A Comparison of ENDF/B-VI and UKFY3 Mass Chain Yields

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I. Introduction

Fission yield data are essential to many applications in nuclear technology, entering into all calculations of integral effects of the fission products. The fission yield is that quantity which characterizes the probability of a particular nuclide or mass to be formed after fission. The aim of this paper is to present a comparison of the mass chain yields contained in version VI of the U.S. Evaluated Nuclear Data File (ENDF/B-VI) and the U.K. evaluation, UKFY3, developed for the European Joint Evaluated File (JEF).

In binary nuclear fission a heavy nucleus is split into two fragments (ternary fission is extremely rare, occurring in less than 0.2% of fission events[1]). This process is non-deterministic with a large number of final states. In many fissioning systems there is a bimodal distribution of fission fragment masses with a predominance of fission fragments in the ~2/5 and ~3/5 mass range of the original nucleus. The fission fragments are formed in highly-excited, neutron-rich states resulting in the immediate release of prompt neutrons to relieve the neutron excess and prompt gammas to lower the excitation energy. These prompt neutrons account for about 99% of the total number of neutrons emitted from fission or an average of 2-3 neutrons. A nucleus so formed may be neutron-rich and unstable against the weak interaction, undergoing beta decay to further reduce the neutron number (alpha decay occurs in a few fission products; positron or electron capture also occur in some low-yield fission products near stability). Each decay forms a “daughter” nuclide of the same mass (A) with an atomic number (Z) one greater than the parent. Fission products may undergo several beta decays along this mass chain before a beta-stable species is formed. A large number of fission products, then, can be formed either directly from fission or through successive beta decays of parent nuclides.

Beta decay often results in the formation of an excited state of the daughter nucleus. This nucleus can de-excite by emitting a gamma ray or a neutron (these delayed neutrons comprise the other ~1% of neutrons released in fission). These beta-delayed gamma rays and neutrons appear with the characteristic half-life of the parent, which can range from about 10^{-3}s for nuclides early in the decay chain to many years for nuclides at later stages in the chain.

Due to the importance of fission nuclide yield data in applied fission calculations, evaluations of yield data have been undertaken in several countries. The most complete and widely-used evaluations are those compiled by England and Rider,[2,3] which is part of the U.S. Evaluated Nuclear Data File (ENDF/B-VI) and by Mills, James, and Weaver,[4,5] developed for the European Joint Evaluated File (JEF). These files contain independent yield, cumulative yield, and mass chain yield information. A nuclide's independent or direct yield indicates the number of atoms of that nuclide produced directly from the fission process after emission of prompt neutrons but before any radioactive decay has taken place (including delayed neutron emission). The cumulative yield, on the other hand, indicates the total number of atoms of the nuclide produced, both directly from fission as well as from radioactive decay of precursor nuclides (after delayed neutron emission). The mass chain yield is the sum of the cumulative yields of all stable nuclides in a given mass chain. In both evaluations experimental data was used where available and supplemented with model data for unmeasured yields.

The England-Rider yield evaluation contains independent and cumulative yields of over 1100 nuclides for 60 fissioning systems (combination of fissioning nuclide and incident neutron energy or spontaneous fission). The evaluation also contains mass chain yields for masses 66-172 for these 60 fissioning systems, representing more than 6400 chain yield values. All chain yields are normalized to 200% (100% each for the light and heavy mass peaks). The Mills yield evaluation contains independent and cumulative yields for 39 fissioning systems. However, Mills has extended the experimental database to include 191 fissioning systems as shown in Appendix A of Ref. 5., which includes fission induced by mono-energetic neutrons. In this comparison the mass chain yields for the 68 fissioning systems including thermal-, epi-thermal, fast-, and high-energy neutron-induced fission and spontaneous fission have been used. Ternary fission yields have been included in the UKFY3 evaluation. They have not been included for ENDF/B-VI although a set is recommended by England and Rider[3] based on work of Madland and Stewart.[1]

II. Models for Yield Distribution

The reliability of the evaluated yield data strongly depends on the experimental values on which they are based. However, measured yield data are not available for all fission products in all fissioning systems under consideration. In these cases the unmeasured yields are estimated from the best available models. Prediction of unknown fission yields relies strongly on interpolation of systematic descriptions of measured fission yields. Two empirical models used to predict fission yields are the Z_p model and the A'_p model both developed by A. C. Wahl.[6-9] The older Z_p model predicts that the independent yields of nuclides of the same mass A, will follow a gaussian distribution centered about a most probable charge Z_p. The A'_p model predicts that the yield distribution of nuclides of the same atomic number Z, will be a gaussian centered at a most probable mass A'_p. Both of these models rely on gaussian width and most probable charge or mass parameters that have been determined empirically. For the Z_p model the full width at half maximum (FWHM) of the gaussian about the most-probable Z_p value is only about 1.5 charge units. The independent yields then vary greatly over the entire mass range.

The model used to describe the mass distribution of fission products represents the familiar double-humped mass distribution of fission products by a sum of up to five gaussian functions. Again the functions are described by parameters found by fitting to measured data.

Although both Z_p and A'_p distributions have a gaussian shape, each has superimposed deviations due to the odd-even effect of neutron and proton pairing. The odd-even effect, in which the yield of nuclides with even atomic number is enhanced relative to odd-atomic number nuclides and similarly for neutron number, was first described by Amiel *et al*.[10,11] in 1972.

The yield distribution between isomeric states of a nuclide have been measured in only a small number of cases. Many times only the combined yield is known due to the inability of some experimental methods to distinguish between energy states of a nuclide. The most widely-used isomeric distribution model is that of Madland and England[12] which gives the yield of each isomer as a non-linear function of its angular momentum. This model is used by evaluators to divide the nuclide's yield between metastable and ground state when the isomeric yield is unmeasured. In the cases where the angular momentum is unknown, the yield is divided equally between the metastable and ground state.

III. Description of Table

Table 1 shows a comparison of the mass chain yields contained in the ENDF and UKFY3 yield files. A total of 70 fissioning systems are represented consisting of all thermal-, fast- and high-energy (14 MeV) neutron-induced and spontaneous fission mass chain yields present in one or both yield evaluations. In addition, a unique epithermal evaluation of ^{239}Pu contained in the UKFY3 file is included. The values in boldface represent UKFY3 yield values, while those in normal font are ENDF/B-VI yield values. The table is divided into 10 parts representing groups of different fissioning systems. The column heading represents the fissioning system for which the mass yields are given. The first part of the heading represents the fissioning nuclide and the final letter represents the incident neutron energy or spontaneous fission (t-thermal, f-fast, e-epithermal, h-high energy, and s-spontaneous fission).

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