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Recommendations for PWR Storage and Transportation Casks That Use Burnup Credit

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1 INTRODUCTION

The concept of taking credit for the reduction in reactivity due to irradiation of nuclear fuel (i.e., fuel burnup) is commonly referred to as burnup credit. In July 1999, the U.S. Nuclear Regulatory Commission (NRC) Spent Fuel Project Office issued Interim Staff Guidance 8 Revision 1 (ISG8R1) to provide recommendations for the use of burnup credit in storage and transport of pressurized water reactor (PWR) spent nuclear fuel (SNF) [1]. These recommendations were subsequently included in the Standard Review Plan for transportation cask and dry storage cask facilities [2, 3]. This paper will provide a discussion of the technical bases for making select revisions to the recommendations of Refs. [1–3].

Although the basic six areas of ISG8R1 (consistent with six sections below) are not likely to change with the planned release of Revision 2 of the ISG8, the individual criteria and specific recommendations will change. The anticipated changes are highlighted here.

2 LIMITS FOR LICENSING BASIS

The research and investigations related to revising ISG8R1 focused on bases to extend the burnup and enrichment limits. Figure 1 shows that the range of existing radiochemical data that are readily available for validation currently extends up to 47.3 GWd/MTU and 4.1 wt % ^{235}U initial enrichment. Risk-informed technical judgement indicates that trends in the calculational bias and uncertainty derived from this database can be extended for use with SNF having initial enrichments up to 5.0 wt % and average assembly burnups limited to 50 GWd/MTU [4]. Reference [5] provides a comprehensive study of the effect of cooling time on burnup credit for various cask designs and SNF compositions (actinides, actinides and major fission products, and all nuclides). Using this study as a basis, it is anticipated that the cooling time for burnup credit will be allowed to be any applicant-selected value between 1 and 40-y cooling time.

3 CODE VALIDATION

The revision to ISG8R1 will likely focus on the issues related to potential extension of the burnup and enrichment limit and the data and methods available for validation. From Fig. 1, it can be seen that the primary source of readily-available assay data in the regime above 4.0 wt % and 40 GWd/MTU is from the Takahama PWR in Japan. Work reported in Ref. [4] has demonstrated that the standard deviation of the calculated-to-experimental nuclide ratios for the Takahama data are comparable to those observed for previous lower enrichment and lower burnup assay data.

An independent analysis of uncertainty trends using different techniques (but based on the same nuclide validation results) shows similar results. These findings are consistent with published results [6] where use of French computational methods and JEF cross-section data to analyze assay data for PWR fuel with 4.5 wt % initial enrichment indicate a calculated-to-measured ratio comparable to that of lower enriched fuel.

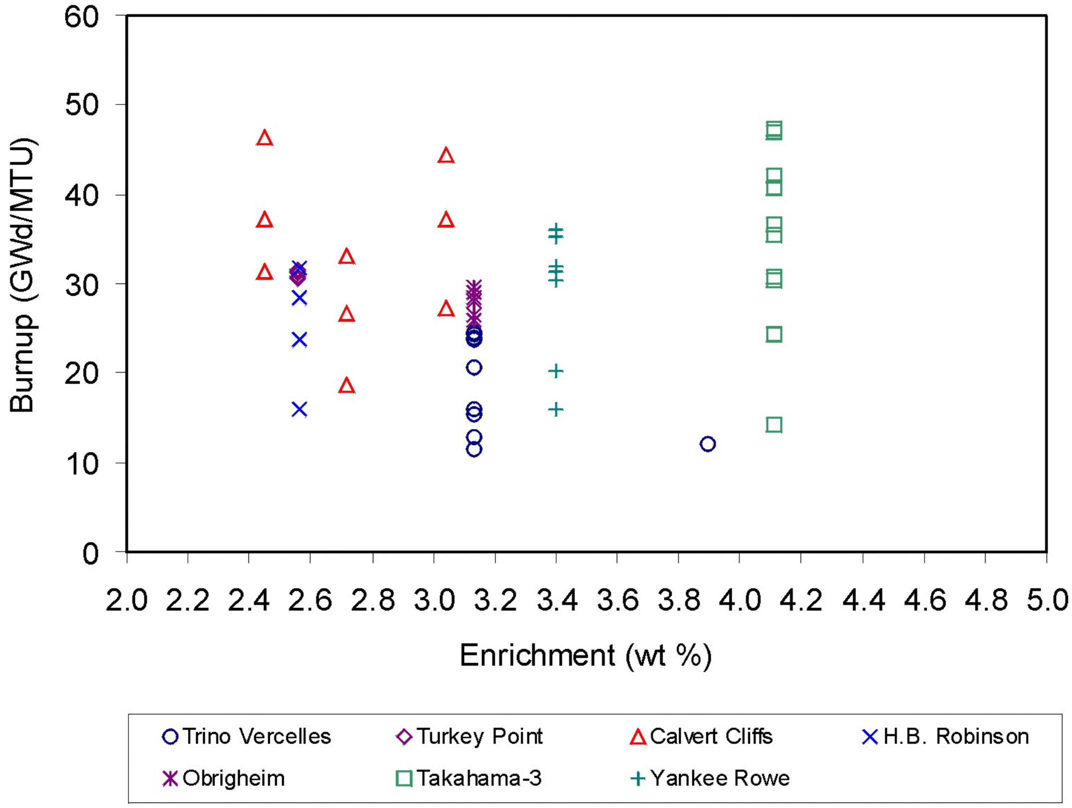

Figure 1. Enrichment and burnup of 56 PWR assay samples available for burnup-credit isotopic validation.

The methodology used to combine the biases and uncertainties for individual isotopes can have a significant impact on the predicted final k_{eff} value and needs to be properly explained and justified. Reference [4] contains a description of various approaches that can be used to obtain estimates of the bias and uncertainty in the SNF compositions. These will be discussed in the full paper.

4 LICENSING-BASIS MODEL ASSUMPTIONS

Changes from ISG8R1 will likely focus on guidance for selecting axial-burnup profiles and methods for allowing burnable absorbers in the safety analysis. To support such changes a review of the publicly available U.S. database [7] of axial-burnup profiles was prepared for the NRC [8].

Although the database represents only 4% of the assemblies discharged through 1994, the review indicates the database provides a good representation of discharged assemblies in terms of fuel vendor/reactor design, types of operation (i.e., first cycles, out-in fuel management and low-leakage fuel management), burnup and enrichment ranges, and use of burnable absorbers. The primary deficiency in the database of Ref. [7] is the number of profiles associated with assembly burnup values > 40 GWd/MTU and initial enrichment values > 4.0 wt %. However, Ref. [8] indicates that there is a high probability that profiles providing the highest reactivity in intermediate burnup ranges will also provide the highest reactivity at higher burnups. Consequently, using risk-informed judgement, the existing database should be adequate for burnups beyond 40 GWd/MTU if appropriate care is taken to adopt profiles that include a margin for potential added uncertainty in moving to higher burnups and initial enrichments.

Given the finite nature of the available database, there is judged to be some low probability that some discharged SNF would have a higher reactivity than the limiting profiles identified for the same burnup group. Using a generic burnup-credit cask model, Ref. [8] investigated the impact of loading single assemblies with a significantly more reactive profile and found the consequences to be small. Thus, the characteristic of the limiting profiles from the database as being statistical outliers, the use of a limiting profile for all assemblies loaded in the cask, and the low consequence associated with the loading of an assembly with a higher reactivity (beyond the selected limiting profile for that burnup group) has led to the recommendation that this publicly available database is an appropriate source for selecting bounding axial-burnup profiles.

Investigations [9–10] have been performed to quantify how the k_{eff} value of a discharged assembly would change due to irradiation with fixed neutron absorbers [integral burnable absorbers (IBAs)] and removable neutron absorbers [burnable poison rods (BPRs)] included in the assembly. A comprehensive range of assembly designs, absorber loadings, and exposure history was used to determine the impact on the k_{eff} value of SNF. The studies show that exposure to BPRs can cause the k_{eff} to increase up to 3% when the maximum number of BPRs and/or the maximum absorber loading is assumed for the maximum exposure time. More typical absorber loadings and exposures (1-cycle of 20 GWd/MTU) lead to increases of < 1% Δk. By comparison, except for one IBA type where the increase was as much as 0.5% Δk, the IBAs actually lead to a decrease in k_{eff} relative to assemblies without IBAs. Thus, a depletion analysis with a maximum realistic loading of BPRs (i.e., maximum neutron poison loading) and maximum realistic burnup for the exposure should provide an adequate bounding safety basis for fuel with or without burnable absorbers.

The results of a parametric study [11] to quantify the effect of CR exposure are summarized in Fig. 2, where it can be seen that, even for significant burnup exposures (up to 45 GWd/MTU), minor axial CR insertions (e.g., < 20 cm) result in an insignificant effect (< 0.2% Δk) on the k_{eff} value of a burnup-credit cask. Control rods, if inserted, are normally placed in first cycle assemblies. However, Ref. [11] shows that full insertion for burnups up to 5–10 GWd/MTU provided an increase in cask k_{eff} values on the same order as seen for BPRs. Thus, since BPRs and CRs can not be inserted in an assembly at the same time, it follows that the inclusion BPRs in the assembly irradiation model (up to burnup values that encompasses realistic operating conditions) should adequately account for the potential increase in k_{eff} that may occur for SNF exposed to CRs during irradiation.

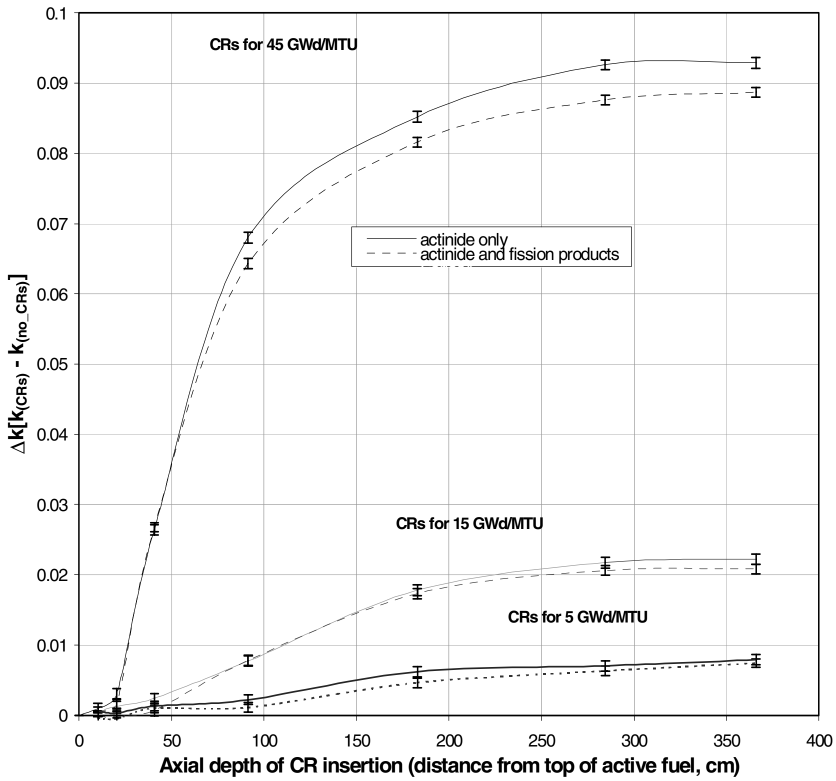

Figure 2. Impact of CR insertion during irradiation on SNF in the GBC-32 cask. *Source*: Ref. [11].

5 LOADING CURVE

Each loading curve should be clearly marked relative to key assembly characteristics (e.g., assembly design type, cooling time, etc.) and only one loading curve should be used for each cask loading opeation.

6 ASSIGNED BURNUP LOADING VALUE

In Regulatory Guide 3.71, NRC endorsed the recommendations of ANSI Standard 8.17-1997 with the exception that credit for fuel burnup may be taken only when the amount of burnup is confirmed by physical measurements. Any request for a plan to measure a random sample of fuel assemblies in lieu of measuring every assembly needs to be justified by a measurement database and specific procedures for executing the plan. Requests for sampling need to consider the demonstrated accuracy of the burnup record system as confirmed in the measurement data base.

7 ESTIMATE OF ADDITIONAL REACTIVITY MARGIN

Until additional experience is gained with the uncertainties associated with actinide-only burnup credit, an estimate of the additional reactivity margin that is available from nuclides not considered in the safety analysis may be used to compensate for uncertainties not readily understood or quantified in the actual safety analysis using actnides. The estimate should be specific to the cask design since the margin will vary depending on the external absorbers in the cask basket. It is anticipated that this information can be used to help justify that difficult-to-quantify uncertainties are adequately covered within the safety envelope of the cask design.

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