LA-3383

LOS ALAMOS SCIENTIFIC LABORATORY
of the
University of California

LOS ALAMOS • NEW MEXICO

Fission Product Yields from Fast (~1 MeV) Neutron Fission of Pu-239

UNITED STATES
ATOMIC ENERGY COMMISSION
CONTRACT W-7405-ENG. 36

Printed in USA. Price $2.00. Available from the Clearinghouse for Federal Scientific and Technical Information, National Bureau of Standards, United States Department of Commerce, Springfield, Virginia

UNIVERSITY OF CALIFORNIA
LOS ALAMOS SCIENTIFIC LABORATORY
(CONTRACT W-7405-ENG-36)
P. O. Box 1663
LOS ALAMOS, NEW MEXICO 87544

October 31, 1966

IN REPLY REFER TO:

To: Copyholders of LA-3383

From: Report Library

Subject: Errata and Addendum to LA-3383

Please attach this sheet to LA-3383 and make the indicated corrections to the Table.

Delete the following lines from Table III, pages 21 and 22 of LA-3383.

35	82	0.001	0.260
36	82	0.000	0.260
38	87	0.000	1.150
41	96	0.008	5.250
42	96	0.000	5.250
50	115	0.000	0.095
53	130	0.009	2.350
54	130	0.000	2.350
61	150	0.014	1.150
62	150	0.000	1.150

The entry for Z = 35, A = 82 was definitely an error. The other deletions are made in view of the possible practical application of the calculations. In the report, the cumulative yields were given for infinite time, but since the half-lives shown below (Ref: Sullivan, W. H., "Trilinear Chart of Nuclides") are so long, it would be practical to consider these nuclides as pseudo-stable.

Z	A	Half-life (years)
37	87	4.7×10^{10}
40	96	$> 2 \times 10^{16}$
49	115	6×10^{15}
52	130	$> 10^{21}$
60	150	$> 10^{16}$

LA-3383
UC-34, PHYSICS
TID-4500 (46th Ed.)

LOS ALAMOS SCIENTIFIC LABORATORY
of the
University of California

LOS ALAMOS • NEW MEXICO

Report written: July 1965

Report distributed: December 30, 1965

Fission Product Yields from Fast (~1 MeV) Neutron Fission of Pu-239

by

Carl A. Anderson, Jr.

ABSTRACT

The sixteen measured yields of fission products from fast fission of Pu-239 published through June, 1965 are given. Information is presented which indicates the restricted range of mass numbers within which mirroring, or reflection, of data is applicable. Use of this information enables generation of fairly reliable guesses for six reflected data points. A curve fit to these data provides interpolated estimates of unmeasured mass chain yields. A modified equal-charge-displacement hypothesis is used to estimate independent and cumulative fission yields of nuclides.

It is hoped that future measurements of fission product yields from fast fission of Pu-239 will make the speculative portions of this report unnecessary.

ACKNOWLEDGMENTS

The author appreciates the helpful information provided by James Terrell on the subject of neutron yield versus mass number. Kurt Wolfsberg, Rolf Peterson, and Morris Battat very kindly reviewed the manuscript and offered valuable suggestions. The staff of the Los Alamos Scientific Laboratory Technical Library assisted in the literature search.

INTRODUCTION

In the shield design and safety analysis of a plutonium fueled fast reactor, it is necessary to determine the radiation which results from fission product decay. To do so, it is first necessary to have good information concerning the fission product nuclide yields.

For lack of sufficient information on plutonium fission, some fast plutonium reactor designers (e.g., Ref. 1) still rely on inappropriate treatments based on thermal fission of U-235 (e.g., Ref. 2). Two extensive compilations of fission product yields, those of Katcoff,[3,4] contain too few measured values of mass chain yields for Pu-239 fast fission* to enable determination of nonmeasured yields by interpolation. Indeed, only one report[5] contains a curve of yield versus mass number for fast fission of Pu-239 on the basis of Katcoff's compilation; this curve agrees better with the experimental data than does the widely used Pu-239 fast fission yield mass number distribution of Burris and Dillon.[6] A recent compilation of fission product yields by Zysin[7] raises the possibility of improving the situation, since it tabulates fast Pu-239 fission yields for 16 mass numbers, as opposed to yields for 8 mass numbers in Katcoff's compilations. Unfortunately, checking a few of the references given by Zysin indicates a number of errors in his compilation (but these are really rather minor errors in so impressive a collection of data as Zysin's). Consequently, the literature was

*Fast fission is rather loosely defined as fission induced by neutrons with energies of the order of 1 or 2 MeV.

searched for original data. This search, while not uncovering data for additional mass numbers, revealed 8 errors in the 29 values given by Zysin, as well as 7 omissions. Virtually all of the errors are due to Zysin's consideration of values listed by Katcoff as original measurements. Thus, for example, the measured yield of Cs-137[8] was corrected by Katcoff for the 1958 value of its half-life[3] and recorrected for the 1960 value of its half-life.[4] Zysin lists all three values as independent determinations. In another error, Brightsen, et al.[9] erroneously list the Pu-239 thermal fission yield of Zr-95 as a fast fission yield, and Zysin copies the error.

MASS CHAIN YIELD DATA

The results of the literature search are given in Table I. Most of the plus-minus deviations given in column 2 are known to be standard deviations of the means, or standard errors, but some of the deviations can only be assumed to be so because the authors are not specific. The plus-minus deviations in column 7 are the standard deviations of the means based on the preceding assumption, using equal weighting of the data. Inclusion of the standard errors is of importance, since they indicate the liberties which may be taken in plotting a curve through the points. The compilations of Katcoff and Zysin are included for comparison.

TABLE I

MEASURED PU-239 FAST FISSION YIELDS

Nuclide	Original Data Yield	Original Data Ref.	Earlier Compilations: Katcoff (Ref. T1) Yield	Earlier Compilations: Katcoff (Ref. T2) Yield	Earlier Compilations: Zysin (Ref. T3) Yield	Chain Yield Based on Original Data	Notes
$_{38}Sr^{89}$	1.8 ± 0.2	T6	- - -	- - -	1.8 ± 0.2	1.8 ± 0.2	
$_{38}Sr^{89}$	2.12 ± 0.09	T7	2.2	2.2	2.2	2.12 ± 0.09	
$_{40}Zr^{95}$	5.3 ± 0.5	T6	- - -	- - -	5.3 ± 0.5	5.3 ± 0.5	
					5.6		1
$_{40}Zr^{97}$	5.01	T8	5.2	5.2	5.2	5.2 ± 0.2	
	5.41	T8					
$_{40}Mo^{99}$	6.04	T8	5.9	6.0			
	5.70	T8			5.9		2
	6.07	T8			6.0	5.78 ± 0.24	
	5.5 ± 0.4	T6			5.5 ± 0.4		
	5.9 ± 0.6	T9			5.9 ± 0.6		
$_{44}Ru^{103}$	6.0 ± 0.7	T9	- - -	- - -	6.0 ± 0.7	5.85 ± 0.61	
	5.7 ± 1.0	T10			5.7 ± 1.0		
$_{44}Ru^{106}$	4.8 ± 0.6	T9	- - -	- - -	4.8 ± 0.6	4.7 ± 0.5	
	4.6 ± 0.8	T10			4.6 ± 0.8		
$_{46}Pd^{109}$	1.67	T8	1.9	2.0	1.9		
	1.48	T5			2.0	1.64 ± 0.06	3
	1.60	T5					
$_{47}Ag^{111}$	0.55 ± 0.06	T9	- - -	- - -	0.55 ± 0.06		
	0.45 ± 0.03	T6			0.45 ± 0.03	0.50 ± 0.03	
	0.237	T5					4
$_{46}Pd^{112}$	0.127	T5	0.14	0.14	0.14	0.152 ± 0.025	
	0.177	T5					
53 hr $_{48}Cd^{115}$	0.045	T5	0.069	0.067	0.069		
	0.075	T5			0.067		
	0.09 ± 0.01	T9			0.09 ± 0.01	- - -	
	0.098 ± 0.008	T6			0.098 ± 0.008		
Total $_{48}Cd^{115}$	0.095 ± 0.010	T9	- - -	- - -	0.095 ± 0.010	0.095 ± 0.010	
33.5 day $_{52}Te^{129}$	0.45 ± 0.09	T9	- - -	- - -	0.45 ± 0.09	- - -	
Total $_{52}Te^{129}$	1.17	T9	- - -	- - -	1.17	1.17	
$_{52}Te^{132}$	3.5 ± 1.0	T9	- - -	- - -	3.5 ± 1.0	3.75 ± 1.0	5
$_{55}Cs^{137}$	7.45 ± 0.20	T4	6.6	6.8	6.6	6.85 ± 0.20	3
					6.8		
					7.45 ± 0.20		
$_{56}Ba^{140}$	5.4 ± 0.5	T9	5.0	5.0	5.4 ± 0.5	5.11 ± 0.21	
	5.14	T8			5.0		
	4.91	T8			4.9 ± 0.4		6
	5.06	T8					
	4.9 ± 0.4	T6					
$_{62}Sm^{153}$	0.50	T8	0.48	0.48	0.48	0.475 ± 0.025	
	0.45	T8					

Notes:
1. Zysin reproduces error of Ref. T8 App. B
2. Ref. T8 mean = 5.94 ± 0.12
3. Half-life correction applied to original data
4. 0.237 rejected
5. Chain yield/Te-132 yield = 1.07
6. Ref. T8 mean = 5.04 ± 0.07

REFERENCES FOR TABLE I

T1. Katcoff, S., "Fission-Product Yields from U, Th and Pu," Nucleonics 16, No. 4, 78 (1958).

T2. Katcoff, S., "Fission-Product Yields from Neutron-Induced Fission," Nucleonics 18, No. 11, 201 (1960).

T3. Zysin, Yu. A., A. A. Lbov, and L. I. Sel'chenkov, Fission Product Yields and Their Mass Distribution (Consultants Bureau, New York, 1964), Russian publication in 1963.

T4. Kafalas, P. and C. E. Crouthamel, "The Absolute Yield of Cs-137 in Fast-Neutron Fission of U-235 and Pu-239," J. Inorg. Nucl. Chem. 4, 239 (1957).

T5. Ford, G. P. and J. S. Gilmore, "Mass Yields from Fission by Neutrons Between Thermal and 14.7 Mev," Los Alamos Scientific Laboratory Report LA-1997 (1956).

T6. Petrzhak, K. A. et al., "Yields of a Number of Fission Products in the Fission of Uranium-235, Uranium-238, and Plutonium-239 by Neutrons," AEC-TR-4696 (1961) Russian publication in 1960.

T7. Bayhurst, B. P., "Fission Yields of Sr^{90}," TID-5787 (1956).

T8. Steinberg, E. P. and M. S. Freedman, "Summary of Results of Fission-Yield Experiments," in Radiochemical Studies: The Fission Products, C. D. Coryell and N. Sugarman, Eds., (McGraw-Hill Book Company, Inc., New York, 1951), Book 3, pp. 1378-1390; and Engelkemeir, D. W. et al., "Determination of Absolute Fast-Neutron Fission Yields in Pu-239," pp. 1331-1333.

T9. Bonyushkin, E. K. et al., "Fragment Yield in the Fission of U-233 and Pu-239 by Fast Neutrons," At. Energ. USSR 10, 13 (1961).

T10. Bak, M. A. et al., "Yields of Ru-103 and Ru-106 on Fission of U-235 and Pu-239 by Fast Neutrons," At. Energ. USSR 6, 577 (1959).

MIRRORING

To supplement, and to make the most efficient use of, the small amount of data available, the technique of mirroring, or reflection, is used. The relation

$$Pu^{239} + n^1 \rightarrow M_{light} + M_{heavy} + \nu n^1 , \qquad (1)$$

where

M = fission product,

ν = a constant,

n^1 = neutron,

has been widely used, but is <u>not</u> generally applicable. Petrzhak,[10] for example, incorrectly assumed the applicability of the above relation for all of his data, using $\nu = 3.0$. The following discussion indicates the limited extent to which mirroring may be used. Terrell[11,12] has derived the relation (assuming a continuous mass distribution):

$$\int_0^{M_i - \nu(M_i)} Y(M)\, dM = \int_0^{M_i} y(M)\, dM + \frac{1}{2}\frac{dy}{dM} \left\langle \sigma^2(\nu; M) \right\rangle + \dots , \qquad (2)$$

where

M_i = initial fission fragment mass,

y = initial mass yield,

Y = final mass yield,

$\nu(M_i)$ = average number of neutrons emitted by fragment of mass M_i,

$\sigma^2(x) = \overline{x^2} - \overline{x}^2$, the conditional variance.

Differentiating Eq. 2 with respect to M_i (and noting that, since the correction term involving σ^2 is both small and fairly independent of M_i, the differential of the correction term may be neglected) one writes

$$Y[M_i - \nu(M_i)] \left[1 - \frac{d\,\nu(M_i)}{d\,M_i}\right] = y(M_i) \; . \tag{3a}$$

This relation applies equally for the light and for the heavy fission fragment which occur in a given fission, whence

$$Y[M_{Li} - \nu(M_{Li})] \left[1 - \frac{d\,\nu(M_{Li})}{d\,M_{Li}}\right] = y(M_{Li}) \tag{3b}$$

and

$$Y[M_{Hi} - \nu(M_{Hi})] \left[1 - \frac{d\,\nu(M_{Hi})}{d\,M_{Hi}}\right] = y(M_{Hi}) \; . \tag{3c}$$

Since, by definition,

$$y(M_{Li}) \equiv y(M_{Hi}) \; , \tag{4}$$

and if

$$\frac{d\,\nu(M_{Li})}{d\,M_{Li}} = \frac{d\,\nu(M_{Hi})}{d\,M_{Hi}} \; , \tag{5}$$

(the validity of Eq. 5 will be discussed later) then

$$Y[M_{Li} - \nu(M_{Li})] = Y[M_{Hi} - \nu(M_{Hi})] \; . \tag{6}$$

Let

$$M_{Lf} = M_{Li} - \nu(M_{Li}) \; , \tag{7}$$

where

M_f = final fission product mass.

It is also known that

$$M_{Hi} + M_{Li} = A_f \; , \tag{8}$$

where

A_f = mass of fissionable (compound) nucleus.

From Eqs. 6, 7, and 8:

$$Y(M_{Lf}) = Y[A_f - M_{Lf} - \nu(M_{Hi}) - \nu(M_{Li})] \; , \tag{9}$$

and defining the total neutron yield associated with the light fission fragment of mass M_{Li} as

$$\nu = \nu(M_{Hi}) + \nu(M_{Li}) \; , \tag{10}$$

there results

$$Y(M_{Lf}) = Y(A_f - M_{Lf} - \nu) \; , \tag{11a}$$

and, similarly,

$$Y(M_{Hf}) = Y(A_f - M_{Hf} - \nu) \ . \qquad (11b)$$

This can be a very useful result. It states that, if one knows the total number of neutrons associated with the fission product mass chain M_{Lf} and if one knows the fission yield for that mass chain, then one knows the fission yield of the mirror imaged mass chain $A_f - M_{Lf} - \nu$. The restriction is that Eq. 5 must be valid.

Just as there is not much data on fission product yields from fast fission of Pu-239, so there is not much on neutron yields for fast fission of Pu-239. However, the available data[11] on neutron yield versus mass number for thermal neutron induced fission of U-233, U-235 and Pu-239, and for spontaneous fission of Cf-252 show a striking similarity (Fig. 1). Terrell draws the conclusion[12] "It is remarkable that the results for these different types of fission look so much alike when shown as functions of fragment mass. It is suggested that the excitation of the fragments depends more on the properties of the fragments than on the mass ratio, and leads to the idea of a universal neutron yield curve." Thus, it does not appear unreasonable to assume that the curve of neutron yield versus mass number for Pu-239 fast fission will follow the same pattern.

Equations 5 and 10 indicate that Eq. 11 is valid only when

$$\frac{d\nu}{d\,M_{Hi}} = 0 \ , \qquad (12)$$

where ν is now plotted against M_{Hi}. The data referred to above show Eq. 12 to be true only for fissions in which the heavy fragment falls on the high mass side of the heavy mass peak (and, concomitantly, the light fragment falls on the low mass side of the light mass peak). For thermal fission of Pu-239, Eq. 12 is valid in the mass number range 137 to 153, in which range $\nu \cong 3.15$ (± 0.2 for $139 < M_H < 149$, ± 0.6 for $M_H = 153$). A further restriction on the use of

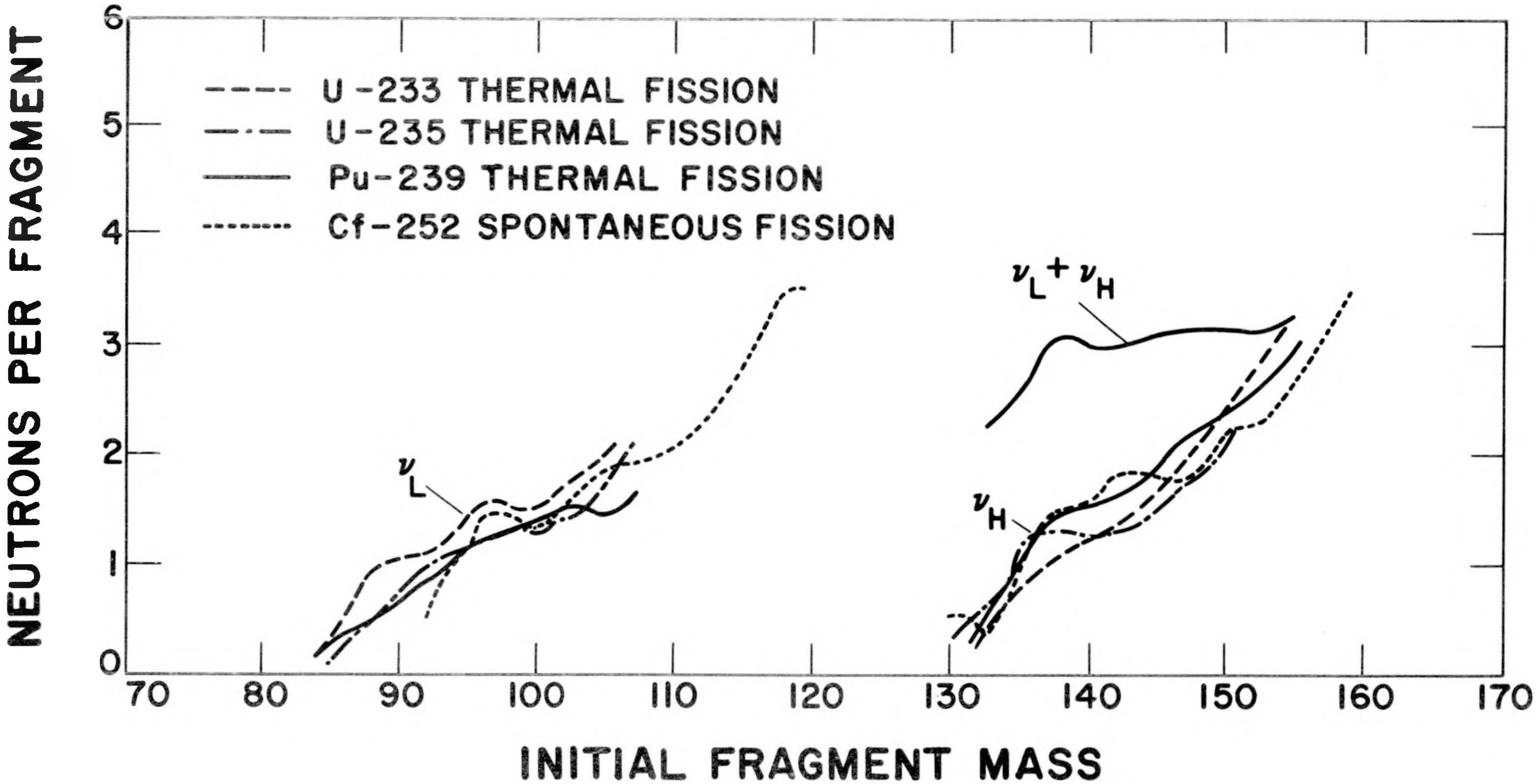

Fig. 1. Neutron Yield versus Initial Fragment Mass Number (from Ref. 11). ν_L, ν_H = neutron yields associated with light and heavy fission fragments, respectively.

Eq. 11 is that ν must be known; because of the difficulty of associating a measured neutron yield with a particular mass chain, ν is known only at mass numbers far from those at which Eq. 12 is invalid. Thus, one may only apply mirroring for Pu-239 fast fission within the range $137 < M_H < 153$.

Since $\bar{\nu}$, the average number of neutrons per fission, is 2.89 ± 0.03 for thermal neutron induced fission of Pu-239 and 3.12 ± 0.15 for fission of Pu-239 by 2.1 MeV neutrons,[13] a value of $\nu = 3.40$ will be used. The spread in neutron yield data (Fig. 1) indicates a possible error of ± 0.5 mass unit in the extrapolation to Pu-239 fast fission. Combining all these errors indicates that mirroring may be used for Pu-239 fast fission data with $\nu = 3.40 \pm 0.55$ for $139 < M_H < 149$, the probable error increasing to ± 0.75 at $M_H = 153$.

It should be mentioned that sharp peaks and valleys in the fission product mass chain yield curve will not be made apparent by the mirroring technique.

MASS CHAIN YIELD CURVES

The data in Table I are plotted as open circles in Fig. 2. Careful use of the technique of mirroring, discussed above, enables generation of additional pseudo-data points (shown as closed circles in Fig. 2) at mass numbers 83.6, 96.6, 139.6, 141.6, 146.6, and 147.6 (reflections of the mass chain yields at mass numbers 153, 140, 97, 95, 90, and 89). A best fit curve is drawn subject to the constraint that the sum of the yields under each peak must be 100%. Figure 2 also shows the curves of Burris and Dillon[6] and of Weaver, et al.[5] for comparison.

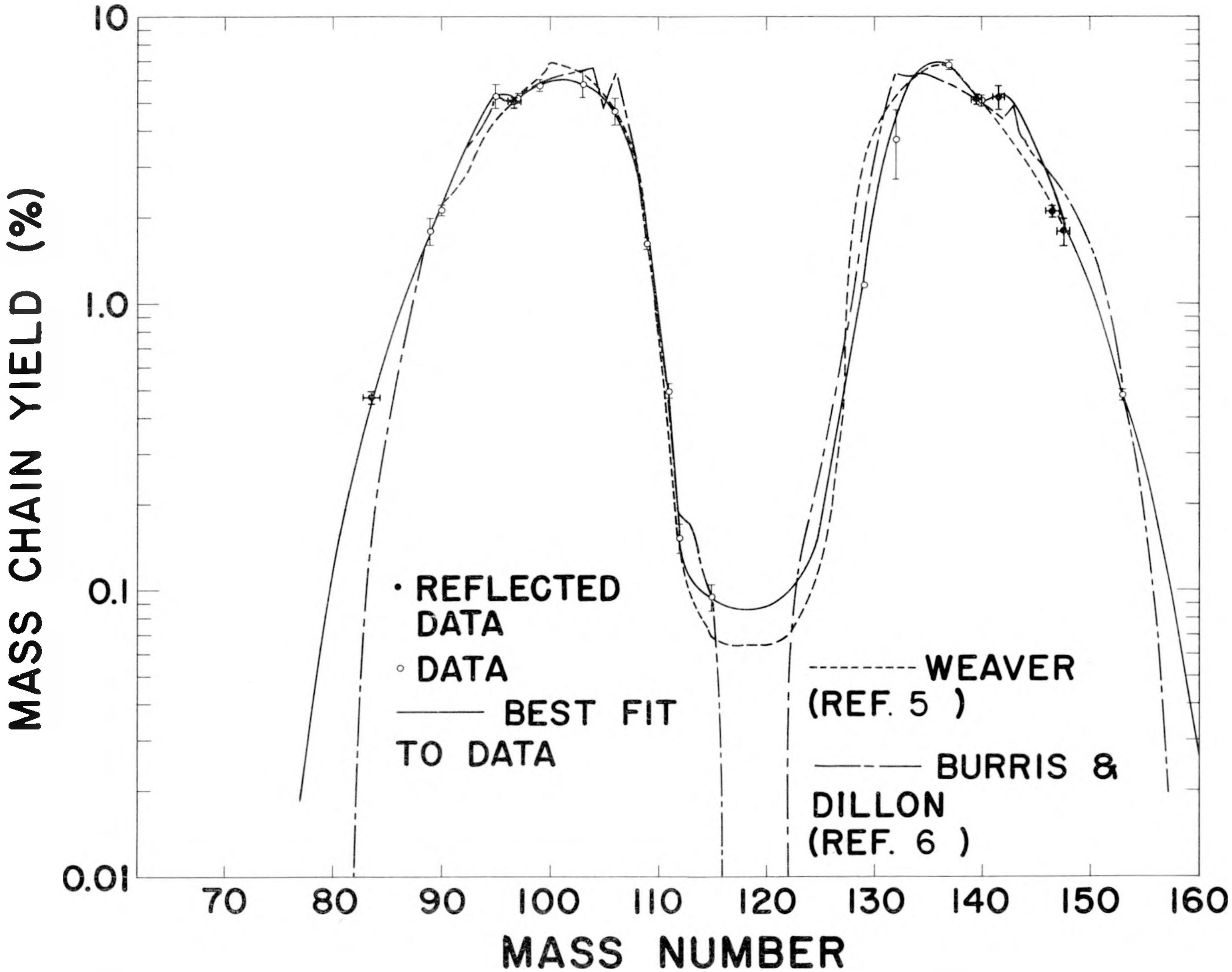

Fig. 2. Fission Product Mass Chain Yields for Pu-239 Fast Fission. Data and Three Fitted Curves.

It should be noted that the mass chain yields most open to question are those in the valley, partly because there are no data from mass number 115 to mass number 129, and partly because the valley yields are most sensitive to changes in the energy of neutrons inducing fission.

Figure 3 reproduces the Pu-239 fast fission yield data and compares them with curves based on experimental fission product yields[3,4,7] for thermal fission of Pu-239 and U-235 (these yields were not checked). Two conclusions from this comparison should be emphasized. The first conclusion is that the U-235 thermal fission yield curve is a bad approximation to the Pu-239 fast fission yield data and should not be used as such. The second conclusion is that Pu-239 fission product mass chain yields are not strongly dependent on energy, except in the valley. This is important because of the wide variation in "fast" neutron spectra which were used for measurement of the fast fission yields under discussion. Thus, in the work of Ford,[14] data are given for fast fission of Pd-109, Pd-112, and Cd-115 from two different "fast" spectra; one a degraded fission spectrum from a fast reactor and the other spectrum from a thick U-235 converter capsule in a reactor thermal column. Several experimenters (e.g., Ref. 10) used a U-235 plate in a reactor thermal column as the source of fast neutrons. The fission energy neutrons passed through about 1 cm of B_4C (a thermal neutron shield) to reach the sample. Inasmuch as the B_4C scattered about 10% of the fission energy neutrons directed from the U-235 plate to the sample, the spectrum at the sample was probably degraded somewhat.

Table II lists the fission product mass chain yields obtained, by interpolation and extrapolation, from Fig. 2. Three significant figures are used merely for consistency, and do not, of course, imply that the numbers are that well known. These yields will now be used to derive the fission product nuclide yields.

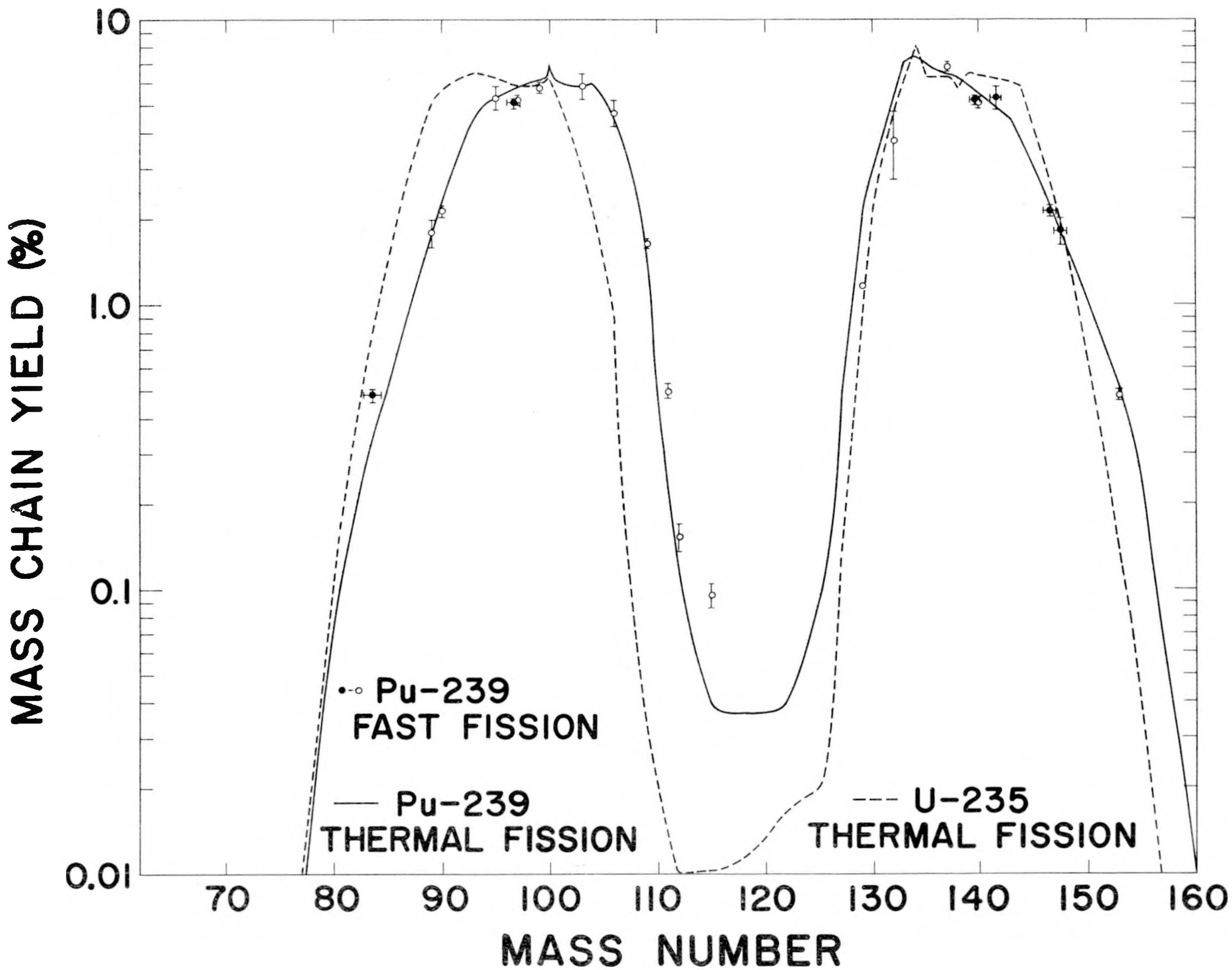

Fig. 3. Comparison of Experimental Data.

TABLE II

MASS CHAIN YIELDS

A	Mass Chain Yield	A	Mass Chain Yield
76	0.00	120	0.089
77	0.019	121	0.092
78	0.039	122	0.097
79	0.070	123	0.110
80	0.110	124	0.129
81	0.178	125	0.167
82	0.26	126	0.28
83	0.38	127	0.43
84	0.52	128	0.71
85	0.69	129	1.20
86	0.90	130	2.35
87	1.15	131	3.40
88	1.43	132	4.55
89	1.80	133	5.70
90	2.12	134	6.45
91	2.60	135	6.85
92	3.15	136	6.95
93	3.80	137	6.85
94	4.60	138	6.10
95	5.30	139	5.30
96	5.25	140	5.10
97	5.20	141	5.35
98	5.50	142	5.40
99	5.80	143	4.90
100	6.00	144	4.30
101	6.00	145	3.55
102	6.00	146	2.85
103	5.85	147	2.25
104	5.60	148	1.75
105	5.30	149	1.43
106	4.70	150	1.15
107	3.70	151	0.89
108	2.70	152	0.70
109	1.67	153	0.48
110	0.82	154	0.36
111	0.50	155	0.26
112	0.15	156	0.180
113	0.11	157	0.120
114	0.099	158	0.072
115	0.095	159	0.045
116	0.089	160	0.026
117	0.087	161	0.014
118	0.086	Sum =	98.981
119	0.086		
Sum =	100.508	Grand Sum =	199.489

FISSION PRODUCT NUCLIDE YIELDS

The equal charge displacement hypothesis[15] has usually been used to determine the independent yields of members of a mass chain. More recent studies by Wolfsberg and others[16,17] indicate that adjustment of the most probable charge by reference to U-235 thermal neutron fission data results in better agreement with experiment for other fission processes. Assuming that Wolfsberg's is the best available treatment of the yield of a nuclide for which the mass chain yield is known, we write:[17]

$$Y_c(Z,A) = Y_c(A)\ \{0.5 + 0.5\ \mathrm{Erf}\ [(Z - Zp(A) + 0.5)/\sigma\sqrt{2}]\}\ , \qquad (13)$$

where

Z	= atomic number of fission product,
A	= mass number of fission product,
$Zp(A)$	= most probable charge,
σ	= a characteristic of the Gaussian distribution assumed for $Y_c(Z,A)$,
$Y_c(A)$	= mass chain yield,
$Y_c(Z,A)$	= cumulative yield of nuclide (Z,A),
$\mathrm{Erf}(x)$	$= \frac{2}{\sqrt{\pi}} \int_0^x e^{-t^2}\, dt$, the error function. (14)

$Zp(A)$, the most probable charge, is given by (for $82 \leq A \leq 100$)

$$Zp(A) = 0.4237A - 2.19 + 0.5(Z_F - 92) - (0.21(A_F - 236) + 0.19(\nu - 2.43) \quad (15a)$$

(for $A \geq 135$)

$$Zp(A) = 0.4331A - 6.06 + 0.5(Z_F - 92) - 0.21(A_F - 236) + 0.19(\nu - 2.43), \quad (15b)$$

where

Z_F = atomic number of fissionable nucleus,

A_F = mass number of compound nucleus,

ν = average number of neutrons emitted per fission.

Although not enough measurements have been made for low yield mass numbers,[17] linear interpolation is assumed to be satisfactory for $101 \leq A \leq 134$, whence (for $101 \leq A \leq 134$)

$$Zp(A) = 0.349A + 5.24 + 0.5(Z_F - 92) - 0.21(A_F - 236) + 0.19(\nu - 2.43). \quad (15c)$$

The Appendix contains the computer program used for the calculations, which were performed on the IBM 7094 computer. Table III gives the resultant values of independent and cumulative fission product yields versus Z and A for Pu-239 fast fission. The mass chain yields given above were used, along with $\sigma = 0.59$ (from Ref. 17) and $E = 1.0$ MeV, where E is the energy of neutrons causing fission. The choice of σ is open to question.[16,17] The value of $Y_c(Z, A)$ is not very dependent on E, since it can be affected only by the dependence of $Y_c(A)$ on E (which Fig. 3 shows to be slight) and the dependence of ν on E (which Eq. 15 shows to have little effect).

For a given A, the computer terminates the fission product decay chain calculation at the first value of Z corresponding to a stable nuclide. This means that a few shielded nuclides, such as Sb-122, are not included in the results--but this is an inconsiderable omission since the yields of such nuclides are extremely small.

TABLE III

INDEPENDENT AND CUMULATIVE FISSION PRODUCT YIELDS VERSUS Z AND A FOR PU-239 FAST FISSION

	PERCENT YIELD	
Z A	INDEPENDENT	CUMULATIVE
30 77	0.007	0.007
30 78	0.006	0.006
30 79	0.003	0.003
31 77	0.010	0.017
31 78	0.023	0.029
31 79	0.030	0.033
31 80	0.023	0.023
31 81	0.011	0.012
31 82	0.003	0.003
32 77	0.002	0.019
32 78	0.010	0.039
32 79	0.034	0.066
32 80	0.066	0.090
32 81	0.090	0.102
32 82	0.073	0.077
32 83	0.039	0.040
32 84	0.012	0.013
32 85	0.002	0.002
33 77	0.000	0.019
33 78	0.000	0.039
33 79	0.004	0.070
33 80	0.020	0.109
33 81	0.071	0.173
33 82	0.151	0.228
33 83	0.215	0.254
33 84	0.190	0.203
33 85	0.107	0.110
33 86	0.038	0.039
33 87	0.009	0.009
33 88	0.001	0.001
34 77	0.000	0.019
34 78	0.000	0.039
34 79	0.000	0.070
34 80	0.001	0.110
34 81	0.005	0.178
34 82	0.032	0.259
34 83	0.119	0.374
34 84	0.277	0.479
34 85	0.413	0.522
34 86	0.403	0.442
34 87	0.256	0.264
34 88	0.102	0.103
34 89	0.026	0.027
34 90	0.004	0.004
35 79	0.000	0.070
35 81	0.000	0.178
35 82	0.001	0.260
35 83	0.006	0.380
35 84	0.040	0.520
35 85	0.162	0.684
35 86	0.415	0.858
35 87	0.691	0.955
35 88	0.745	0.849
35 89	0.541	0.567
35 90	0.240	0.244
35 91	0.071	0.072
35 92	0.013	0.013
35 93	0.002	0.002
36 82	0.000	0.260
36 83	0.000	0.380
36 84	0.000	0.520
36 85	0.006	0.690
36 86	0.042	0.900
36 87	0.191	1.145
36 88	0.543	1.392
36 89	1.030	1.598
36 90	1.218	1.463
36 91	0.999	1.071
36 92	0.533	0.546
36 93	0.183	0.184
36 94	0.040	0.040
36 95	0.005	0.005
37 85	0.000	0.690
37 87	0.005	1.150
37 88	0.038	1.430
37 89	0.199	1.797
37 90	0.627	2.090
37 91	1.346	2.417
37 92	1.894	2.440
37 93	1.770	1.954
37 94	1.099	1.139
37 95	0.422	0.428
37 96	0.089	0.090
37 97	0.012	0.012
37 98	0.001	0.001
38 87	0.000	1.150
38 88	0.000	1.430
38 89	0.003	1.800
38 90	0.030	2.120
38 91	0.181	2.598
38 92	0.687	3.127
38 93	1.687	3.641
38 94	2.746	3.884
38 95	2.836	3.264
38 96	1.674	1.764
38 97	0.647	0.659
38 98	0.172	0.173
38 99	0.029	0.029
38100	0.003	0.003
39 89	0.000	1.800
39 90	0.000	2.120
39 91	0.002	2.600
39 92	0.022	3.150
39 93	0.157	3.799
39 94	0.700	4.584
39 95	1.912	5.176
39 96	2.952	4.716
39 97	3.033	3.692
39 98	2.217	2.390
39 99	1.065	1.094
39100	0.325	0.328
39101	0.084	0.085
39102	0.016	0.016
39103	0.002	0.002
40 90	0.000	2.120
40 91	0.000	2.600
40 92	0.000	3.150
40 93	0.001	3.800
40 94	0.016	4.600
40 95	0.123	5.299
40 96	0.526	5.242
40 97	1.444	5.136
40 98	2.764	5.154
40 99	3.498	4.591
40100	2.896	3.224
40101	1.770	1.854
40102	0.810	0.826
40103	0.268	0.270
40104	0.064	0.064
40105	0.011	0.011
40106	0.001	0.001
41 93	0.000	3.800
41 95	0.001	5.300
41 96	0.008	5.250
41 97	0.064	5.200
41 98	0.343	5.497
41 99	1.173	5.765
41100	2.555	5.779
41101	3.451	5.306
41102	3.537	4.363
41103	2.683	2.953
41104	1.509	1.573
41105	0.628	0.639
41106	0.181	0.182
41107	0.034	0.034
41108	0.004	0.004
42 95	0.000	5.300
42 96	0.000	5.250
42 97	0.000	5.200
42 98	0.003	5.500
42 99	0.035	5.800
42100	0.219	5.999
42101	0.683	5.989
42102	1.572	5.936
42103	2.640	5.593
42104	3.285	4.858
42105	3.066	3.707
42106	2.037	2.220
42107	0.906	0.940
42108	0.279	0.283
42109	0.054	0.054
42110	0.006	0.006
43 99	0.000	5.800
43101	0.011	6.000
43102	0.064	6.000
43103	0.255	5.848
43104	0.728	5.586
43105	1.523	5.230
43106	2.236	4.455
43107	2.202	3.142
43108	1.527	1.810
43109	0.680	0.735
43110	0.181	0.187
43111	0.045	0.045
43112	0.004	0.004
44 99	0.	5.800
44101	0.000	6.000
44102	0.000	6.000
44103	0.002	5.850
44104	0.014	5.600
44105	0.070	5.300
44106	0.242	4.698
44107	0.546	3.688
44108	0.846	2.656
44109	0.833	1.568
44110	0.493	0.680
44111	0.275	0.320
44112	0.057	0.061
44113	0.022	0.023
44114	0.008	0.008
44115	0.002	0.002
45103	0.000	5.850
45105	0.000	5.300
45106	0.002	4.700
45107	0.012	3.700
45108	0.044	2.700
45109	0.101	1.669
45110	0.137	0.817
45111	0.170	0.490
45112	0.078	0.139
45113	0.066	0.089
45114	0.053	0.060
45115	0.034	0.036
45116	0.016	0.016
45117	0.006	0.006
45118	0.002	0.002
46105	0.000	5.300
46106	0.000	4.700
46107	0.000	3.700
46108	0.000	2.700
46109	0.001	1.670
46110	0.003	0.820
46111	0.010	0.500
46112	0.011	0.150
46113	0.021	0.109
46114	0.036	0.097
46115	0.051	0.087
46116	0.054	0.070
46117	0.044	0.050
46118	0.028	0.030
46119	0.014	0.014
46120	0.005	0.005
46121	0.001	0.001
47107	0.	3.700
47109	0.000	1.670
47111	0.000	0.500
47112	0.000	0.150
47113	0.001	0.110
47114	0.002	0.099
47115	0.008	0.095
47116	0.019	0.088
47117	0.034	0.084
47118	0.048	0.078
47119	0.051	0.065
47120	0.043	0.049
47121	0.028	0.029

TABLE III (CONTINUED)

47122	0.014	0.014	52132	2.344	4.236	58144	0.246	4.298
47123	0.005	0.005	52133	3.437	4.636	58145	0.691	3.530
47124	0.002	0.002	52134	3.457	3.980	58146	1.202	2.748
48111	0.000	0.500	52135	2.474	2.634	58147	1.332	1.928
48112	0.000	0.150	52136	1.034	1.057	58148	0.952	1.103
48113	0.000	0.110	52137	0.266	0.267	58149	0.466	0.492
48114	0.000	0.099	52138	0.038	0.038	58150	0.145	0.147
48115	0.000	0.095	52139	0.003	0.003	58151	0.027	0.027
48116	0.001	0.089	53127	0.000	0.430	58152	0.003	0.003
48117	0.003	0.087	53129	0.001	1.200	59141	0.000	5.350
48118	0.008	0.086	53130	0.009	2.350	59143	0.000	4.900
48119	0.020	0.085	53131	0.064	3.400	59144	0.002	4.300
48120	0.037	0.086	53132	0.311	4.547	59145	0.020	3.550
48121	0.053	0.082	53133	1.036	5.672	59146	0.101	2.849
48122	0.057	0.071	53134	2.321	6.301	59147	0.315	2.244
48123	0.051	0.056	53135	3.664	6.298	59148	0.609	1.713
48124	0.036	0.037	53136	4.140	5.197	59149	0.798	1.290
48125	0.020	0.021	53137	2.975	3.243	59150	0.672	0.819
48126	0.011	0.011	53138	1.252	1.291	59151	0.356	0.383
48127	0.004	0.004	53139	0.327	0.331	59152	0.124	0.127
48128	0.001	0.001	53140	0.059	0.059	59153	0.024	0.024
49113	0.	0.110	53141	0.007	0.007	59154	0.003	0.003
49115	0.000	0.095	54129	0.000	1.200	60143	0.	4.900
49117	0.000	0.087	54130	0.000	2.350	60144	0.000	4.300
49118	0.000	0.086	54131	0.000	3.400	60145	0.000	3.550
49119	0.001	0.086	54132	0.003	4.550	60146	0.001	2.850
49120	0.003	0.089	54133	0.028	5.700	60147	0.006	2.250
49121	0.010	0.092	54134	0.148	6.449	60148	0.037	1.750
49122	0.025	0.096	54135	0.545	6.843	60149	0.138	1.428
49123	0.049	0.105	54136	1.690	6.887	60150	0.317	1.136
49124	0.075	0.112	54137	3.253	6.496	60151	0.449	0.833
49125	0.097	0.118	54138	3.677	4.968	60152	0.422	0.549
49126	0.123	0.134	54139	2.656	2.987	60153	0.226	0.250
49127	0.108	0.112	54140	1.384	1.443	60154	0.086	0.089
49128	0.076	0.077	54141	0.503	0.510	60155	0.020	0.020
49129	0.040	0.041	54142	0.110	0.111	60156	0.003	0.003
49130	0.018	0.018	54143	0.013	0.013	61147	0.000	2.250
49131	0.004	0.004	55133	0.000	5.700	61149	0.002	1.430
50115	0.	0.095	55135	0.007	6.850	61150	0.014	1.150
50117	0.000	0.087	55137	0.351	6.847	61151	0.057	0.889
50118	0.000	0.086	55138	1.103	6.071	61152	0.146	0.695
50119	0.000	0.086	55139	2.145	5.132	61153	0.211	0.461
50120	0.000	0.089	55140	2.988	4.431	61154	0.215	0.304
50121	0.000	0.092	55141	2.970	3.481	61155	0.138	0.159
50122	0.001	0.097	55142	1.856	1.967	61156	0.056	0.058
50123	0.005	0.110	55143	0.671	0.685	61157	0.014	0.014
50124	0.016	0.129	55144	0.148	0.149	61158	0.002	0.002
50125	0.047	0.165	55145	0.019	0.019	62147	0.	2.250
50126	0.132	0.266	55146	0.001	0.001	62149	0.000	1.430
50127	0.255	0.367	56135	0.000	6.850	62150	0.000	1.150
50128	0.404	0.481	56137	0.003	6.850	62151	0.001	0.890
50129	0.497	0.537	56138	0.029	6.100	62152	0.005	0.700
50130	0.533	0.552	56139	0.167	5.299	62153	0.019	0.480
50131	0.316	0.320	56140	0.656	5.088	62154	0.055	0.359
50132	0.128	0.128	56141	1.770	5.250	62155	0.095	0.254
50133	0.035	0.035	56142	2.954	4.920	62156	0.102	0.161
50134	0.006	0.006	56143	2.894	3.578	62157	0.069	0.083
51121	0.000	0.092	56144	1.795	1.944	62158	0.028	0.030
51123	0.000	0.110	56145	0.678	0.697	62159	0.007	0.008
51125	0.002	0.167	56146	0.158	0.160	62160	0.001	0.001
51126	0.014	0.280	56147	0.023	0.023	63151	0.000	0.890
51127	0.062	0.429	56148	0.002	0.002	63153	0.000	0.480
51128	0.218	0.699	57139	0.001	5.300	63155	0.006	0.260
51129	0.592	1.129	57140	0.012	5.100	63156	0.019	0.180
51130	1.409	1.961	57141	0.099	5.350	63157	0.035	0.118
51131	1.883	2.203	57142	0.473	5.394	63158	0.037	0.067
51132	1.763	1.892	57143	1.270	4.849	63159	0.027	0.035
51133	1.164	1.199	57144	2.108	4.052	63160	0.012	0.013
51134	0.517	0.523	57145	2.142	2.839	63161	0.003	0.003
51135	0.159	0.160	57146	1.386	1.546	64155	0.000	0.260
51136	0.022	0.022	57147	0.574	0.596	64156	0.000	0.180
51137	0.002	0.002	57148	0.150	0.152	64157	0.002	0.120
52125	0.000	0.167	57149	0.026	0.026	64158	0.005	0.072
52126	0.000	0.280	57150	0.003	0.003	64159	0.010	0.045
52127	0.001	0.430	58140	0.000	5.100	64160	0.012	0.025
52128	0.011	0.710	58141	0.000	5.350	64161	0.008	0.012
52129	0.070	1.199	58142	0.096	5.400	65159	0.000	0.045
52130	0.380	2.341	58143	0.951	4.900	65161	0.002	0.014
52131	1.133	3.335				66161	0.000	0.014

REFERENCES

1. McNelly, M. J., "Liquid Metal Fast Breeder Reactor Design Study (1000 MWe UO_2-PuO_2 Fueled Plant)," General Electric Co., Atomic Power Equipment Dept. Report GEAP-4418 (1964).

2. Stehn, J. R. and E. F. Clancy, "Fission-Product Radioactivity and Heat Generation," Proc. U. N. Intern. Conf. Peaceful Uses At. Energy, 2nd Geneva, 1958 13, 49 (1958).

3. Katcoff, S., "Fission-Product Yields from U, Th and Pu," Nucleonics 16, No. 4, 78 (1958).

4. Katcoff, S., "Fission-Product Yields from Neutron-Induced Fission," Nucleonics 18, No. 11, 201 (1960).

5. Weaver, L. E., P. O. Strom, and P. A. Killeen, "Estimated Total Chain and Independent Fission Yields for Several Neutron-Induced Fission Processes," Naval Radiological Defense Laboratory Report NRDL-TR-633 (1963).

6. Burris, L., Jr. and I. G. Dillon, "Estimation of Fission Product Spectra in Discharged Fuel from Fast Reactors," Argonne National Laboratory Report ANL-5742 (1957).

7. Zysin, Yu. A., A. A. Lbov, and L. I. Sel'chenkov, Fission Product Yields and Their Mass Distribution (Consultants Bureau, New York, 1964), Russian publication in 1963.

8. Kafalas, P. and C. E. Crouthamel, "The Absolute Yield of Cs-137 in Fast-Neutron Fission of U-235 and Pu-239," J. Inorg. Nucl. Chem. 4, 239 (1957).

9. Brightsen, R. A., E. L. Bernier, A. C. Pappas, and A. Y. Sakakura, "Fission Yields," in Radiochemical Studies: The Fission Products, C. D. Coryell and N. Sugarman, Eds., (McGraw-Hill Book Company, Inc., New York, 1951), Book 3, pp. 2003-2011.

10. Petrzhak, K. A. et al., "Yields of a Number of Fission Products in the Fission of Uranium-235, Uranium-238, and Plutonium-239 by Neutrons," AEC-TR-4696 (1961) Russian publication in 1960.

11. Terrell, J., "Neutron Yields from Individual Fission Fragments," Phys. Rev. 127, 880 (1962).

12. Terrell, J., "Prompt Neutrons from Fission," IAEA Symposium on the Physics & Chemistry of Fission, 22 March 1965 (Paper SM-60/43).

13. "Reactor Physics Constants," Argonne National Laboratory Report ANL-5800, Second Edition (1963).

14. Ford, G. P. and J. S. Gilmore, "Mass Yields from Fission by Neutrons Between Thermal and 14.7 Mev," Los Alamos Scientific Laboratory Report LA-1997 (1956).

15. Glendenin, L. E., C. D. Coryell, and R. R. Edwards, "Distribution of Nuclear Charge in Fission," in Radiochemical Studies: The Fission Products, C. D. Coryell and N. Sugarman, Eds., (McGraw-Hill Book Company, Inc., New York, 1951), Book 1, pp. 489-516.

16. Wolfsberg, K., "Nuclear Charge Distribution in Fission: Fractional Yields of Krypton and Xenon Isotopes from Thermal Neutron Fission of U-233 and Pu-239 and from 14-MeV Neutron Fission of U-235 and U-238," Phys. Rev. 137, B929 (1965).

17. Wolfsberg, K., "A Method for Estimating Fractional Yields from Low- and Medium-Energy Neutron Induced Fission," Los Alamos Scientific Laboratory Report LA-3169 (1964).

APPENDIX

IBM-7094 PROGRAM FOR ESTIMATION OF FISSION PRODUCT YIELDS (FORTRAN II LANGUAGE)

Note: In addition to the information shown in Table III of this report, the computer provides:

1. Printout of selected isomer yields that are of importance for fission product heating calculations.
2. Punched card output of nuclide and isomer yields.
3. Printout of mass chain yield, most probable Z, and first stable Z versus A.
4. Printout of fissionable nuclide, fission energy (E) and Gaussian distribution characteristic (σ) used in the calculations.

Necessary inputs are:

1. Mass chain yields.
2. Identification of fissionable nucleus (23 ≡ U-233, 25 ≡ U-235, 28 ≡ U-238, and 49 ≡ Pu-239).
3. σ
4. E

```
      COMMONYC,YI

      COMMONYC,YI
      DIMENSIONZP(170),YC(75,170),YI(75,170),F(170),A(170)
     1,Z(75),ZMAX(170)
      DIMENSIONAM(18),AG(18),ZM(18),YIM(18),YIG(18),YCM(18),
     1YCG(18),AA(15),AB(15),YIA(15),YIB(15),YCA(15),YCB(15)
    1 FORMAT(12F6.3)
   89 FORMAT(I2,8X,2I5,10X,2E10.3)
   90 FORMAT(I2,7X,2F6.1,9X,2E10.3)
  100 FORMAT(24H0            PERCENT YIELD)
  101 FORMAT(30H0 Z   A   INDEPENDENT CUMULATIVE)
  102 FORMAT(2I3,F9.3,F11.3)
  103 FORMAT(4F9.3)
  104 FORMAT(34H0      A         F        ZP       ZMAX)
  105 FORMAT(18F4.0)
  106 FORMAT(I4,2F4.2,4I15)
  107 FORMAT(35H FISSION OF Z        A    ENERGY SIGMA)
  108 FORMAT(3X,F12.0,F7.0,F6.1,F8.2)
  110 FORMAT(7X,2F6.1,2F10.3)
  111 FORMAT(39H0ISOMERS Z     A   INDEPENDENT CUMULATIVE)
C---------------------
C     ZF=ATOMIC NUMBER     AF=MASS NUMBER+1
C     F(IA)=MASS CHAIN YIELD OF WEAVER ET AL
C     YC=CUMULATIVE YIELD OF NUCLIDE Z,A
C     YI=INDEPENDENT YIELD OF NUCLIDE,Z,A
C     E=MEDIAN ENERGY OF NEUTRON CAUSING FISSION, MEV
C     SIG=CHARACTERISTIC OF GAUSSIAN DISTRIBUTION
C     ZMAX=FIRST STABLE NUCLIDE
C---------------------
      READINPUTTAPE10,106,IOPT,SIG,E,SPARE1,SPARE2,
     1SPARE3,SPARE4
   13 READINPUTTAPE10,1,(F(IA),IA=76,161)
      IF(IOPT-23)42,41,42
   41 ZF=92.0
      AF=234.0
      C1=0.115
      GNUT=2.50
   42 CONTINUE
      IF(IOPT-25)44,43,44
   43 ZF=92.0
      AF=236.0
      C1=0.135
      GNUT=2.43
   44 CONTINUE
      IF(IOPT-28)46,45,46
   45 ZF=92.0
      AF=239.0
      C1=0.138
      GNUT=2.41
   46 CONTINUE
      IF(IOPT-49)13,47,13
   47 ZF=94.0
      AF=240.0
      C1=0.111
      GNUT=2.87
      DELZ=0.5*(ZF-92.0)-0.21*(AF-236.0)+0.19*(GNUT+C1*E-2.43)
      DO2IA=76,161
    2 A(IA)=FLOATF(IA)
      DO3IA=76,100
    3 ZP(IA)=0.4237*A(IA)-2.19+DELZ
      DO4IA=101,134
    4 ZP(IA)=0.3494*A(IA)+5.24+DELZ
      DO5IA=135,161
    5 ZP(IA)=0.4331*A(IA)-6.06+DELZ
      DO11IZ=30,70
      DO11IA=76,161
      Z(IZ)=FLOATF(IZ)
      IF(Z(IZ)-ZP(IA)+0.5)10,6,6
   10 YC(IZ,IA)=F(IA)*(0.5-0.5*ERR169((ZP(IA)-Z(IZ)-0.5)
     1/(1.414*SIG)))
      GOTO11
    6 YC(IZ,IA)=F(IA)*(0.5+0.5*ERR169((Z(IZ)-ZP(IA)+0.5)
     1/(1.414*SIG)))
   11 CONTINUE
      DO7IZ=30,70
      YC(IZ,75)=0.0
      DO7IA=76,161
      YC(29,IA)=0.0
    7 YI(IZ,IA)=YC(IZ,IA)-YC(IZ-1,IA)
      READINPUTTAPE9,105,(ZMAX(IA),IA=76,161)
      DO40IA=76,161
      IZM=ZMAX(IA)
      IZM1=IZM+1
      DO40IZ=IZM1,70
   40 YC(IZ,IA)=0.0
      AF1=AF-1.0
      WRITEOUTPUTTAPE9,107
      WRITEOUTPUTTAPE9,108,ZF,AF1,E,SIG
      WRITEOUTPUTTAPE9,104
      WRITEOUTPUTTAPE9,103,(A(IA),F(IA),ZP(IA),Z MAX(IA),IA=76,161)
      WRITEOUTPUTTAPE9,100
      WRITEOUTPUTTAPE9,101
      DO12IZ=30,70
      DO12IA=76,161
      IF(YC(IZ,IA)-0.001)12,8,8
    8 WRITEOUTPUTTAPE9,102,IZ,IA,YI(IZ,IA),YC(IZ,IA)
      WRITEOUTPUTTAPE11,89,IOPT,IZ,IA,YI(IZ,IA),YC(IZ,IA)
   12 CONTINUE
      DO56K=1,18
      YIM(K)=0.0
      YCM(K)=0.0
      AG(K)=0.0
      ZM(K)=0.0
      YIG(K)=0.0
      YCG(K)=0.0
   56 AM(K)=0.0
      DO57K=1,15
      AA(K)=0.0
      AB(K)=0.0
      YIA(K)=0.0
      YIB(K)=0.0
      YCA(K)=0.0
   57 YCB(K)=0.0
      ZM(1)=34.0
      ZM(2)=36.0
      ZM(3)=36.0
      ZM(4)=39.0
      ZM(5)=41.0
      ZM(6)=41.0
```

```
      ZM(7)=43.0
      ZM(8)=43.0
      ZM(9)=45.0
      ZM(10)=45.0
      ZM(11)=52.0
      ZM(12)=52.0
      ZM(13)=52.0
      ZM(14)=52.0
      ZM(15)=53.0
      ZM(16)=54.0
      ZM(17)=54.0
      ZM(18)=56.0
      AM(1)=83.0
      AM(2)=83.0
      AM(3)=85.0
      AM(4)=91.0
      AM(5)=95.0
      AM(6)=97.0
      AM(7)=99.0
      AM(8)=102.0
      AM(9)=103.0
      AM(10)=105.0
      AM(11)=127.0
      AM(12)=129.0
      AM(13)=131.0
      AM(14)=133.0
      AM(15)=131.0
      AM(16)=133.1
      AM(17)=135.0
      AM(18)=137.0
      DO51K=1,18
   51 AG(K)=AM(K)+0.1
      DO52K=11,15
      AA(K)=AM(K)+0.1
   52 AB(K)=AM(K)+0.2
      YIM(1)=0.5*YI(34,83)
      YIM(2)=0.5*YI(36,83)
      YIM(3)=0.5*YI(36,85)
      YIM(4)=0.5*YI(39,91)
      YIM(5)=0.5*YI(41,95)
      YIM(6)=0.5*YI(41,97)
      YIM(7)=0.5*YI(43,99)
      YIM(8)=0.5*YI(43,102)
      YIM(9)=0.5*YI(45,103)
      YIM(10)=0.5*YI(45,105)
      YIM(11)=0.5*YI(52,127)
      YIM(12)=0.5*YI(52,129)
      YIM(13)=0.5*YI(52,131)
      YIM(14)=0.5*YI(52,133)
      YIM(16)=0.5*YI(54,133)
      YIM(17)=0.5*YI(54,135)
      YIM(18)=0.5*YI(56,137)
      DO53K=1,18
   53 YIG(K)=YIM(K)
      DO54K=11,15
      YIA(K)=YIM(K)
   54 YIB(K)=0.0
      YCM(1)=0.56*(YC(34,83)-YI(34,83))+YIM(1)
      YCG(1)=0.44*(YC(34,83)-YI(34,83))+YIM(1)
      YCM(2)=YC(36,83)-YIM(2)
      YCG(2)=YC(36,83)
      YCM(3)=YC(36,85)-YIM(3)
      YCG(3)=0.19*YCM(3)+YIM(3)
      YCM(4)=0.6*(YC(39,91)-YI(39,91))+YIM(4)
      YCG(4)=YC(39,91)
      YCM(5)=0.03*(YC(41,95)-YI(41,95))+YIM(5)
      YCG(5)=YC(41,95)
      YCM(6)=0.98*(YC(41,97)-YI(41,97))+YIM(6)
      YCG(6)=YC(41,97)
      YCM(7)=0.76*(YC(43,99)-YI(43,99))+YIM(7)
      YCG(7)=YC(43,99)
      YCM(8)=0.5*YC(43,102)
      YCG(8)=YCM(8)
      YCM(9)=YC(45,103)-YIM(9)
      YCG(9)=YC(45,103)
      YCM(10)=YC(45,105)-YIM(10)
      YCG(10)=YC(45,105)
      YCM(11)=0.22*(YC(52,127)-YI(52,127))+YIM(11)
      YCA(11)=0.78*(YC(52,127)-YI(52,127))+YIM(11)
      YCB(11)=0.98*YCM(11)
      YCM(12)=0.36*(YC(52,129)-YI(52,129))+YIM(12)
      YCA(12)=0.64*(YC(52,129)-YI(52,129))+YIM(12)
      YCB(12)=YCM(12)
      YCM(13)=0.15*(YC(52,131)-YI(52,131))+YIM(13)
      YCA(13)=0.85*(YC(52,131)-YI(52,131))+YIM(13)
      YCB(13)=0.2*YCM(13)
      YCM(14)=0.72*(YC(52,133)-YI(52,133))+YIM(14)
      YCA(14)=0.28*(YC(52,133)-YI(52,133))+YIM(14)
      YCB(14)=0.13*YCM(14)
      YCA(15)=YCA(13)+YCB(13)
      YCB(15)=0.8*YCM(13)
      YCM(16)=0.024*(YC(54,133)-YI(54,133))+YIM(16)
      YCG(16)=YC(54,133)
      YCM(17)=0.3*(YC(54,135)-YI(54,135))+YIM(17)
      YCG(17)=YC(54,135)
      YCM(18)=0.92*(YC(56,137)-YI(56,137))+YIM(18)
      YCG(18)=YC(56,137)
      WRITEOUTPUTTAPE9,111
      DO62K=1,18
      IF(YCM(K)-0.001)60,61,61
   61 WRITEOUTPUTTAPE9,110,(ZM(K),AM(K),YIM(K),YCM(K))
      WRITEOUTPUTTAPE11,90,(IOPT,ZM(K),AM(K),YIM(K),YCM(K))
   60 CONTINUE
      IF(YCG(K)-0.001)62,63,63
   63 WRITEOUTPUTTAPE9,110,(ZM(K),AG(K),YIG(K),YCG(K))
      WRITEOUTPUTTAPE11,90,(IOPT,ZM(K),AG(K),YIG(K),YCG(K))
   62 CONTINUE
      DO66K=1,15
      IF(YCA(K)-0.001)64,65,65
   65 WRITEOUTPUTTAPE9,110,(ZM(K),AA(K),YIA(K),YCA(K))
      WRITEOUTPUTTAPE11,90,(IOPT,ZM(K),AA(K),YIA(K),YCA(K))
   64 CONTINUE
      IF(YCB(K)-0.001)66,67,67
   67 WRITEOUTPUTTAPE9,110,(ZM(K),AB(K),YIB(K),YCB(K))
      WRITEOUTPUTTAPE11,90,(IOPT,ZM(K),AB(K),YIB(K),YCB(K))
   66 CONTINUE
      GOTO13
      END(1,0,0,0,0,0,0,0,0,1,0,0,0,0,0)
```