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Technical note

Determination of dependence of fissile fraction in MOX fuels on spent fuel storage period for different burnup values

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ABSTRACT

The purpose of this technical note is to remove one of the limitations of a derived expression in a previously published article (Özdemir et al., 2011). The original article focused on deriving (computationally) an expression for calculating total fissile fraction of mixed oxid (MOX) fuels depending on discharge burnup of spent fuel and desired burnup of MOX fuel; consequently, such an expression was obtained and put forward, together with its limitations. One of the limitations has been that all the computations and therefore the resulting expression are based on the assumption of a spent fuel storage period of 5 years. This follow-up study simply aims to obtain a correction factor for spent fuel storage periods other than 5 years; thus to remove one major restriction on use of the expression derived in the original article.

1. Introduction

When spent Light Water Reactor fuels are processed by the standard Purex method, plutonium (Pu) and uranium (U) in spent fuel (SF) are obtained as pure and separate streams. The recovered Pu has a fissile content, consisting of ^{239}Pu and ^{241}Pu, greater than 60 weight percent (w/o) typically (although it mainly depends on discharge burnup of SF). The recovered Pu can be recycled as MOX, mixed U + Pu oxides, fuel after being blended with a U makeup in a MOX fabrication plant. U makeup, which has a small fissile fraction, acts as a diluent to reduce the fissile fraction of Pu recovered from SF to levels suitable for LWRs.

The burnup that can be obtained from MOX fuel ($B_{d,MOX}$) depends on: (1) isotopic composition of Pu, which is closely related to the discharge burnup of SF ($B_{d,SF}$) from which Pu is recovered; (2) the type of U makeup material used (depleted U, natural U, or recovered U); and (3) fraction of makeup material in the mix, which in turn determines the total fissile fraction of MOX (ε_{MOX}).

Using the Non-Linear Reactivity Model (Driscoll et al., 1990) and the code MONTEBURNS 2.0 (Poston and Trellue, 1999) a step-by-step procedure for computing ε_{MOX} was introduced in the original article (Özdemir et al., 2011). As was intended, the resulting expression turned out to be simple enough for quick/hand calculations of ε_{MOX} required to reach a desired burnup ($B_{d,MOX}$) for a given discharge burnup of SF ($B_{d,SF}$) and for a specified U makeup. However, note that the expression in the original article is based on the assumption of a SF storage period of 5 years.

The resulting expression in the original article (Özdemir et al., 2011) is reintroduced below.

$$\varepsilon_{MOX} = (d_0 + d_1 B_{d,SF}) - \left[\frac{B_{d,MOX} - c_0 B_{d,SF} - c_1}{100(b_0 B_{d,SF} + b_1)}\right](d_0 + d_1 B_{d,SF} - \varepsilon_{makeup}) \quad (1)$$

For a given U makeup material, Eq. (1) provides an easy means to calculate ε_{MOX} for different $B_{d,MOX}$ and $B_{d,SF}$ values, most accurately in the range of 33,000–50,000 MWd/tonHM (Heavy Metal) and with satisfactory accuracy up to above 70,000 MWd/tonHM. ε_{makeup} in Eq. (1) is the fissile content of U makeup in weight percent (w/o). Coefficients d_0 and d_1 are not dependent on U makeup, while coefficients b_0, b_1, c_0 and c_1 vary with U makeup. Numerical values of all the coefficients in Eq. (1) can be found in (Özdemir et al., 2011), and are also given in Section 3 of this paper for convenience.

As mentioned above, one of the basic assumptions made while deriving Eq. (1) is the "5-year storage/cooling period" prior to recovering Pu from SF. Isotopic composition of Pu is influenced by the length of the storage period mainly due to the decay of fissile ^{241}Pu (with a half life of 14.4 years). For storage periods shorter than 5 years, Eq. (1) yields acceptable results, with the maximum error being less than 3% at the minimum storage period of 150 days. However, for storage periods considerably longer than 5 years, error from use of Eq. (1) becomes meaningful. For fuels notably older than 5 years, the coefficients in Eq. (1) should be recalculated. This may seriously limit the use of Eq. (1).

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The purpose of this study is to investigate the effect of SF storage time on Eq. (1) and, if possible, come up with a correction factor to be affixed to Eq. (1) for any storage period different from (de facto, notably longer than) 5 years.

2. Calculations

In order to observe the effect of storage time on Eq. (1); for different storage times and burnup values of interest, several runs are to be made utilizing the same code (the MONTEBURNS 2.0) with the same computational factors/parameters used in the original article. The outputs thus obtained are analyzed in an attempt to have an appropriate and easy-to-use correction factor to be affixed to Eq. (1). The ratio of ε_{MOX} value computed using the code for a specified SF storage period different from 5 years to ε_{MOX} value calculated by Eq. (1), which is for a storage period of 5 years, is defined as the "Correction Factor for SF Storage Period" (CFSP).

All the assumptions and/or approximations involved in the course of deriving Eq. (1) – except the assumption of a storage time of 5 years – are automatically adopted here, and given in Appendix A. The computational flow chart for investigation of effect of the storage period on Eq. (1) is presented in Fig. 1.

Note that computations are performed only for natural U makeup, because there is no reason to think that dependence on storage time is affected by the type of makeup material. In other words, dependence on storage time is expected to be nearly the same for all the U makeups under consideration. Though, a few extra runs were made to check how the results would change if, for example, 0.3-w/o depleted U was used as makeup. At arbitrarily selected storage periods of 20 and 40 years, deviations of CFSP value for 0.3-w/o depleted U from the value for natural U were found to be about 0.1% in the lower burnup range (near 33,000 MWd/ton), and about 0.3% in the higher burnup range (around 50,000 MWd/ton). To sum it up, results to be obtained for natural U are also valid for the other U makeups.

3. Results

For $B_{d,SF}$ and $B_{d,MOX}$ values in the original article and for varying storage times, ε_{MOX} values are computed (by the code) for storage times other than 5 years, then by dividing these ε_{MOX} values to those obtained from Eq. (1) for a storage time of 5 years, CFSP values are calculated. Results are depicted in Fig. 2.

It is found that CFSP is dependent linearly on $B_{d,SF}$ and $B_{d,MOX}$, and by a second-order polynomial on length of the storage period. The expression for CFSP is then:

$$\mathrm{CFSP} = a_0 + a_1 t + a_2 t^2 + (a_3 + a_4 t)B_{d,SF} + (a_5 + a_6 t)B_{d,MOX}; \quad t \leqslant 100 \text{ years} \tag{2}$$

where t is length of the storage period in years. Eq. (2) is valid for t values through about 100 years, with the coefficients below:

$$a_i = \begin{cases} +9.89125E-1 & i=0 \\ +3.50050E-3 & i=1 \\ -2.10000E-5 & i=2 \\ -5.51500E-8 & i=3 \\ +1.70450E-8 & i=4 \\ -5.73500E-8 & i=5 \\ -1.84100E-8 & i=6 \end{cases}$$

Initially, before deciding on structure of the fit in Eq. (2), several data points up to 200 years were obtained. It was observed that, beyond about 100 years, CFSP was nearly constant, that is, not a function of time. Over a SF storage period of about 100 years, the main dependence on the storage time is due to ^{241}Pu (with a half life of 14.4 years). Amount of ^{241}Pu becomes insignificant in about 100 years; so, its effect on storage time disappears. This trend can be observed in Fig. 2. Beyond 100 years or so, dependence on storage time may primarily be due to ^{238}Pu (with a half life of 86 years). However, ^{238}Pu is not fissile and its amount in SF is considerably smaller than that of ^{241}Pu. Therefore, decay of ^{238}Pu means a reduc-

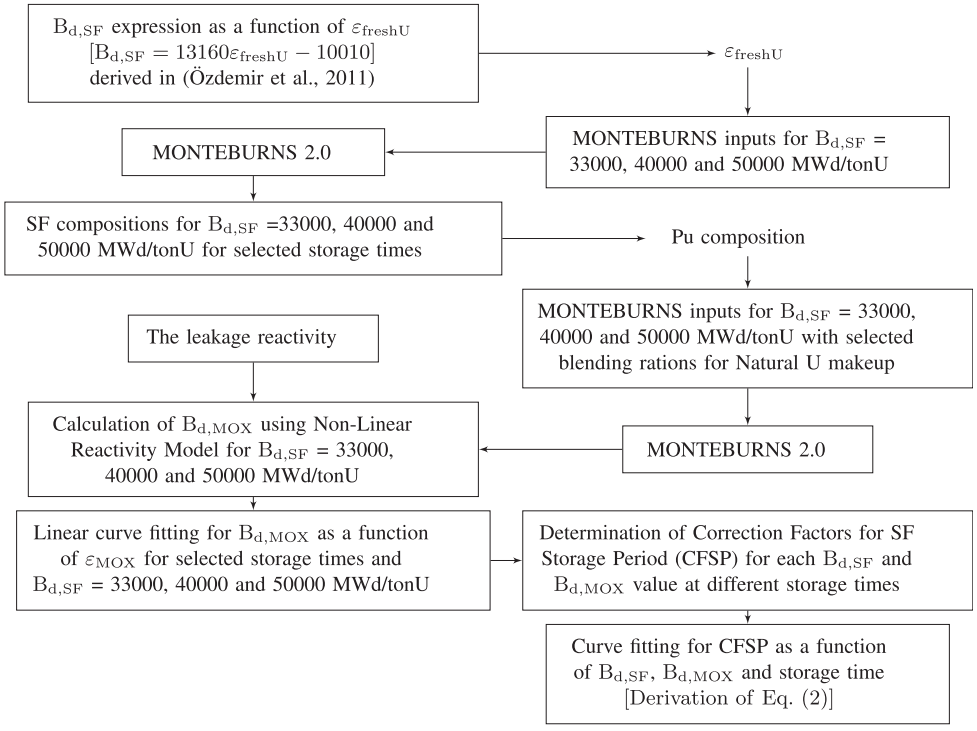

Fig. 1. Computational flow diagram.