UNITED STATES
NUCLEAR REGULATORY COMMISSION
ADVISORY COMMITTEE ON REACTOR SAFEGUARDS
WASHINGTON, DC 20555 - 0001

November 21, 2006

MEMORANDUM TO: ACRS Members

FROM: Charles G. Hammer, Senior Staff Engineer
Technical Support Branch, ACRS

SUBJECT: TRANSMITTAL OF STATUS REPORT AND PROPOSED SCHEDULE REGARDING REGULATORY GUIDE 1.207 (DG-1144), "GUIDELINES FOR EVALUATING FATIGUE ANALYSES INCORPORATING THE LIFE REDUCTION OF METAL COMPONENTS DUE TO THE EFFECTS OF THE LIGHT-WATER REACTOR ENVIRONMENT FOR NEW REACTORS"

The Materials, Metallurgy, and Reactor Fuels Subcommittee will meet on December 6, 2006, to review Regulatory Guide 1.207 (DG-1144), "Guidelines for Evaluating Fatigue Analyses Incorporating the Life Reduction of Metal Components Due to the Effects of the Light-Water Reactor Environment for New Reactors." The full Committee will review this Regulatory Guide during the 538th ACRS meeting, December 7-9, 2006.

To prepare for these meetings, the following documents are attached:

1. Status Report

2. Proposed Schedule for December 6, 2006, Subcommittee meeting

3. Proposed Schedule for December 7, 2006, full Committee meeting

Other review materials including: RG 1.207, NUREG/CR-6909 Rev. 1, and Staff Responses to Public Comments, were transmitted to you separately by a memorandum dated November 16, 2006. If you have any questions, please contact me at (301) 415-7363 or cgh@nrc.gov.

cc wo/Attachments: J. Larkins
M. Snodderly
S. Duraiswamy
C. Santos

UNITED STATES
NUCLEAR REGULATORY COMMISSION
ADVISORY COMMITTEE ON REACTOR SAFEGUARDS
WASHINGTON, DC 20555 - 0001

ADVISORY COMMITTEE ON REACTOR SAFEGUARDS
REVIEW OF REGULATORY GUIDE 1.207 (DG-1144)
GUIDELINES FOR EVALUATING FATIGUE ANALYSES INCORPORATING THE LIFE REDUCTION OF METAL COMPONENTS DUE TO THE EFFECTS OF THE LIGHT-WATER REACTOR ENVIRONMENT FOR NEW REACTORS
December 6, 2006
ROCKVILLE, MARYLAND

**- STATUS REPORT -**

PURPOSE:

The purpose of this session is to review the Regulatory Guide 1.207 (DG-1144) being developed by the Office of Research (RES) to address the effects of the reactor coolant environment on the fatigue life of metal reactor coolant pressure boundary materials. Earlier versions of DG-1144 included guidance for carbon steel, low-alloy steel, and austenitic steel materials, and the current version of RG 1.207, also includes guidance for nickel-chromium-iron (Ni-Cr-Fe) alloy materials. The committee will hear presentations by and hold discussions with representatives of RES.

During the 532$^{nd}$ ACRS meeting in May 2006, the committee had no objection to the staff's proposal to issue DG-1144 for public comment and wished the opportunity to review the draft final version after reconciliation of public comments. In the interim, the RES staff has issued draft DG-1144 and has received several comments from the public. The staff has also prepared draft responses to these comments.

BACKGROUND:

In Appendix A, "General Design Criteria for Nuclear Power Plants," to Title 10, Part 50, of the *Code of Federal Regulations* (10 CFR Part 50), " Domestic Licensing of Production and Utilization Facilities," General Design Criterion (GDC) 1, "Quality Standards and Records," requires, in part, that structures, systems, and components that are important to safety must be designed, fabricated, erected, and tested to quality standards commensurate with the importance of the safety function performed. In addition, GDC 30, "Quality of Reactor Coolant Pressure Boundary," requires, in part, that components that are part of the reactor coolant pressure boundary must be designed, fabricated, erected, and tested to the highest practical quality standards.

Augmenting those design criteria, 10 CFR 50.55a, " Codes and Standards," endorses the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code for design of safety-related systems and components. In particular, Section 50.55a(c), " Reactor Coolant Pressure Boundary," requires, in part, that components of the reactor coolant pressure boundary must meet the requirements for Class 1 components in Section III, "Rules for Construction of Nuclear Power Plant Components," of the ASME Boiler and Pressure Vessel Code. Specifically, those Class 1 requirements contain provisions, including fatigue design curves, for determining a component's suitability for cyclic service. These fatigue design curves are based on strain-controlled tests performed on small polished specimens, at room temperature, in air environments. Thus, these curves do not address the impact of the reactor coolant system environment.

RG 1.207 provides guidance for use in determining the acceptable fatigue life of ASME pressure boundary components, with consideration of the light-water reactor (LWR) environment. In so doing, this guide describes a methodology that the NRC staff considers acceptable to support reviews of applications that the agency expects to receive for new nuclear reactor construction permits or operating licenses under 10 CFR Part 50, design certifications under 10 CFR Part 52, and combined licenses under 10 CFR Part 52 that do not reference a standard design. Because of significant conservatism in quantifying other plant-related variables (such as cyclic behavior, including stress and loading rates) involved in cumulative fatigue life calculations, the design of the current fleet of reactors is satisfactory, and the plants are safe to operate.

<u>DISCUSSION</u>:

The ASME Section III design curves, developed in the late 1960s and early 1970s, are based on tests conducted in laboratory air environments at ambient temperatures. The original code developers applied margins of 2 on strain and 20 on cyclic life to account for variations in materials, surface finish, data scatter, and environmental effects (including temperature differences between specimen test conditions and reactor operating experience). However, the developers lacked sufficient data to explicitly evaluate and account for the degradation attributable to exposure to aqueous coolants. More recent fatigue test data from the United States, Japan, and elsewhere show that the LWR environment can have a significant impact on the fatigue life of carbon and low-alloy steels, as well as austenitic stainless steel and nickel alloy materials.

Two distinct methods can be used to incorporate LWR environmental effects into the fatigue analysis of ASME Class 1 components. The first method involves developing new fatigue curves that are applicable to LWR environments. Given that the fatigue life of ASME Class 1 components in LWR environments is a function of several parameters, this method would necessitate developing several fatigue curves to address potential parameter variations. An alternative would be to develop a single *bounding* fatigue curve, which may be overly conservative for most applications. The second method involves using an environmental correction factor (Fen) to account for LWR environments by correcting the fatigue usage calculated with the ASME "air" curves. This method affords the designer greater flexibility to calculate the appropriate impacts for specific environmental parameters. In addition, applicants have already used this method in their license renewal applications.

The NRC staff has selected the Fen method, as described in NUREG/CR-6909, "Effect of LWR Coolant Environments on the Fatigue Life of Reactor Materials." In particular, Appendix A to that report describes a methodology that the staff considers acceptable to incorporate the effects of reactor coolant environments on fatigue usage factor evaluations of metal components. In addition, NUREG/CR-6909 provides a comprehensive review of, and technical basis for, the methodology proposed in RG 1.207, including analysis of each parameter affecting the fatigue evaluations. In developing the underlying Argonne National Laboratory (ANL) models, the researchers analyzed existing data to predict fatigue lives as a function of temperature, strain rate, dissolved oxygen level in water, and sulfur content of the steel. The resultant method postulates a strain threshold, below which environmental effects on fatigue life do not occur. By definition, Fen is the ratio of fatigue life of the component material in a room temperature air environment to its fatigue life in LWR coolant at operating temperature. To incorporate environmental effects into the fatigue evaluation, the fatigue usage is calculated using ASME Section III Code provisions, and the fatigue design curve is multiplied by the correction factor.

A second concern regarding the ASME fatigue design curves involves nonconservatism of the current ASME stainless steel air design curve. More recent evaluations of stainless steel and nickel alloy test data indicate that the ASME curve is inconsistent with the appropriate test materials and conduct of the fatigue test. Consequently, through RG 1.207, the NRC staff endorses a new stainless steel air design curve. Section 5.1.8 of NUREG/CR-6909 provides a comprehensive review of, and technical basis for, that new design curve. The Fen values defined for stainless steel in NUREG/CR-6909 should be used in conjunction with the new stainless steel air design curve when evaluating the fatigue usage of ASME Class 1 components.

In addition, the staff evaluated the incorporation of the Fen approach methodology in fatigue analyses for Ni-Cr-Fe alloys (e.g., Alloy 600 and 690) and welds. Section 6 of NUREG/CR-6909 discusses the technical basis for incorporating the environmental effects on nickel alloys and welds. In summary, fatigue evaluations for Ni-Cr-Fe alloys are based on the fatigue design curve for austenitic stainless steels. However, the existing fatigue data for Ni-Cr-Fe alloys and their welds are not consistent with the current ASME Code fatigue design curve for austenitic stainless steels. The data are either comparable or slightly conservative with the updated ANL model for austenitic stainless steels. Thus, the new fatigue design curve proposed for austenitic stainless steels adequately represents the fatigue behavior of Ni-Cr-Fe alloys and their welds. Therefore, the new design curve for austenitic stainless steels may also be used for Ni-Cr-Fe alloys and their welds. The staff finds it acceptable to use the new austenitic stainless steels air design curve in Ni-Cr-Fe alloys environmental fatigue evaluations. Consequently, Section 6 of NUREG/CR-6909 presents the respective Fen equations to be used for Ni-Cr-Fe alloys and their welds.

Section 7 of NUREG/CR-6909 evaluates the ASME design curve margins. In conducting that evaluation, researchers reviewed data available in the literature to assess the subfactors (excluding environment) necessary to account for the effects of various uncertainties and differences between actual components and laboratory test specimens. The researchers also performed statistical analyses using Monte Carlo simulations to develop fatigue design curves, using the " 95/95 criterion". In other words, the curves should provide 95% confidence that 95% of the population will have a greater fatigue life than predicted by the design curves. The NRC staff deems this criterion acceptable because the fatigue design curves are based on crack initiation, rather than component failure, and therefore, additional margin exists between crack initiation and actual component failure.

The results of the Monte Carlo simulations indicate that for both carbon steels, low-alloy steels, and austenitic stainless steels, the current ASME Code procedure of adjusting the mean test data by a factor of 20 for life is conservative compared to the 95/95 criterion. The results also indicate that a minimum factor of 12 for cyclic life of these materials will satisfy the 95/95 criterion. Figures 9, 10, and 37 of NUREG/CR-6909 present the resultant new air design curves, using margins of 12 for life and 2 for stress, for carbon steel, low -alloy steel, austenitic stainless steel, respectively. RG 1.207 uses these new air design curves, thus, an applicant that chooses to adopt the guidance procedure to determine the fatigue life of stainless steels, these air design curves should be used. However, the existing ASME air design curves for carbon and low-alloy steels may also be used with the procedure in this guide to determine the fatigue life of those materials, since their use will yield conservative results.

The NRC staff reviewed and found acceptable several methods for calculating Fen. Only the types of stress cycles or load set pairs that exceed strain threshold criteria for carbon steels, low-alloy steels, and austenitic stainless steels need to be considered for Fen calculations. The evaluation options depend on the complexity of the analyzed transient condition and the detail of the evaluation. For example, in an evaluation in which the results of detailed transient analyses are available to determine the necessary parameters (strain rate, temperature, and others), the “modified rate approach” (presented and referenced in Section 4.2.14 of NUREG/CR-6909) is an acceptable methodology for determining the Fen values. This methodology involves a strain-based integral for evaluating conditions for which temperature and strain rate change, resulting in variation of Fen over time. This detailed approach calculates the Fen values based on the strain history for each load set in the fatigue analysis evaluation, considering the effects of strain rate and temperature variations for each incremental segment in the strain history. Such results may be used to reduce the conservatism in the calculated Fen values. For a simplified calculation yielding a more conservative result for a complex or poorly defined set of transients, the temperature is equal to the average temperature in the transient or segment. The calculated Fen values are then used to incorporate environmental effects into ASME fatigue usage factor evaluations using Equation A.20 of NUREG/CR-6909.

EXPECTED COMMITTEE ACTION:

The Committee is expected to provide a report to the Commission recommending a course of action on this matter.

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SUBCOMMITTEE ON MATERIALS, METALLURGY, AND NUCLEAR FUELS
REVIEW OF REGULATORY GUIDE 1.207 (DG-1144)
GUIDELINES FOR EVALUATING FATIGUE ANALYSES INCORPORATING THE LIFE REDUCTION OF METAL COMPONENTS DUE TO THE EFFECTS OF THE LIGHT-WATER REACTOR ENVIRONMENT FOR NEW REACTORS
December 6, 2006
ROCKVILLE, MARYLAND

**-PROPOSED SCHEDULE-**

Cognizant Staff Engineer: Charles G. Hammer, cgh@nrc.gov (301) 415-7363

| Topics | Presenters | Time |
|---|---|---|
| **Opening Remarks** | S. Armijo, ACRS | 1:30 - 1:35 pm |
| **Overview of Regulatory Guide 1.207 (DG-1144)** | H. Gonzalez, RES | 1:35 - 2:00 pm |
| **Discussion of technical basis for Regulatory Guide 1.207 and NUREG/CR-6909** | O. Chopra, Argonne National Laboratory | 2:00 - 3:30pm |
| **- Break -** | | 3:30 - 3:40 pm |
| **Discussion of public comments and staff responses for Regulatory Guide 1.207 and NUREG/CR-6909** | H. Gonzalez, RES<br>O. Chopra, ANL | 3:40 - 4:30 pm |
| **Subcommittee Discussion** | S. Armijo, ACRS | 4:30 - 5:00 pm |

**Note**

- Presentation time should not exceed 50 percent of the total time allocated for specific items. The remaining 50 percent of the time is reserved for discussion.

- 35 copies of the presentation materials to be provided to the Subcommittee.

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REDUCTION OF METAL COMPONENTS DUE TO THE EFFECTS OF
THE LIGHT-WATER REACTOR ENVIRONMENT FOR NEW REACTORS
December 7, 2006
ROCKVILLE, MARYLAND

**-PROPOSED SCHEDULE-**

Cognizant Staff Engineer: Charles G. Hammer, cgh@nrc.gov (301) 415-7363

| Topics | Presenters | Time |
|---|---|---|
| **I. Opening Remarks** | S. Armijo, ACRS | 10:45 - 10:50 am |
| **II. Overview of Regulatory Guide 1.207 (DG-1144)** | H. Gonzalez, RES | 10:50 - 11:20 am |
| **III. Discussion of technical basis for RG 1.207 and NUREG/CR-6909** | H. Gonzalez, RES<br>O. Chopra, Argonne National Laboratory | 11:20 - 12:00 pm |
| **IV. Committee Discussion** | S. Armijo, ACRS | 12:00 - 12:15 pm |

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