Key precursor data in aggregate delayed-neutron calculations

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The reactivity calculations with the delayed neutron (DN) six-group parameter sets in ENDF/B-VI were reported to give significant underestimates for long period (tens of seconds). The parameter sets were obtained form the summation calculations with ENDF/B-VI fission yields and decay data files. In this paper, we try to identify the precursor data that cause the significant underestimates. Because of the relatively long time scale, we examine the DN activity after infinite irradiation, and find that the summation calculation gives significantly smaller DN activity at about 30 s than the currently used six-group parameter set by Tuttle, although this feature does not looks important for the DN activity after a fission burst. From the time dependence of the DN activity, we find that the fission yields of ^{88}Br, ^{136}Te, and ^{137}I are the most probable sources for the underestimate. Furthermore, in order to achieve the required precision (5 %) for the DN activity, it is also necessary to perform precise measurements of their Pn values.

1. Introduction

The delayed-neutron six-group parameter sets in ENDF/B-VI were derived from delayed-neutron (DN) summation calculations for the first time. However, reactivity calculations with these parameter sets were found to give appreciable underestimates for long period (tens of seconds) compared with the sets obtained from macroscopic measurements [1]. In this paper, we examine the summation calculations and identify precursor data responsible for the underestimate.

First, we examine the DN activity after infinite irradiation, $N_d(t)$, because the irradiation time in a operating reactor is essentially infinite compared with half lives of DN precursors. Second, we examine the difference between the summation calculation and Tuttle's evaluation obtained from macroscopic measurements. From this analysis, we identify precursor data (fission yields and decay data) relevant to the underestimates.

2. Analyses

The summation calculation with ENDF/B-VI fission yield and decay data is compared with Tuttle's evaluation [2][3] obtained from macroscopic measurements. As shown in Fig.1 , the difference between the two evaluations are evident for $N_d(t)$ at about 30 s, although the deviation is not so clear in the activity after a fission burst (Fig.2). Here, the definitions of the irradiation conditions are shown in Fig.3. This behavior of $N_d(t)$ must be responsible for the underestimate for long periods (tens of seconds) in reactivity calculations. We define $\Delta N_d(t)$ as the difference of the DN activity between the summation calculation and Tuttle's evaluation, and examine it in detail.

The difference $\Delta N_d(t)$ stems most probably from DN precursors whose half lives are about 30 s with large DN yields. The DN yield of precursor i after infinite irradiation, N_{di} is given by

$$N_{di} = P_{ni} Y_{si} \ .$$

where P_{ni} is the delayed-neutron emission probability of nuclide i. The quantity Y_{si} can be regarded as the “cumulative fission yield” of precursor i for infinite irradiation. It is defined, with the usual cumulative fission yield Y_{ci} and the decay constant λ_i, as

$$Y_{si} = Y_{ci} / \lambda_i + \sum_{j \neq i} b_{j \to i} Y_{cj} / \lambda_j$$

Here, $b_{j \to i}$ is the branching ratio decaying from nuclide j to i. Figure 4 shows the DN yields from individual precursors after infinite irradiation. From this figure, we see that ^{137}I, ^{87}Br, ^{88}Br, ^{138}I and ^{136}Te are possible sources of the difference $\Delta N_d(t)$.

We assume that the sources of $\Delta N_d(t)$ are erroneous independent fission yields and/or Pn values since the decay constants of the five precursors are precisely known as shown in Fig. 5. As for $\Delta N_d(t)$, we neglect buildup of the precursors decaying from parent nuclides because the fission yields of the parents are sufficiently small. To identify the erroneous data, we fit $\Delta N_d(t)$ to the following function

$$\Delta \overline{N_d}(t) = \sum_i a_i e^{-\lambda_i t} \ .$$

Here, λ_i's are the decay constants of the five precursors, and a_i's are fitting parameters. As shown in Fig. 6 , this fitting works well especially for ^{238}U, for which $\Delta N_d(t)$ takes large values. Then, the deficit of the total DN yield in the summation calculation can be written as

$$\int_0^\infty \Delta \overline{N_d}(t) dt = \sum_i \frac{a_i}{\lambda_i} .$$

Hence, the deficit of the DN yield from precursor i is given by a_i / λ_i.

Figure 7 shows the DN yields (A) and the obtained deficits (B) of the five precursors. For ^{88}Br and ^{136}Te , the sum of their DN yields are also shown because their half lives are too close to obtain a_i values separately in the fitting. From this figure, we see that the DN yields from ^{88}Br, ^{136}Te, and ^{137}I are substantially different between the summation calculation and Tuttle’s evaluation. Unfortunately, the $\Delta N_d(t)$ value is found too large to be explained by uncertainties of precursor data given in ENDF/B-VI [4]. However, the most probable sources of the underestimate must be their fission yields because of their large uncertainties (23 % for ^{88}Br and ^{136}Te, 8 % for ^{137}I) as shown in Fig. 8. We also note that the uncertainties of their Pn values are also relatively large (6-9 %, see Fig.9) compared with the required precision (5 %) for $N_d(t)$. Actually, the latest evaluation in Table of Isotopes (8th ed.) gives slightly different Pn values with larger uncertainties than ENDF/B-VI.

3. Conclusion

The underestimate in the reactivity calculation with ENDF/B-VI must be attributed to behavior of $N_d(t)$ at about 30 s. The fission yields of ^{88}Br, ^{136}Te, and ^{137}I are the most probable sources for the underestimate so that much higher precision is required for these values. Furthermore, in order to achieve the required precision (5 %) for $N_d(t)$, it is also necessary to perform precise measurements of their Pn values. Therefore it is highly desirable to improve the fission yields and Pn values of ^{88}Br, ^{136}Te, and ^{137}I.

References

[1] G.D.Spriggs, Nucl. Sci. Eng. 114, (1993) 342-351.
[2] R.J. Tuttle, Nucl. Sci. and Eng. 56, (1975) 37-71.
[3] R.J. Tuttle, INDC(NDS)-107/G+Special (1979)
[4] T.Miyazono et al, Proc. 1996 Sympo. on Nucl. Data, JAERI-Conf 97-005, (1997) 83-88.

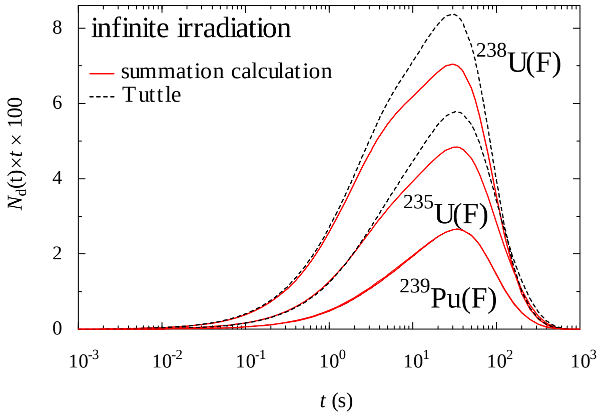

Fig.1 Delayed-neutron activities obtained from summation calculations and Tuttle's six-group parameter sets after infinite irradiation.

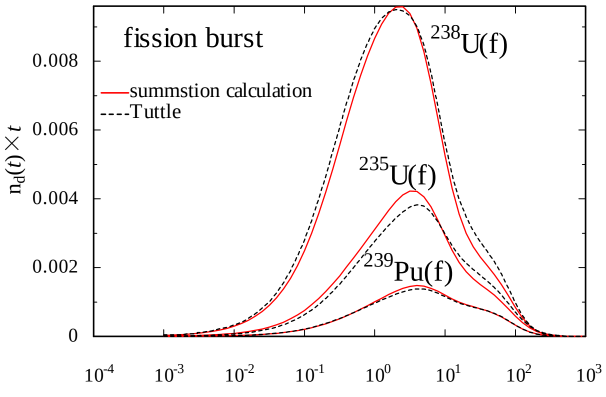

Fig.2 Delayed-neutron activities obtained from summation calculations and Tuttle's six-group parameter sets after fission bursts.

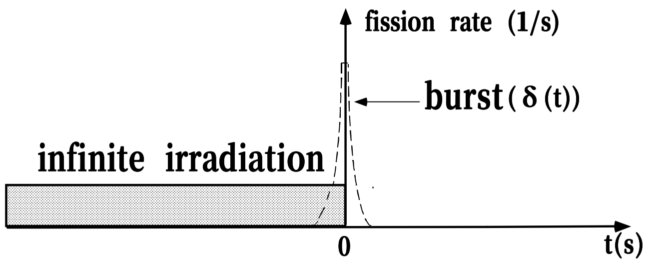

Fig.3 The definitions of infinite irradiation

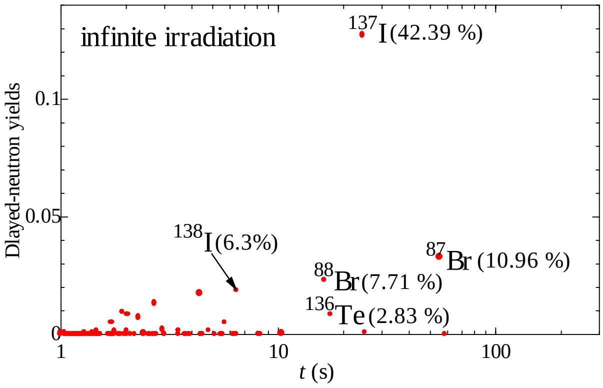

Fig.4 The delayed-neutron yields for ^{238}U(f). The values in the parentheses show ratios of individual DN yields to the total DN yields.

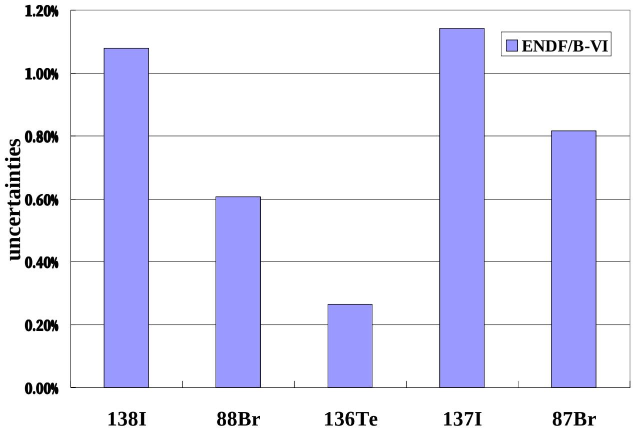

Fig.5 The uncertainties of the decay constants of ^{138}I, ^{88}Br, ^{136}Te, ^{137}I, and ^{87}Br.

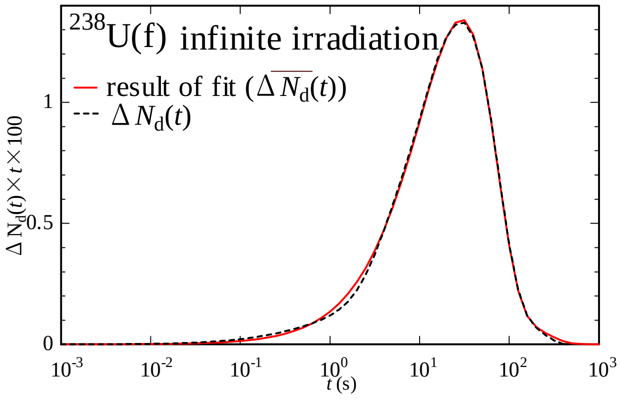

Fig.6 Result of the fitting.

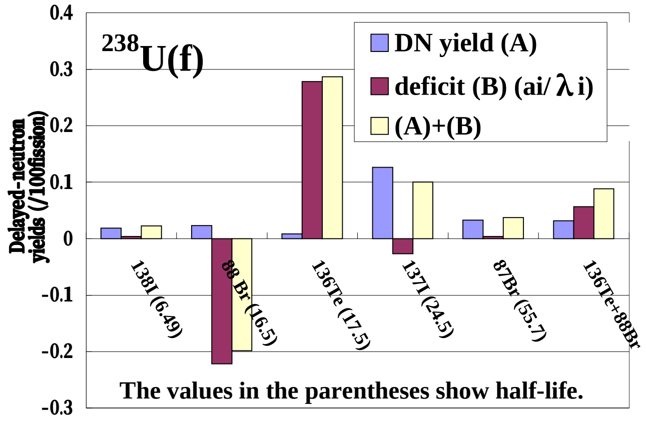

Fig.7 DN yields from individual precursors after infinite irradiation. Shown are the DN yields (A) and their deficits (B) in the summation calculation.

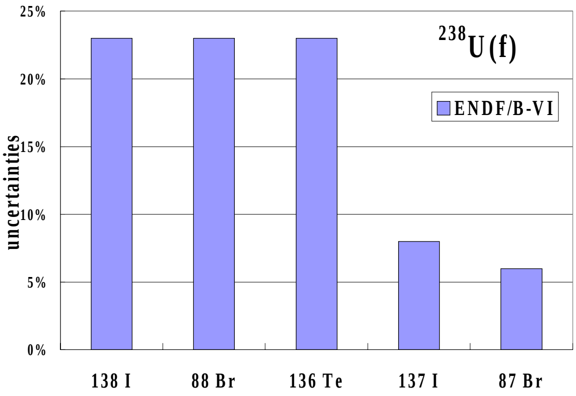

Fig.8 The uncertainties in the cumulative fission yields of ^{138}I, ^{88}Br, ^{136}Te, ^{137}I, and ^{87}Br for ^{238}U(f).

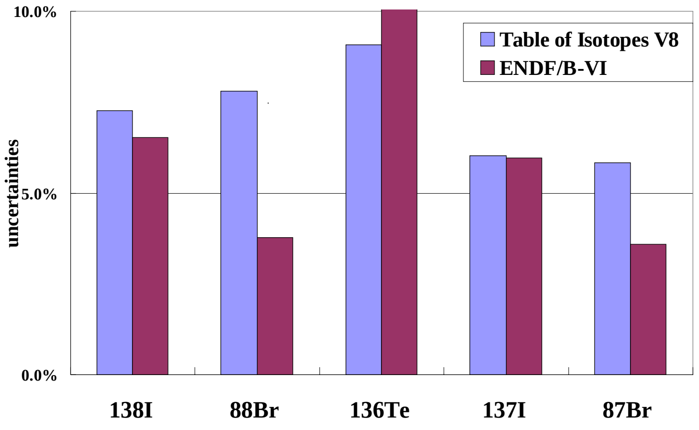

Fig.9 The uncertainties of Pn for ^{138}I, ^{88}Br, ^{136}Te, ^{137}I, and ^{87}Br.