Time-Limited Aging Analysis

4.3.3.1.1 ASME Section III, Class 1

For components designed or analyzed to ASME Class 1 requirements, the review procedures, depending on the applicant's choice, that is, 10 CFR 54.21(c)(1)(i), (ii), or (iii), are:

4.3.3.1.1.1 10 CFR 54.21(c)(1)(i)

A list of the assumed transients used in the existing CUF calculations for the current operating term and operating transient experience is reviewed to ensure that the number of assumed transients would not be exceeded during the period of extended operation.

4.3.3.1.1.2 10 CFR 54.21(c)(1)(ii)

A list of the increased number of assumed transients projected to the end of the period of extended operation and operating transient experience is reviewed to ensure that the transient projection is adequate. The revised CUF calculations based on the projected number of assumed transients are reviewed to ensure that the CUF remains less than unity at the end of the period of extended operation.

The code of record should be used for the re-evaluation, or the applicant may update to a later code edition pursuant to 10 CFR 50.55a. In the latter case, the reviewer verifies that the requirements in 10 CFR 50.55a are met.

4.3.3.1.1.3 10 CFR 54.21(c)(1)(iii)

The applicant's proposed program to ensure that the effects of aging on the intended function(s) will be adequately managed for the period of extended operation is reviewed. If the applicant proposed component replacement before its CUF exceeds unity, the reviewer verifies that the CUF for the replacement will remain less than unity during the period of extended operation.

Other applicant proposed programs will be reviewed on a case-by-case basis.

4.3.3.1.2 ANSI B31.1

For piping designed or analyzed to ANSI B31.1 requirements, the review procedures, depending on the applicant's choice, that is, 10 CFR 54.21(c)(1)(i), (ii), or (iii), are:

4.3.3.1.2.1 10 CFR 54.21(c)(1)(i)

A list of the assumed thermal cycles used in the existing allowable stress determination and operating cyclic experience is reviewed to ensure that the number of assumed thermal cycles would not be exceeded during the period of extended operation.

4.3.3.1.2.2 10 CFR 54.21(c)(1)(ii)

A list of the increased number of assumed thermal cycles projected to the end of the period of extended operation and operating cyclic experience is reviewed to ensure that the thermal cycle projection is adequate. The revised allowable stresses based on the projected number of assumed thermal cycles and Table 4.3-1 are reviewed to ensure that they remain sufficient as required by the code during the period of extended operation.

The code of record should be used for the re-evaluation or the applicant may update to a later code edition pursuant to 10 CFR 50.55a. In the latter case, the reviewer verifies that the requirements in 10 CFR 50.55a are met.

4.3.3.1.2.3 10 CFR 54.21(c)(1)(iii)

The applicant's proposed program to ensure that the effects of aging on the intended function(s) will be adequately managed for the period of extended operation is reviewed. If the applicant proposed component replacement before it exceeds the assumed thermal cycles, the reviewer verifies that the allowable stresses for the replacement will remain sufficient as required by the code during the period of extended operation. Other applicant-proposed programs will be reviewed on a case-by-case basis.

4.3.3.1.3 Other Evaluations Based on CUF

The review procedures in Subsection 4.3.3.1.1 of this review plan section apply.

4.3.3.1.4 ASME Section III, Class 2 and 3

The review procedures in Subsection 4.3.3.1.2 of this review plan section apply.

4.3.3.2 Generic Safety Issue

The reviewer verifies that the applicant has addressed the staff recommendation for the closure of GSI–190 contained in a December 26, 1999, memorandum from Ashok Thadani to William Travers (Ref. 11). The reviewer verifies that the applicant has addressed the effects of the coolant environment on component fatigue life as aging management programs are formulated in support of license renewal. If an applicant has chosen to assess the impact of the reactor coolant environment on a sample of critical components, the reviewer verifies the following:

1. The critical components include, as a minimum, those components selected in NUREG/CR–6260 (Ref. 10).

2. The sample of critical components have been evaluated by applying environmental correction factors to the existing ASME Code fatigue analyses.

3. Formulas for calculating the environmental life correction factors are those contained in NUREG/CR–6583 (Ref. 12) for carbon and low–alloy steels, and in NUREG/CR–5704 (Ref. 13) for austenitic stainless steels.

4.3.3.3 FSAR Supplement

The reviewer verifies that the applicant has provided a FSAR supplement on the summary description of the evaluation of the metal fatigue TLAA. Table 4.3-2 of this review plan section contains examples of acceptable FSAR supplement information for this TLAA. The reviewer verifies that the applicant has provided a FSAR supplement using a format similar to that in Table 4.3-2.

4.3.4 Evaluation Findings

The reviewer verifies that sufficient and adequate information has been provided to satisfy the provisions of this review plan section and that the staff's evaluation supports conclusions of the following type depending on the applicant's choice of 10 CFR 54.21(c)(1)(i), (ii), or (iii), to be included in the staff's safety evaluation report.

> The staff evaluation concludes that the applicant has provided an acceptable demonstration, pursuant to 10 CFR 54.21(c)(1), that, for the metal fatigue TLAA, (i) the analyses remain valid for the period of extended operation, (ii) the analyses have been projected to the end of the period of extended operation, or (iii) the effects of aging on the intended function(s) will be adequately managed for the period of extended operation. The staff also concludes that the FSAR supplement contains an appropriate summary description of the metal fatigue TLAA evaluation for the period of extended operation.

4.3.5 Implementation

Except in those cases in which the applicant proposes an acceptable alternative method, the method described herein will be used by the staff in its evaluation of conformance with Commission regulations.

4.3.6 References

1. ASME Boiler and Pressure Vessel Code, Section III, "Rules for Construction of Nuclear Power Plant Components," American Society of Mechanical Engineers.

2. ANSI/ASME B31.1, "Power Piping," American National Standards Institute.

3. ANSI/ASME B31.7-1969, "Nuclear Power Piping," American National Standards Institute.

4. SECY-93-049, "Implementation of 10 CFR Part 54, 'Requirements for Renewal of Operating Licenses for Nuclear Power Plants,'" March 1, 1993.

5. Staff Requirements Memorandum from Samuel J. Chilk, dated June 28, 1993.

6. NUREG-0933, "A Prioritization of Generic Safety Issues," Supplement 20, July 1996.

7. Letter from William T. Russell of NRC to William Rasin of the Nuclear Management and Resources Council, dated July 30, 1993.

8. SECY-94-191, "Fatigue Design of Metal Components," July 26, 1994.

9. SECY-95-245, "Completion of The Fatigue Action Plan," September 25, 1995.

10. NUREG/CR-6260, "Application of NUREG/CR-5999 Interim Fatigue Curves to Selected Nuclear Power Plant Components," March 1995.

11. Letter from Ashok C. Thadani of the Office of Nuclear Regulatory Research to William D. Travers, Executive Director of Operations, dated December 26, 1999.

12. NUREG/CR-6583, "Effects of LWR Coolant Environments on Fatigue Design Curves of Carbon and Low–Alloy Steels," March 1998.

13. NUREG/CR-5704, "Effects of LWR Coolant Environments on Fatigue Design Curves of Austenitic Stainless Steels," April 1999.

Table 4.3-1. Stress Range Reduction Factors

Number of Equivalent Full Temperature Cycles	Stress Range Reduction Factor
7,000 and less	1.0
7,000 to 14,000	0.9
14,000 to 22,000	0.8
22,000 to 45,000	0.7
45,000 to 100,000	0.6
100,000 and over	0.5

Table 4.3-2. Examples of FSAR Supplement for Metal Fatigue TLAA Evaluation

TLAA	Description of Evaluation	Implementation Schedule
Metal Fatigue	In order not to exceed the design limit on fatigue usage and the number of design cycles, the aging management program monitors and tracks the number of critical thermal and pressure test transients, and monitors the cycles for the selected reactor coolant system components. The aging management program will address the effects of the coolant environment on component fatigue life by assessing the impact of the reactor coolant environment on a sample of critical components that include, as a minimum, those components selected in NUREG/CR–6260. The sample of critical components can be evaluated by applying environmental correction factors to the existing ASME Code fatigue analyses. Formulas for calculating the environmental life correction factors are contained in NUREG/CR–6583 for carbon and low–alloy steels and in NUREG/CR–5704 for austenitic stainless steels.	Evaluation will be completed by…