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December 10, 1979

Mr. Richard P. Denise
Acting Asst. Director for Reactor Safety
Division of Systems Safety
Office of Nuclear Reactor Regulation
U. S. Nuclear Regulatory Commission
Washington, D. C. 20555

Dear Mr. Denise:

In your letter to me dated November 8, 1979, you requested that Exxon Nuclear review the draft report "Cladding, Swelling and Rupture Models for LOCA Analysis" and provide written comments to you. You also requested that we specifically address the topics for discussion set forth in the enclosure to your letter. The attachment to this letter provides our responses to your requests. Our comments regarding the draft report are included within the response to the six discussion topics you transmitted.

Our principal conclusion from the review is that the rupture/blockage data in your draft report supports the conservatism of the current ENC rupture/blockage model. The data does suggest that a temperature ramp rate effect may be incorporated into the ENC rupture/blockage model to remove unnecessary conservatisms.

Please contact me should you have any questions regarding this report.

Sincerely,

G. F. Owsley, Manager
Reload Fuel Licensing

GFO:gf
Attachment
As noted

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ATTACHMENT to ENC Letter, G. F. Owsley to R. P. Denise, dated December 10, 1979

ENC COMMENTS ON NRC DRAFT REPORT NUREG-0630

CLADDING, SWELLING AND RUPTURE MODELS FOR LOCA ANALYSIS

TOPIC 1

Confirm that the Zircaloy cladding models displayed in Section 4.0 and which are referenced in Section 5.0 are the models that are used in your licensing LOCA analyses. Confirm that your models have been displayed accurately (i.e., to within ± 5%). If you are unable to respond affirmatively to the above results, provide the appropriate references and describe the discrepancies.

Reference (a) has properly referenced and displayed the ENC rupture/blockage model except for the definition of thin wall hoop stress. As specified in the ENC documentation (Page 14 of XN-75-6), ENC uses the definition of thin wall hoop stress appropriate for rupture conditions where the internal pressure is much greater than the external pressure.

$$\sigma = \frac{\Delta P \, r_i}{t}$$

This definition of hoop stress is appropriate because the rupture/blockage data is usually taken under low external pressure conditions (atmospheric external pressure) and the conditions at time of rupture predicted by the ENC model are after blowdown when the external (system) pressure is near atmospheric.

In reference (a) the average clad radius is used in the equation for hoop stress rather than the inside clad radius, r_i, used by ENC. Average clad radius to evaluate hoop stress appears to have been used consistently in the reduction of data for reference (a). In order to be consistent with the NRC's average radius definition of hoop stress, the curves in reference (a) corresponding to ENC models should be shifted to 8% higher hoop stress values. This slight displacement does not affect the conclusions of reference (b) that ENC models and analyses remain in accordance with 10 CFR 50.46, Appendix K. Furthermore, sensitivity calculations were made which confirmed that this small shift does not affect the conclusions of references (c) and (d); application of the NRC rupture/blockage model would not affect licensing limits on plants licensed with ENC analyses.

TOPIC 2

The location, magnitude and shapes of superplastic strain peaks and low-ductility valleys cannot be determined precisely from prototypical rod burst tests because there are too few such experiments with enough controlled variables. Do you have any information that would suggest altering the shapes and magnitudes of the strain and blockage correlation curves?

Blockage

ENC considers that blockage models should be based directly on multi-rod test data. The bases of the ENC blockage model is the original ORNL multi-rod burst tests[(e)]. ENC considers that the results of the original ORNL MRBTs continue to be applicable. Their principal shortcoming is that the results are very likely

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overly conservative at high temperatures (β region) since the inert atmosphere of these tests precluded oxidation and accompanying clad embrittlement. The recent multi-rod burst data (fast and slow temperature ramp rate) was shown in reference (b) to be well represented by the ENC blockage model. It is noted that the magnitude of the multi-rod blockage data plotted in reference (b) has not been reduced to account for the fact that small bundle blockages are greater than large bundle blockages as discussed in reference (a). It is concluded that on the basis of multi-rod test data, the present ENC blockage model is in conformance with 10 CFR 50.46, Appendix K.

ENC considers that the methods used in reference (a) to extrapolate single rod burst strain to flow blockage are overly conservative for two reasons: first, the non-prototypic uniform environment in single rod tests leads to higher burst strains than would occur in a fuel assembly and, secondly, the reduced axial extent of strains in the α + β and β low ductility regions was not considered.

Burst tests on the effect of localized temperatures have shown that the small circumferential and axial temperature variations typical of rods in fuel assemblies significantly reduce burst strains. Because of the high degree of thermal uniformity obtained in single rod tests, the nature of the ballooning and rupture process leads to burst strains which tend to be higher than can be expected in a fuel bundle. Equating maximum strains achievable in a SRBT to the maximum local strain in a rod bundle and then using MRBT results for the ratio of maximum strain to average strain leads to bundle flow blockage results higher than anticipated in fuel assemblies and higher than found in MRBTs. This is why the NRC model curves bound the MRBT data in reference (a) with such large margins.

The α to α + β region extrapolation method used in reference (a) to create the NRC blockage model only accounted for the effect of reduced ductility in the circumferential direction; the method did not account for the additional reduction in blockage caused by the reduced axial extent of ballooning that also exists in the low ductility region. The reduced axial extent of the ballooned region decreases the coplaner nature of a blockage and, thus, reduces the magnitude of the blockage. Taking the axial extent of the balloon to be reduced in proportion to the circumferential strain implies the blockage would be reduced in proportion to the square of the circumferential strain. This squared rather than linear proportionality is confirmed by the original ORNL data which included multi-rod tests in both the α and α + β regions. The ratio of the average blockage in the α and α + β regions was .32, while the corresponding average strain ratio was 0.62 and the strain ratio squared was 0.38. Thus, the square of the strain ratio conservatively predicted the α + β region blockage from the α region blockage data. Figure 1 shows the low ramp rate blockage predictions (data points) using this squared method. The points shown on Figure 1 represent the key ANL low ramp rate data (5°C/sec) used by NRC to construct the low ramp burst strain and blockage curves in reference (a). The method used to convert this single rod data to flow blockage was identical to that described in reference (a), except that the squared strain method was used to account for the reduced axial extent of blockage. The ENC blockage model is shown in this figure to conservatively represent this key ANL data. Furthermore, the ENC model grossly overestimates the blockage in the β region due to lack of consideration of oxidation effects, and should be revised to be more consistent with the new data taken in a steam environment.

Based on the above, it is concluded that the ENC rupture strain and blockage model adequately represents the new strain and blockage data (except for an overconservatism in the low ramp rate β region) and meets the criteria of 10 CFR 50.46, Appendix K. The ENC strain and blockage model will be revised to remove the overconservatism in the β phase region for low ramp rates.

It is ENC's recommendation that the low ramp rate blockage model in reference (a) be revised in the α + β and β regions to consider the reduced axial extents of strain that are associated with the α + β and β regions as suggested above.

TOPICS 3 & 4

Most of the recent (since 1974) prototypical data were supported by public funds and are publicly available. It therefore appears practical and beneficial to develop standardized rupture temperature, strain, and blockage curves. The curves in the report (or modifications that we might make) could serve as an interim licensing standard, and an industry standards committee could develop revised curves based on present and future research results.

It may be appropriate to require that approved vendor cladding models be revised to conform with the correlations that will appear in the final version of the report. If your present models are in agreement with, or conservatively overpredict, the NRC correlations over the range of temperature and stress of interest, and if you wish not to change your present curves, your ECCS model revision could simply consist of explicit limits on the range of applicability of your correlations.

ENC would support the concept of an industry standard committee to develop revised curves providing this committee would have the authorization to recommend changes in the model as new data becomes available. The interim curves should be developed based on the recommendations presented in Topics 1 and 2 and should be such that the rupture strain and rupture blockage curves remain consistent; that is, trends in rupture strain and blockages should be consistent so their combined effect in ECCS calculations is properly predicted.

TOPIC 5

The alpha-plus-beta strain and blockage "valleys" portray a real phenomenon, but the exact location of the very steep sides of the valley may be unknowable for real LOCA conditions. Sensitivity analyses could be done to account for uncertainties in the location of the curves and in prediction of the rupture temperature and stress, but this would have the effect of narrowing the allowable calculated valley and creating a pseudo singularity in the analysis. It might be better for the licensing analysis to be insensitive to this feature.

The ENC rupture/blockage model (inherently composite) conservatively has a narrow "valley". The new fast ramp data shows this "valley" to be substantially wider with shallower sides than the present ENC model, and the slow ramp data shows no "valley" at all (β side removed). The NRC blockage model for the slow data also shows a much shallower slope on the α side. It is also noted that the NRC

model is already a bounding model with respect to strain and blockage. Further, since flow blockage is a bundle average parameter, the effect of rod-to-rod variations or uncertainties in rupture stress is not considered significant. Thus, the necessity of an uncertainty analysis is not apparent. In any event, ECCS analyses by each individual vendor should be treated consistently with regard to how rupture/balloon considerations are used to determine allowable licensing limits.

TOPIC 6

The on-going NRC research program has produced data over a wide range of conditions. Based on discussions with those performing licensing LOCA analyses, it appears that the actual range of interest may be quite narrow, and that the future program could be beneficially focused on a narrower range.

ENC considers that future research programs on rupture blockage should be directed toward the rupture stress range of interest to confirm the low blockages that exist in the $\alpha + \beta$ and β regions under slow ramp rate conditions. In addition, future programs should include more of the temperature variations between and around rods that are typical of reactor LOCA conditions. Small circumferential and axial temperature variations have been shown to reduce rupture strain and blockages. The more uniform temperature that exists in single and multi-rod tests to date are considered to have produced overly conservative blockage results. Future tests need to include:

- Guide tubes.
- Typical local power distributions.
- Axial power distributions consistent with license limits.
- Future tests should discriminate between
  - (i) Failure under blowdown hydraulic conditions;
  - (ii) Failure under adiabatic heatup conditions; and
  - (iii) Failure under reflood hydraulic conditions.

NOTED REFERENCES

(a) NRC Draft Report NUREG-0630, "Cladding, Swelling and Rupture Models for LOCA Analysis," dated November 8, 1979

(b) ENC letter, G. F. Owsley to D. G. Eisenhut, dated November 2, 1979

(c) ENC letter, G. F. Owsley to D. G. Eisenhut, dated November 7, 1979

(d) ENC letter, G. F. Owsley to D. G. Eisenhut, dated November 16, 1979

(e) ORNL #752 dated January 1972.

FIGURE 1 BLOCKAGE PREDICTION BASED ON CONSIDERING
REDUCED AXIAL EXTENT OF STRAIN