REGULATORY PERSPECTIVE ON CONFIRMATORY BURNUP MEASUREMENTS FOR BURNUP CREDIT IN SPENT NUCLEAR FUEL TRANSPORTATION PACKAGES

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ABSTRACT

In an effort to make spent fuel transportation packages more efficient, applicants for transportation package Certificates of Compliance under Part 71 of Title 10 of the U.S. Code of Federal Regulations (10 CFR Part 71), "Packaging and Transportation of Radioactive Material,"[1] have increasingly sought burnup credit in the package criticality analysis. The U.S. Nuclear Regulatory Commission (NRC) Division of Spent Fuel Storage and Transportation published Interim Staff Guidance 8 (ISG-8) Revision 2, "Burnup Credit in the Criticality Safety Analyses of PWR Spent Fuel in Transport and Storage Casks," in September of 2002.[2] This document provides guidance regarding acceptable approaches to burnup credit criticality analyses for intact spent PWR assemblies in transportation packages.

One of the recommendations in ISG-8 is that the user of a burnup credit spent fuel transportation package perform a measurement that confirms the reactor record for each assembly to be loaded. This also appears as a requirement in International Atomic Energy Agency (IAEA) TS-R-1, "Regulations for the Safe Transport of Radioactive Material," Paragraph 674.[3] This measurement would be difficult for the over 1000 dry cask storage systems which are already loaded in the U.S. Unloading dry spent fuel casks would increase the potential for fuel handling incidents as well as operational dose to workers. NRC is evaluating possible alternatives to the out-of-core burnup measurement recommendation in ISG-8, including additional administrative requirements for package loading, as well as a misload analysis based on the existing spent fuel inventory. This paper will discuss considerations related to the out-of-core confirmatory burnup measurement and its proposed alternatives.

I. INTRODUCTION

Transportation of spent nuclear fuel (spent fuel) is governed by the regulations set forth in Part 71 of Title 10 of the *Code of Federal Regulations* (10 CFR Part 71), "Packaging and Transportation of Radioactive Material."[1] The requirements applicable to criticality safety include 10 CFR 71.55(b), which requires that the most reactive credible configuration of the contents, moderation to the most credible extent (with fresh water), and optimum reflection be considered in analyses for demonstrating subcriticality. In addition, 10 CFR 71.83 requires that fissile contents for which pertinent properties (e.g., isotopic abundance, mass, concentration, and degree of irradiation) are unknown be packaged assuming these properties have "credible values that will cause the maximum neutron multiplication."[1]

Designers of spent fuel transportation packages have traditionally evaluated criticality safety assuming the fuel is unirradiated (i.e., fresh). The isotopic composition of fresh fuel is well-specified, whereas the isotopic composition of spent fuel can vary significantly based upon an assembly's design and irradiation history. Thus, package designs based upon the bounding assumption of fresh fuel contents do not need to address the analytical complexities associated with spent fuel contents.

The fresh-fuel approach has typically been adequate, as the capacity of spent fuel transportation package designs submitted to the NRC for certification has been limited by other design parameters (e.g., heat load and radiation source terms). In these packages, subcriticality was maintained through use of spacing and/or flux traps between assemblies. However, more recent transportation package designs have sought to increase capacities in order to reduce the number of shipments and overall cost of spent fuel transportation. Also, initial enrichments have increased due to higher enrichment fuel now being irradiated in reactors. Additionally, licensees are seeking to transport spent fuel already loaded in dry cask storage systems which have not been analyzed to meet the 10 CFR Part 71 criticality safety requirements with the fresh-fuel assumption. Therefore, spent fuel transportation package designs have recently sought credit for the irradiation of spent fuel. Burnup credit accounts for the reduction in reactivity resulting from the net reduction of fissile nuclides and the production of actinide and fission-product neutron absorbing isotopes during fuel irradiation.

NRC's Division of Spent Fuel Storage and Transportation (SFST) developed Interim Staff Guidance 8 (ISG-8), "Burnup Credit in the Criticality Safety Analyses of PWR Spent Fuel in Transport and Storage Casks,"[2] to provide guidance to the NRC staff for reviewing the use of burnup credit in criticality analyses for spent fuel transportation package designs. The initial ISG-8 was published in May 1999 and has been revised twice (July 1999 and September 2002) as additional data has become available through various research programs. At each revision, the guidance has been modified to expand the burnup credit that may be applied in criticality analyses for spent fuel transportation packages, as can be supported by the available data. To date, burnup credit has not been considered for transportation of BWR spent fuel.

II. BURNUP MEASUREMENT IN ISG-8, REVISION 2

One of the recommendations in ISG-8, Revision 2, is that the user of a burnup credit spent fuel transportation package perform a measurement that confirms the reactor record for each assembly to be loaded. This recommendation is consistent with the requirement in International Atomic Energy Agency (IAEA) TS-R-1, "Regulations for the Safe Transport of Radioactive Material," Paragraph 674.[3] According to IAEA TS-G-1.1, "Advisory Material for the IAEA Regulations for the Safe Transport of Radioactive Material," Paragraph 674.2,[4] the "pre-shipment measurement needs to be performed in order to assure that the fissile material characteristics meet the criteria (e.g., total exposure and decay) specified in the assessment."

The supporting documentation for ISG-8, Revision 2, "Technical Recommendations for the Criticality Safety Review of PWR Storage and Transportation Casks That Use Burnup Credit,"[5] states that a measurement should be performed prior to loading that is able to confirm the recorded assembly average burnup. Although this guidance also states that burnup "uncertainties should be less than 5% for PWR assemblies," the measurement recommended by ISG-8, Revision 2 is intended to prevent the loading of assemblies with high recorded burnup uncertainties. Additionally, the measurement is intended to prevent the misloading of underburned assemblies, or assemblies which do not otherwise meet the package loading criteria.

The assigned burnup loading value for each assembly, for comparison to the package loading curve, should consider any uncertainties related to the recorded burnup value. Since the uncertainty in the measurement and the uncertainty in the reactor record are independent, these uncertainties should both be included in adjusting the reactor record burnup down to an assigned burnup loading value.

III. POTENTIAL ALTERNATIVES TO MEASUREMENT IN ISG-8, REVISION 3

Applicants for Certificates of Compliance for spent fuel transportation packages under 10 CFR Part 71 have been reluctant to include measurement programs in their package operating procedures, due to the additional cost, fuel movement, and personnel dose associated with such programs. Additionally, burnup measurements would be difficult for the over 1000 multi-purpose dry cask storage systems which are already loaded in the U.S., many of which will need burnup credit in order to meet the criticality safety requirements of §71.55. Unloading dry spent fuel casks would increase the potential for fuel handling incidents as well as operational dose to workers.

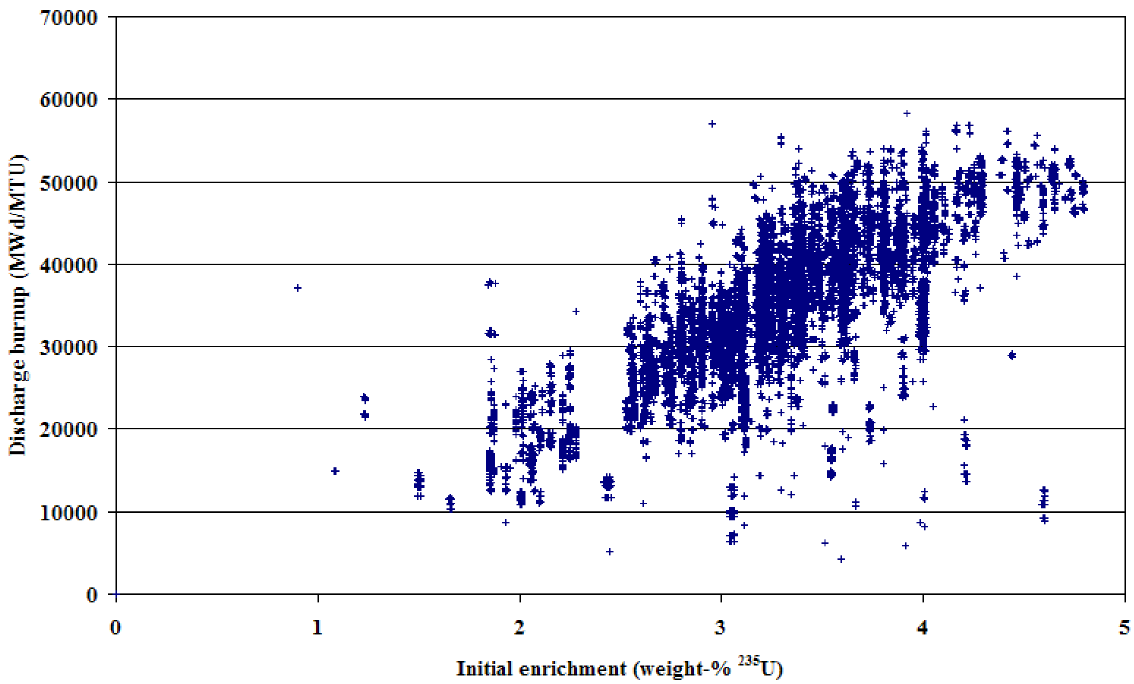
NRC is currently evaluating potential alternatives to the out-of-core burnup measurement recommendation in ISG-8, Revision 2. Acceptable alternatives would need to provide an equivalent or better level of protection against the effects of a spent fuel misload. These alternatives may include a misload analysis based on the existing spent fuel inventory, combined with additional administrative requirements for package loading.

III.A Criticality Analysis of Potential Fuel Misloads

The recommendation in ISG-8, Revision 2 for a burnup verification measurement is intended to prevent the misloading of assemblies due to operator error, incorrect burnup records, or incorrect assembly identification. The misloading of an underburned assembly results in an increase in reactivity. This increase is dependent on a number of factors such as the enrichment, cooling time, and the amount of burnup relative to those assemblies meeting the loading criteria. A misload analysis can provide some indication of the sensitivity of a transportation package to the misloading of high reactivity (i.e., underburned) assemblies. The change in reactivity as a result of misloading one or a number of high reactivity assemblies can provide some indication of the maximum reactivity change expected with the addition of subsequent misloaded assemblies.

A potential misload analysis should demonstrate that the package remains adequately subcritical under scenarios involving a single severely underburned assembly, or multiple moderately underburned assemblies. This demonstration should include any related code biases and uncertainties, as well as an appropriate administrative margin. The assumptions in the misload analysis should be based on the population of discharged fuel assemblies intended to be shipped in the package (see Figure 1 for an example of a U.S. discharged fuel population). For example, if the most underburned assemblies in the storage inventory can be identified, then the misload analysis should be based upon a credible event involving the misload of one or a combination of those assemblies. The analysis should also evaluate the most reactive storage locations involving the potentially misloaded assemblies.

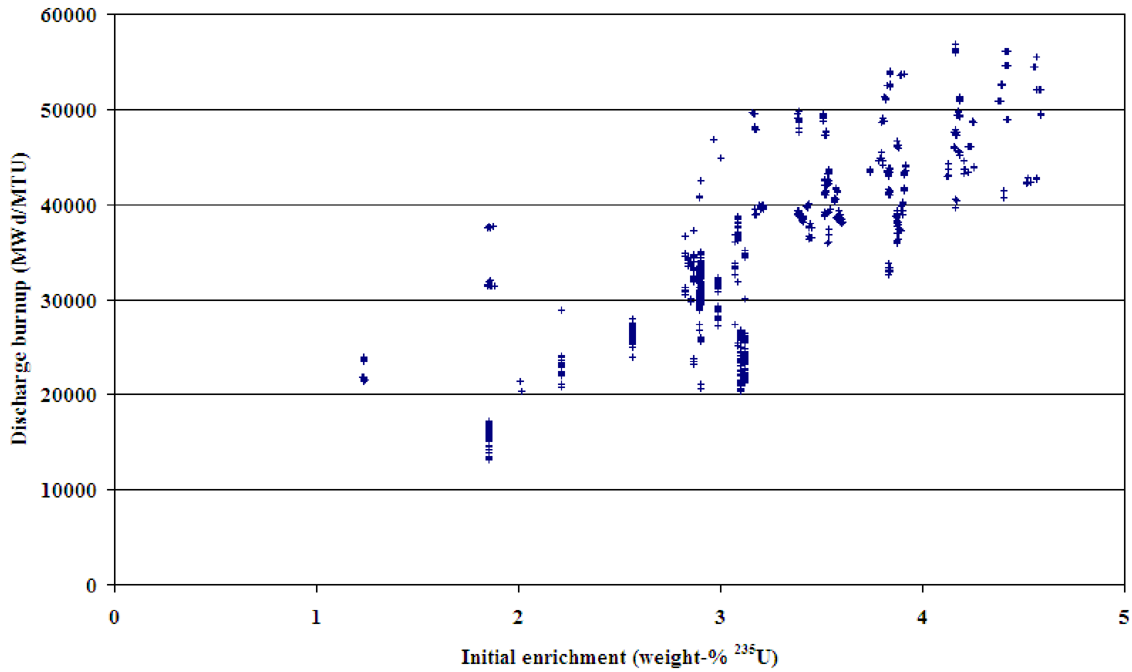
Figure 1: Burnup versus enrichment for discharged inventory of U.S. 15x15 fuel assemblies as of 2002[6]



Ideally, a more general approach to misload analysis characterized by the assembly type would be used. However, where it can be shown that the discharged population in a facility exhibits burnup values well within the overall mean population for a given assembly type, a more site-specific approach may be used. Figure 2 is an example of a discharged fuel population at a single reactor site, which shows this particular site does not have any high reactivity assemblies available to misload.

A misload analysis, coupled with properly implemented administrative procedures, may provide an adequate degree of protection against the reactivity effects of a misloaded fuel assembly. The assumptions used in the misload analysis (e.g., burnup and initial enrichment) can be used as the basis for the administrative procedures for package loading. This is discussed in further detail in the next section.

Figure 2: **Burnup versus enrichment for discharged inventory of 15x15 fuel assemblies at single plant as of 2002[6]**



III.B Administrative Procedures for Burnup Credit Package Loading

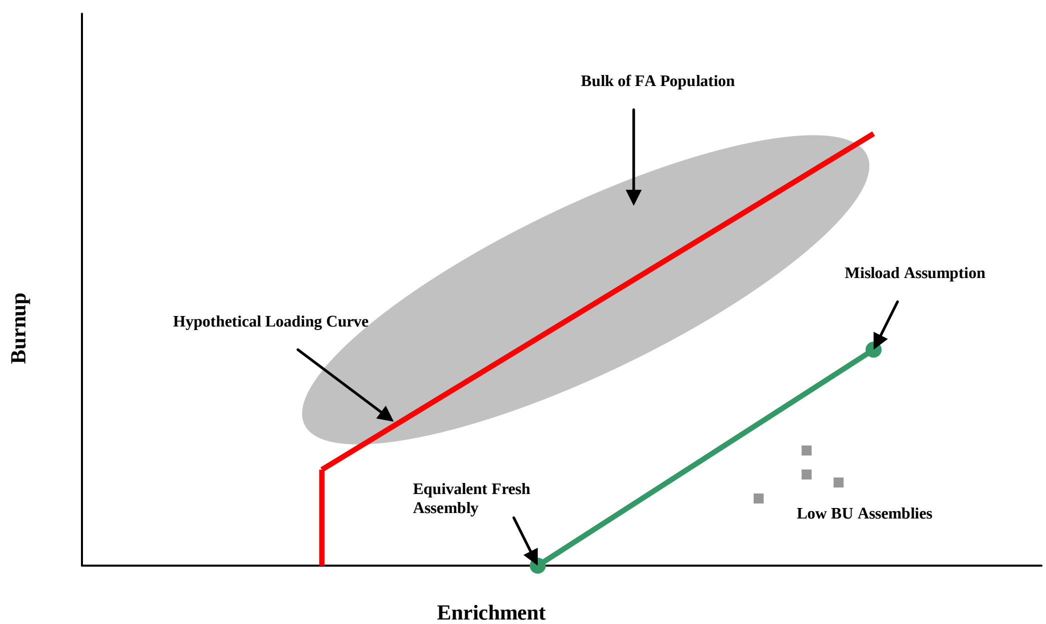
In addition to the misload analysis in the criticality evaluation of a package for spent fuel transportation, the operating procedures for that package should include additional administrative procedures designed to prevent the misloading of high-reactivity assemblies. These administrative procedures could include, but are not limited to, the following:

- Verification that no fresh fuel assemblies are in the spent fuel pool at the time of package loading
- A full audit of the spent fuel pool contents, including visual verification of each fuel assembly identification number, should be performed within one year prior to package loading
- Visual verification and/or qualitative assembly radiation measurement prior to placing each spent fuel assembly in the package, in order to verify that fuel has been burned
- Visual identification of the location of high reactivity fuel assemblies in the spent fuel pool both prior to package loading, and again prior to release of the package for shipment. Determination of reactivity status of each assembly could be based on the loading curve for the package, or on the burnup and initial enrichment assumptions used in the misload analysis
- Fuel assemblies for which the identification number is not able to be determined should have quantitative burnup measurements prior to loading.

One method of identifying high reactivity assemblies in a population of discharged assemblies is comparing burnup and enrichment against the assumptions used in the misload analysis. In the figure below, the gray oval represents the area on the burnup vs. enrichment plot where most discharged fuel assemblies typically lie, with respect to a hypothetical burnup credit package loading curve. The assemblies with burnups and initial enrichments lying in the oval, but under the loading curve, are not likely to have a large effect if misloaded into a transportation package. The low burnup assemblies in the lower right of the plot, however, still retain a large amount of reactivity, and could potentially cause a criticality problem if misloaded into the package, assuming fresh water in-leakage.

The misload analysis in the criticality evaluation for the package should have identified a low burnup, high initial enrichment fuel assembly, for which the package will remain adequately subcritical even if such an assembly were misloaded. A fresh assembly with an enrichment giving it roughly equivalent reactivity to the assumed misloaded assembly can also be identified, and a line between these two assemblies on the burnup versus initial enrichment plot represents a line of roughly equivalent reactivity. Above this line, the misload analysis demonstrates that a misload of any single assembly does not cause a criticality concern, while assemblies below this line have not been evaluated. These low burnup assemblies represent where the focus of administrative verification should lie. Prior to loading a burnup credit spent fuel transportation package, a package user would identify the location of all such assemblies in the spent fuel pool. After loading, but prior to shipment, the user would again verify that the assemblies of concern remain in the spent fuel pool.

Figure 3: Using misload assumptions to identify high reactivity assemblies



For spent fuel assemblies that are already loaded in seal-welded, multi-purpose, dry storage canisters, many of these administrative procedures are not practical, as they would require opening and potential destruction of the canister. In this case, verification steps in the package operating procedures should focus on the records of the spent fuel pool contents at the time of loading. These records, as well as the records of the dry storage cask contents, should be compared to the results of an audit of the current spent fuel pool contents to verify that the correct assemblies are loaded in the package, prior to release of the package for shipment. Other administrative procedures may be applied to sealed spent fuel canisters, as this situation is still under consideration by NRC staff.

IV. SUMMARY

NRC is evaluating alternatives to the out-of-core burnup measurement recommendation in ISG-8, Revision 2, which may include a misload analysis based on the existing spent fuel inventory, combined with additional administrative requirements for package loading. As stated above, the misload analysis should be based on the characteristics of the population of discharged fuel assemblies intended to be shipped in the package. Additional administrative procedures should be designed in order to lower the probability of high reactivity fuel assemblies being misloaded into spent fuel transportation packages. The details of the expected makeup of the misload analysis and the administrative procedures are currently under consideration by NRC, and staff will seek input from industry and other public stakeholders prior to publishing a revision to ISG-8.

V. REFERENCES

1. Code of Federal Regulations, Title 10, Part 71, “Packaging and Transportation of Radioactive Material,” January 1, 2009.
2. U.S. Nuclear Regulatory Commission, *Spent Fuel Project Office Interim Staff Guidance – 8, Rev. 2 – Burnup Credit in the Criticality Safety Analyses of PWR Spent Fuel in Transport and Storage Casks*, U.S. NRC, September, 27, 2002.
3. International Atomic Energy Agency, *Regulations for the Safe Transport of Radioactive Material*, IAEA Safety Standards Series No. TS-R-1, IAEA, Vienna (2005) (See paragraph 674).
4. International Atomic Energy Agency, *Advisory Material for the IAEA Regulations for the Safe Transport of Radioactive Material*, IAEA Safety Guide No. TS-G-1.1, IAEA, Vienna (2002) (See paragraph 674.2).
5. C. J. Withee and C. V. Parks, *Technical Recommendations for the Criticality Safety Review of PWR Storage and Transportation Casks That Use Burnup Credit*, U.S. NRC, Oak Ridge National Laboratory, September, 2002.
6. Energy Information Administration, *RW-859 Nuclear Fuel Data*, EIA, Washington, D.C., October 2004.