AREVA

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U.S. Nuclear Regulatory Commission
Washington, D.C. 20555-0001

Additional Information – EMF-93-177(P) Revision 1, "Mechanical Design for BWR Fuel Channels"

Ref. 1: Letter, Jerald S. Holm (FANP) to Document Control Desk (NRC), "Request for Review and Approval of EMF-93-177(P) Revision 1, 'Mechanical Design for BWR Fuel Channels'," NRC:05:002, January 14, 2005.

Framatome ANP requested the NRC's review and approval of the topical report EMF-93-177(P) Revision 1, "Mechanical Design for BWR Fuel Channels" in Reference 1. A presentation to the NRC on the topical report was made on March 23, 2005. Framatome ANP committed during the meeting to provide additional information to support the NRC review. The additional information is presented in Attachment A.

Framatome ANP considers some of the information contained in the attachment to this letter to be proprietary. The affidavit provided with the original submittal of the reference topical report (Reference 1) satisfies the requirements of 2.390(b) to support the withholding of this information from public disclosure.

Sincerely,

Jerald S. Holm

Jerald S. Holm, Director
Regulatory Affairs
Framatome ANP, Inc.

Enclosures

cc: M. C. Honcharik
Project 728

T007

Attachment A

Additional Information for NRC Review of EMF-93-177(P) Revision 1

1. Definition of a Limit Analysis versus a Plastic Analysis

   The ASME B&PV Code defines the limit analysis and plastic analysis in several paragraphs. These paragraphs from the Code are repeated below and are followed by additional discussion on the relevance to the fuel channel topical report.

   First, the definitions for a limit analysis:

   > "**Limit Analysis:** Limit Analysis is a special case of plastic analysis in which the material is assumed to be ideally plastic (nonstrain hardening). In limit analysis, the equilibrium and flow characteristics at the limit state are used to calculate the collapse load. The two bounding methods which are used in limit analysis are the lower bound approach, which is associated with a statically admissible stress field, and the upper bound approach, which is associated with a kinematically admissible velocity field..."

   > "**Limit Analysis – Collapse Load:** The methods of limit analysis are used to compute the maximum load that a structure assumed to be made of ideally plastic material can carry. At this load, which is termed the collapse load, the deformations of the structure increase without bound."

   > "**Collapse Load – Lower Bound:** If, for a given load, any system of stresses can be found which everywhere satisfies equilibrium, and nowhere exceeds the material yield strength, the load is at or below the collapse load. This is the lower bound theorem of limit analysis which permits calculations of a lower bound to the collapse load."

   > "**Plastic Hinge:** A plastic hinge is an idealized concept used in Limit Analysis. In a beam or a frame, a plastic hinge is formed at the point where the moment, shear and axial force lie on the yield interaction surface. In plates and shells, a plastic hinge is formed where the generalized stresses lie on the yield surface."

   In contrast to the above, the ASME Code describes a plastic analysis as:

   > "**Plastic Analysis:** Plastic analysis is that method which computes the structural behavior under given loads considering the plasticity characteristics of the materials, including strain hardening and stress redistribution occurring in the structure."

   > "**Plastic Analysis – Collapse Load:** A plastic analysis may be used to determine the collapse load for a given combination of loads on a given structure. The following criterion for determination of the collapse load shall be used. A load-deflection or load-strain curve is plotted with load as

> the ordinate and deflection or strain as the abscissa. The angle that the linear part of the load-deflection or load-strain curve makes with the ordinate is called θ. A second straight line, hereafter called the collapse limit line, is drawn through the origin so that it makes an angle $\Phi = \tan^{-1}(2\tan\theta)$ with the ordinate. The collapse load is the load at the intersection of the load-deflection or load-strain curve and the collapse limit line. If this method is used, particular care should be given to ensure that the strains or deflections that are used are indicative of the load carrying capacity of the structure."

As stated above, the limit analysis is a special case of the plastic analysis. The basic concept of the limit analysis is to simplify the calculation and identify the load at the onset of plastic deformation. A clear demarcation between elastic behavior and yielding is identified by the limit analysis. To this end, an elastic, perfectly-plastic stress-strain curve is required for a limit analysis so that a distinct collapse load is obtained. Also, the intent is to not allow geometric strengthening (large deflections) that would also permit the redistribution of loads and stresses.

A plastic analysis is more realistic in that strain-hardening and geometric non-linearity (large deflections) are permitted. The Revision 0 topical report made use of a large deflection option because a stable solution could not be achieved at the desired differential pressure levels for the channel designs. The error was made by using the analysis to infer the point of collapse based on load and then applying the limit analysis criteria. Instead, when the large deflection option is used, it is required by the Code to resort to the double-elastic-slope criteria (i.e., $\Phi = \tan^{-1}(2\tan\theta)$) to establish the collapse load, as described above, for a plastic analysis.

The Revision 1 report follows the plastic analysis collapse load method and criteria. A conservative stress-strain curve was selected, and it is the same as used in the Revision 0 report for a plastic analysis of the fuel channel under accident conditions. The curve includes strain hardening. As before, the large deflection option is used. With the relatively simple geometry, a well-behaved and stable solution was achieved up to the maximum pressure load.

2. Changes in Deformation Results for Normal Operation and Anticipated Operational Occurrence (AOO)

The results from the deformation analysis for normal operation and AOO changed when the analysis was redone because a different stress-strain curve was used.

In the Revision 0 deformation analysis, the stress-strain curve was elastic, perfectly-plastic with yielding occurring at $0.5S_U$ or [ ]. The curve is shown in Figure 6.2 of the Revision 0 report. This is the same stress-strain curve as used for the incorrect "limit" analysis. The particular stress-strain curve was selected consistent with the Code requirements for a limit analysis. That is, the Code requires the yield point to be set at the lesser of $1.5S_m$ and $0.5S_U$.

The stress-strain curve used for the Revision 1 analysis is also shown in the Revision 0 report in Figure A.2. Strain-hardening is included and the yield point occurs at [ ] ksi.

While the one portion of the analysis was found to be in error, the deformation portion of the analysis was judged to be acceptable because it was conservative and did not conflict with the Code requirements. In addition, the stress-strain curve was known to be conservative.

However, when the calculations were revised for the Revision 1 report, the same inputs (e.g., stress-strain curve, etc.) were used for the deformation portion of the analysis as for the plastic analysis collapse load portion. Again, the inputs are conservative for calculating deformations. Because the stress-strain curve is higher than before, a higher pressure limit is now calculated based on deformation for normal operation and AOO.

3. Basis for 70 psi as the Failure Point for the Ultimate Failure Analysis

The plastic analysis collapse load calculation must be carried up to a sufficiently high pressure to ensure the pressure limit result is identified in case it is more restrictive than the pressure limit obtained from the deformation analysis.

For example, the deformation analysis for the 80-mil fuel channel resulted in a [ ] psi limit for normal operation and AOO. For the plastic analysis collapse load to be more restrictive, a collapse load must be calculated at a pressure of less than [ ], which equals [ ] psi. In other words, if the collapse load is found to be less than [ ] psi when performing the plastic analysis collapse load, then the pressure limit result will be established at a value less than [ ] psi.

In the Revision 1 report, the plastic analysis collapse load was performed up to 70 psi because of the desire to reach the collapse load so a comparison could be made to the deformation analysis result. As presented in the March 23rd meeting with the NRC, the collapse load was never achieved. Thus, the collapse load was assumed to occur above 70 psi. However, the analysis was carried out far higher than necessary not because it was required but to gain a better understanding of the problem. For future analyses, it should not be necessary to perform the analysis any higher than the [ ].

4. Range of Applicability

The intent was to apply the methods and criteria to small variations in wall thicknesses. The topical report methods and criteria will be restricted to the conditions defined below:

> The fuel channel topical report methods and criteria may be applied to similar fuel channel designs with a like configuration – a square box with radiused corners open at the top and bottom ends. The wall thicknesses shall fall within the range of current designs, between thicknesses of [ ]. The channels shall be fabricated from either Zircaloy-2 or Zircaloy-4. The material properties in the topical report shall conservatively apply to the channel design.

5. Revisions to Channel Bulge and Bow Data

In the March 23rd meeting, a discussion occurred on the change in the report to allow additions to the channel measurement data base without resubmitting the data to the NRC. Framatome ANP, Inc.[3] (FANP) responded by pointing to other areas where similar allowances were made. As for channel deformation data, poolside examinations are periodically performed to measure fuel rod growth and fuel assembly growth. Updates to fuel rod and fuel assembly growth data have been permitted without review by the NRC, provided the changes are limited.

For example, the TER (in Reference 3) states the following with regard to changing the PWR axial growth correlations:

> "If either the upper or lower bounds of the new axial growth model change by more than one standard deviation from the lower and upper bounds of the base axial growth model in Reference 5 the new model is required to be submitted to NRC for review."

A similar response was provided to the NRC in the Reference 4 letter to address the irradiation growth of the ATRIUM™-10[4] design:

> "SPC will submit the correlation for review and approval, if the correlation predictions (best fit and limits) change more than one standard deviation from those shown in the figure (in the referenced attachment) due to the inclusion of new data in the correlation; and SPC will resubmit the correlation if the equation form of the fit has changed."

FANP commits to resubmit the channel bulge and bow data statistics if the two-sigma upper and lower bounds change by more than one standard deviation.

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[3] Framatome ANP, Inc., is an AREVA and Siemens company.

[4] ATRIUM is a trademark of Framatome ANP, Inc.

6. Review of References

After reviewing the analyses that were performed with ABAQUS, it was found that the ABAQUS code is not used in the Revision 1 report. In the Revision 0 report, ABAQUS, NASTRAN, ANSYS and KWUSTOSS were used, depending on the analysis. Note that the first three are commercially available codes while KWUSTOSS is a special-purpose in-house finite element code that is used for dynamic analyses. ANSYS was previously used only in a minor part of a calculation in conjunction with KWUSTOSS to aid in deriving the stiffness matrices described in Appendix B. As discussed in the March 23rd meeting, the current plan is to use only ANSYS for the pressure limit calculation. However, FANP would like to reserve the option to use the other two commercial codes in the future for the pressure limit calculation. All three commercial codes are well recognized in the industry, and all have the demonstrated ability to perform the analyses described in the topical report.

7. Finite Element Codes for Future Analyses

FANP proposes to use ANSYS, ABAQUS or NASTRAN for the pressure limit calculation. All three codes possess an extensive feature set with the capabilities to perform the fuel channel deformation and strength analyses that are described in the topical report. There is no technical reason for the current change from ABAQUS. The change was completely motivated by the lease costs and maintenance fees for the codes.

As already mentioned, the KWUSTOSS code is an in-house finite element code that is specialized to perform efficient dynamic analyses. The KWUSTOSS code, which is described in Appendix B of the report, will continue to be used for the dynamic analysis of the fuel channel. A change from KWUSTOSS to another code could represent a significant departure from the approved methodology.

References

1. EMF-93-177(P)(A) Revision 0 and Supplement 1, *Mechanical Design for BWR Fuel Channels*, Siemens Power Corporation – Nuclear Division, August 1995.

2. EMF-93-177(P) Revision 1, *Mechanical Design for BWR Fuel Channels*, Framatome ANP, Inc., January 2005.

3. EMF-92-116(P)(A) Revision 0, *Generic Mechanical Design Criteria for PWR Fuel Designs*, Siemens Power Corporation, February 1999.

4. Letter, H. Donald Curet (SPC) to NRC Document Control Desk, "ATRIUM-10 Irradiation Growth Evaluation," HDC:97:038, May 1, 1997.