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Estimation of the Fuel Depletion Code Bias and Uncertainty in Burnup-Credit Criticality Analysis

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1. Introduction

In the past, criticality safety analyses for commercial light-water-reactor (LWR) spent nuclear fuel (SNF) storage and transportation canisters assumed the spent fuel to be fresh (unirradiated) fuel with uniform isotopic compositions. This fresh-fuel assumption provides a well-defined, bounding approach to the criticality safety analysis that eliminates concerns related to the fuel operating history, and thus considerably simplifies the safety anslysis. However, because this assumption ignores the inherent decrease in reactivity as a result of irradiation, it is very conservative. The concept of taking credit for the reduction in reactivity due to fuel burnup is commonly referred to as burnup credit.

Implementation of burnup credit requires the computational prediction of the nuclide inventories (compositions) for the dominant fissile and absorbing nuclide species in spent fuel. In addition to that, the bias and uncertainty in the predicted concentration of all nuclides used in the analysis be established by comparisons of calculated and measured radiochemical assay data.

In this paper, three methods for considering the bias and uncertainty will be reviewed. The estimated bias and uncertainty that the results of 3rd method are presented.

2. Calculation Methods for Δk(BU)

ΔK(BU) is the bias and uncertainty in a burnup-credit analysis due to the predicted nuclide inventories used in the criticality calculation. This section describes three methods for estimating ΔK(BU).

2.1 Basic Calculation [2]

Before we review three methods, we need to define $\overline{X}_i$, the average E/C (evaluated to calculated ratio) and its standard deviation s_i. $\overline{X}_i$ and s_i are defined as Eq. (1) and (2). $E_{i,j}$ and $C_{i,j}$ are measured and calculated inventory of nuclide i in benchmark j and n is total number of benchmark problems used.

$$\overline{X}_i = \frac{1}{n}\sum_{j=1}^{n}\left(\frac{E_{i,j}}{C_{i,j}}\right), \quad (1)$$

$$s_i = \sqrt{\frac{1}{n-1}\sum_{j=1}^{n}(X_{i,j}-\overline{X}_i)^2}. \quad (2)$$

2.2 Bounding Method [2]

The calculated nuclide concentrations are adjusted in a way that always leads to a more reactive system. In other words, the concentration of fissile nuclides is always increased, while the concentration of absorbing nuclides is always decreased, in order to maximize the k_{eff} of the system. The bounding value is calculated with Eq. (3).

$$M_i = C_i(\overline{X}_i \pm 2s_i), \quad (3)$$

where M_i is the bounding concentration of nuclide i.

2.3 Direct Difference Method [2]

With this approach, two spent fuel material compositions (corresponding to the calculated and measured case) are modeled in the cask criticality analysis, for each fuel depletion benchmark case. The resulting k_{eff} values for the two criticality runs are compared to yield a ΔK(BU) value for each fuel depletion benchmark case like Eq. (4). This approach is less overly-conservative than the "bounding" approach.

$$\Delta K(BU) = k_{eff}(calculated) - k_{eff}(measured). \quad (4)$$

2.4 New Method by James E. Hopf [1]

The main difficulty with the direct-difference method is that to use a given fuel depletion benchmark case, measured data must be available for all isotopes that are to be modeled in the subsequent criticality analysis. In this method, if no measured concentration is available for a given isotope, for a given benchmark case, that isotope's concentration is adjusted to its worst-case value, based on the "bounding method" discussed earlier like Eq. (5).

$$E^{bounding}{}_i = C_i(\overline{X}_i \pm 2s_i), \quad (5)$$

where $E^{bounding}{}_i$ is the estimated concentration of nuclide i.

3. Available Measured Data

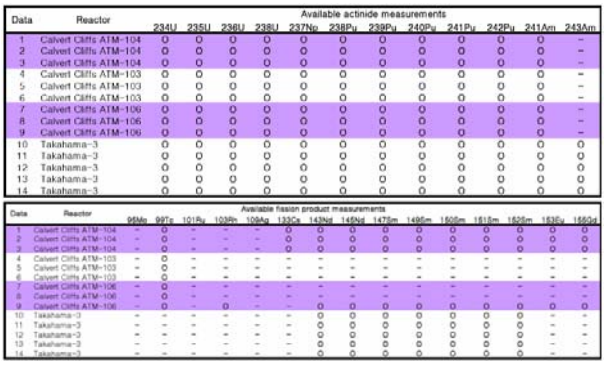
The considering nuclide subset for the burnup credit calculation is in the table 1. In order to calculate ΔK(BU), 14 benchmark problems are used (Calvert Cliffs:9, Takahama-3: 5[3]). The available measured data are shown in the table 2. In case of fission product, the measured data are not many. In addition to that, in

these benchmark problems, the measured data of 95Mo, 101Ru, 103Rh, and 109Ag are not available. These data are only available in the TMI-1 benchmark problems. We can have the E/C (evaluated to calculated ratio) results of these nuclides (95Mo, 101Ru, 103Rh, 109Ag) from James E. Hopf and these results are used to estimate the measured nuclide inventory with bounding method. In the depletion calculation, ORIGEN-ARP and ORIGEN-S in the SCALE 5.0 package are used.

Table 1. Considering nuclide subset

Actinide (12)	234U, 235U, 236U, 238U, 237Np, 238Pu, 239Pu, 240u, 241Pu, 242Pu, 241Am, 243Am
Fission product (15)	95Mo, 99Tc, 101Ru, 103Rh, 109Ag, 133Cs, 143Nd, 145Nd, 147Sm, 149Sm, 150Sm, 151Sm, 152Sm, 153Eu, 155Gd

Table 2. Available measured data



4. ΔK(BU) calculation

The way to calculate ΔK(BU) is shown in the Figure 1. The criticality calculation is performed with KENO V.a and the geometry configuration is shown in the Figure 2. 12 fuel assemblies are in the ss304 cask that is filled with water.

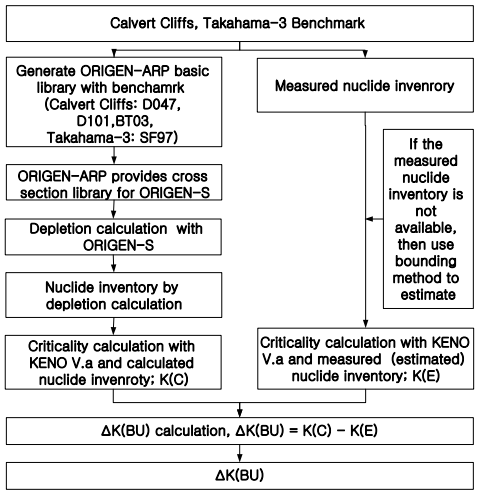


Figure 1. The flow diagram to calculate ΔK(BU).

The calculation is performed with two cases. The first case is considering actinide only and the other case is considering actinide and fission product. Calculation results are shown in Table 3. With the 95% confidence, the estimated ΔK(BU) are 0.020806 and 0.014269 for actinide only case and actinide and fission product case respectively.

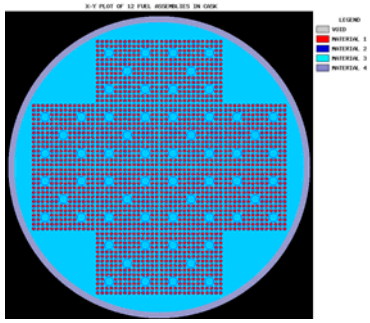


Figure 2. The geometry for the ΔK(BU) calculation (12 Calvert Cliffs D047 fuel assemblies in the cask).

Table 3. Estimated ΔK(BU) with 95% confidence

	95% (2σ) confidence level ΔK(BU)=K(C)-K(E)
Actinide (12)	ΔK(BU)=0.001898±0.018908(2σ) Min: -0.017010 / **Max: 0.020806**
Actinide (12) + Fission Product (15)	ΔK(BU)=-0.005367±0.019636(2σ) Min: -0.025003 / **Max: 0.014269**

5. Conclusions

Three methods for considering the bias and uncertainty due to the prediction of the nuclide inventory are reviewed. Among them, the direct difference method with bounding method is used to estimate ΔK(BU). In our analysis structure, ΔK(BU) are estimated in case of actinide only case and actinide and fission product case.

These estimated ΔK(BU) will be used in the next phase of this study.

ACKNOWLEDGEMENT

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