REQUEST FOR ADDITIONAL INFORMATION

RELATED TO AREVA NP, INC.

TOPICAL REPORT BAW-10247PA, REVISION 0, SUPPLEMENT 1P, REVISION 0,

"REALISTIC THERMAL-MECHANICAL FUEL ROD METHODOLOGY FOR BOILING WATER REACTORS SUPPLEMENT 1: QUALIFICATION OF RODEX4 FOR RECRYSTALLIZED ZIRCALOY-2 CLADDING"

RAI 1

The following relates to cladding corrosion and hydriding.

a. Please provide the individual corrosion data along with cladding temperature (radial and axial location and fluence/time) and recrystallized annealed (RXA) Zircaloy-2 (Zr-2) model prediction and identify the fuel design the data was taken from. Also, include the maximum power level and burnup for each of the operating cycles for each rod. Do any of these data come from plants with power uprates? If so, please identify the data along with percentage uprate in power along with uprated core average power. This will help assess whether the data is applicable to today's fuel designs and operating envelopes.

b. No model was provided for hydrogen pickup of RXA Zr-2. NRC has developed cladding embrittlement criteria for loss-of coolant accident and reactivity initiated accident based on hydrogen content. Does AREVA intend to include a hydrogen pickup model for accident analyses? If so, does AREVA intend to submit hydrogen pickup models for RXA Zr-2 and cold-worked, stress-relief annealed Zr-2 as part of this review, also please provide supporting hydrogen concentration data for these models.

RAI 2

The following are related to understanding the thermal and irradiated creep model coefficients and verify the calculation of thermal and irradiated creep.

a. Possible Typos – i) Should there be parenthesis around each of the following terms, the axial creep rate term and the axial creep strain term in Equation 24 and 25. ii) The last line on page 10 refers to H_6, should this be H_5 instead? iii) The first sentence on page 11 suggests that the data were fine tuned rather than the model coefficients, please modify if this is not true. If the data were fine tuned please explain in detail how this was done.

b. Fitting parameters for thermal creep, H_2, H_3, and H_4 are not provided. Please provide these values. Also provide some discussion of how the primary creep is initialized at time=0.

c. Fitting parameters, H_6 and H_7 are defined differently on pages 11 and 13. Please specify which values are used and why they are different on these pages.

d. Fitting parameters for irradiation creep, L_2 and L_4 could not be found in the submittal for the revised RXA Zr-2 model. Please provide these values.

e. Please provide equivalent figures to Figures 7.26 – 7.30 in EMF-2994(P) for the re-calibrated thermal and irradiation creep models for RXA Zr-2 material. Also provide the creep rate versus fluence on the same figure for thermal and irradiation creep at different stress levels up to 120 megapascal that demonstrates the fluence level where irradiation creep dominates.

RAI 3

The following are related to understanding the creep data and how this data is used to develop the coefficients to the creep model.

a. Please confirm whether the creep data is from fuel rods or from non-fueled tubes (see b and c below).

b. If data from fuel rods at what fluence level is hard contact established for the fuel designs from which the irradiated data were taken? Please provide references for the irradiated creep data at fluences below which fuel-cladding hard contact is not experienced if creep data is from fuel rods. If these data are not publicly available please provide the data and model predictions identifying the maximum hoop stress/pressure, temperature and fluence (fuel rod data). How were the diameters of these fuel rods accurately measured axially and azimuthally prior to irradiation? An issue with fuel rod creep data is that it is difficult to separate primary and secondary creep quantitatively due to the limited amount of data versus time/fluence.

c. If data is from non-fueled tubes supply plots of hoop strain vs fluence for a given temperature and stress (for pressurized tubes held at relatively constant temperature).

RAI 4

Several assumptions have been applied in developing this creep model including the following: 1) radial stress can be ignored in determining creep in the hoop direction (Halden data appears to suggest it cannot be ignored); 2) the yield strength decrease in anisotropy in hoop and axial direction also applies to the creep anisotropy; and 3) P can be used to quantitatively define how creep anisotropy changes with fluence. The creep data provided is very limited and appears to be only in the compressive stress direction that suggests it does not provide justification for the above assumptions. In order to demonstrate that these and other assumptions are valid please provide comparisons to the following RXA Zr-2 in-reactor creep data.

- In-reactor creep data for RXA Zr-2 cladding tubes from the following Halden experiments (Halden reports): IFA-585 (HWR-471, HWR-413 and HWR-677); IFA-663 (HWR-755); and cladding liftoff experiment IFA-610 (HWR-877, HWR-919).

- Also provide comparisons to the creep database for RXA Zr-2 cladding in Franklin, D.G., G.E. Lucas, A.L. Bement. 1983. “Creep of Zirconium Alloys in Nuclear Reactors”, ASTM STP 815, American Society for Testing and Materials, West Conshohocken, PA.

- These comparisons of creep predictions and data should be for both tensile and compressive stress states when available and gap estimates for cladding liftoff. These data will help determine if the assumptions for the creep model are valid and if primary and secondary irradiation creep are modeled correctly in terms of fluence, temperature and stress.

RAI 5

The following are related to understanding the application of the RXA Zr-2 creep model for licensing analyses and whether proposed application is justified.

a. Is RODEX4 creep calculated at mid-wall and if so is irradiated data adjusted for mid-wall creep? If not please explain how cladding creep is calculated?

b. Provide justification for the use of the multiplier on sigma (Section 5.0) to obtain an upper bound model for irradiated creep given the limited amount of irradiated creep data. The multiplier does not appear to provide a 95/95 upper tolerance.

c. What impact does the new RXA Zr-2 creep properties have on creep collapse (ovality) for AREVA boiling water reactor (BWR) fuel designs with RXA Zr-2 cladding? Provide data that demonstrates the RXA Zr-2 creep model is acceptable for application to cladding creep collapse.

RAI 6

Does the new RXA Zr-2 creep model impact fission gas release analyses, e.g., does the code need to be recalibrated against release data? If not please provide justification for why recalibration is not necessary.

RAI 7

It is the intent to place limits on the application of the corrosion and creep models. What is the cladding temperature and burnup/fluence limitation for the corrosion and creep models? Provide justification based on the data that supports these limitations.

RAI 8

Does the ridging parameter K_{hg} in Equation 6.86 in EMF-2994 impact licensing analyses? If so, please explain why this ridging parameter is not impacted with the introduction of RXA Zr-2 cladding.

RAI 9

The following relate to the axial growth model for RXA Zr-2.

a. Pacific Northwest National Laboratory is unable to replicate model predictions of axial strain shown in Figure 9. It appears that the value for the c coefficient may be in error, please confirm or provide a discussion of why the coefficients in the submittal are correct. Please verify that the correct model parameters are given in the submittal.

b. It appears that the slope of the growth model versus fluence should be lower because growth is underpredicted at low fluence and overpredicted on average at high fluence. At what burnup/fluence level is hard contact experienced for these fuel designs based on; 1) RODEX4 calculations, and 2) data analysis. To illustrate the adequacy of the growth model dependence on fluence and temperature please provide plots of predicted minus measured axial strain as a function of fast fluence and cladding temperature. If there are under or overpredictions on average please explain why this is acceptable for each of the licensing analyses of rod internal pressure, fuel temperature (melting and stored energy) and cladding strain. Identify the fuel design for each set of growth data. Have additional growth data become available since the submittal to better determine the accuracy of the growth model? If so, please provide this data.

c. Axial rod growth is also dependent on axial stresses on the fuel rods which is dependent on spacer spring loads (Section 4.0) and pellet/cladding interaction (PCI). Please identify differences in spacer spring design and loads between those designs from which the data were taken and those from current fuel designs. Please identify any other axial loads on the fuel rods besides PCI. Based on the near linear dependence with fluence it appears that there is little growth due to PCI. Please discuss this further. Were these data from fuel assemblies utilizing tie rods?

RAI 10

The following relate to the free volume predictions with RODEX4 for RXA Zr-2.

a. Please provide the free volume data (Section 7.0) (also as-fabricated volume along with how this is determined) along with burnup and fuel design from which data were taken. There appears to be a small overprediction **[ ]** of void volume at burnup greater than **[ ]** (Figure 14). Is this related to the overprediction of growth at high fluences? Please provide a discussion of why this acceptable.

b. In addition, the growth model appears to be based on only 19 data points. Have any additional data been collected since this submittal and if available provide these data?

RAI 11

Please provide the rod pressure limit for BWR fuel rods with RXA Zr-2 cladding. Also justify this limit based on the upper bound creep model for RXA Zr-2 and lower bound fuel swelling model.

RAI 12

Please provide sample calculations for the following safety analyses using the approved RODEX-4 methodology for RXA Zr-2 cladding. For each sample calculation, provide discussion on how power histories are selected and how the uncertainties are perturbed, and plots of the selected power histories. The uncertainties (values and parameter perturbed) and how they are perturbed need to be identified such that similar analyses can be performed with the FRAPCON-3.4 code with statistical analysis sampling capabilities.

a. Maximum rod internal pressure
b. Fuel melting calculation
c. Maximum cladding hoop strain increment