FINAL SAFETY EVALUATION BY THE OFFICE OF NUCLEAR REACTOR REGULATION

TOPICAL REPORT ANP-10336P, REVISION 0

"Z4B FUEL CHANNEL IRRADIATION PROGRAM

AREVA INC.

PROJECT NO. 728

1.0 INTRODUCTION AND BACKGROUND

By letter dated July 2, 2015, AREVA Inc. (AREVA) submitted Topical Report (TR) ANP-10336P, Revision 0, "Z4B Fuel Channel Irradiation Program," to the U.S. Nuclear Regulatory Commission (NRC) for review and approval for referencing in licensing actions of an expanded lead use channel (LUC) program. The operation of boiling water reactor (BWR) plants has, in recent years, been affected by greater than expected fuel channel distortion. This has resulted in safety concerns, such as slow and stuck control blades and inoperable control blades, requiring costly risk mitigation operating strategies. AREVA has developed a new fuel-channel material, Z4B. AREVA's preliminary irradiation experience with recrystallized annealed (RXA) Z4B lead use channels, beta-quenched (BQ) Z4B lead use channels, and with spacer grid strips in a material test program, suggest superior performance with respect to channel distortion with the materials Zircaloy-2 (Zry-2) and Zircaloy-4 (Zry-4) currently used as BWR channel material. The proposed expanded lead use channel program will allow Z4B channels to be exposed to the spectrum of limiting in-reactor conditions necessary to develop the predictive models for batch application of Z4B channels (References 1 and 2).

The observed channel distortion is attributed to three phenomena that are likely to become effective at extended in-core fuel residence times: (1) differential irradiation growth due to fluence gradients, (2) shadow corrosion due to hydrogen uptake, and (3) stress relaxation. These phenomena are realizations of degradation mechanisms that are dependent on the irradiation history of the local nuclear, thermal-hydraulic and mechanical environment over the channel's in-core residence time. This requires relevant data from LUCs in positions with limiting histories of the independent variables for use in the formulation of the predictive models of channel distortion. To this end, AREVA's Z4B fuel channel irradiation program (Reference 4) includes two components: a limit on the quantity of Z4B fuel channels in the core, and an augmented surveillance procedure within each normal Technical Specification testing interval to assure the 'status quo ante' level of safety.

2.0 REGULATORY EVALUATION

The regulatory guidance for the review of fuel system materials and designs is set forth in NUREG-0800, "Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants (SRP)," (Reference 3) and in particular in SRP Section 4.2, "Fuel System Design." The SRP guidance for BWR fuel bundle channels addresses control blade interference and insertability as set forth in SRP Section 4.2.II.1.A.v. In particular, for this review it states: Channel material changes can also impact the differential growth, stress relaxation, and the amount of bulge, and, therefore, must be evaluated. If interference is determined to be possible, tests are needed to demonstrate control blade/rod insertability consistent with assumptions in safety analyses. Additional in-reactor surveillance (e.g. insertion times) may also be necessary for new designs, dimensions, and materials to demonstrate satisfactory performance.

Furthermore, Standard Technical Specifications include guidance for lead test assemblies (LTAs) that encompasses LUCs:

> Fuel assemblies shall be limited to those fuel designs that have been analyzed with NRC staff approved codes and methods, and have been shown by tests or analyses to comply with all safety design bases. A limited number of LTAs that have not completed representative testing may be placed in non-limiting core regions.

The constraint in this statement of "non-limiting core regions" appears to address limits in the context of fuel rod performance. These are not the same as limits on fuel channel performance. Since the intent of the LUC program is to generate data with regard to the performance of fuel channels with a new material, the LUCs should be subjected to at least some limiting in-reactor histories. Furthermore, in view of AREVA's LUC program objectives, the fact that channel bow is a degradation process, and the introduction of enhanced in-reactor surveillance, the NRC staff finds the unrestricted placement of Z4B LUCs within the core (including control cell locations) acceptable subject to the limitations and conditions of this safety evaluation placed on the number of LUCs in the core and a supplemental in-reactor surveillance program.

3.0 TECHNICAL EVALUATION

We note that AREVA has not requested approval of the Z4B channels, but rather an approval for an expanded LUC program. As such, the central issue is whether an expanded LUC program of stepwise increases in the number of LUCs in operating BWRs (as formulated in Reference 4) results in more than a minimal increase in the likelihood of sufficient channel distortion to render the control blades inoperable. In principle, given a batch of N LUCs, the estimate that k less than N ($k<N$) will exceed a specified distortion limit is equal to the product of N times the estimate of the probability that one LUC out of the future population exceeds the distortion limit. Under this principle, to demonstrate that the accepted probability of exceeding the distortion limit is at least constant as the number of LUCs increase in the core is directly a function of the experimentally based estimate of the probability of a single LUC exceeding the limit.

Consequently, since the probability of a LUC exceeding its deformation limit is not computable from surveillance data, surveillance data alone cannot be used to justify an increase in the number of LUCs in the core. For that, further post-irradiation examination (PIE) results and analysis are required before proceeding. Thus, the AREVA's LUC program is limited to 8 percent of the core exclusive of other non-LUC assembly programs.

3.1 Z4B Channel Design, Fabrication and Composition

The channel design specification for the Z4B LUCs remain the same as for the currently approved Zry-2 and Zry-4 fuel channels used in currently operating BWRs. Z4B-RXA and Z4B-BQ have the same alloy composition; they differ from Zry-4 in higher iron and chromium content. Z4B-RXA and Z4B-BQ differ in that the latter receives a BQ heat treatment that has demonstrated inducing a reduced growth rate in Zircaloys. The small chemistry differences between Zry-4 and Z4B do not have a significant impact on the un-irradiated mechanical properties of the fuel channel materials in that the Z4B ultimate strength and yield strength are greater than or equal to those of the previously NRC approved Zry-4 (Reference 1). However, limited evidence has been presented that this remains true for Z4B at the fluence and temperature levels of interest.

3.2 Z4B Channel Operating Experience

AREVA's irradiation experience with Z4B LUCs is summarized in Table 2 of Reference 4. The table shows, as of July 2014, the different levels of experience gained for 58 fuel assemblies delivered to six different BWRs since 2009. The relevant data with respect to their in-core performance is associated with the 22 fuel channels having reactor codes C04, A33, and C05. These have undergone PIE. This dataset is insufficient for an adequate statistical analysis that is required for predicting the end of life Z4B fuel channel deformation with the high level of confidence required for acceptance of an increase in percentage of reload LUCs, as requested in Reference 4.

However, the data shown in Figures 1 - 5 of Reference 4 is suggestive of superior performance with respect to the current operating Zry-4 fuel channels. In Figure 1 the fuel channel growth as a function of equivalent burnup is in general well below the currently approved nominal growth. In Figure 2, a comparison is made of channel bulge of 100 mil Z4B fuel channels and Zry-4 sister channels (i.e., fuel channels in symmetric core locations, and thus subject to the same irradiation history) as a function of equivalent burnup. The data show a small, but systematically smaller, channel bulge for Z4B as compared to Zry-4. A similar comparison with similar results is shown in Figure 3 for 114/67 mil fuel channels. The key observation is that the performance of Z4B fuel channels appears to improve systematically over Zry-4 fuel channels with increasing equivalent burnup.

The effect of fluence gradient is shown in Figures 4 and 5. The data on fuel channel bow as a function of this parameter indicates a roughly comparable performance of Z4B versus Zry-4 sister fuel channels.

4.0 LIMITATIONS AND CONDITIONS

Licensees referencing the expanded Z4B LUC program must ensure compliance with the following limitations and conditions:

1. Z4B lead use channels may be used in quantities up to 8 percent of the total number of channels in the core. This limit is exclusive of other lead assembly programs. The NRC has approved this expanded LUC program in order to acquire data which may demonstrate Z4B fuel channels have improved resistance to fuel channel distortion.

2. The supplemental surveillance plan, described in Section 2.1 of the TR, must be fulfilled.

3. Channel growth, bulge, and bow measurements from at least 10 percent of the Z4B channels irradiated under the expanded LUC program must be collected following the second cycle of operation. Upon discharge, this data must be collected from at least 50 percent of the Z4B LUCs. This requirement is void upon batch approval of Z4B channels.

4. Upon availability, all data collected will be added to AREVA's database and compared with Zircaloy-4 predictive models.

5. As further in-reactor experience and measurements are collected, AREVA will continue to demonstrate that Z4B LUCs satisfy design requirements for each reload cycle.

6. To assure continued in-reactor performance of the LUCs with regard to unanticipated channel distortion, AREVA must provide an annual report, documenting the ongoing experience with the enhanced LUC program, including any anomalous indications identified in the supplemental surveillance plan, and provide an updated database of post-irradiation measurements.

7. Existing BWR channel distortion - control blade interference counter measures, including fuel management guidelines and augmented monitoring and inspection programs will continue to be applied for cores containing Z4B channels.

5.0 CONCLUSIONS

In its proposal of a Z4B Fuel Channel Irradiation Program, AREVA requests a stepwise approach to increasing the quantities of Z4B RXA and Z4B-BQ fuel channels in operating BWRs. This approach is deemed to allow the nuclear industry to benefit from the improved safety performance of Z4B RXA and Z4B-BQ fuel channels prior to full reload implementation. As discussed in Sections 3.0 and 3.2, AREVA has not presented sufficient data and analysis to support such a program. However, LUC irradiation programs of new materials exposed to varying in-reactor operating strategies, nuclear conditions, and water chemistry are needed, and have been approved by the NRC in the past in order to gain experience and gather data for full-core application. In view of this, the NRC staff finds acceptable an AREVA LUC irradiation program that is limited to 8 percent of the core with unrestricted placement of Z4B LUCs within the core.

Licensees referencing this AREVA LUC program will need to comply with the limitations and conditions listed in Section 4.0. The NRC staff concludes for the AREVA LUC program based on the considerations discussed above, that (1) there is reasonable assurance that the health and safety of the public will not be endangered by operation in the proposed manner, (2) such activities will be conducted in compliance with the commission's regulations, and (3) issuance of this safety evaluation will not be inimical to the common defense and security or to the health and safety of the public.

6.0 REFERENCES

1. EMF-93-177(P)(A), Revision 1, "Mechanical Design for BWR Fuel Channels," Framatome ANP, August 2005 (Agencywide Documents Access and Management System (ADAMS) Accession No.ML052370370).

2. EMF-93-177-A, Revision 1, Supplement 1P-A, Revision 0, "Mechanical Design for BWR Fuel Channels Supplement 1: Advanced Methods for New Channel Designs," AREVA NP, September 2013 (ADAMS Accession No. ML14198A133).

3. NUREG-0800, "Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants," Chapter 4, Section 4.2, Revision 3, "Fuel System Design," March 2007 (ADAMS Accession No. ML070740002).

4. ANP-10336P, Revision 0, "Z4B Fuel Channel Irradiation Program" June 2015 (ADAMS Accession No. ML15188A230).

Attachment: Resolution of Comments

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