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# LOS ALAMOS SCIENTIFIC LABORATORY
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# Fission Product Yields from
# Fast (~1 MeV) Neutron Fission of Pu-239

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To: Copyholders of LA-3383

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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 | $4.7 \times 10^{10}$ |
| 40 | 96 | $> 2 \times 10^{16}$ |
| 49 | 115 | $6 \times 10^{15}$ |
| 52 | 130 | $> 10^{21}$ |
| 60 | 150 | $> 10^{16}$ |

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**LOS ALAMOS ● NEW MEXICO**

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

by

Carl A. Anderson, Jr.
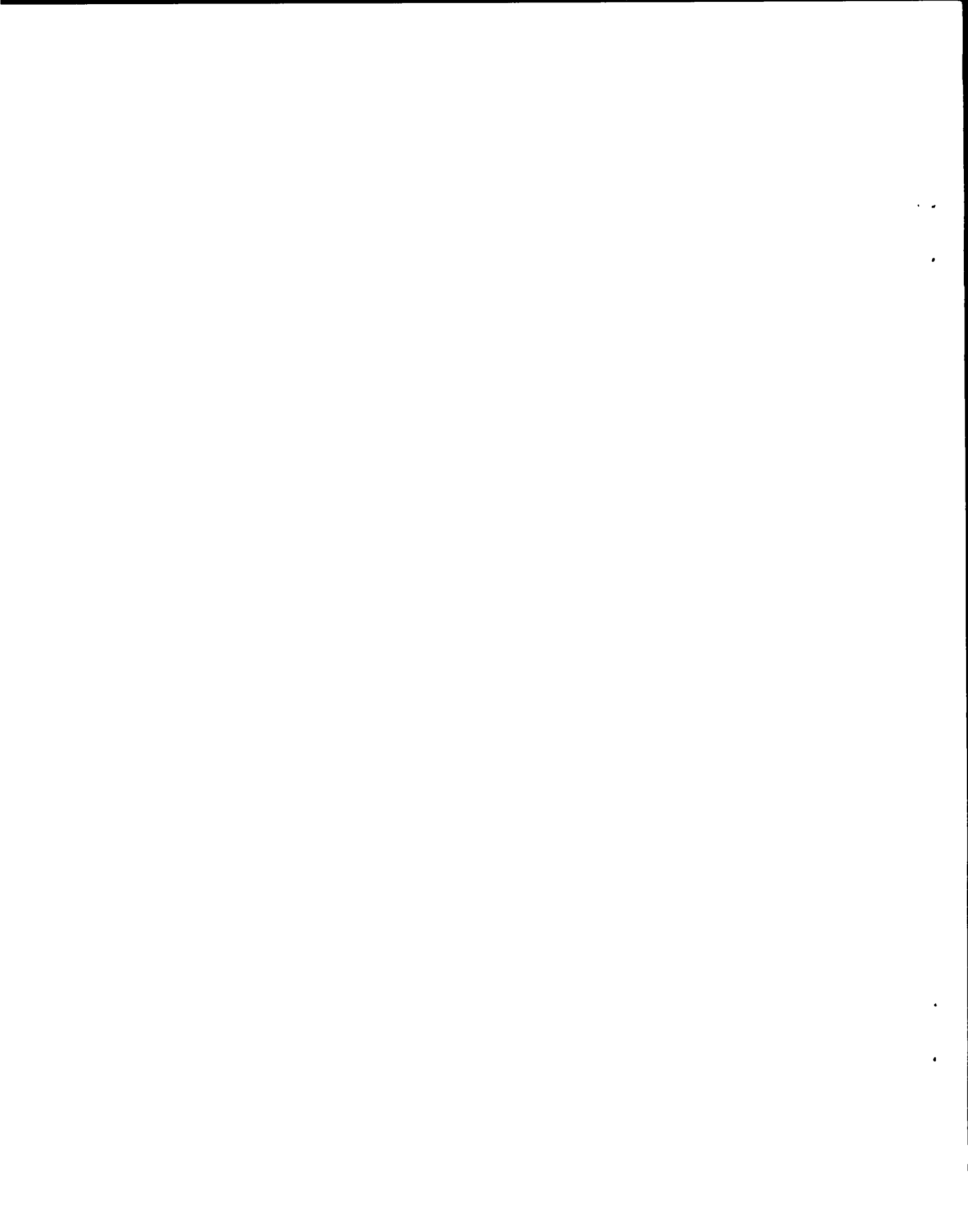
# ABSTRACT

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
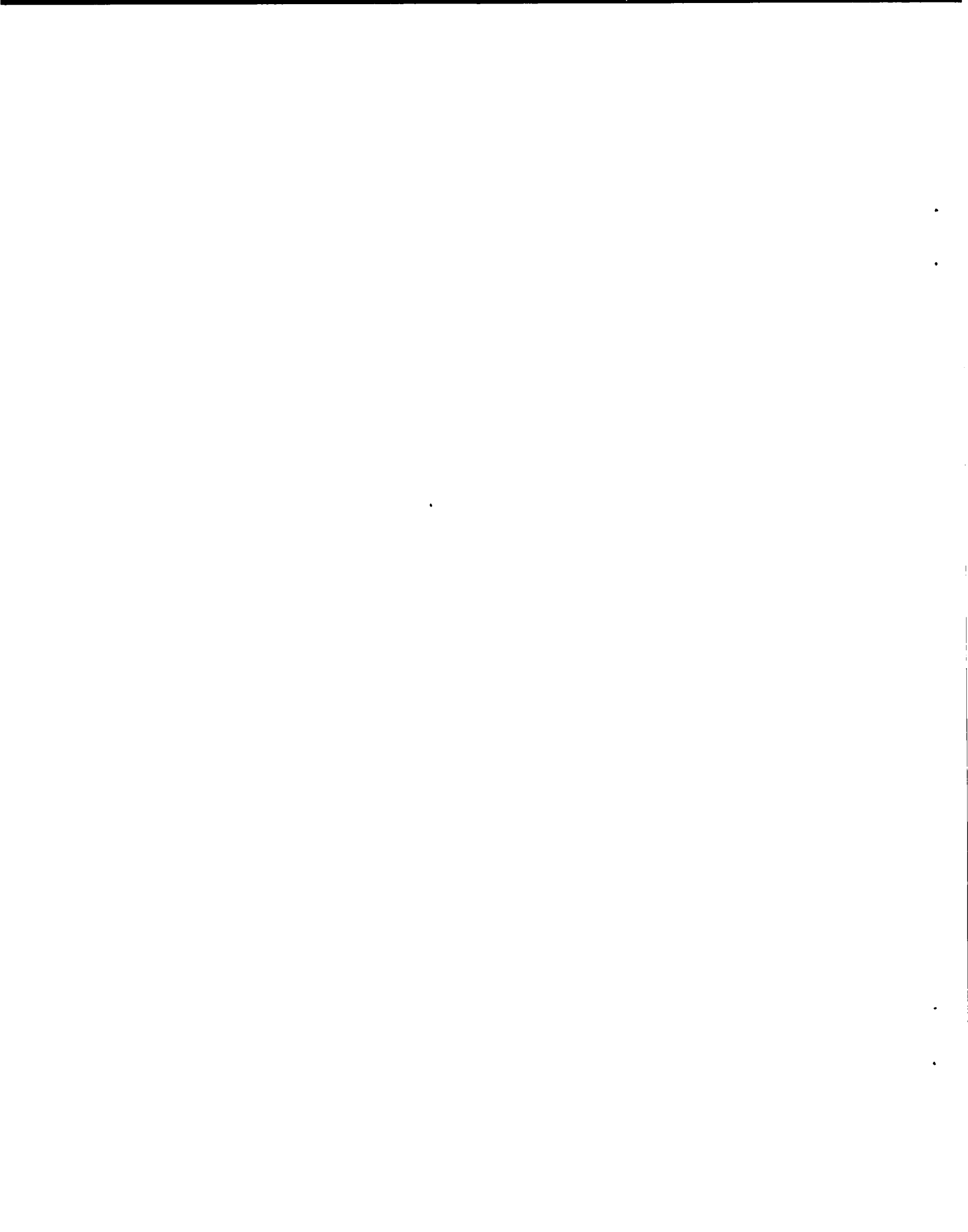
# INTRODUCTION

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

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

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

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

where

      $M$ = fission product,

      $\nu$ = 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):

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

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 $\sigma^2$ 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,

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

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 $\nu$ 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 $\nu \simeq 3.15$ ($\pm 0.2$ for $139 < M_H < 149$, $\pm 0.6$ for $M_H = 153$). A further restriction on the use of
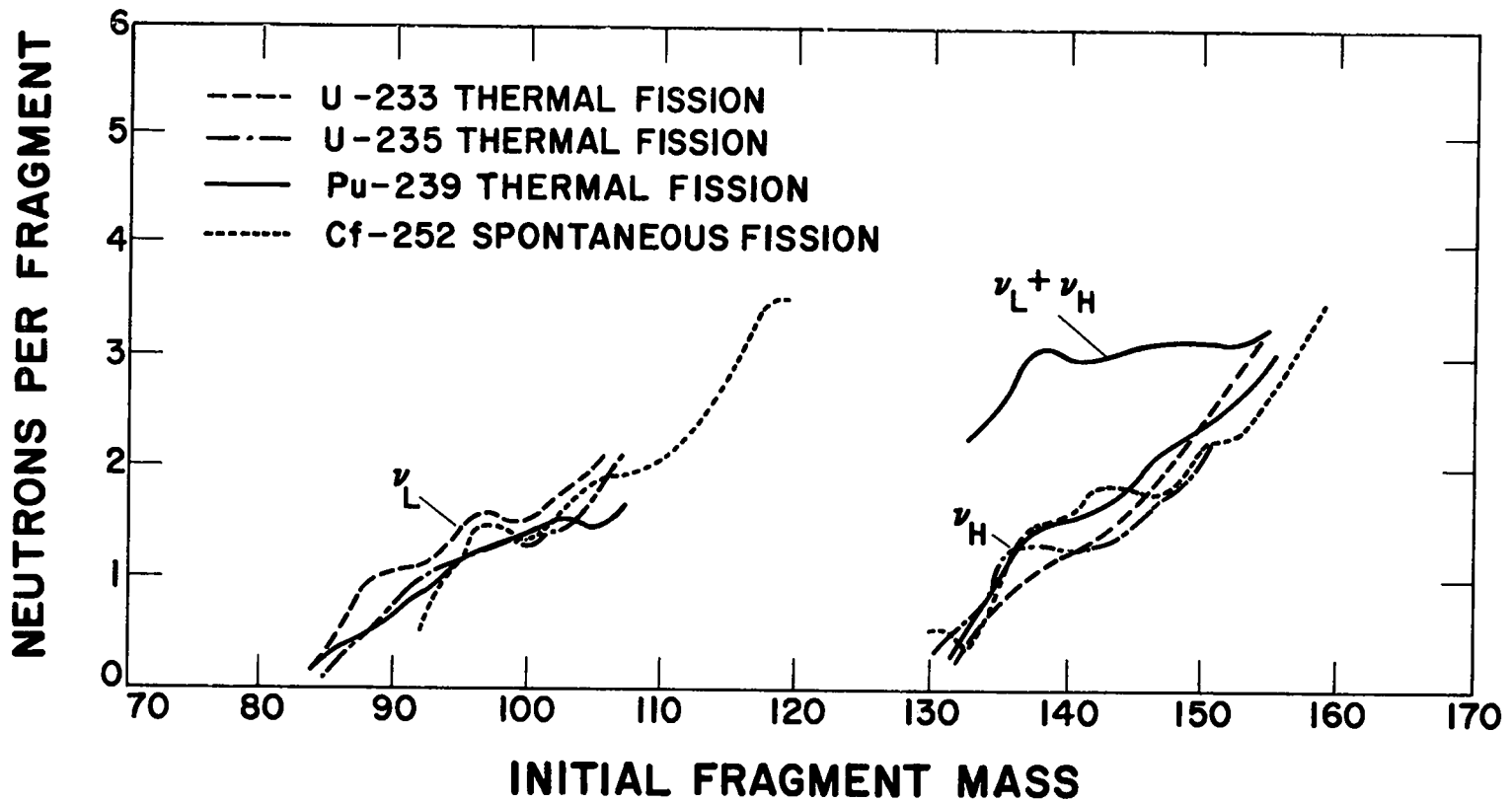
Fig. 1. Neutron Yield versus Initial Fragment Mass Number (from Ref. 11). $\nu_L$, $\nu_H$ = neutron yields associated with light and heavy fission fragments, respectively.

Eq. 11 is that $\nu$ must be known; because of the difficulty of associating a measured neutron yield with a particular mass chain, $\nu$ 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 $2.89 \pm 0.03$ for thermal neutron induced fission of Pu-239 and $3.12 \pm 0.15$ 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 $\pm 0.5$ 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 $\pm 0.75$ 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.
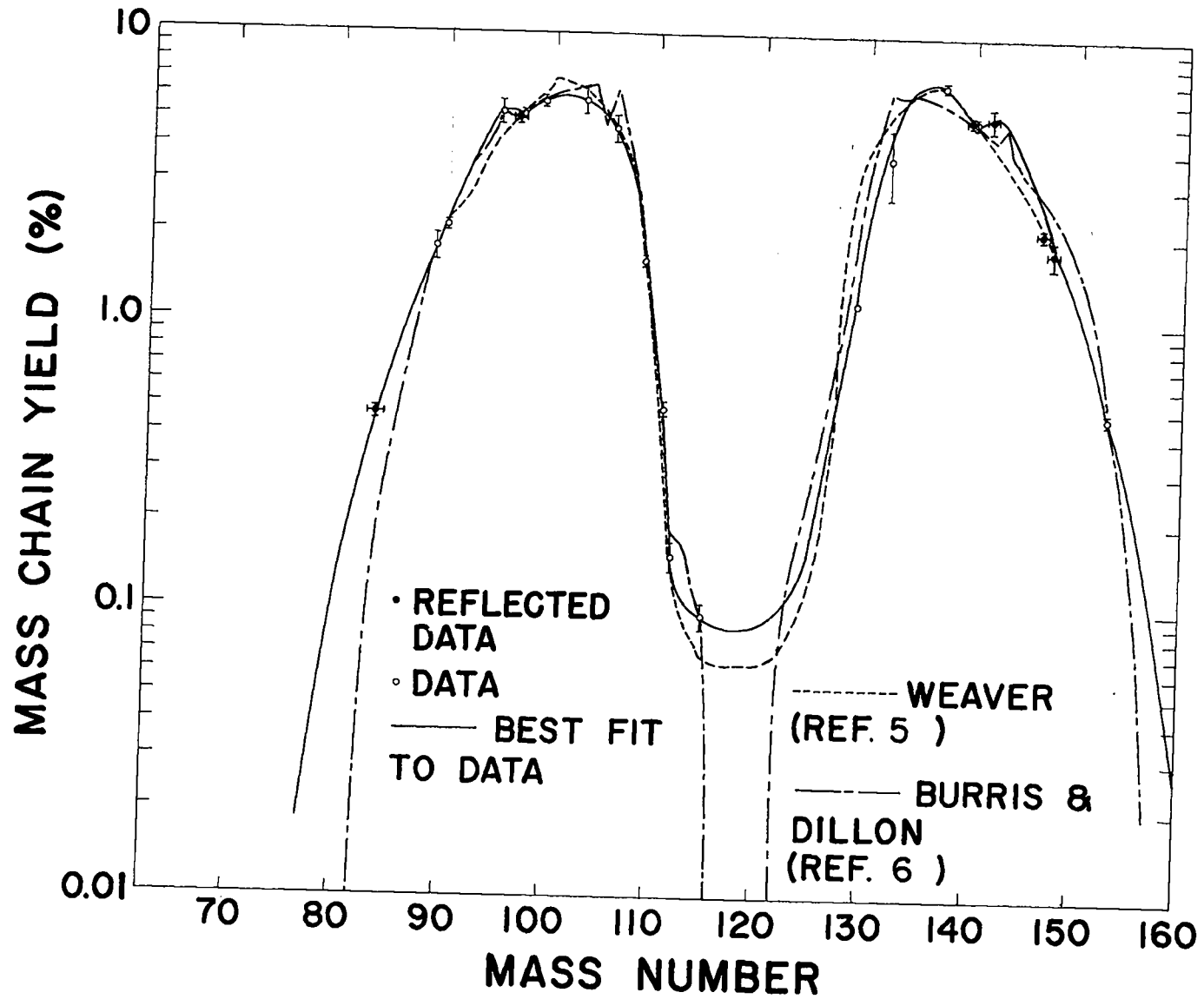
Fig. 2. Fission Product Mass Chain Yields for Pu-239 Fast Fission. Data and Three Fitted Curves.

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.
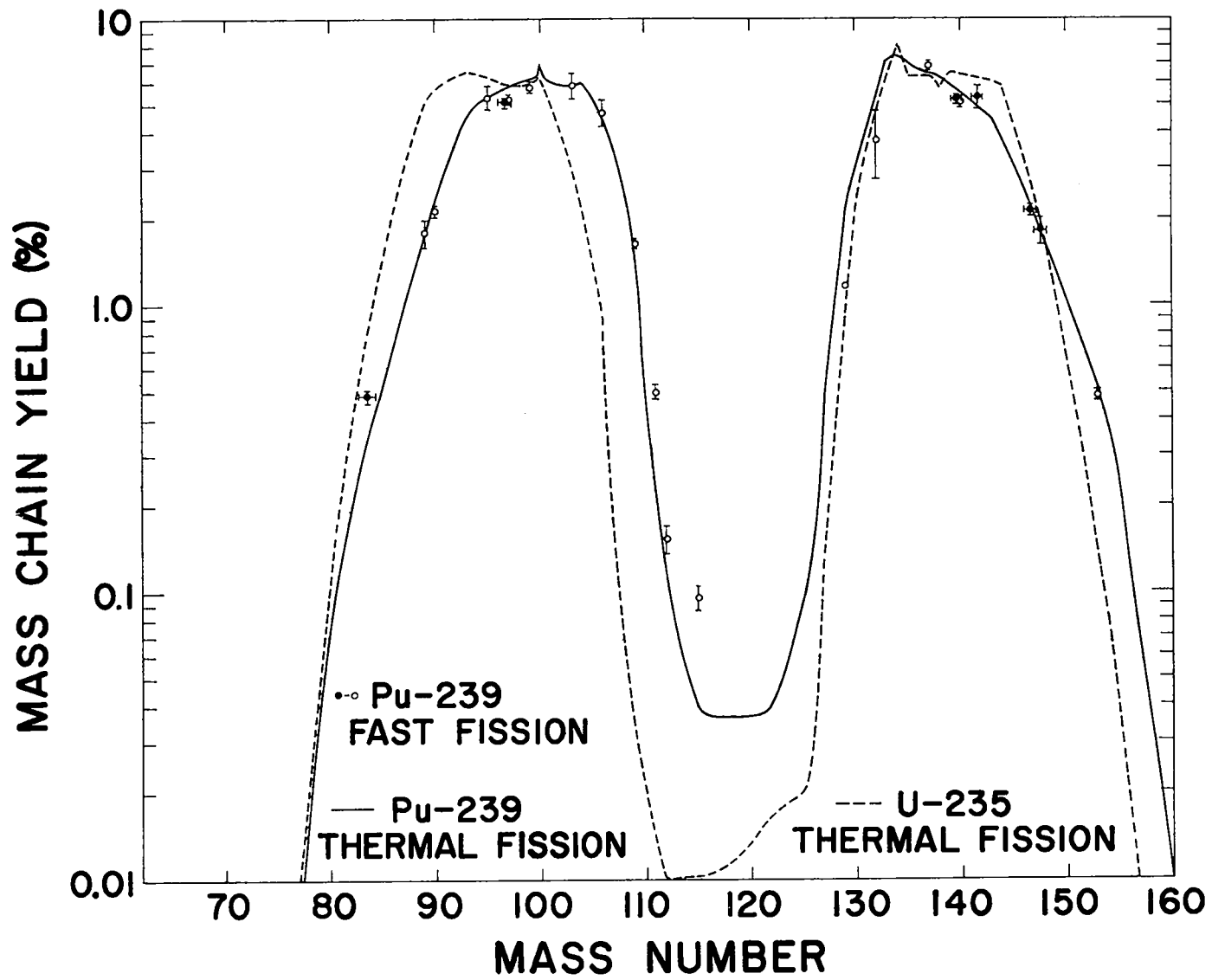
Fig. 3. Comparison of Experimental Data.

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 |

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# 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]

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

where

| | |
|---|---|
| $Z$ | = atomic number of fission product, |
| $A$ | = mass number of fission product, |
| $Zp(A)$ | = most probable charge, |
| $\sigma$ | = 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 $(Z, A)$, |

$$\text{Erf}(x) = \frac{2}{\sqrt{\pi}} \int_0^x e^{-t^2} dt, \text{ the error function.} \tag{14}$$

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

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

$$(15a)$$

(for A ≥ 135)

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

$$(15b)$$

where

$Z_F$ = atomic number of fissionable nucleus,

$A_F$ = mass number of compound nucleus,

$\nu$ = 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 ≤ A ≤ 134, whence (for 101 ≤ A ≤ 134)

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

$$(15c)$$

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 $\sigma$ 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 $\nu$ 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

| Z | A | PERCENT YIELD INDEPENDENT | CUMULATIVE | | Z | A | IND. | CUM. | | Z | A | IND. | CUM. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 30 | 77 | 0.007 | 0.007 | | 37 | 91 | 1.346 | 2.417 | | 42 | 105 | 3.066 | 3.767 |
| 30 | 78 | 0.006 | 0.006 | | 37 | 92 | 1.894 | 2.440 | | 42 | 106 | 2.037 | 2.220 |
| 30 | 79 | 0.003 | 0.003 | | 37 | 93 | 1.770 | 1.954 | | 42 | 107 | 0.906 | 0.940 |
| 31 | 77 | 0.010 | 0.017 | | 37 | 94 | 1.099 | 1.139 | | 42 | 108 | 0.279 | 0.283 |
| 31 | 78 | 0.023 | 0.029 | | 37 | 95 | 0.422 | 0.428 | | 42 | 109 | 0.054 | 0.054 |
| 31 | 79 | 0.010 | 0.033 | | 37 | 96 | 0.089 | 0.090 | | 42 | 110 | 0.006 | 0.006 |
| 31 | 80 | 0.023 | 0.023 | | 37 | 97 | 0.012 | 0.012 | | 43 | 99 | 0.000 | 5.800 |
| 31 | 81 | 0.011 | 0.012 | | 37 | 98 | 0.001 | 0.001 | | 43 | 101 | 0.011 | 6.000 |
| 31 | 82 | 0.003 | 0.003 | | 38 | 87 | 0.000 | 1.150 | | 43 | 102 | 0.064 | 6.000 |
| 32 | 77 | 0.002 | 0.019 | | 38 | 88 | 0.000 | 1.430 | | 43 | 103 | 0.255 | 5.848 |
| 32 | 78 | 0.010 | 0.039 | | 38 | 89 | 0.003 | 1.800 | | 43 | 104 | 0.728 | 5.586 |
| 32 | 79 | 0.034 | 0.066 | | 38 | 90 | 0.030 | 2.120 | | 43 | 105 | 1.523 | 5.230 |
| 32 | 80 | 0.066 | 0.090 | | 38 | 91 | 0.181 | 2.598 | | 43 | 106 | 2.236 | 4.455 |
| 32 | 81 | 0.090 | 0.102 | | 38 | 92 | 0.687 | 3.127 | | 43 | 107 | 2.202 | 3.142 |
| 32 | 82 | 0.073 | 0.077 | | 38 | 93 | 1.687 | 3.641 | | 43 | 108 | 1.527 | 1.810 |
| 32 | 83 | 0.039 | 0.040 | | 38 | 94 | 2.746 | 3.884 | | 43 | 109 | 0.680 | 0.735 |
| 32 | 84 | 0.012 | 0.013 | | 38 | 95 | 2.836 | 3.264 | | 43 | 110 | 0.181 | 0.187 |
| 32 | 85 | 0.002 | 0.002 | | 38 | 96 | 1.674 | 1.764 | | 43 | 111 | 0.045 | 0.045 |
| 33 | 77 | 0.000 | 0.019 | | 38 | 97 | 0.647 | 0.659 | | 43 | 112 | 0.004 | 0.004 |
| 33 | 78 | 0.000 | 0.039 | | 38 | 98 | 0.172 | 0.173 | | 44 | 99 | 0. | 5.800 |
| 33 | 79 | 0.004 | 0.070 | | 38 | 99 | 0.029 | 0.029 | | 44 | 101 | 0.000 | 6.000 |
| 33 | 80 | 0.020 | 0.109 | | 38 | 100 | 0.003 | 0.003 | | 44 | 102 | 0.000 | 6.000 |
| 33 | 81 | 0.071 | 0.173 | | 39 | 89 | 0.000 | 1.800 | | 44 | 103 | 0.002 | 5.850 |
| 33 | 82 | 0.151 | 0.228 | | 39 | 90 | 0.000 | 2.120 | | 44 | 104 | 0.014 | 5.600 |
| 33 | 83 | 0.215 | 0.254 | | 39 | 91 | 0.002 | 2.600 | | 44 | 105 | 0.070 | 5.300 |
| 33 | 84 | 0.190 | 0.203 | | 39 | 92 | 0.022 | 3.150 | | 44 | 106 | 0.242 | 4.698 |
| 33 | 85 | 0.107 | 0.110 | | 39 | 93 | 0.157 | 3.799 | | 44 | 107 | 0.546 | 3.688 |
| 33 | 86 | 0.038 | 0.039 | | 39 | 94 | 0.700 | 4.584 | | 44 | 108 | 0.846 | 2.656 |
| 33 | 87 | 0.009 | 0.009 | | 39 | 95 | 1.912 | 5.176 | | 44 | 109 | 0.833 | 1.568 |
| 33 | 88 | 0.001 | 0.001 | | 39 | 96 | 2.952 | 4.716 | | 44 | 110 | 0.493 | 0.680 |
| 34 | 77 | 0.000 | 0.019 | | 39 | 97 | 3.033 | 3.692 | | 44 | 111 | 0.275 | 0.320 |
| 34 | 78 | 0.000 | 0.039 | | 39 | 98 | 2.217 | 2.390 | | 44 | 112 | 0.057 | 0.061 |
| 34 | 79 | 0.000 | 0.070 | | 39 | 99 | 1.065 | 1.094 | | 44 | 113 | 0.022 | 0.023 |
| 34 | 80 | 0.001 | 0.110 | | 39 | 100 | 0.325 | 0.328 | | 44 | 114 | 0.008 | 0.008 |
| 34 | 81 | 0.005 | 0.178 | | 39 | 101 | 0.084 | 0.085 | | 44 | 115 | 0.002 | 0.002 |
| 34 | 82 | 0.032 | 0.259 | | 39 | 102 | 0.016 | 0.016 | | 45 | 103 | 0.000 | 5.850 |
| 34 | 83 | 0.119 | 0.374 | | 39 | 103 | 0.002 | 0.002 | | 45 | 105 | 0.000 | 5.300 |
| 34 | 84 | 0.277 | 0.479 | | 40 | 90 | 0.000 | 2.120 | | 45 | 106 | 0.002 | 4.700 |
| 34 | 85 | 0.413 | 0.522 | | 40 | 91 | 0.000 | 2.600 | | 45 | 107 | 0.012 | 3.700 |
| 34 | 86 | 0.403 | 0.442 | | 40 | 92 | 0.000 | 3.150 | | 45 | 108 | 0.044 | 2.700 |
| 34 | 87 | 0.256 | 0.264 | | 40 | 93 | 0.001 | 3.800 | | 45 | 109 | 0.101 | 1.669 |
| 34 | 88 | 0.102 | 0.103 | | 40 | 94 | 0.016 | 4.600 | | 45 | 110 | 0.137 | 0.817 |
| 34 | 89 | 0.026 | 0.027 | | 40 | 95 | 0.123 | 5.299 | | 45 | 111 | 0.170 | 0.490 |
| 34 | 90 | 0.004 | 0.004 | | 40 | 96 | 0.526 | 5.242 | | 45 | 112 | 0.078 | 0.139 |
| 35 | 79 | 0.000 | 0.070 | | 40 | 97 | 1.444 | 5.136 | | 45 | 113 | 0.066 | 0.089 |
| 35 | 81 | 0.000 | 0.178 | | 40 | 98 | 2.764 | 5.154 | | 45 | 114 | 0.053 | 0.060 |
| 35 | 82 | 0.001 | 0.260 | | 40 | 99 | 3.498 | 4.591 | | 45 | 115 | 0.034 | 0.036 |
| 35 | 83 | 0.006 | 0.380 | | 40 | 100 | 2.896 | 3.224 | | 45 | 116 | 0.016 | 0.016 |
| 35 | 84 | 0.040 | 0.520 | | 40 | 101 | 1.770 | 1.854 | | 45 | 117 | 0.006 | 0.006 |
| 35 | 85 | 0.162 | 0.684 | | 40 | 102 | 0.810 | 0.826 | | 45 | 118 | 0.002 | 0.002 |
| 35 | 86 | 0.415 | 0.858 | | 40 | 103 | 0.268 | 0.270 | | 46 | 105 | 0.000 | 5.300 |
| 35 | 87 | 0.691 | 0.955 | | 40 | 104 | 0.064 | 0.064 | | 46 | 106 | 0.000 | 4.700 |
| 35 | 88 | 0.745 | 0.849 | | 40 | 105 | 0.011 | 0.011 | | 46 | 107 | 0.000 | 3.700 |
| 35 | 89 | 0.541 | 0.567 | | 40 | 106 | 0.001 | 0.001 | | 46 | 108 | 0.000 | 2.700 |
| 35 | 90 | 0.240 | 0.244 | | 41 | 93 | 0.000 | 3.800 | | 46 | 109 | 0.001 | 1.670 |
| 35 | 91 | 0.071 | 0.072 | | 41 | 95 | 0.001 | 5.300 | | 46 | 110 | 0.003 | 0.820 |
| 35 | 92 | 0.013 | 0.013 | | 41 | 96 | 0.008 | 5.250 | | 46 | 111 | 0.010 | 0.500 |
| 35 | 93 | 0.002 | 0.002 | | 41 | 97 | 0.064 | 5.200 | | 46 | 112 | 0.011 | 0.150 |
| 36 | 82 | 0.000 | 0.260 | | 41 | 98 | 0.343 | 5.497 | | 46 | 113 | 0.021 | 0.109 |
| 36 | 83 | 0.000 | 0.380 | | 41 | 99 | 1.173 | 5.765 | | 46 | 114 | 0.046 | 0.097 |
| 36 | 84 | 0.000 | 0.520 | | 41 | 100 | 2.555 | 5.779 | | 46 | 115 | 0.051 | 0.087 |
| 36 | 85 | 0.006 | 0.690 | | 41 | 101 | 3.451 | 5.306 | | 46 | 116 | 0.054 | 0.070 |
| 36 | 86 | 0.042 | 0.900 | | 41 | 102 | 3.537 | 4.363 | | 46 | 117 | 0.044 | 0.050 |
| 36 | 87 | 0.191 | 1.145 | | 41 | 103 | 2.683 | 2.953 | | 46 | 118 | 0.026 | 0.030 |
| 36 | 88 | 0.543 | 1.392 | | 41 | 104 | 1.509 | 1.573 | | 46 | 119 | 0.014 | 0.014 |
| 36 | 89 | 1.030 | 1.598 | | 41 | 105 | 0.628 | 0.639 | | 46 | 120 | 0.005 | 0.005 |
| 36 | 90 | 1.218 | 1.463 | | 41 | 106 | 0.181 | 0.182 | | 46 | 121 | 0.001 | 0.001 |
| 36 | 91 | 0.999 | 1.071 | | 41 | 107 | 0.034 | 0.034 | | 47 | 107 | 0. | 3.700 |
| 36 | 92 | 0.533 | 0.546 | | 41 | 108 | 0.004 | 0.004 | | 47 | 109 | 0.000 | 1.670 |
| 36 | 93 | 0.183 | 0.184 | | 42 | 95 | 0.000 | 5.300 | | 47 | 111 | 0.000 | 0.500 |
| 36 | 94 | 0.040 | 0.040 | | 42 | 96 | 0.000 | 5.250 | | 47 | 112 | 0.000 | 0.150 |
| 36 | 95 | 0.005 | 0.005 | | 42 | 97 | 0.000 | 5.200 | | 47 | 113 | 0.001 | 0.110 |
| 37 | 85 | 0.000 | 0.690 | | 42 | 98 | 0.003 | 5.500 | | 47 | 114 | 0.002 | 0.099 |
| 37 | 87 | 0.005 | 1.150 | | 42 | 99 | 0.035 | 5.800 | | 47 | 115 | 0.008 | 0.095 |
| 37 | 88 | 0.038 | 1.430 | | 42 | 100 | 0.219 | 5.999 | | 47 | 116 | 0.019 | 0.088 |
| 37 | 89 | 0.199 | 1.797 | | 42 | 101 | 0.683 | 5.989 | | 47 | 117 | 0.034 | 0.084 |
| 37 | 90 | 0.627 | 2.090 | | 42 | 102 | 1.572 | 5.936 | | 47 | 118 | 0.048 | 0.078 |
| | | | | | 42 | 103 | 2.646 | 5.593 | | 47 | 119 | 0.051 | 0.065 |
| | | | | | 42 | 104 | 3.285 | 4.858 | | 47 | 120 | 0.043 | 0.049 |
| | | | | | | | | | | 47 | 121 | 0.028 | 0.029 |

TABLE III (CONTINUED)

See Attached
Errata Sheet

| ID | | | ID | | | ID | | |
|---|---|---|---|---|---|---|---|---|
| 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 | 1.696 | 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 | 0.066 | 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 | 0.017 | 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 | 0.006 | 5.400 | 65159 | 0.000 | 0.045 |
| 52130 | 0.380 | 2.341 | 58143 | 0.051 | 4.900 | 65161 | 0.002 | 0.014 |
| 52131 | 1.133 | 3.335 | | | | 66161 | 0.000 | 0.014 |

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# 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 ($\sigma$) used in the calculations.

Necessary inputs are:

1. Mass chain yields.

2. Identification of fissionable nucleus (23 $\equiv$ U-233, 25 $\equiv$ U-235, 28 $\equiv$ U-238, and 49 $\equiv$ Pu-239).

3. $\sigma$

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
  101 FORMAT(30H0 Z   A        PERCENT YIELD)
  102 FORMAT(2I3,F9.3,F11.3)                INDEPENDENT CUMULATIVE)
  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
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      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)
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      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)
```