The JEFF fission yield evaluations

Introduction

The JEFF fission yield libraries are all created using a common philosophy based upon the work of Crouch [1]. The JEFF fission yield libraries (JEF-1, JEF-2.2, JEFF-3.0, JEFF-3.1.1) are taken from the UKFY1 [2], UKFY2 [3,4,5] and UKFY3 [6] libraries.

The methodology applied in each case is based upon the principle that experimental data is key to understanding fission product yields. Firstly, the available experimental data was collected into a data base, this was then analysed to give best estimates of measured values, gaps were then filled using fits to models (mass yields using the five Gaussian approximation [7], charge distribution using the Wahl Zp model [8], isomeric splitting by the Madland and England model [9,10] and ternary yields using empirical or semi-empirical fitting [11,12]. The yields were then adjusted using a least squares method to fit physical constraints with changes being made based upon the inverse of the variance. Finally, the adjusted yields are converted to ENDF-6 format and tested using a range of benchmarks including physical constraints, delayed neutron emission summation calculations, decay heat pulse calculations, and spent fuel measurements of composition and decay heat.

Experimental Database and analysis

The available open literature, EXFOR and historic reports collected by the UK working starting with Crouch [1] were compiled into a database. From UKFY2 this was split into three sections absolute yield measurements per fission, yield ratios and “ratio of ratio” measurements. The current UK database includes 15820 yield measurements (12908 absolute, 1441 ratios and 1471 “ratio of ratio”). The reported uncertainties are used unless they appear unrealistically small, when a set of criteria are used to determine a reasonable value. The principle of the database is that no measurement is removed but rather flagged as “not useable” if found to be inconsistent with other experiments.

Analysis of the database

The analysis is carried out iteratively. Firstly the absolute yield are analysed to give mean values based upon inverse variance weighted averaging of the experimental data. The uncertainty is adopted as the maximum of the internal and external standard deviations. An automatic procedure based upon the normalised residual [13] was used to down-weight measurements that were inconsistent with the average and its standard deviation. Secondly, the ratio and “ratio of ratio” measurements were, where possible, converted to absolute values using the first estimates of the standard yields used in the measurements and the mean values and uncertainties determined again. This second process was repeated until the resulting yields and uncertainties converged. This resulted in files of best estimate yields and uncertainties.

Generating complete fission yield distributions

The yields and uncertainties were then used to fit the mass and charge distributions (five Gaussian and Wahl Zp models) the model predictions were then used to fill gaps in the distribution so that yields were available for all nuclides in the mass region of 50 to 200 amu with yields greater that 10^{-12} per fission. The Madland and England model was used to split the yields between long-lived isomeric states where no measurements were available. The ternary fission yields were fitted using empirical relationships in UKFY1 and UKFY2, but the more theoretical model of Carjans et al [11] as implemented by Serot [12] was used in UKFY3.

The uncertainty assigned to all modelled yields were based upon the agreement between measured yields and the fitted yield, although the uncertainty was capped to avoid problems with later adjustment.

Physical adjustment of independent yields

A generalised least squares procedure was used to iteratively fit the independent yields to the physical constraints of the fission process. These include nucleon conservation, neutron conservation, proton conservation and complementary yield equality for up to the twenty most important charge pairs.

The adjustment was weighted by the accuracy of the data so that measured yields with small uncertainties were adjusted less than modelled yields with large uncertainties. The uncertainty of an adjusted yield was increased by the amount of the final adjustment.

Calculation of cumulative yields

The cumulative yields were calculated from the independent yields using the Q matrix approach, where decay chains are followed and the cumulative yields are a direct result of the matrix multiplication of the independent yields with a Q matrix each element of which determines the fraction of a nuclide j that decays to a nuclide i so that the cumulative yield is the sum of $Q_{j,i} * Y_i$ for all nuclides that decay to i.

The cumulative yield uncertainties are determined from a) experiment, b) model or c) model and experiment. Where experiments exist the uncertainty is assigned to be the uncertainty from the data analysis plus any difference from the adjusted cumulative yield. Where no experimental datum exist an uncertainty from the combination of the mass and charge components is used. Where cumulative yield measurements exist the uncertainty is back calculated, such that the precursor nuclide is given an uncertainty such that the known uncertainty of the daughter would be calculated.

Formatting and testing

The adjusted independent and cumulative yields were then written in the ENDF-6 format [13] and tested to confirm the physical constraints listed above, that important fission products for applications agree with the experimental data (^{137}Cs, ^{148}Nd, ^{99}Mo etc). The files are then used to calculate benchmarks sensitive to fission yields; delayed neutron emission, decay heat and spent fuel composition.

References

1. Crouch et al

2. ...