Doris Mendiola - Comments on Draft Regulatory Guide DG-1144 and NUREG/CR-6909

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The subject letter, NRC:06:039, is attached. Should you have questions or comments, please contact Mark Burzynski at 434.832.4695.

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Thank you.

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Comments on Draft Regulatory Guide DG-1144 and NUREG/CR-6909

Ref.: 1. Federal Register Notice (71FR47584), Draft Regulatory Guide: Issuance, Availability

Dear Mr. Gonzalez:

The NRC solicited comments on both Draft Regulatory Guide 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," and NUREG/CR–6909, "Effect of LWR Coolant Environments on the Fatigue Life of Reactor Materials," in the referenced Federal Register notice. The NRC requested comments by September 25, 2006.

AREVA NP appreciates the opportunity to provide comments on draft Regulatory Guide DG-1144 and NUREG/CR–6909. In general, AREVA has significant comments regarding the need for the proposed conservative methods as well as acceptability of some of the technical methods. These comments are outlined below.

1. General Comments from AREVA NP

a. Regulatory Analysis for DG -1144 notes that:

> *After about 20 years of research effort addressing the environmental degradation of fatigue crack nucleation, it has become apparent that exposure to light-water reactor environments has a detrimental effect on the fatigue life of metal components, which affects the major categories of structural materials (i.e., carbon steel, low -alloy steel, and austenitic stainless steel).*

AREVA agrees with laboratories fatigue tests results concerning demonstration of the role of pressurized water reactor (PWR) environment on the low cycle fatigue (LCF) behavior of reactor materials. However, AREVA is not aware of any operating experience that supports the need for these conservative design rules. The NRC should cite specific examples where operating events associated with a significant environmental effect have been at the root cause of fatigue failure. The NRC should also cite where in the fatigue analyses

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supporting the original design, it was necessary to account for environmental effect to demonstrate the need for this regulatory guidance.

b. The Regulatory Analysis states that the "costs associated with implementing this guidance are expected to be minimal." AREVA believes that an increase in the Cumulative Fatigue Usage Factors (as suggested in DG-1144) will lead to more analyzed piping break locations, to more installed pipe whip restraints, and to designs that will be more detrimental for normal (thermal expansion) operating conditions.

   In addition, there will be more restrictions on the Design Transients (in the Functional Specifications) and the analyses will have to be performed with added accuracy, such as performing elasto-plastic finite element analyses, to be able to reduce the conservatisms inherent to the current design and analysis methods. However, it is not usual to perform elasto-plastic finite element analyses at a design stage and this added complexity to new plant designs is unwarranted. Analysis costs will increase significantly owing to the involved nature of the F(en) calculation, particularly related to the determination of strain rate. This method will also require more detailed analyses of piping and components due to the severe nature of the F(en) penalty. For example, it can be anticipated that more locations in stainless steel piping will have to be evaluated using finite element approaches (NB-3200) instead of the traditional simplified rules in NB-3600.

c. The Regulatory Analysis has the following statements:

   This guidance will complement and be consistent with current established practices applied throughout the commercial nuclear power industry for license renewal evaluations.

   The practice reported in NUREG/CR-6260 applied to several plants and identified locations of interest for consideration of environmental effects using the fatigue design curves that incorporated environmental effects. Section 5.4 of NUREG/CR-6260 identified the following component locations to be most sensitive to environmental effects for PWRs.

   1. Reactor vessel shell and lower head
   2. Reactor vessel inlet and outlet nozzles
   3. Surge line
   4. Charging nozzle
   5. Safety injection nozzle
   6. Residual Heat Removal system Class 1 piping

   It is not understandable why the guidance for new plants, in spite of better materials, more modern nondestructive testing technologies, and improved manufacturing process, is not restricted to a limited number of locations. In lieu of evaluating the entire Class 1 systems for the environmental effects on fatigue, AREVA believes an approach that parallels the license renewal approach would provide more reasonable assurance that the environmental effects are bounded sufficiently.

d. The Regulatory Analysis for DG -1144 notes that:

> *The ASME Board of Nuclear Codes and Standards, Subcommittee on Environmental Fatigue, is still developing a Code Case and non-mandatory procedure to provide guidance regarding the application of an environmental correction factor for fatigue analyses. This task was assigned to the PVRC Steering Committee on Cyclic Life and Environmental Effects, which recommended revising the Code fatigue design curves (Welding Research Council Bulletin 487, " PVRC Position on Environment al Effects on Fatigue Life in LWR Applications"); however, despite years of deliberation, the ASME Subcommittee on Environmental Fatigue has not yet approved this proposal and has not reached a consensus regarding the approach or methodology that will be used for guidance.*

AREVA does not believe the NRC should establish very conservative design rules without peer consensus. The fact that consensus has not been reached in the industry highlights both that the research is not sufficiently finalized to be conclusive and that the correct method of treatment of environmental effects is not clearly established. For example, there is not enough evidence to support the combination of all detrimental effects. It is not appropriate to treat simultaneously all the detrimental effects of size, surface finish, loading history, data scatter, material variability, dissolved oxygen in the water, strain rate, and temperature to calculate the environmental fatigue penalty. AREVA believes that there are cases where, when one effect is taken at its worst (at saturation), the other effects do not further negatively affect the fatigue resistance of the component. Therefore, AREVA believes that for fatigue the "Cumulative Penalties" methodology is overly conservative.

e. The current ASME Code fatigue methodology is overly conservative. Examples of the conservatisms that are inherent to methodology include:

- use of conservative values for fatigue strength reduction factors,
- the piping stress indices,
- the piping stress methodology,
- use of Tresca criterion for the calculation of the stress intensity,
- use, in the design methodology, of minimum specified mechanical properties in place of representative materials properties,
- the fatigue plasticity penalty factor (K_e),
- design transients are more severe than the actual transients,
- grouping various transients into analysis sets in which each set is bounded by the most severe transient in the set, and
- there are fewer transients during the plant lifetime than specified in the Functional Specs.

It would be preferable to review the whole methodology rather than limiting efforts to the materials aspects.

f. There is no guidance in DG-1144 or CR-6909 regarding how to treat carbon steel and low alloy steel, which are "protected" from the primary coolant environment by stainless steel (or Alloy 690) cladding. AREVA believes it is reasonable to assume that there will not be any environmental effects on clad carbon steel and low alloy steel. For completeness, the guidance should address this subject.

2. Technical Comments from AREVA NP

a. The majority of the LCF tests were performed at high temperature on polished specimens in the NUREG/CR-6909. About ninety percent of the tests were done at high temperature (between 260°C and 325°C) in isothermal conditions with triangular strain signals leading to constant strain rates. These test conditions are not representative of realistic thermo-mechanical loadings applied on components during operation. Indeed, the triangular form of cycles with two slopes and a constant temperature chosen for the laboratory fatigue tests is very different from the actual cycles applied during operating transients, which contain successions of high strain rates and low strain rates with a variable temperature. Because the tests performed in the laboratory specimens are not representative of in-service reactor components, it is not clear that the F(en) factors derived from those tests apply to the components and operating conditions in a nuclear plant.

b. After a micro-structural crack has formed, the crack depth is approximately 0.3 mm and a surface finish effect is no longer required, since the fatigue process occurs at the crack tip. Surface finish effect were only established in air. It is supposed to affect the fatigue life by a factor of three. NUREG/CR-6909 recommends treating the environmental effect on a rough surface by multiplying F(en) factor by approximately 3 but this accumulation is not proven by sufficient data obtained on representative surface at various strain amplitudes in PWR environment.

c. Loading sequence effects should not be considered as an additional penalty for the factor of 12.0, as suggested in NUREG/CR-6909. During normal operation of the nuclear power plant, the cycles are reasonably well distributed for the entire life of the plant. Therefore, the Loading Sequence effect is not required. Furthermore, such a loading sequence is not supported by reviewed and accepted experimental results.

d. There should be a real threshold for both temperature and strain rate. In other words, below a certain temperature (150°C or 180°C), or above a certain strain rate (0.4 percent or 1 percent per second) penalty F(en) value should be 1.0. That has been shown clearly in the Figure 12 of the 2005 PVP Paper No. 71409 and in the Figure 10 of the 2005 PVP Paper No. 71410. These two technical papers are from William J. O'Donnell, William John O'Donnell, and Thomas P. O'Donnell.

e. The proposition of a new fatigue curve in air is based on insufficiently supported test results and some of which were obtained on unrepresentative materials. For instance, a paper cited in the NUREG/CR-6909 [reference 105] is used as data for this fatigue curve to analyze mean stress effect. Nevertheless, the material used in this reference has an inordinate high reduction of fatigue strength due to mean stress.

   In section 5.1.1 of NUREG/CR-6909, for example, it can be possible to obtain three different best-fit mean S - N curves for austenitic stainless steels types 304, 316 or 316 NG.

Other authors like Jaske and O'Donnell in 1977 or Tsutsumi in 2000 (see PVP 2000 – Vol. 410-2) have also proposed best fit mean S – N curve expressions for similar austenitic stainless steels (304, 316, 310, and 347), which are different from those proposed in NUREG/CR-6909.

Significant differences of about ± 20 percent are noticed on the fatigue life according to the best-fit S - N curve selected which shows that the S – N curve determination is a function of the chosen materials and associated fatigue test database. NUREG/CR-6909 does not sufficiently demonstrate that the tested materials and fatigue test data used for the definition of a reference best-fit mean S – N curve are representative of modern materials.

The fatigue ε – N data are typically expressed by using one equation to cover the two domains (i.e., LCF and high cycle fatigue (HCF)). The proposed modification of the reference mean S – N curve comes from the consideration of recent fatigue test results corresponding to the HCF domain, whereas, for reactor components, design studies are mainly concerned with the LCF domain.

f. The conclusions in NUREG/CR-6909 regarding evaluations of the mean stress effect seem to be solely based on the paper published by Bettis Bechtel Inc. (see PVP 1999 - Vol. 386). This paper suggests - for an austenitic stainless steel type 304 - that the mean stress effect can reach 26 percent of the strain amplitude in the LCF domain and in the intermediate domain of fatigue life ($N < 10^6$ cycles).

   This evaluation of the mean stress effect seems too conservative and is probably mainly due to the selection of the tested materials by the Bettis Bechtel Inc. laboratory, which are not representative of modern materials. In fact, this result is essentially based on a fatigue test program performed on two stainless steel type 304 materials with very different tensile and fatigue properties.

   The new reference design fatigue curve in air is established in section 5.1.1 of NUREG/CR-6909 by using insufficiently supported data, since portions of the data were obtained on unrepresentative material. The hot yield strength of the tested materials can for example vary as much as 100 percent (152 to 338 MPa at 288°C). This strong scatter of mechanical properties is attributed to variations in cold working from the surface to the center of the forgings supplied for the study. In these conditions, depending on the cold working level, it is well known that the material can present significant variations of its fatigue life in the LCF domain and in the intermediate domain.

   Fatigue strength results were obtained by AREVA for $N = 10^7$ cycles on standard polished specimens in air at room temperature on a 304L austenitic stainless steel. These results (JIP 2006 – Paris, May 30-31, June 1, 2006) have shown that, in the case where progressive deformation and cold work associated to loading conditions are very limited, the maximum reduction of endurance limit is of about 10 percent, compared to 26 percent found in reference [105] cited in NUREG/CR-6909.

g. In NUREG/CR-6909 section 5.1.5, the surface finish conditions reproduced on LCF test specimens by using a 50-grit sandpaper to obtain circumferential striations - with an average surface roughness of 1.2 μm - is not sufficiently representative of those obtained on reactor components. In fact, the roughness parameter alone is not sufficient to ensure that surface finish is representative of those obtained during manufacturing of components. In addition, only two tests that were performed on rough specimens were reported in NUREG/CR-6909. This is not sufficient to determine a roughness surface effect.

Fatigue tests performed on turned and ground specimens by AREVA (S. Petitjean – Fatigue 2002) have shown that the radius at the bottom of machining striations is a second critical parameter to characterize the surface roughness, in addition to average value of roughness amplitude.

In conclusion, the reduction factor attributed to surface finish that comes from only one surface condition and a limited number of tests cannot be used for real components.

h. The majority of the LCF tests on polished specimens in NUREG/CR-6909 were performed at high temperature. Ninety percent of the tests were performed at high temperature (between 260°C and 325°C) and in isothermal conditions with triangular strain variations leading to constant strain rates.

   These test conditions are not fully representative of realistic thermo-mechanical loadings applied on components during operation. Indeed, the triangular form of cycles with two slopes and a constant temperature chosen for the laboratory fatigue tests is very different from the actual cycles applied during operating transients, which contain successions of high strain rates and low strain rates with a variable temperature. Because the tests performed in the laboratory specimens are not representative of in-service reactor components, it is not clear that the Fen factors derived from those tests apply to the components and operating conditions in a nuclear plant.

3. Conclusions and Recommendation from AREVA NP

AREVA recognizes the environmental effects demonstrated by laboratory fatigue tests on reactor materials. Nevertheless, AREVA believes that alternative methods for fatigue analysis provided in NUREG/CR-6909 and DG 1144 are too conservative and should not be used for the design of new reactors. The four main reasons for this recommendation are:

a. NUREG/CR-6909 only deals with materials aspects of environmental fatigue, and addresses it with a very conservative approach, while the whole methodology of fatigue is already treated at design stage with a conservatism that cannot be removed.

b. The concept of cumulative penalties, which leads to multiply by the environmental factor F(en), the reduction factor of 12, which already integrates surface finish, size effect, material variability, and loading sequence effect is too severe. In addition, AREVA believes that combining some of these effects is not justified.

c. There are too many uncertainties in the transposition of the specimen fatigue test results obtained in a PWR environment to component fatigue. For example, the results gathered in NUREG/CR-6909 are linked to laboratory tests for which the loading conditions are simple but not representative of the field operating conditions, where the loading parameters history (e.g., temperature gradient, pressure, strain rate, and dissolved oxygen) is much complex.

d. Past fatigue failures observed in nuclear power plants were due to failure of the designer/analyst to consider the actual loading conditions, such as thermal stratification, turbulent penetration, and thermal mixing. These past fatigue failures were not attributed to the fact that the designer/analyst used either a non-conservative methodology or non-conservative Design Fatigue Curves. In other words, there is no field experience on steel components, either in-air or in LWR environment, that points to the necessity to modify the current Design Fatigue Curves.

AREVA agrees that if, in the future, it becomes apparent that the environmental effects have an impact on component fatigue for the current fleet of nuclear power plants or for the new nuclear power plants, additional methods may need to be applied to the fatigue analyses.

In summary, AREVA NP is not aware of any operating experience that supports the need for these conservative design rules. Nor does AREVA believe that the NRC should establish very conservative design rules without industry peer consensus. The guidance for new plants should be restricted to a limited number of locations consistent with the approach taken for license renewal reviews. It would be preferable to review the whole methodology, including a new methodology for selecting the list of design transients relevant for environmental analysis, rather than limiting efforts to the materials aspects. Finally, if the NRC continues with the guidance in DG-1144 and NUREG/CR-6909 as written, considerable flexibility should be provided for the use of alternative methods to those provided.

AREVA NP looks forward to continued interactions with the NRC on this subject to ensure appropriate regulatory guidance is provided for new plant applications. Mr. Mark J. Burzynski is the point of contact for AREVA NP on this matter. He may be reached by telephone at 434.832.4695 or by e-mail at Mark.Burzynski@areva.com.

Sincerely,

Ronnie L. Gardner

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AREVA NP Inc.

cc: J. F. Williams
Project 733