RAI Volume 3, Chapter 2.2.1.2.1, Fourth Set, Numbers 25 and 26, Supplemental Question:

> Where in the responses to RAIs 3.2.2.1.2.1-4-025 and 3.2.2.1.2.1-4-026 did DOE justify crediting the five metal isotopes (^{95}Mo, ^{99}Tc, ^{101}Ru, ^{103}Rh, and ^{109}Ag)? Only 11 radiochemical analysis (RCA) samples, all from TMI-1 RCA data, were supplied for most of these metals. The measurement methods used for these samples involved relatively low-precision techniques resulting in large experimental uncertainties. No justification was provided to support the small sample size as bounding the inventory of pressurized water reactor (PWR) spent nuclear fuel (SNF) assemblies and the associated uncertainties in the data.
>
> Given the lack of data, provide additional information on how the uncertainties associated with measuring and predicting the isotopic composition as well as the uncertainties in the available RCA samples are accounted for when representing the bounding isotopic composition for the various PWR assembly fuel types and operating histories.

1. SUPPLEMENTAL RESPONSE

Each of the radiochemical analysis (RCA) data sets has a different total number of nuclides that were measured, but collectively these data sets include measurements for all of the principal isotopes identified in SAR Table 2.2-9, including the five metal isotopes listed in the RAI. These data sets were evaluated using the "direct-difference" method (Gauld 2003, Section 3.2.3) to quantify the net bias and uncertainty in the k_{eff} calculation due to the variability in the predicted nuclide concentrations. All publicly available at the time of LA submittal RCA data were included in the evaluations. In order for the direct-difference method to be used, the data population needs to include measurements for all radionuclides selected for burnup credit analyses. The Three Mile Island (TMI) data set contains measurements for the five metal fission products cited in the RAI. When using the direct-difference approach, individual isotopic measurement uncertainty is not evaluated directly but is reflected across the sample population and captured in the k_{eff} results. The TMI data have larger experimental uncertainties, which are noticeable in the Δk_{eff} calculations, and therefore result in a larger overall variance within the Δk_{eff} sample population. By using the direct-difference approach, the individual laboratory systematic errors are captured along with the individual nuclide uncertainties, and the aggregate effect is calculated as a Δk_{eff} value. By evaluating the RCA data collectively with the direct-difference approach, the net bias and uncertainty on k_{eff} (Δk_{ISO}) is determined for the system of interest. The mean bias within the total sample set is 0.0067 but due to the large variance within the sample set and the fact that the data are not normally distributed, the distribution-free tolerance limit method is used to calculate the lower-bound tolerance limit, which incorporates a very large uncertainty penalty (as compared to a normally distributed sample population), resulting in a net bias and uncertainty (Δk_{ISO}) of −0.0249 (Figure 1). This large Δk_{eff} penalty is primarily due to the spread (uncertainty) in the data as well as the low sample count, and is applied directly in the calculation of the critical limit.

The collective uncertainty penalty factor associated with the Δk_{eff} distribution (0.0067 − (−0.0249) = 0.0316) is much larger than the effects on k_{eff} of the uncertainty associated with the measurements of the individual nuclides for the metal fission products. Example reactivity sensitivity factors provided in *Evaluation of Cross-Section Sensitivities in Computing Burnup Credit Fission Product Concentrations* (Gauld and Mueller 2005, Table 16) demonstrate that the differential change in system k_{eff} due to a change in the macroscopic cross sections (which is reflective of changes in the isotopic number density), $\frac{\delta k / k}{\delta n / n}$, (^{103}Rh, 8.24×10^{-3}; ^{99}Tc, 2.8×10^{-3}; ^{95}Mo, 1.46×10^{-3}; ^{109}Ag, 1.11×10^{-3}; ^{101}Ru, 8.95×10^{-4}) is bounded by the collective Δk_{eff} uncertainty (i.e., 3.16×10^{-2}). The large Δk_{ISO} penalty factor, which is used in conjunction with conservative assumptions relative to fuel types and operating histories, provides reasonable assurance that uncertainties in isotopic predictions are bounded in the loading curve analysis. As additional data become available and can be included in the sample population, the data uncertainty is expected to decrease, resulting in a smaller isotopic bias and uncertainty (Δk_{ISO}) and greater margins in the current analysis results.

Considering that nuclear power reactors operate within comparably tight technical specification requirements on flux distributions and consequently on the effects on reactivity predictions, an isotopic bias and uncertainty (Δk_{ISO}) of −0.0249 represents a very large bias on k_{eff}. *Guidance on the Regulatory Requirements for Criticality Analysis of Fuel Storage at Light-Water Reactor Power Plants* (Kopp 1998, Section 5.A.5.d), provides guidance for assigning isotopic bias and uncertainty in spent fuel pool burnup credit criticality analyses and states: "In the absence of any other determination of the depletion uncertainty, an uncertainty equal to 5 percent of the reactivity decrement to the burnup of interest is an acceptable assumption." Application of this NRC-approved methodology for calculating isotopic bias and uncertainty is illustrated in Figure 2 for pressurized water reactor (PWR) commercial spent nuclear fuel (SNF) and, as such, demonstrates the substantial conservatism in the licensing basis isotopic bias and uncertainty term (Δk_{ISO}) as compared to what is currently practiced at spent fuel pools. Figure 2 shows 5% of the reactivity decrement for initial enrichments of 2.0 wt% to 5.0 wt% ^{235}U over a burnup range up to 50 GWd/MTU and the Δk_{ISO} term used in the licensing basis critical limit for isotopic bias and uncertainty.

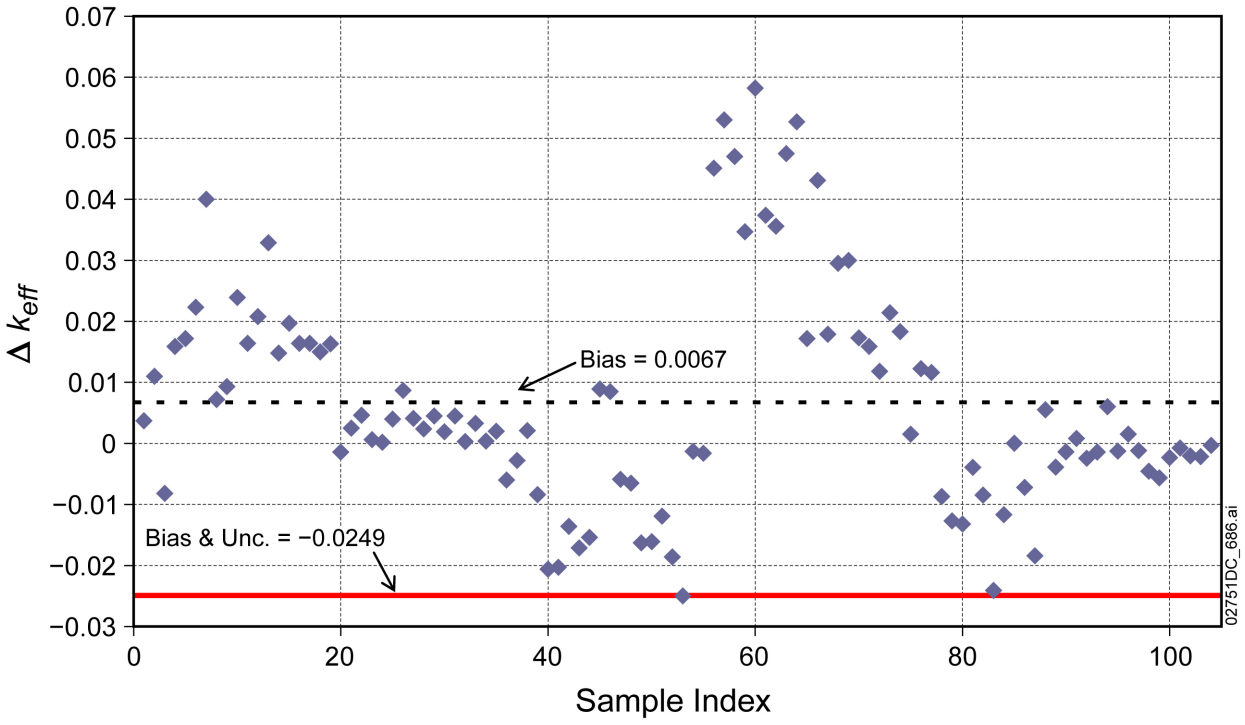


Figure 1. Δk_{eff} Values between Calculated and Measured Isotopic Compositions

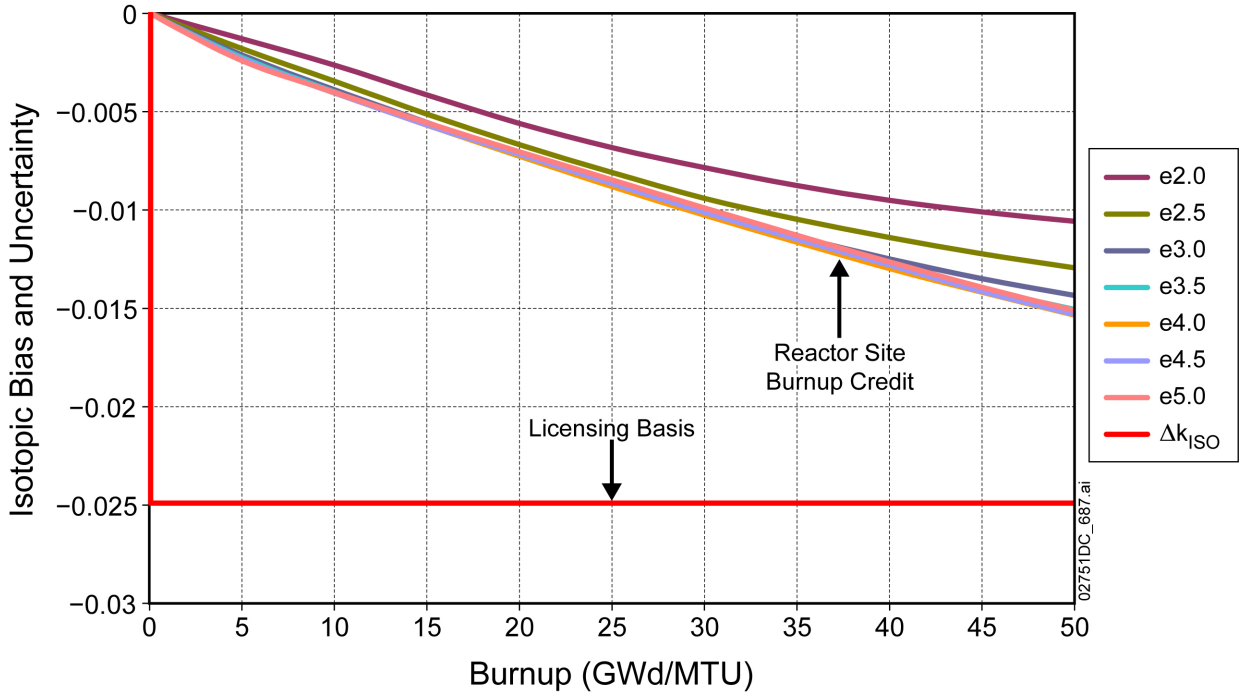


Figure 2. Comparison of Isotopic Bias and Uncertainty Used in Spent Fuel Pools (reactor site burnup credit) and for Spent Fuel Disposal (licensing basis)

2. COMMITMENTS TO NRC

None.

3. DESCRIPTION OF PROPOSED LA CHANGE

None.

4. REFERENCES

Gauld, I.C. 2003. *Strategies for Application of Isotopic Uncertainties in Burnup Credit.* NUREG/CR-6811. Washington, D.C.: U.S. Nuclear Regulatory Commission. ACC: LLR.20091023.0002.

Gauld, I.C. and Mueller, D.E. 2005. *Evaluation of Cross-Section Sensitivities in Computing Burnup Credit Fission Product Concentrations.* ORNL/TM-2005/48. Oak Ridge, Tennessee: Oak Ridge National Laboratory. ACC: MOL.20060912.0060.

Kopp, L. 1998. "Guidance on the Regulatory Requirements for Criticality Analysis of Fuel Storage at Light-Water Reactor Power Plants." Memorandum from L. Kopp (NRC) to T. Collins (NRC), August 19, 1998, with attachment. ACC: HQO.19990520.0004.

RAI Volume 3, Chapter 2.2.1.2.1, Fourth Set, Number 36, Supplemental Question:

Where in the response to RAI 3.2.2.1.2.1-4-036 did DOE account for uncertainties in modeling isotopic compositions for boiling water reactor (BWR) spent nuclear fuel (SNF)?

Given the lack of BWR radiochemical assay (RCA) samples and the greater complexities of BWR SNF characteristics, justify that the analytical methods and supporting data used to generate the BWR loading curve adequately bound the BWR SNF inventory.

1. SUPPLEMENTAL RESPONSE

Uncertainties in modeling boiling water reactor (BWR) isotopic compositions have been evaluated using one- and two-dimensional methods to model the greater complexities of the BWR fuel assemblies, and are provided in *Summary Report of Code to Code Comparisons Performed for the Dispsoal Criticality Analysis Methodology* (BSC 2002) and *Code-to-code Comparison of One- and Two-Dimensional Methods* (Mays 2004). The two-dimensional analyses were used to refine the modeling representations used by the one-dimensional code, and sensitivity studies were used to ensure that the effects of the greater complexitites introduced by the heterogeneities of the more modern (i.e., assemblies that incorporate design features resulting in strong flux gradients) BWR fuel assemblies are adequately captured when generating isotopic compositions for comparative evaluations. Confirmation of the BWR analytical methods for providing conservative isotopic compositions (with respect to criticality) is provided in *Isotopic Generation and Confirmation of the BWR Application Model* (Wimmer 2004, Sections 6.3.1 and 6.3.2) where comparisons were made against radiochemical assay (RCA) data and commercial reactor critical (CRC) data to demonstrate that the BWR design basis configuration is bounding up to and including BWR 9 × 9 assembly designs.

A summary of key points that provide confidence that the BWR loading curve is bounding of the BWR SNF inventory is as follows:

1. The BWR RCA data were combined with the PWR RCA data in establishing the isotopic bias and uncertainty penalty factor, Δk_{ISO}. BWR bias and uncertainty are calculated using 30 RCA data points, represented by "simple" (i.e., older and less heterogeneous) BWR designs in *Calculation of Isotopic Bias and Uncertainty for BWR SNF* (BSC 2003a). The simple lattice design RCAs are directly applicable to the 7 × 7 design basis lattice used in generating the BWR loading curve. Calculating the bias and uncertainty for the BWRs by themselves results in a Δk_{ISO} value of −0.021 (BSC 2003a, Table 6-1) which is bounded by the combined Δk_{ISO} term of −0.0249 used in generating the BWR loading curve (SNL 2008, Table 4-2). Hence, a conservative isotopic bias and uncertainty is used.

2. Comparisons against the Limerick RCA data, which are representative of modern BWR assembly designs due to the use of integral burnable absorbers and part-length rods (BSC 2003b, Section 5.2), were reported by Mays (2004, Table 6-9). In these

comparisons (conservatively calculated isotopic compositions versus measured isotopic compositions) the BWR isotopic database spent fuel isotopic compositions average 0.20 Δk_{eff} conservative (i.e., higher) results with a minimum of 0.17 Δk_{eff}. Although the comparisons are limited in number, the magnitude of the Δk_{eff} difference provides confidence that the design basis is bounding of the more complex assembly designs. This, coupled with the additional conservatism that the entire fuel assembly is represented at the most limiting (i.e., maximum) enrichment (including the natural enriched axial blanket fuel at the ends of the assemblies) for assemblies that have varied enrichments, ensures that the BWR loading curve is bounding by a significant amount.

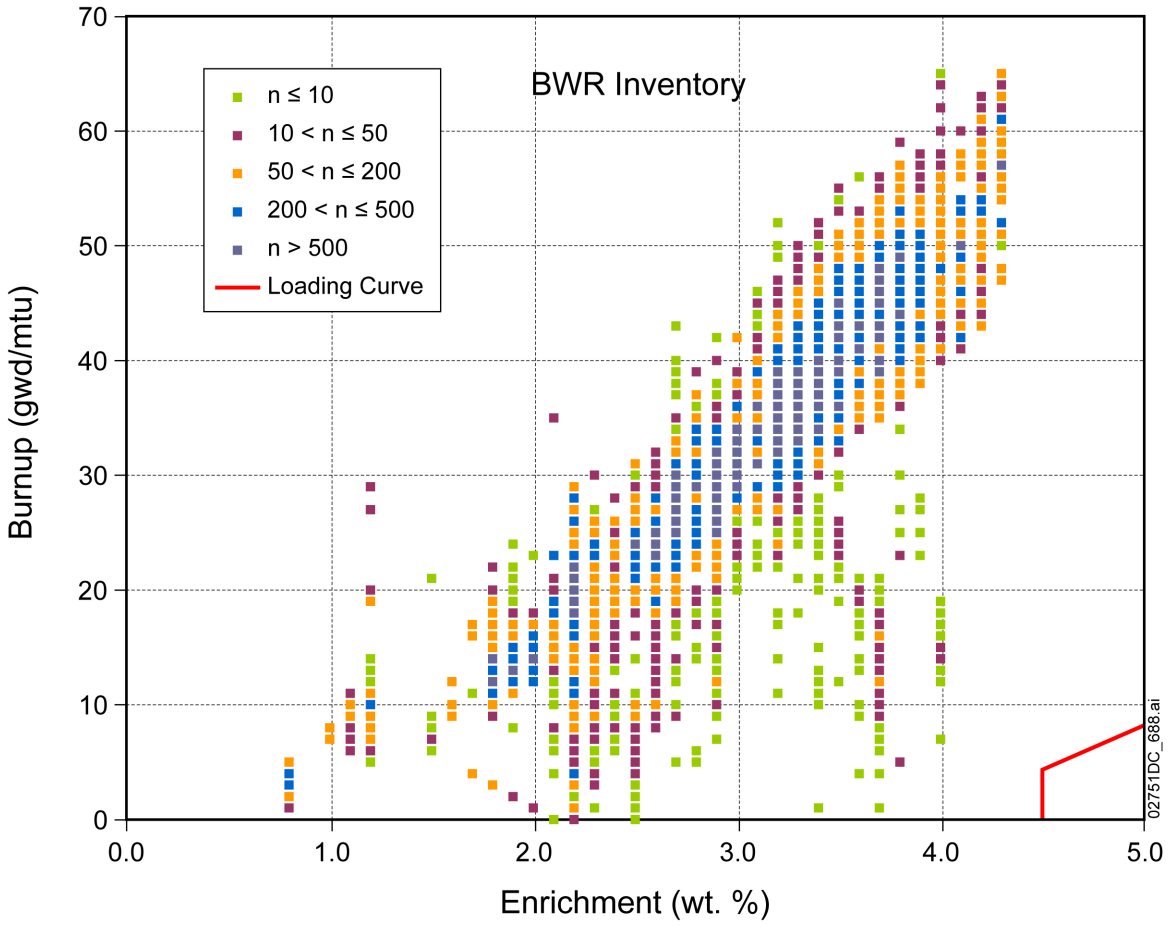
3. Fresh fuel evaluations were performed in *44-BWR Waste Package Loading Curve Evaluation* (BSC 2004, Table 23) and demonstrated that the 7 × 7 is a more reactive assembly design in a waste package configuration than the 8 × 8 and 9 × 9 designs.

4. BWR fuel assemblies with initial enrichments for which burnup credit is taken (assemblies that are over 4.5 wt% enriched), will have substantial margin between what would be needed to meet the loading curve requirements and the projected assembly discharge burnups (Figure 1 shows assemblies above 4.0 wt% enrichment are in excess of 40 GWd/MTU burnup representing a margin of at least 30 GWd/MTU for assemblies requiring burnup credit).

Because 4.5 wt% ^{235}U is the maximum enrichment that can be loaded into disposal canisters as fresh fuel, some BWR burnup credit is necessary to accommodate fuel assemblies with higher initial enrichments (i.e., > 4.5 wt% ^{235}U) than the projected waste stream inventory illustrated in Figure 1. As can be seen in Figure 1, only a very small amount of burnup credit, ~8 GWd/MTU (less than what is obtained in a typical irradiation cycle), is required for disposal of BWR fuel assemblies up to 5.0 wt% ^{235}U initial enrichment. Note at this low burnup and below, modern BWR assemblies have Gd_2O_3 remaining in the fuel, which reduces their reactivity. The BWR design basis assembly used in the generation of the BWR loading curve is a GE-2a 7 × 7 assembly with no burnable absorbers, no water rods, and depleted under extreme conditions to harden the neutron spectrum and breed in excess plutonium as discussed in *Isotopic Generation and Confirmation of the BWR Application Model* (Wimmer 2004; Massie 2004). This assembly design is representative of a "simple" BWR assembly design as compared to the newer and more advanced fuel designs that incorporate the use of integral burnable absorbers, part-length rods, water holes, higher initial enrichments as well as axially varying enrichments, and other features (all designed to increase overall fuel residency time, i.e., extend burnup). The design improvements of the more advanced designs ultimately result in a net decrease in the total fissile mass available in the fuel assembly at discharge (i.e., fuel is replaced with burnable absorber, and removed from part-length rods and water holes).

Assembly designs that have not been explicitly analyzed in the LA are required to be evaluated to ensure acceptability from a postclosure criticality perspective in accordance with SAR Section 5.10. Specifically, SAR Table 5.10-3 describes a number of administrative controls to be included in the license specifications required by 10 CFR 63.43. As described in SAR Section 5.10.2.4.2 and Table 5.10-3, these administrative controls will be compiled in the Technical Requirements Manual, and maintained by the DOE in accordance with the

requirements of the license specifications. SAR Section 2.2.1.4.1 presents the methodology and analyses required to confirm that waste forms and canisters are acceptable from a postclosure criticality perspective. The administrative controls described in SAR Section 5.10.2 and SAR Table 5.10-3 require that similar analyses be completed prior to receiving individual waste forms or canisters/waste package design configurations that are not explicitly analyzed in the license application.



Source: SNL 2008, Figure 6-33.

NOTE: Parameter “n” is the number of assemblies within each burnup/enrichment bin.

Figure 1. BWR Loading Curve

2. COMMITMENTS TO NRC

None.

3. DESCRIPTION OF PROPOSED LA CHANGE

None.

4. REFERENCES

BSC (Bechtel SAIC Company) 2002. *Summary Report of Code to Code Comparisons Performed for the Disposal Criticality Analysis Methodology.* TDR-UDC-NU-000005 REV 00. Las Vegas, Nevada: Bechtel SAIC Company. ACC: MOL.20020603.0127.

BSC 2003a. *Calculation of Isotopic Bias and Uncertainty for BWR SNF.* CAL-DSU-NU-000003 REV 00A. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20031030.0007.

BSC 2003b. *Limerick Unit 1 Radiochemical Assay Comparisons to SAS2H Calculations.* CAL-DSU-NU-000002 REV 00A. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20030825.0001.

BSC 2004. *44-BWR Waste Package Loading Curve Evaluation.* CAL-DSU-NU-000008 REV 00A. Las Vegas, Nevada: Bechtel SAIC Company. ACC: DOC.20040825.0005; DOC.20050801.0009.

Massie, H.L., Jr. 2004. *Isotopic Generation and Confirmation of the BWR Application Model.* 32-5035847-02. Las Vegas, Nevada: Areva. ACC: DOC.20050125.0010.[a]

Mays, C.W. 2004. *Code-to-code Comparison of One- and Two-Dimensional Methods*. 32-5048840-00. Las Vegas, Nevada: Areva. ACC: DOC.20041015.0003.

SNL (Sandia National Laboratories) 2008. *CSNF Loading Curve Sensitivity Analysis.* ANL-EBS-NU-000010 REV 00. Las Vegas, Nevada: Sandia National Laboratories. ACC: DOC.20080211.0001.

Wimmer, L.B. 2004. *Isotopic Generation and Confirmation of the BWR Appl. Model.* 32-5035847-01. Las Vegas, Nevada: Areva. ACC: DOC.20040630.0007.[a]

NOTE: [a] Provided as an enclosure to letter from Williams to Sulima dtd 03/31/2009. "Yucca Mountain – Request for Additional Information – Volume 3, Chapter 2.2.1.2.1 (Scenario Analysis), 4th Set (U.S. Department of Energy's Safety Analysis Report Section 2.2.1.2) – Submittal of Department of Energy Reference Citations."