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Research Supporting Implementation of Burnup Credit in Transport and Storage Casks

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ABSTRACT

The U.S. NRC has initiated a research program to support the development of technical bases and guidance that will help the NRC staff implement the concept of burnup credit into licensing activities for transport and dry cask storage. This paper provides a review of the major areas of investigation: (1) specification of axial burnup profiles, (2) assumption on cooling time, (3) allowance for assemblies with burnable absorbers, (4) the additional burnup recommended by NRC for fuel with initial enrichments over 4 wt %, and (5) experiment evaluation.

I. INTRODUCTION

The Oak Ridge National Laboratory (ORNL) is supporting the U.S. Nuclear Regulatory Commission (NRC) Office of Regulatory Research (RES) in a program to facilitate effective implementation of burnup credit in the criticality safety assessment of transport and dry storage casks. The goal is to develop technical bases for recommendations on criteria and guidance that can be considered by the NRC Spent Fuel Project Office (SFPO), which is responsible for licensing burnup-credit cask designs. Since the SFPO issuance of their Interim Staff Guidance (ISG8)[1] in July, 1999, the effort of the NRC research has shifted to identifying work needed to develop expanded guidance relative to selected elements of ISG8, to implement software enhancements that can facilitate the use of computational methods in safety analyses, and to develop a technical basis for the NRC/SFPO to use in considering future revisions of ISG8. A baseline report[2] was prepared to review the status of burnup credit and to provide a strawman prioritization for areas where additional guidance, information, and/or improved understanding were considered to be beneficial to the effective implementation of burnup credit in transport and dry storage casks. As a result of the initial review and input from industry and licensing staff, the current focus areas for the NRC research program were established and will be discussed below.

II. AXIAL BURNUP PROFILE

As indicated by ISG8, the axial burnup profile is an extremely important component of the safety analysis. However, ISG8 provides little information on an acceptable approach to address this issue in the licensing application. Thus, the research program has sought to develop and propose initial guidance that can be readily implemented by industry and readily reviewed by NRC staff. As a starting point for initial guidance, ORNL staff sought to review and evaluate the database[3] of 3169 axial burnup profiles that represent a large, but not exhaustive, sampling of typical and atypical assembly profiles resulting from irradiation in 20 U.S. pressurized-water reactors. Work has previously been performed[4] to identify the axial profiles within the database that provide the highest neutron multiplication factors (k_{eff}) over selected burnup ranges. This information has been used to propose artificial bounding profiles for each burnup range. Figure 1 shows the spread of k_{eff} values that result from the set of profiles available from a selected burnup range, together with the actual bounding profile from the database and the proposed (artificial) bounding profile of Ref. 4. The figure shows the mean k_{eff} value and indicators for 1, 2, and 3 standard deviations. An examination of the calculated k_{eff} values reveals that, for each of the 12 burnup ranges, the k_{eff} value associated with the actual bounding axial profile, is more than 3 standard deviations above the mean and, in most cases, is more than 5 standard deviations above the mean. In other words, the limiting profiles can be considered statistical outliers, as opposed to representative of typical spent nuclear fuel (SNF) profiles. Consequently, one can infer that the probability that other axial profiles

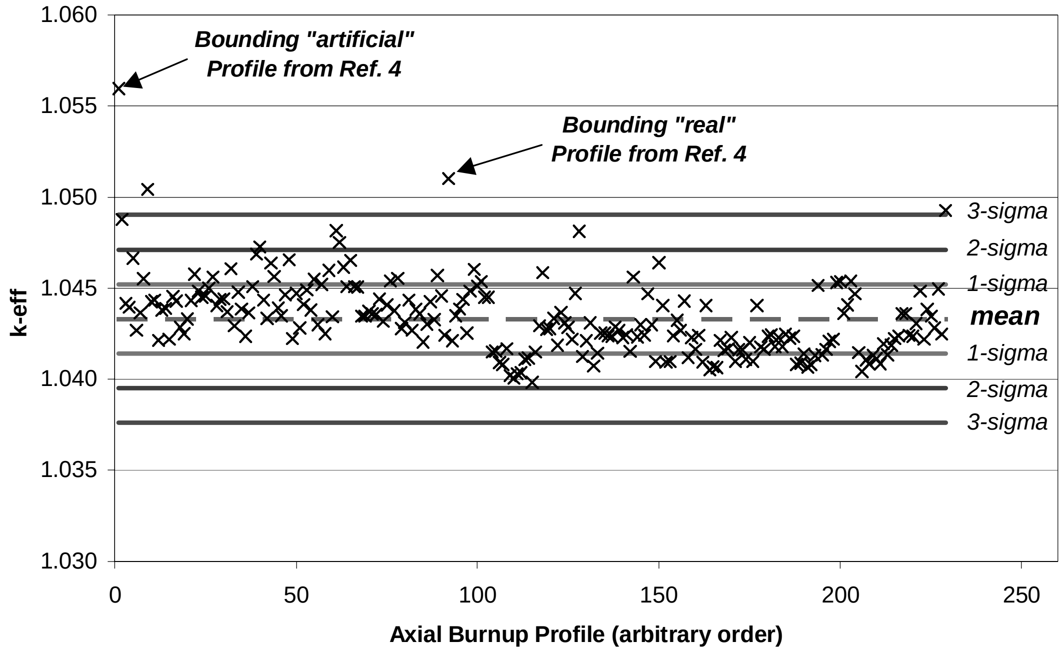

Figure 1. Values of k_{eff} for an infinite planar array as a function of database[3] axial profiles for 38-42 GWd/t. Figure taken from Ref. 10.

exist that are notably more reactive than the limiting profile (determined from the database) is very small. When one considers that the limiting profiles are based on statistical outliers and that these limiting profiles will be applied to all assemblies in a burnup credit cask, it is clear that this approach results in significant conservatism in comparison to reality. Work is in progress to use risk-informed insights to enable criteria for development and use of a more realistic profile in a safety analysis. For example, if axial-profile measurements for each assembly were performed prior to loading, a profile deemed bounding of the "typical" profiles could be used in the safety analysis and the profile for the as-loaded assembly would be checked for adherence. Initial work indicates a significant benefit can potentially be achieved from such an approach.

III. COOLING TIME

The ISG8 recommends safety analyses be performed at a fixed cooling time of 5 years. For burnup-credit criticality safety analyses performed at 5 years, increasing cooling time results in an increasing conservative safety margin out to approximately 100 years but with an insignificant additional benefit for cooling times greater than ~50 years. A cooling time of 40 years provides a k_{eff} value that approximately equates to the k_{eff} value at 200-year cooling, which might be considered a practical lifetime for dry storage and transport casks. Thus, this rationale leads to a conclusion that cooling times up to 40 years can be assumed in developing the safety basis. To address concerns with use of storage casks beyond the assumed 200-y storage time and to lay a consistent foundation that enables future extension beyond the actinide-only assumption, it has been suggested that a value of 10 years be assumed as the cooling time limit for safety analysis. The rationale is that the best-estimate results, for k_{eff} at a 10-year cooling time, are always greater than the maximum k_{eff} in the secondary peak (10,000-to-30,000-year time frame). The NRC will be considering the technical and practical merits associated with allowing cooling times besides 5 years.

IV. BURNABLE ABSORBERS

The ISG8 restricts the use of burnup credit to assemblies that have not contained burnable absorbers during any part of their exposure. This restriction eliminates a large portion of the currently discharged spent fuel assemblies in a burnup credit cask. Using a comprehensive range of assembly designs and poison loadings, ORNL has recently completed studies to demonstrate the impact of burnable poison rods (BPRs) and integral burnable absorbers on the k_{eff} of SNF in a cask environment. Although variations are observed for different BPR designs, maximum increases have been found to be ~1 to 3% Δk when maximum BPR loading and exposure time (up to three power cycles) are assumed for typical initial enrichment and discharge burnup combinations.[5] Similarly, the maximum increase observed for integral burnable absorbers was less than 0.5% Δk. The studies provide a base characterization for the effect of burnable absorbers on SNF and provide a basis for various approaches that could be used in a safety assessment (e.g., assume limiting BPRs in the depletion up to a specified burnup level). Other, less-conservative approaches that incorporate information regarding the percentage of assemblies exposed to BPRs for multiple cycles will be explored during the coming year.

V. LOADING OFFSET FOR HIGH INITIAL ENRICHMENTS

Currently, ISG8 limits credit for burnup to 40 GWd/t and initial enrichments to 4 wt %, although allowance for initial enrichments up to 5 wt % is permitted with an added burnup margin. The major reason for these recommended limitations is the lack of chemical assay data for higher burnups and enrichments. Extending the area of applicability for the existing chemical assay measurements, by making use of trends in the bias and uncertainty, has proven to be challenging because of the limited amount of experimental data and the large number of different parameters that can affect the bias. Several studies[6,7] do suggest, however, that the effect of enrichment on the isotopic uncertainties is minimal. The published French results[6] for Gravelines spent fuel using French computational methods and JEF cross-section data indicate a level of agreement that is comparable to that of lower-enrichment fuel. In addition, sensitivity-based methods have been applied at ORNL to assess the influence of nuclear data bias and uncertainties on the isotopic compositions and the k_{eff} of a spent fuel storage cask.[7] These studies indicate that there is a strong correlation between spent fuel systems with a constant enrichment-to-burnup ratio. The results suggest that existing isotopic assay data may be highly applicable to regimes well beyond that of the data and that the basic depletion phenomena do not change significantly with relatively minor increases in enrichment (i.e., from 4 wt % to 5 wt %). However, there is currently insufficient experimental data to validate these findings. It is anticipated that, as new assay data become available, it will be possible to combine the limited amount of experimental data with the sensitivity-based methods to provide additional evidence to support predictions beyond the range where the majority of experimental data exist.

VI. EVALUATION OF EXPERIMENTAL DATA

A review and evaluation of existing and proposed experimental data is underway at ORNL to help demonstrate and rank the relevance of experiments for methods validation using quantitative criteria and help identify experimental needs. Existing (albeit some are proprietary) experimental data include chemical assays of SNF nuclide inventories, critical experiments performed with fresh fuel in cask-like geometries, reactivity-worth measurements, subcritical experiments, and critical configurations in operating reactors. The potential value and limitations of each of these types of experiments were reviewed in Ref. 2. To assist in understanding and assessing the value of these experiment types, sensitivity/uncertainty (S/U) methods discussed in Ref. 8 are being used to provide information on the strengths and potential limitations of various types of experiments relative to validation needs for burnup credit. Existing fresh fuel (UO_2-fuel and mixed-oxide) critical experiments, reactor-critical configurations, reactivity-worth experiments, and measured chemical assay data are being studied with prototypic S/U methods.[9] Guidance on the best types of experiments, and/or combination of types of experiments, is being developed.

VII. SUMMARY DISCUSSION

A major focus over the next year is to investigate various approaches for increasing the allowable inventory of SNF in a burnup-credit cask design. If the restriction on burnable absorbers is removed, the potential inventory that can be considered for loading in a burnup credit cask will be expanded. However, the loading curves (burnup vs initial enrichment) developed with current ISG8 recommendations would eliminate a large portion of the SNF inventory because of insufficient burnup for the specified initial enrichment. Work to investigate approaches for developing a technical basis for some portion of fission product credit is being pursued. Efforts in the coming year will also seek to study various risk-informed approaches that may reduce the conservatism associated with the development of loading curves (i.e., lower the required burnup value needed for a specific initial enrichment). For example, the use of typical or average axial profiles may be acceptable if it can be demonstrated that the impact of using bounding profiles for a portion (some realistic upper limit based on the probability for multiple assemblies with atypical profiles) of the loading does not present an unacceptable risk to safety. To investigate such approaches conclusively will require additional information regarding the range of operating conditions (e.g., soluble boron concentration, moderator temperature) seen in typical and atypical reactor operations. Such information could allow the use of statistical analyses to help determine appropriate "typical" conditions and help assess the probability of "outlier" conditions that would normally be the basis for bounding analyses. *The goal is to develop criteria and/or recommendations that are technically credible, practical, and cost effective while maintaining needed safety margins.*

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REFERENCES

1. "Spent Fuel Project Office Interim Staff Guidance - 8, Rev. 1 - Limited Burnup Credit," U.S. Nuclear Regulatory Commission, July 30, 1999.

2. C. V. Parks, M. D. DeHart, and J. C. Wagner, *Review and Prioritization of Technical Issues Related to Burnup Credit for LWR Fuel*, NUREG/CR-6665 (ORNL/TM-1999/303), U.S. Nuclear Regulatory Commission, Oak Ridge National Laboratory, February 2000.

3. R. J. Cacciapouti and S. Van Volkinburg, *Axial Burnup Profile Database for Pressurized Water Reactors*, YAEC-1937, Yankee Atomic Electric Company, May 1997.

4. T. A. Parish and C. H. Chen, "Bounding Axial Profile Analysis for the Topical Report Database," Nuclear Engineering Dept., Texas A&M University, March 1997.

5. J. C. Wagner and C. V. Parks, "Impact of Burnable Poison Rods on PWR Burnup Credit Criticality Safety Analyses," *Trans. Am. Nucl. Soc.* **83**, 130–134, 2000.

6. N. Thiollay, J. P. Chauvin, B. Roque, A. Santamarina, J. Pavageau, J. P. Hudelot, and H. Toubon, "Burnup Credit for Fission Product Nuclides in PWR (UO_2) Spent Fuels," presented at the *Sixth International Conference on Nuclear Criticality Safety, ICNC 99*, September 20-24, Versailles, France, 1999.

7. I. C. Gauld and C. V. Parks, *Review of Technical Issues Related to Predicting Isotopic Compositions and Source Terms for High-Burnup LWR Fuel*, NUREG/CR-6701 (ORNL/TM-2000/277), U.S. Nuclear Regulatory Commission, Oak Ridge National Laboratory, January 2001.

8. B. L. Broadhead et al., *Sensitivity and Uncertainty Analyses Applied to Criticality Validation*, NUREG/CR-6655, Vols. 1–2 (ORNL/TM-13692/V1, V2), U.S. Nuclear Regulatory Commission, Oak Ridge National Laboratory, November 1999.

9. B. L. Broadhead, "Value Rankings of Selected Critical Experiments for Burnup Credit Validations," *Trans. Am. Nucl. Soc.* **83**, 124-126, 2000.

10. C. V. Parks, I. C. Gauld, J. C. Wagner, B. L. Broadhead, and M. D. DeHart, "Research Supporting Implementation of Burnup Credit in the Criticality Safety Assessment of Transport and Storage Casks," *Proc. of the Twenty-Eighth Water Reactor Safety Information Meeting*, October 23–25, 2000, Bethesda, Maryland, 2001.