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FINAL REPORT FOR SUBCONTRACT 9-XQ2-X1738-1

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ABSTRACT

In keeping with the statement of work, I have examined the fission product yields of 60 fissioning reactions. In co-authorship with the UTR (University Technical Representative) Talmadge R. England "Evaluation and Compilation of Fission Product Yields 1993," LA-UR-94-3106(ENDF-349) October, (1994) was published. This is an evaluated set of fission product yields for use in calculation of decay heat curves with improved accuracy has been prepared. These evaluated yields are based on all known experimental data through 1992. Unmeasured fission product yields are calculated from charge distribution, pairing effects, and isomeric state models developed at Los Alamos National Laboratory. The current evaluation has been distributed as the ENDF/B-VI fission product yield data set.

INTRODUCTION

Fission product yields are useful for many purposes, including understanding of the nature of the fission process, determining uranium burnup, calculating fission product inventories, performing shielding calculations, evaluation of neutron absorption effects, and calculating decay heating power. Of these, the most demanding is the calculation of decay heating power, because a complete set of direct, independent fission yields for all fission products with a half-life longer than a few tenths of a second, their half-lives, a Q values and errors associated with each are required.

For reliable and consistent nuclear calculation, it is desirable to have an accurate set of nuclear data. The United States National Nuclear Data Center at Brookhaven National Laboratory has published such an Evaluated Nuclear Data File (ENDF/B-VI). The General Electric Company has published evaluated fission yield data in a document NEDO-12154. This fission yield evaluation has been expanded in cooperation with the Fission Yield Subcommittee and decay Heat and Actinide Subcommittee of CSEWG (Cross Section Evaluation Working Group) for inclusion in the ENDF/B files. Table I shows the areas expanded specifically for each version of those files.

DISCLAIMER

TABLE I. Evaluation Evolution

EVALUATION	PRE-ENDF	ENDF/B-IV	ENDF/B-V	ENDF/B-VI
Report	NEDO-12154	NEDO-12154-1	NEDO-12154-2E	ENDF-349
Year	1972	1974	1978	1993
Fission Reactions	10	10	20	60
Cum. yields	YES	YES	YES	YES
Ind. Yields	NO	YES	YES	YES
Isomer Ratios	NO	NO	YES	YES
Odd-Even Pairing	NO	YES	YES	YES
Delayed Neutrons	NO	NO	YES	YES
Charge Balance	NO	YES	YES	YES
Ternary Fission	NO	NO	YES	YES
References	812	956	1119	1600
Input Values	6000	12400	18000	36000
Final Yields	11000	22000	44000	132000

The latest ENDF/B-VI version incorporates about 132,000 yields and their uncertainties in 60 sets of about 1100 values for independent yields before delayed neutron (DN) emission by 271 precursors, and a like number of cumulative yields after DN emission. The sets include 60 fission reactions of heavy nuclides including several fission neutron energies. The models used, data sources, evaluation methods, the integral tests made will be discussed.

GENERAL APPROACH

Not every one of the 1153 independent fission product yields required for each fissionable nuclide has been measured. All of the unmeasured values have been calculated from the best available models. All chain yields are normalized to 100% for the light and heavy mass peaks separately. Within each mass, a Gaussian charge distribution has been assumed about the most probable charge, Zp, with a constant standard deviation of 0.560 charge units, except where individual charge dispersion widths have been evaluated by others such as J. K. Dickens (83DIC1) and A. C. Wahl (86WAH1). Odd-even proton and neutron pairing effects are superimposed. All Zp values have been adjusted within their limits of error to obtain and acceptable proton material balance from the sum of binary and ternary fission yields.

The direct yields to the metastable and ground state isomers are nuclear spin dependent. These direct yields are apportioned to each isomer (where the spins are known) by the model of Madland (76MAD2). Delayed neutron emission is treated by including a proper treatment for fission yields of delayed neutron emitters. As a result all independent fission yields are now appropriately given before delayed neutron emission, and all cumulative fission yields are given after delayed neutron emission in the traditional manner. All recommended yields are the result of weighted averages of experimental values. A systematic error of 2% is combined with the reported random error of each absolute fission yield in which a systematic error has not been included by its author. Mass spectrometric measurements have been assigned errors no smaller than 0.5% relative.

Radiochemical measurements, because of the uncertainties in absolute accuracies of decay schemes and counting efficiencies, have been assigned errors no smaller than 20% for all measurements made before 1955, and 10% for those made since 1955. A few discrepant measurements were rejected by traditional statistical criteria such as the Dixon Range Test.

DISCUSSION OF ERRORS

The chain yields in the peak regions are known to about 1% in the well known measured fissionable nuclides, and to about 14% in the less well measured fissionable nuclides. The chain yields in the wings and valley are less well known and range from about 8 to 30%. The U235T yields are strikingly better known. Table II looks at the makeup of the better known U235T chain yield errors. It shows that these smaller errors are the result of many determinations rather than abnormally small errors assigned to individual measurements. The average individual measurement is about (+/-) 3% but in some cases about an average of 20 measurements result in the deviation of the mean being smaller than (+/-) 1%.

TABLE II. Individual Measurement Errors
for Most Accurate U235T FP Masses

MASS	INDIV. SIGMA,%	N	UNWEIGHTED SIGMA OF MEAN,%	WEIGHTED SIGMA OF MEAN,%
83	1.94	9	0.6	0.5
85	2.58	36	0.4	0.4
86	1.85	12	0.5	0.5
131	4.30	30	0.8	0.4
132	3.84	25	0.8	0.4
133	3.94	21	0.9	0.4
134	3.09	18	0.7	0.4
135	3.20	16	0.8	0.4
136	1.59	10	0.5	0.4
137	3.23	17	0.8	0.5
143	2.09	17	0.5	0.4
144	3.07	25	0.6	0.4
145	2.02	18	0.5	0.4
146	2.11	19	0.5	0.4
147	3.32	20	0.7	0.7
148	2.45	27	0.5	0.4
150	2.00	17	0.5	0.5
MEAN	2.74	20	0.6	0.4

Because of the difficulty in obtaining data free of systematic errors and experience shown in Table II, it is concluded that current yield recommendations should not be given accuracy assignments smaller than about (+/-) 0.4% in the ENDF files.

CONCLUSIONS

The full report ENDF-349 is available from the authors on diskettes or can be downloaded from the internet node t2.lanl.gov open to all where the user signs on as ANONYMOUS for name and inserts his E-mail mane for a password. The evaluated fission yields have been further extrapolated to include additional unmeasured low yield (0.23%) nuclides and renormalized by a maximum of 0.23% to a total of 200% for both fission product yield peaks combined. The resulting independent and cumulative fission yields are available on computer tape as ENDF files from U.S.A. National Nuclear Data Center, Brookhaven National Laboratory, Upton, New York 11973. Appendices A through F contain the mass chain yields for the 60 fission reactions evaluated.

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REFERENCES

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86WAH1 A. C. WAHL, Private communication to T. R. England of Zp, Sigma, Mass Yields, NU, EOZ, EON, Average Z and RMS Charge Dispersion from U235T, U233T, Pu239T, and Cf252S fission.