Issue: Burnup Credit in the Criticality Safety Analyses of PWR Spent Fuel in Transport and Storage Casks

Introduction:

Unirradiated reactor fuel has a well-specified nuclide composition that provides a straightforward and bounding approach to the criticality safety analysis of transport and storage casks. As the fuel is irradiated in the reactor, the nuclide composition changes and, ignoring the presence of burnable poisons, this composition change will cause the reactivity of the fuel to decrease. Allowance in the criticality safety analysis for the decrease in fuel reactivity resulting from irradiation is typically termed burnup credit. Extensive investigations have been performed both within the United States and by other countries in an effort to understand and document the technical issues related to burnup credit.

The U.S. Nuclear Regulatory Commission (NRC) *Standard Review Plan for Transportation Packages for Spent Nuclear Fuel*, NUREG-1617, provides the existing recommendations for the staff to proceed with acceptance, on a cask-specific basis, of a burnup credit approach in the criticality safety analysis of pressurized water reactor (PWR) spent fuel casks. Based on the technical information provided in the literature, together with confirmatory analyses by NRC research program, the following Recommendations expand the existing guidance in the Standard Review Plan to: (1) extend the range of allowed burnup and cooling time; (2) allow loading of assemblies exposed to burnable absorbers; (3) removing the loading offset for initial ^{235}U enrichments between 4 and 5 percent; and (4) indicate an acceptable source for selecting a bounding axial burnup profile(s). The Recommendations endorse only burnup credit based on actinide compositions. A document providing more detailed and background information for this Interim Staff Guidance is provided in an attachment to a separate memorandum from staff.[1] The NRC staff will issue additional guidance and/or recommendations as more information is obtained from research programs directed at burnup credit and as experience is gained through future licensing activities. Except as specified in the following Recommendations, the application of burnup credit does not alter the current guidance and recommendations provided by the NRC staff for criticality safety analysis of transport and storage casks.

Applicability:

This revision to ISG-8 supersedes Revisions 0 and 1 of the ISG in their entirety.

The recommendations that follow are applicable to intact fuel. If burnup credit is requested for damaged fuel (basically intact, not debris), the recommendations of this guidance should be applied, as appropriate, to account for uncertainties that can be associated with the damaged fuel and establish an isotopic inventory and assumed fuel configuration for normal and accident conditions that bounds the uncertainties.

Recommendations:

1. **Limits for the Licensing Basis.** Available data supports allowance for burnup credit where the licensing safety analysis is based on actinide compositions associated with UO_2 fuel irradiated in a PWR to an assembly-average burnup value up to 50 GWd/MTU and cooled out-of-reactor for a time period between 1 and 40 years. The range of available measured assay data for irradiated UO_2 fuel indicates that an extension of the licensing basis beyond 5.0 wt % is not warranted. Even within this range of parameters, the reviewer needs to exercise care in assessing whether the analytic methods and assumptions used are appropriate, especially near the ends of the range. Use of actinide compositions associated with burnup values or cooling times outside these specifications should be accompanied by the measurement data and/or justified extrapolation techniques necessary to adequately extend the isotopic validation and quantify or bound the bias and uncertainty.

2. **Code Validation.** The computational methodologies used for predicting the actinide compositions and determining the neutron multiplication factor (k-effective) should be properly validated. Bias and uncertainties associated with predicting the actinide compositions should be determined from benchmarks of applicable fuel assay measurements. Bias and uncertainties associated with the calculation of k-effective should be derived from benchmark experiments that closely represent the important features of the cask design and spent fuel contents. The particular set of nuclides used to determine the k-effective value should be limited to that established in the validation process. The licensing basis safety analysis should utilize bias and uncertainty values that can be justified as bounding based on the quantity and quality of the experimental data. Particular consideration should be given to bias uncertainties arising from the lack of critical experiments that are highly prototypical of spent fuel in a cask.

3. **Licensing-Basis Model Assumptions.** The actinide compositions used to determine a value of k-effective for the licensing safety basis (as described in Recommendation 1) should be calculated using fuel design and in-reactor operating parameter values that appropriately encompass the range of design and operating conditions for the proposed contents. The calculation of the k-effective value should be performed using cask models, appropriate analysis assumptions, and code inputs that allow adequate representation of the physics. Of particular concern should be:

   a.) the need to account for and effectively model the axial and horizontal variation of the burnup within a spent fuel assembly (e.g., the selection of the axial burnup profiles, number of axial material zones, etc.); and
   b.) the need to consider the potential for increased reactivity due to the presence of burnable absorbers or control rods (fully or partially inserted) during irradiation.

   The axial burnup profile database of Reference 2 provides a source of realistic, representative data that can be used for establishing a profile to use in the licensing basis safety analysis. However, care should be taken to select a profile that will encompass the range of potential k-effective values for the proposed contents, particularly near the upper end of the ranges in Recommendation 1.

A licensing basis modeling assumption where the assemblies are exposed during irradiation to the maximum (neutron absorber) loading of burnable poison rods for the maximum burnup is an appropriate analysis assumption that encompasses all assemblies that may or may not have been exposed to burnable absorbers.[3,4] Such an assumption in the licensing basis safety analysis should also encompass the impact of exposure to fully inserted or partially inserted control rods in typical domestic PWR operations.[5] Assemblies exposed to atypical insertions of control rods (e.g., full insertion for one full cycle of reactor operation) should not be loaded unless the safety analysis explicitly considers such operational conditions. If the assumption on burnable poison rod exposure is less than the maximum for which burnup credit is requested, then a justification commensurate with the selected value should be provided (e.g., the lower the value, the greater the need to support the assumption with available data and/or indicate how administrative controls will prevent a misload of an assembly exposed beyond the assumed value).

4. **Loading Curve.** A loading curve is a plot that demonstrates, as a function of initial enrichment, the assigned burnup value above which fuel assemblies may be loaded in the cask. Separate loading curves should be established for each set of applicable licensing conditions. For example, a separate loading curve should be provided for each minimum cooling time to be considered in the cask loading. The applicability of the loading curve to bound various fuel types or burnable absorber loadings should be justified. To limit the opportunity for misloading, only one loading curve should be used for each cask loading.

5. **Assigned Burnup Loading Value.** Administrative procedures should be established to ensure that the cask will be loaded with fuel that is within the specifications of the approved contents. The administrative procedures should include a measurement that confirms the reactor record for each assembly. Procedures that confirm the reactor records using measurement of a sampling of the fuel assemblies will be considered if a database of measured data is provided to justify the adequacy of the procedure in comparison to procedures that measures each assembly.

   The measurement technique may be calibrated to the reactor records for a representative set of assemblies. For confirmation of assembly reactor burnup record(s), the measurement should provide agreement within a 95 percent confidence interval based on the measurement uncertainty. The assembly burnup value to be used for loading acceptance (termed the assigned burnup loading value) should be the confirmed reactor record value as adjusted by reducing the record value by a combination of the uncertainties in the record value and the measurement.

6. **Estimate of Additional Reactivity Margin.** The available experimental database relevant to use of burnup credit in the safety analysis of a PWR cask is not as extensive as the database available to support licensing with the unirradiated fuel assumption. The process of assuring that appropriate values and conditions have been applied in the safety analysis is also more difficult. For example, there may be uncertainties that are not directly evaluated in the modeling or validation processes for actinide-only burnup credit (e.g., k-effective validation uncertainties caused by a lack of critical experiment benchmarks with either actinide compositions that match those in spent fuel or material distributions that represent reactive ends of spent fuel in casks). Also, there may be

potential uncertainties in the models that calculate the licensing-basis actinide inventories (e.g., caused by any outlier assemblies with higher-than-modeled reactivity such as may be caused by prolonged use of control rod insertion during irradiation, axial profiles not encompassed by the data of Reference 2, or exposure to unanticipated operating conditions that increase reactivity). Decisions on the adequacy of the safety analysis relevant to these difficult-to-quantify uncertainties are more straightforward if design-specific analyses are provided that estimate the additional reactivity margins available from absorber nuclides (fission product and actinides) not included in the licensing safety basis (as described in Recommendation 1). The reviewer should assess the estimated reactivity margins to determine their adequacy for offsetting any potential uncertainties introduced by the type of effects discussed above.

Approved: ***/RA/*** *(Original Signed by C. L. Miller for:)* 9/27/02
E. William Brach **Date**

References:

1. C. J. Withee, Memorandum to M. Wayne Hodges, “ISG-8, REV. 2, SUPPORTING DOCUMENT,” U.S. Nuclear Regulatory Commission, September 27, 2002.

2. R. J. Cacciapouti and S. Van Volkinburg, "Axial Burnup Profile Database for Pressurized Water Reactors," YAEC-1937 (May 1997). Available as Data Package DLC-201 from the Radiation Safety Information Computational Center at Oak Ridge National Laboratory, http://www-rsicc.ornl.gov/ORDER.html.

3. J. C. Wagner and C. V. Parks, *Parametric Study of the Effect of Burnable Poison Rods for PWR Burnup Credit*, NUREG/CR-6761 (ORNL/TM-2000/373), U.S. Nuclear Regulatory Commission, Oak Ridge National Laboratory, March 2002.

4. C. E. Sanders and J. C. Wagner, *Study of the Effect of Integral Burnable Absorbers on PWR Burnup Credit*, NUREG/CR-6760 (ORNL/TM-2000/321), U.S. Nuclear Regulatory Commission, Oak Ridge National Laboratory, March 2002.

5. C. E. Sanders and J. C. Wagner, *Parametric Study of the Effect of Control Rods for PWR Burnup Credit*, NUREG/CR-6759 (ORNL/TM-2001/69), U.S. Nuclear Regulatory Commission, Oak Ridge National Laboratory, February 2002.