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FAST REACTOR FISSION YIELDS FOR ^{240}Pu AND ^{242}Pu

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ABSTRACT

Absolute fast reactor fission yield data are presented for ^{240}Pu and ^{242}Pu irradiated in EBR-II. The measurement technique was isotope dilution mass spectrometry for over 40 mass numbers.

SUMMARY

In this report, relative to a continuing program dedicated to the measurement of fast reactor fission yields and the selection of burnup monitors for fast breeder reactor (FBR) fuels, measured absolute fast reactor fission yields are presented for the stable and long-lived isotopes of Kr, Rb, Sr, Zr, Mo, Ru, Sb, Xe, Cs, Ba, La, Ce, Nd, and Sm for samples of ^{240}Pu and ^{242}Pu irradiated in EBR-II. The principal measurement technique was isotope dilution mass spectrometry and it is believed that these data represent the most comprehensive set of mass spectrometrically measured ^{240}Pu and ^{242}Pu fast fission yields reported to date. Other USDOE reports relative to this program are:

TID-26209, Status Report (1973)

ICP-1050-I, ^{233}U, ^{235}U, and ^{238}U Fast Reactor Fission Yields (1975)

ICP-1050-II, ^{239}Pu and ^{241}Pu Fast Reactor Fission Yields (1977)

ICP-1050-III, ^{237}Np Fast Reactor Fission Yields (1977)

In the future, these data will be augmented with absolute ^{233}U, ^{235}U, ^{239}Pu, and ^{241}Pu fast reactor yields determined on samples irradiated in a harder neutron spectrum than those in the current program.

CONTRIBUTING PERSONNEL

The wide scope of this project required contributions from a number of scientists and technicians with specialized disciplines. Listed below are individuals who provided significant contributions and made this report possible.

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I. INTRODUCTION

Based on a review[1] conducted in 1973 of the nuclear data and analytical chemistry methodology requirements for the accurate determination of burnup for fast reactor fuels, it was concluded that the preferred method for measuring burnup in Fast Breeder Reactor (FBR) fuels was the fission product-residual heavy atom method. Also noted was that the greatest uncertainty in this method was the uncertainty of the fission yield values used to establish the number of fissions.

To improve the accuracy of this method, a program is under way to measure absolute fast reactor fission yields for many heavy element nuclides in a neutron spectrum characteristic of mixed oxide fueled LMFBRs, and to develop reliable methods for the accurate determination of burnup in a variety of fuels. As a result of this program, fast reactor fission yields were reported[2,3,4] for over 40 stable and long-lived isotopes of samples of ^{233}U, ^{235}U, ^{238}U, ^{237}Np, ^{239}Pu and ^{241}Pu irradiated in the Experimental Breeder Reactor-II (EBR-II)/

This report gives fast reactor fission yield data obtained from two samples of ^{240}Pu and two samples of ^{242}Pu irradiated in EBR-II.

II. IRRADIATION PACKAGE

The sample irradiation was conducted in Row 8 of EBR-II. The irradiation package contained multiple capsules of ^{233}U, ^{235}U,^{238}U, ^{237}Np, ^{239}Pu, ^{240}Pu, ^{241}Pu, ^{242}Pu, ^{241}Am, and ^{243}Am for fission yield measurements, spectrum monitors to characterize the neutron spectrum, and samples of ^{233}U, ^{235}U, ^{239}Pu, ^{240}Pu, ^{241}Pu, and ^{242}Pu for the measurement of the capture-to-fission ratio, α. Details relative to the ^{240}Pu and ^{242}Pu capsule contents, irradiation time, reactor location, estimated flux levels, and neutron spectrum are given in Table I.

TABLE I

IRRADIATION AND NEUTRON SPECTRUM DATA

Reactor - Experimental Breeder Reactor-II (EBR-II),
Idaho National Engineering Laboratory (INEL),
Idaho Falls, Idaho

Irradiation Time - 1340h with reactor at 62.5 Mw. Downtime while samples in reactor: 1500h.

Position - Row-8 (See Figure 1)

	^{240}Pu Capsules		^{242}Pu Capsules	
Capsule Number	8	15	9	22
Capsule content - mg PuO_2	3746	3808	4699	4283
	Atom Percent			
^{238}Pu	0.002		---	
^{239}Pu	0.769		0.756	
^{240}Pu	98.426		0.005	
^{241}Pu	0.630		0.005	
^{242}Pu	0.173		99.189	
Location, +cm above reactor mid-plane	+12	+21	+23	+15
Est. flux, $n/cm^2/s$	7.2E14	5.1E14	5.8E14	5.9E14
Mean neutron energy, keV	425	325	385	400
Spectral Index $^{238}U/^{235}U$ fission rate	0.017	0.009	0.014	0.015
Fission product $^{150}Nd/^{143}Nd$ isotopic ratio	0.2380	0.2325	0.2889	0.2885

II-A. Fission Yield Capsules

The highly enriched target isotopes as oxide powders were individually mixed with high purity (99.99+%) nickel powder, weld-sealed in nickel capsules machined from 99.99+% pure nickel rod, and loaded into a standard EBR-II, B-7A subassembly for the irradiation. The geometry of the sample loading and the location of the ^{240}Pu and ^{242}Pu samples is shown in Figure 1.

II-B. Neutron Spectrum Monitor Capsules

To characterize the neutron spectrum, twelve spectrum monitor capsules, each containing nine monitors, were included in the irradiation package as shown in Figure 1. Table II lists the monitors, the nuclear reactions, and the measured reaction products.

II-C. Capture-to-Fission Ratio Capsules

For the determination of α, three nickel capsules, each containing duplicate oxide samples of highly enriched ^{233}U, ^{235}U, ^{239}Pu, ^{240}Pu, ^{241}Pu, and ^{242}Pu sealed in stainless steel needles were irradiated. These capsules were located adjacent to the spectrum monitor capsules as shown in Figure 1. The measured capture-to-fission ratio values and comparison to the calculated values in the Fast Test Reactor have been previously reported.[2]

TABLE II

SPECTRUM MONITORS

Monitor	Reaction	Measured Product
Co wire	n,γ	^{60}Co
Sc powder	n,γ	^{46}Sc
Fe wire	n,p	^{54}Mn
Ni wire	n,p	^{58}Co
Ti wire	n,p	^{46}Sc
Cu wire	n,α	^{60}Co
^{237}Np oxide	n,f	^{137}Cs
^{238}U oxide	n,f	^{137}Cs
^{235}U oxide	n,f	^{137}Cs

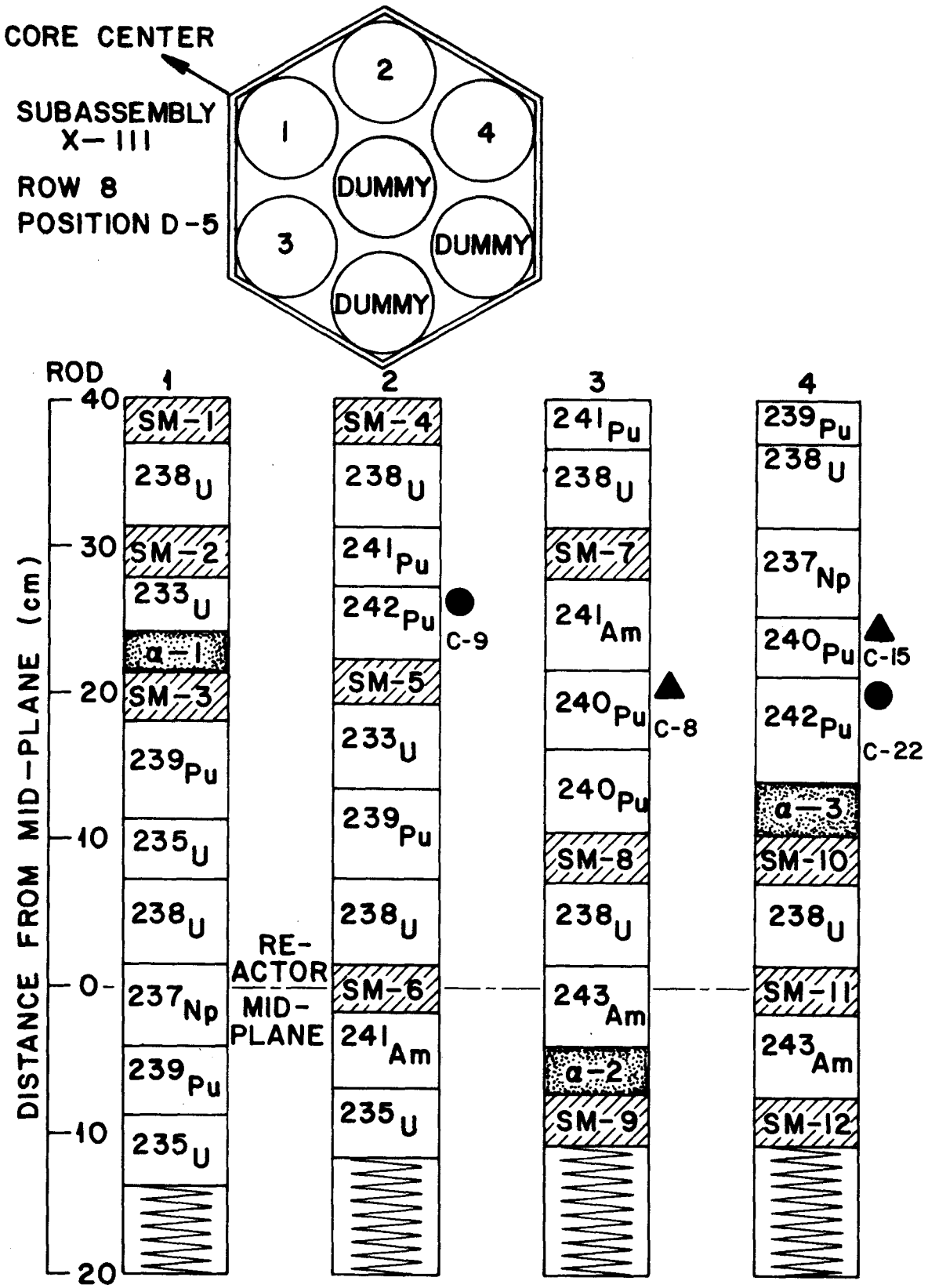

Fig. 1 EBR-II Irradiation Assembly - Location of Fission Yield, Spectrum Monitor, and Capture-to-Fission Ratio Capsules.

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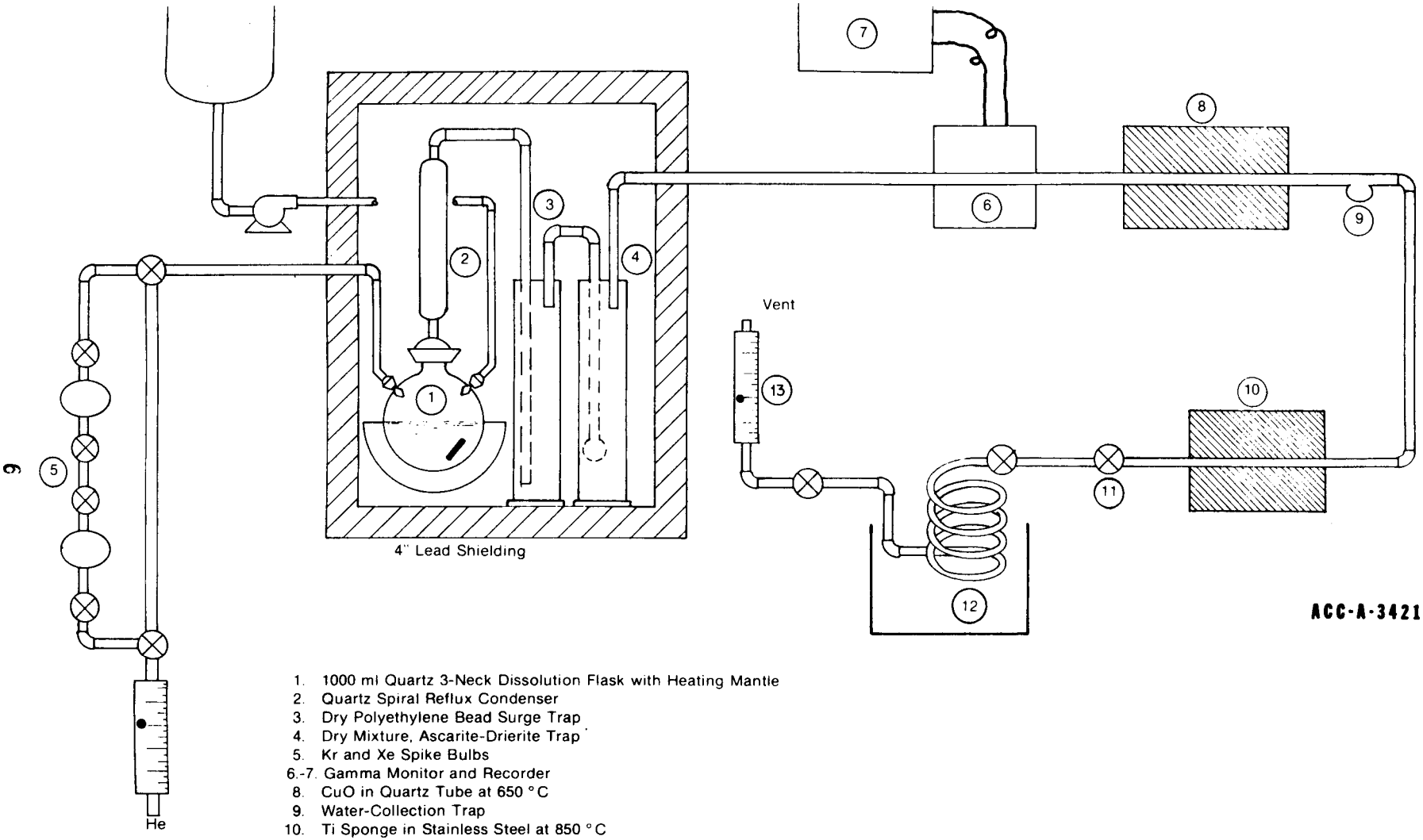
III. SAMPLE DISSOLUTION AND ANALYSIS

III-A. Dissolution of Fission Yield Samples

Each of the ^{240}Pu and ^{242}Pu samples was individually dissolved using a mixture of 10M HNO_3 (quartz distilled)-0.1M HF in a quartz flask equipped with a quartz reflux condenser. A schematic diagram of the dissolution and gas collection apparatus is shown in Figure 2. The individual fission yield capsules to be dissolved were placed in the quartz dissolver containing 50 mL of quartz distilled water, and the entire system was purged with helium. After purging, a slight positive pressure was placed on the system and all joints were monitored with a helium leak detector to establish system integrity. The dissolving acid was added in 100-mL increments and the temperature of the dissolver was increased. When the clad had been violated as evidenced by the detection of ^{85}Kr activity, measured quantities of $^{78-80}Kr$ and ^{129}Xe isotopic spikes were introduced into the dissolution flask from the spike-addition manifold by switching the helium flow. The fission gases were swept from the dissolver flask and through the collection train (Figure 2) with helium at a flow of ~100 cc/min during the entire dissolution. Traps of polyethylene beads and Ascarite-Drierite removed spray, water vapor and some acidic gases, respectively. Hydrogen and organic vapors were removed on CuO at 650°C, and NO_x on titanium sponge at 850°C, respectively. The krypton and xenon fission gases and respective spikes were trapped on 5-A Molecular Sieve traps immersed in liquid nitrogen. Two collection traps were used. Gas collection was continued for at least one hour after the dissolution was considered complete, as evidenced by cessation of the evolution of ^{85}Kr from the dissolver flask, and by visual examination of the dissolver flask for sample residue. The average dissolution time was 10-15h.

After dissolution, the two collection traps were removed and counted for ^{85}Kr. In no case was ^{85}Kr activity detected on the backup trap. The gases were removed from the primary collection trap and the Kr and Xe separated using gas chromatography. The individual fission gases and respective spikes were collected and analyzed using mass spectrometry.



1. 1000 ml Quartz 3-Neck Dissolution Flask with Heating Mantle
2. Quartz Spiral Reflux Condenser
3. Dry Polyethylene Bead Surge Trap
4. Dry Mixture, Ascarite-Drierite Trap
5. Kr and Xe Spike Bulbs
6.-7. Gamma Monitor and Recorder
8. CuO in Quartz Tube at 650 °C
9. Water-Collection Trap
10. Ti Sponge in Stainless Steel at 850 °C
11. By-Pass Valve
12. Molecular Sieve 5A at - 190 °C (2 Traps)
13. Outlet Flowmeter and Vent

Fig. 2 Dissolution and Gas Collection Apparatus.

Following dissolution, the sample solution was allowed to stand several hours, then filtered and weighed. The filter was counted, using gamma-ray spectrometry, to determine completeness of dissolution.

III-B. Fission Product Analysis

The atoms of the individual non-gaseous fission products for each of the ^{240}Pu and ^{242}Pu samples were determined using isotope dilution mass spectrometry. Weighed aliquots of the sample solution were removed from the weighed dissolver solution and mixed with weighed quantities of the respective spike isotope for each element measured. Usually, four spiked and four unspiked aliquots were analyzed for each element. Highly purified reagents were used for the chemical separation. Whenever feasible, the spike isotopes were standardized by two independent methods.

A list of the spike isotopes and a brief identification of the separation procedures used is given in Table III. A more detailed description of the chemical separation and mass spectrometric procedures is given in Reference 3.

III-C. Dissolution and Analysis of Spectrum Monitor Samples

Seven of the 12 spectrum monitor capsules were analyzed. The nonfissionable monitors were counted using a calibrated Ge(Li) detector and a 4096 channel analyzer system. The fissionable monitors were individually dissolved, cesium chemically separated, and ^{137}Cs determined using gamma-ray analysis. Based on the determined reaction rates, the neutron spectra were characterized using the fitting code SPECTRA[5]. The results and a comparison to the expected neutron spectrum in the Fast Test Reactor (FTR) and in a conceptual 1000 MW_e LMFBR have been previously reported.[2] The values for the mean neutron energies given in Table I of this report were derived from these measurements.

Both the neutron spectrum data and the measured capture-to-fission ratios indicate this irradiation was conducted in a neutron environment approximating that expected for the FTR and a conceptual mixed-oxide fueled 1000 MW_e LMFBR.

TABLE III

ANALYTICAL SEPARATION PROCEDURES
AND ISOTOPE DILUTION SPIKES

Element Separated	Added Spike	Separation Procedure	Element Separated	Added Spike	Separation Procedure
Rb	^{85}Rb	Ion exchange	Cs	^{133}Cs	Ion exchange on same sample aliquot used for Rb.
Sr	^{87}Sr	Ion exchange on same sample aliquot used for Rb.	Ba	^{135}Ba	Ion exchange on same sample aliquot used for Rb.
Zr	^{90}Zr	Zr coprecipitated with Th $(IO_3)_4$ followed by ion exchange.	La	^{138}La	Sequential chromatographic ion exchange.
			Ce	^{136}Ce	
Mo	^{94}Mo	Solvent extraction	Nd	^{150}Nd	
Ru	^{96}Ru	Distillation of RuO_4.	Sm	^{144}Sm	

IV. PLUTONIUM-240 FAST REACTOR FISSION YIELDS

Two encapsulated samples of $^{240}PuO_2$ were irradiated in EBR-II and analyzed. One of the samples, capsule-8, was located ∿12 cm above the reactor mid-plane; the other, capsule-15, was located ∿21 cm above the reactor mid-plane (Figure 1). The neutron environment for these two samples is given in Table I.

IV-A. Determination of Number of Fissions

IV-A-1. Total Fissions by Summation Technique

The total number of fissions for each of the ^{240}Pu capsules was determined using the summation method. This method is based on the fact that the sum of all of the fission product atoms in one of the peaks in the mass yield curve is equal to the number of fissions. The preferred peak for measurement is the heavy mass peak because the fission product elements in this peak are more easily measured, and an accurate measurement of a larger fraction of this peak is possible.

With current thermal ionization isotope dilution mass spectrometry technology, approximately 90% of the heavy mass peak can be reliably measured. The unmeasured masses are usually associated with monoisotopic elements such that isotope dilution is not practical, or they are associated with elements which have non-metallic properties and are not easily measured using conventional thermal ionization. In this report, the unmeasured values were obtained by interpolation and estimation. For those mass numbers which were not measured but were bounded by measured quantities (ie, mass 141 and 153), the values were obtained by linear interpolation between the adjacent masses. For the region from mass 130 to 126, the values were interpolated based on the measured values of ^{131}Xe and ^{125}Sb, assuming a smoothly changing function. For the mass region 124 to one-half the mass of the compound target nucleus less neutron emission, the values were estimated using limited radiochemical data[6] as a guide. The number of atoms in the region from mass 155 to 160 was estimated by extrapolation using the measured values for masses 145 to 154 and extending the mass yield curve from mass 154 to 160.

The fractions of the heavy mass peak determined by measurement, interpolation, and estimation, and the uncertainties associated with each value are given in Table IV for ^{240}Pu capsule-15. Also given is the uncertainty in the <u>total</u> number of fissions, 0.7% relative.

IV-A-2. <u>Corrections for Extraneous Fissions</u>

Unlike the situation for ^{239}Pu and ^{241}Pu fast fission[3], in which >99% of the total fissions resulted from fissioning of the principal target nuclide, the ^{240}Pu raw data must be corrected for fissioning from other sources. This occurs because ^{240}Pu has a low spectrum-averaged fission cross section in the neutron environment of the irradiation compared to the much larger spectrum-averaged fission cross section for the minor plutonium isotopes (^{239}Pu and ^{241}Pu) present in the ^{240}Pu targets. The fraction of extraneous fissions was estimated based on a calculation involving the quantity and initial isotopic composition of the target material, the neutron spectra based on data derived from the spectrum monitor capsules, and the spectrum-averaged

TABLE IV

COMPONENTS AND ERRORS RELATIVE TO DETERMINING THE TOTAL NUMBER OF FISSIONS, ^{240}Pu

(Capsule-15)

Prior to correction for other sources of fission

Measured Atoms	% Total Fissions	Relative Error, %
Sb	0.088	11.2
Xe	21.929	0.6
Cs	21.329	0.2
Ba	6.494	1.9
La	5.984	5.1
Ce	10.308	1.8
Nd	17.525	0.7
Sm	5.347	0.9
Σ Measured Atoms	89.004	0.5
Linear Interpolation Mass 141	5.154	5.4
Linear Interpolation Mass 153	0.470	10.2
Interpolation Mass 130-126	4.66	8.3
Extrapolation Mass 155-160	0.51	20.0
Estimation, Mass 120-124	0.19	50.0
TOTAL	99.988	0.7

fission and capture cross sections for the minor isotopes.

For the ^{240}Pu target in capsule-15, it is estimated that approximately 4.4% of the total fissions originated from the ^{239}Pu component; 8.1% from the ^{241}Pu component; and 87.5% from the principal isotope, ^{240}Pu. For capsule-8, the estimated contribution from ^{239}Pu and ^{241}Pu fissioning was 3.4% and 5.3%, respectively. The uncertainty assigned to the fraction of extraneous fissions is 10% relative. The <u>total</u> measured number of fissions for each capsule was corrected for the fraction of extraneous fissions to arrive at a <u>net</u> number of fissions attributable to the principal target nuclide.

The measured <u>total</u> atoms of each individual mass was corrected for the number of atoms produced from the other sources of fission to arrive at the <u>net</u> number of atoms using the following relationship:

$$\text{Net atoms } i = G_i - [(G_T F^{239} FY_i^{239}) - (G_T {}^{241}FY_i^{241})]$$

where

G_T = total number of atoms in heavy mass peak

G_i = measured total number of atoms of the individual nuclide

F^{239}, F^{241} = fraction of the total fissions resulting from ^{239}Pu or ^{241}Pu

FY_i^{239}, FY_i^{241} = fast reactor fission yield of the individual nuclide for ^{239}Pu or ^{241}Pu fast fission.

The measured total number of atoms, the <u>net</u> number of atoms after correction for other sources of fission, and the net fast reactor fission yields for the individual mass numbers are given in Tables VI and VII. The errors associated with the correction procedure are included in the total propagated errors determined for each individual mass.

IV-B. <u>Isotopic Composition of Fission Product Elements</u>

The isotopic composition of each fission product element measured is given in Table V. The values given in this table are after correction for the extraneous sources of fission. The errors are the random measurement errors obtained prior to correction for extraneous

TABLE V

ISOTOPIC COMPOSITION OF ELEMENTS FOR ^{240}Pu FAST FISSION HEAVY MASS PEAK

	CAPSULE			CAPSULE	
	8	15		8	15
Xenon			Neodymium		
131	a	0.1569	143	0.2655 ±0.0002	0.2671 ±0.0002
132	a	0.2126	144	0.2328 ±0.0002	0.2337 ±0.0001
134	a	0.3282	145	0.1833 ±0.0001	0.1835 ±0.0001
136	a	0.3023	146	0.1505 ±0.0001	0.1498 ±0.0001
131/136	a	0.5190	148	0.1047 ±0.0001	0.1038 ±0.0001
Cesium			150	0.0632 ±0.0001	0.0621 ±0.0001
133	a	0.3257 ±0.0001	150/143	0.2380	0.2325
135	a	0.3570 ±0.0001	Samarium		
137	a	0.3173 ±0.0002	147	0.4044 ±0.0004	0.4181 ±0.0080
133/137	a	1.0265	149	0.2532 ±0.0002	0.2496 ±0.0021
Cerium			151	0.1605 ±0.0002	0.1575 ±0.0011
140	0.5356 0.0038	0.5310 ±0.0011	152	0.1231 ±0.0002	0.1190 ±0.0014
142	0.4644 0.0037	0.4690 ±0.0011	154	0.0587 ±0.0002	0.0557 ±0.0008
140/142	1.1533	1.1322	150/147	0.1452	0.1332
			152/147	0.3044	0.2846

[a] Not reported, because gas leakage from the capsule during irradiation perturbed the isotopic values for Xe and Cs.

TABLE V (Cont'd)

ISOTOPIC COMPOSITION OF ELEMENTS FOR ^{240}Pu FAST FISSION
LIGHT MASS PEAK

	CAPSULE			CAPSULE	
	8	15		8	15
Krypton			Molybdenum		
83	a	0.1820	95	0.2026 ±0.0004	0.2020 ±0.0003
84	a	0.3122			
86	a	0.5058	97	0.2359 ±0.0003	0.2353 ±0.0002
83/86	a	0.3598	98	0.2502 ±0.0005	0.2513 ±0.0002
Rubidium			100	0.3112 ±0.0009	0.3115 ±0.0005
85	a	0.3363 ±0.0002			
87	a	0.6637 ±0.0002	95/100	0.6510	0.6485
85/87	a	0.5067	Ruthenium		
Strontium			101		0.2563 ±0.0002
88	0.3562 ±0.0041	0.3469 ±0.0048	102		0.2643 ±0.0001
90	0.6438 ±0.0047	0.6531 ±0.0058	104		0.2723 ±0.0002
88/90	0.5533	0.5312	106		0.2071 ±0.0061
Zirconium			104/101		1.063
91	0.1275 ±0.0007	0.1292 ±0.0003	106/101		0.8080
92	0.1570 ±0.0007	0.1575 ±0.0001			
93	0.2081 ±0.0019	0.2033 ±0.0002			
94	0.2303 ±0.0030	0.2314 ±0.0003			
96	0.2770 ±0.0004	0.2786 ±0.0002			
91/96	0.4603	0.4637			

[a] Not reported, because gas leakage from the capsule during irradiation perturbed the isotopic values for Kr and Rb.

fissions. In nearly all cases, except for krypton and xenon for which only one sample was collected and analyzed, the isotopic values are based on the analysis of four individual sample aliquots.

The listing of relative isotopic data is considered important because it is more precise and accurate than fission yield data. Thus, when additional data from other sources becomes available, a more meaningful comparison will be possible, especially with respect to the changes in the relative isotopic abundances as a function of neutron energy.

Although little is known relative to the effect of neutron energy on ^{240}Pu fission yields, the differences in the isotopic data given in Table V for neodymium and samarium indicate a slight neutron energy dependency and correlate with the mean neutron energies for fission for the two capsules (Table I).

IV-C. Absolute Fission Yields

During the course of the analysis and data review, it became evident for capsule-8, that complete gas recovery was not achieve; the recovered number of krypton and xenon atoms relative to neodymium and other non-gaseous fission products was low compared to capsule-15 and the expected relative fission yields. Comparison of relative atom ratios indicated ~10% loss of fission gas. Further investigation indicated the loss of fission gas occurred during the irradiation rather than during the analysis procedure. This conclusion is based on the perturbed isotopic composition of the recovered krypton and xenon fractions and perturbed isotopic composition of the rubidium and cesium fractions, especially where the gaseous precursor had a half-life of several minutes or more.

Although a loss of fission gases from capsule-8 was evident, the sample was analyzed for all of the other measurable nuclides. To determine the number of fissions for capsule-8 based on the sum of the atoms in the heavy mass peak, measured fission yields for the xenon and cesium isotopes determined on capsule-15 were substituted for the unmeasured masses. In essentially all cases, the fission yields determined on capsule-8 agreed within 2% relative of those determined on

capsule-15. The yields determined on capsule-8 were combined with those of capsule-15 to give a pooled value. The error propagation included the substitution of yield data from capsule-15 to capsule-8.

As detailed in Section IV-A-2, all of the reported yields were corrected for other sources of fissions. It is most interesting to note that for ^{240}Pu, the heavy mass peak yields based on the net fissions from ^{240}Pu generally agree within ±1% relative of the yields based on the measured total atoms of each individual nuclide and the sum of the total atoms. This results from the fact that the average mass of the heavy mass peak is only slightly shifted to higher mass with an increase in the mass of the target nuclide, and that the shape of the heavy mass peak is similar for the various fissioning nuclides. For the mass region from the valley to the top of the heavy mass peak, the yields for ^{239}Pu fast fission are slightly greater than those for ^{240}Pu fission and the ^{241}Pu yields are slightly less. The reverse situation occurs for the region from the top of the mass peak to the wing. The net effect of the corrections for ^{239}Pu and ^{241}Pu fission on ^{240}Pu fission yields is that they tend to cancel. Thus, if the number of fissions from ^{239}Pu and ^{241}Pu are similar, relatively large uncertainties in the fractional sources of fission from ^{239}Pu and ^{241}Pu can be tolerated with little effect on the final ^{240}Pu yields.

The following data are presented in Tables VI and VII for each of the two analyzed ^{240}Pu capsules: a) the total number of atoms for each measured mass, b) the net number of atoms after correction for extraneous fission for each measured mass, c) the estimated number of atoms or fission yields for the unmeasured mass numbers, d) the net number of ^{240}Pu fissions based on the sum of the net number of ^{240}Pu fission product atoms in the heavy mass peak, e) the fission yield for each mass number obtained by dividing the measured and estimated net number of fission product atoms of that mass number by the sum of the net number of atoms in the heavy mass peak, and f) the propagated uncertainty associated with each value.

The fission yields for the two samples are summarized in Table VIII. For the present, the yields for the two capsules have been combined. When more measurements become available, it may be possible to separate the effect of neutron energy on ^{240}Pu fission yields.

IV-C-1. Heavy Mass Peak

IV-C-1-a. Mass Region 120-124. The number of atoms in this mass region was estimated based on the measured number of ^{125}Sb atoms and limited radiochemical data.[6] A 50% relative uncertainty was assigned to this value.

IV-C-1-b. Mass 125. The atoms of mass 125 were determined from a radiochemical measurement of ^{125}Sb.

IV-C-1-c. Mass Region 126-130. For capsule-15, the number of atoms for each mass number was obtained by interpolation. A smooth function was assumed between the measured values of ^{125}Sb and ^{131}Xe. The sum of the atoms in this region is 4.7% of the total atoms in the heavy mass peak. The uncertainty on the sum, 8.3% relative, was obtained by assuming a 15% relative systematic error for each individual mass number estimate and includes the error due to the uncertainty in the measured atoms of ^{125}Sb and xenon.

IV-C-1-d. Xenon (Mass 131, 132, 134, 136). Xenon data were obtained from capsule-15 only.

IV-C-1-e. Cesium (Mass 133, 135, 137). Cesium data are only reported for capsule-15, because capsule-8 lost gas during the irradiation. This gas loss was sufficient to perturb the isotopic composition of cesium for capsule-8. The relative abundance of ^{133}Cs compared to the other cesium isotopes was significantly less than expected because of loss of ^{133}Xe from the capsule. For capsule-15, the value for mass 137 is based on the sum of the measured atoms of ^{137}Cs and ^{137}Ba.

IV-C-1-f. Barium (Mass 138). The atoms of mass 138 were determined from an analysis of barium. A comparison of the number of mass 137 atoms based on separate analysis of ^{137}Cs and ^{137}Ba showed

agreement after decay corrections within 3%. Considering that only a small fraction (<10%) of the ^{137}Cs had decayed to ^{137}Ba and that ^{137}Ba was a minor fraction of the total barium, this is considered good agreement. It also indicates no serious natural barium contamination problem.

IV-C-1-g. Lanthanum (Mass 139). The only stable fission product isotope of lanthanum is mass 139. The abundance of mass 139 in natural lanthanum is 99.91%. The only other stable natural occurring isotope of lanthanum is mass 138. Thus, not only is natural lanthanum a serious problem, correction for the amount of natural contamination is difficult. The large error associated with the measured atoms of fission product lanthanum and the resulting fission yields is caused by a significant fraction (~50%) of natural lanthanum in the analyzed samples.

IV-C-1-h. Cerium (Mass 140, 142). Three isotopes of cerium mass 140, 142, and 144 were measured. The atoms of ^{144}Ce were summed with the atoms of ^{144}Nd to give the total atoms of mass 144.

IV-C-1-i. Mass 141. The number of atoms for mass 141 was obtained by linear interpolation between the measured atoms of ^{140}Ce and ^{142}Ce. The number of mass 141 atoms represents 5.2% of the total number of atoms in the heavy mass peak. The propagated relative uncertainty is 5.4%, which includes an assigned 5% relative systematic error and the error due to the uncertainty in the measured ^{140}Ce and ^{142}Ce values.

IV-C-1-j. Neodymium (Mass 143,144,145,146,148,150). The isotopic composition of the neodymium isotopes for the two capsules is given in Table V. The value for 144 is based on the sum of the net atoms of ^{144}Nd plus ^{144}Ce. The small systematic change in the neodymium isotopic composition between capsule-8 and capsule-15 correspond with that expected for the harder neutron spectrum experienced by capsule-8 (i.e., a broadening in this region of the mass yield curve with increasing neutron energy). This is similar to the change in the isotopic composition of neodymium with neutron energy observed for other fissioning heavy elements.[2,3]

IV-C-1-k. Samarium (Mass 147,149,151,152,154). The isotopic composition of the samarium isotopes for the two capsules is given in Table V. The same broadening effect of the mass yield curve and correlation with neutron energy as discussed for neodymium were observed for the samarium data.

The values for ^{147}Sm were corrected using a half-life of 2.623y. For ^{151}Sm, the decay correction was based on a half-life of 93y.

IV-C-1-ℓ. Mass 153. The atoms of mass 153 were obtained by linear interpolation between the measured atoms of ^{152}Sm and ^{154}Sm. The net number of mass 153 atoms represents 0.47% of the heavy mass peak. The propagated uncertainty is 10.2% relative, which includes an assigned 10% relative systematic error for mass 153, and the error associated with the measured samarium atoms.

IV-C-1-m. Mass Region 155-160. The number of atoms in this mass region was obtained by extrapolation of the measured number of atoms in the 150-154 mass region to mass 160. This mass region comprises 0.51% of the total heavy mass peak and a 20% relative uncertainty was assigned to this value.

IV-C-2. Light Mass Peak

The yields for all measured isotopes in the light mass peak were obtained by dividing the net number of atoms of each measured mass by the sum of the net number of atoms in the heavy mass peak.

IV-C-2-a. Mass Region 75-82. For capsule-15, the number of atoms in the mass region 75-82 was obtained by extrapolation of the measured atoms of the krypton isotopes to mass 75. A 20% relative uncertainty was assigned to this value. No results are given for capsule-8 because of loss of krypton during the irradiation.

IV-C-2-b. Krypton (Mass 83, 84, 86). The isotopic composition of krypton for capsule-15 is given in Table V. No data are given for capsule-8 because of gas loss during irradiation. Mass 85 data are not included with the other krypton data because ~80% of this mass number exists in the form of ^{85}Rb. The measured atoms of ^{85}Kr are

summed with those of ^{85}Rb and given with the rubidium data. (See section V-C-2-a for a discussion of fine structure in this region of the mass yield curve.)

IV-C-2-c. Rubidium (Mass 85, 87). The relative isotopic data for rubidium for capsule-15 are given in Table V. The abundance of mass 85 was obtained by summing the measured atoms of ^{85}Kr and ^{85}Rb.

IV-C-2-d. Strontium (Mass 88, 90). The isotopic composition for strontium for the two capsules is given in Table V. The amount of mass 90 is based on the sum of ^{90}Sr plus ^{90}Zr. The difference in the isotopic data between the two capsules correlate with a broadening of the wing of the light mass peak with increasing neutron energy.

IV-C-2-e. Mass 89. The number of atoms of mass 89 was obtained by linear interpolation between the measured atoms of ^{88}Sr and ^{90}Sr. A 7% relative systematic error was assigned to this value.

IV-C-2-f. Zirconium (Mass 91,92,93,94,96). The isotopic composition of ^{240}Pu fission product zirconium is given in Table V. Because the amount of natural zirconium in the samples ranged from 25-35%, the errors associated with the fission product data are larger than for some of the other fission product elements. The source of the natural contamination is believed to be the quartz dissolution flasks, normally annealed in a zirconia lined furnace in the fabrication process.

The large errors associated with the zirconium data preclude making any definite statement regarding the effect of neutron energy on the zirconium yields, but the effect is expected to be small.

IV-C-2-g. Molybdenum (Mass 95,97,98,100). The isotopic data for ^{240}Pu fission product molybdenum for the two capsules are given in Table V. No significant neutron energy effect is noted.

IV-C-2-h. Mass 99. The number of atoms of mass 99 was determined by linear interpolation between the measured atoms of ^{98}Mo and ^{100}Mo. A 5% relative systematic error was assigned to this value.

IV-C-2-i. Ruthenium (Mass 101,102,103,104,105,106). The isotopic composition of ^{240}Pu fission product ruthenium for capsule-15

is given in Table V and the fast reactor yields in Table VI. The larger uncertainty associated with the mass 106 values results from the fact that at the time of measurement, ^{106}Ru was a minor peak compared to the other ruthenium isotopes and significant decay corrections ($t_{1/2}$ = 369d) were required. To determine the ruthenium fission yield values for capsule-15, we used a combined measurement and calculational method, because some ruthenium had plated-out on the wall of the dissolver or precipitated from the solution. This method assumes no isotopic fractionation occurred in the precipitation process and that the isotopic composition of the ruthenium in solution is representative of the total fission product ruthenium. To obtain the total ruthenium concentration, all of the measured and estimated atoms in the light mass peak, except those in the mass region 101 through 106 inclusive, are summed and subtracted from the total number of atoms in the heavy mass peak. This difference, the total atoms in the mass region 101 through 106, is subsequently allocated to each mass number based on the measured ruthenium isotopic composition. The reliability of this technique was previously established[3,4] when results obtained on solutions in which no precipitation had occurred compared favorably to results obtained using this technique.

The values for the number of atoms of mass 103 and 105 were obtained by linear interpolation between the measured values for ^{102}Ru and ^{104}Ru, and between ^{104}Ru and ^{106}Ru, respectively. A systematic error of 7% relative was assigned to these values.

Comparable ruthenium data for capsule-8 are not given because too large of a fraction of the light mass peak was unmeasured.

IV-C-2-j. Mass 107,108,109,110,111,112,113. The number of atoms for these mass numbers was obtained by reflection of the corresponding masses on the heavy mass peak. A systematic uncertainty of 25% relative was assigned to each value.

IV-C-2-k. Mass 114-119. The number of atoms in this mass region was estimated and a 50% relative uncertainty was assigned.

TABLE VI

MEASURED TOTAL ATOMS, CORRECTED NET ATOMS, AND FISSION YIELDS FOR ^{240}Pu

CAPSULE 15 - HEAVY MASS PEAK

Mass No.	Measured Total Atoms $x10^{17}$	Corrected Net Atoms $x10^{17}$	Fission Yield	σ
120-124	0.15 ±0.075	0.13 ±0.08	0.19	0.11
125-Sb	0.070±0.008	0.062±0.009	0.088	0.013
126	0.16 ±0.03	0.14 ±0.03	0.19	0.04
127	0.32 ±0.06	0.28 ±0.06	0.40	0.09
128	0.59 ±0.10	0.52 ±0.10	0.74	0.14
129	1.00 ±0.15	0.87 ±0.15	1.25	0.21
130	1.65 ±0.25	1.44 ±0.25	2.07	0.35
131-Xe	2.716±0.019	2.379±0.031	3.418	0.035
132-Xe	3.705±0.023	3.224±0.042	4.633	0.045
133-Cs	5.528±0.020	4.850±0.054	6.969	0.061
134-Xe	5.738±0.032	4.976±0.066	7.150	0.067
135-Cs	6.054±0.014	5.316±0.056	7.638	0.062
136-Xe	5.277±0.035	4.583±0.063	6.585	0.066
137-Cs+Ba	5.378±0.023	4.724±0.058	6.787	0.064
138-Ba	5.164±0.098	4.535±0.109	6.517	0.140
139-La	4.758±0.243	4.167±0.247	5.987	0.331
140-Ce	4.353±0.077	3.822±0.087	5.491	0.103
141	4.098±0.222	3.599±0.225	5.171	0.302
142-Ce	3.844±0.069	3.376±0.077	4.851	0.091
143-Nd	3.711±0.028	3.262±0.044	4.687	0.050
144-Nd+Ce	3.255±0.023	2.854±0.038	4.102	0.043
145-Nd	2.557±0.018	2.241±0.030	3.220	0.033
146-Nd	2.095±0.015	1.829±0.025	2.629	0.027
147-Sm	1.767±0.038	1.553±0.041	2.232	0.056
148-Nd	1.449±0.012	1.268±0.018	1.822	0.021
149-Sm	1.066±0.013	0.927±0.017	1.333	0.021
150-Nd	0.870±0.009	0.759±0.013	1.090	0.015
151-Sm	0.671±0.008	0.585±0.010	0.841	0.013
152-Sm	0.508±0.011	0.442±0.014	0.635	0.017
153	0.374±0.038	0.325±0.038	0.466	0.055
154-Sm	0.241±0.005	0.207±0.010	0.298	0.012
155-160	0.41 ±0.08	0.35 ±0.08	0.50	0.12
Σ	79.517±0.551	69.595±0.879	99.980	

TABLE VI (Cont'd)

MEASURED TOTAL ATOMS, CORRECTED NET ATOMS, AND FISSION YIELDS FOR ^{240}Pu

CAPSULE 15 - LIGHT MASS PEAK

Mass No.	Measured Total Atoms $x10^{17}$	Corrected Net Atoms $x10^{17}$	Fission Yield	σ
75-82	0.40 ±0.08	0.35 ±0.08	0.51	0.11
83-Kr	0.182±0.001	0.158±0.002	0.227	0.002
84-Kr	0.311±0.002	0.271±0.003	0.390	0.004
85-Kr+Rb	0.351±0.005	0.304±0.007	0.437	0.009
86-Kr	0.504±0.003	0.439±0.005	0.630	0.006
87-Rb	0.685±0.012	0.600±0.014	0.863	0.019
88-Sr	0.774±0.016	0.666±0.017	0.957	0.024
89	1.098±0.074	0.960±0.075	1.379	0.107
90-Zr+Sr	1.423±0.021	1.254±0.025	1.802	0.034
91-Zr	1.749±0.011	1.541±0.019	2.214	0.023
92-Zr	2.135±0.011	1.878±0.021	2.699	0.027
93-Zr	2.748±0.012	2.424±0.026	3.484	0.033
94-Zr	3.128±0.013	2.759±0.030	3.964	0.037
95-Mo	3.563±0.057	3.146±0.065	4.520	0.089
96-Zr	3.775±0.021	3.323±0.039	4.774	0.048
97-Mo	4.151±0.064	3.664±0.074	5.264	0.101
98-Mo	4.432±0.068	3.913±0.078	5.623	0.108
99	4.960±0.265	4.382±0.269	6.297	0.385
100-Mo	5.488±0.087	4.851±0.099	6.971	0.137
101-Ru	5.247±0.187	4.605±0.219	6.617	0.249
102-Ru	5.417±0.193	4.748±0.226	6.822	0.257
103	5.504±0.435	4.822±0.541	6.929	0.616
104-Ru	5.587±0.199	4.893±0.233	7.031	0.265
105	4.930±0.398	4.309±0.496	6.192	0.564
106-Ru	4.269±0.200	3.721±0.242	5.346	0.275
107			3.29	0.98
108			2.04	0.62
109			1.20	0.37
110			0.69	0.22
111			0.37	0.11
112			0.16	0.05
113			0.09	0.02
114-119			0.22	0.12

TABLE VII

MEASURED TOTAL ATOMS, CORRECTED NET ATOMS, AND FISSION YIELDS FOR ^{240}Pu

	CAPSULE 8 - HEAVY MASS PEAK			
Mass No.	Measured Total Atoms $x10^{17}$	Corrected Net Atoms $x10^{17}$	Fission Yield	σ
120-124	Not estimated			
125-Sb	0.116±0.013	0.105±0.014	0.090	0.012
126	a			
127	a			
128	a			
129	a			
130	a			
131-Xe	b			
132-Xe	b			
133-Cs	b			
134-Xe	b			
135-Cs	b			
136-Xe	b			
137-Cs+Ba	b			
138-Ba	8.187±0.153	7.417±0.164	6.342	0.149
139-La	7.721±0.393	6.997±0.398	5.983	0.309
140-Ce	7.256±0.137	6.605±0.145	5.648	0.116
141	6.778±0.366	6.166±0.369	5.272	0.284
142-Ce	6.301±0.122	5.727±0.129	4.897	0.103
143-Nd	5.946±0.045	5.396±0.061	4.614	0.074
144-Nd+Ce	5.222±0.038	4.731±0.053	4.046	0.064
145-Nd	4.112±0.029	3.725±0.041	3.185	0.050
146-Nd	3.383±0.024	3.058±0.034	2.615	0.042
147-Sm	2.788±0.012	2.527±0.023	2.161	0.034
148-Nd	2.347±0.020	2.127±0.026	1.819	0.030
149-Sm	1.751±0.004	1.582±0.013	1.352	0.021
150-Nd	1.420±0.015	1.284±0.018	1.098	0.020
151-Sm	1.108±0.004	1.003±0.009	0.858	0.013
152-Sm	0.849±0.015	0.769±0.017	0.657	0.019
153	0.628±0.064	0.568±0.064	0.486	0.055
154-Sm	0.407±0.005	0.367±0.010	0.314	0.012
155-160	0.66 ±0.13	0.59 ±0.13	0.50	0.11
Σ		116.949±1.836[c]		

[a] No extrapolation, because mass 131 not measured.

[b] Not reported, because Kr and Xe escaped during irradiation.

[c] Total net fissions = $\frac{\Sigma \text{ corrected net atoms}}{1\text{-fractional yields for the unmeasured masses derived from capsule-15.}}$

TABLE VII (Cont'd)

MEASURED TOTAL ATOMS CORRECTED NET ATOMS, AND FISSION YIELDS FOR ^{240}Pu

CAPSULE 8 - LIGHT MASS PEAK

Mass No.	Measured Total Atoms $x10^{17}$	Corrected Net Atoms $x10^{17}$	Fission Yield	σ
75-82	Not estimated			
83-Kr	a			
84-Kr	a			
85-Kr+Rb	a			
86-Kr	a			
87-Rb	a			
88-Sr	1.305±0.023	1.172±0.025	1.002	0.025
89	1.816±0.123	1.645±0.124	1.407	0.107
90-Zr+Sr	2.326±0.034	2.118±0.037	1.811	0.039
91-Zr	2.811±0.027	2.555±0.033	2.184	0.040
92-Zr	3.461±0.030	3.146±0.037	2.690	0.048
93-Zr	4.569±0.053	4.170±0.060	3.566	0.070
94-Zr	5.067±0.040	4.613±0.052	3.945	0.069
95-Mo	5.682±0.032	5.170±0.049	4.421	0.072
96-Zr	6.105±0.048	5.550±0.064	4.746	0.083
97-Mo	6.616±0.022	6.019±0.049	5.146	0.080
98-Mo	7.020±0.024	6.384±0.053	5.458	0.085
99	7.871±0.401	7.162±0.405	6.124	0.356
100-Mo	8.721±0.045	7.940±0.726	6.789	0.109
101-Ru	b			
102-Ru	b			
103	b			
104-Ru	b			
105	b			
106-Ru	b			
107			3.32	0.95
108			2.07	0.60
109			1.22	0.35
110			0.70	0.21
111			0.37	0.11
112			0.16	0.04
113			0.09	0.02
114-119			0.22	0.12

[a]Not reported, because Kr and Xe escaped during irradiation.

[b]Not computed by subtraction method, because large fraction of peak not measured.

TABLE VIII

SUMMARY OF ^{240}Pu FAST REACTOR FISSION YIELDS

HEAVY MASS PEAK

	CAPSULE			
Mass No.	8	15	$\bar{X}$	σ
120-124		0.19	0.19	0.11
125-Sb	0.090	0.088	0.089	0.011
126		0.19	0.19	0.04
127		0.40	0.40	0.09
128		0.74	0.74	0.14
129		1.25	1.25	0.21
130		2.07	2.07	0.35
131-Xe		3.418	3.418	0.035
132-Xe		4.633	4.633	0.045
133-Cs		6.969	6.969	0.061
134-Xe		7.150	7.150	0.067
135-Cs		7.638	7.638	0.062
136-Xe		6.585	6.585	0.066
137-Cs+Ba		6.787	6.787	0.064
138-Ba	6.342	6.517	6.429	0.113
139-La	5.983	5.987	5.985	0.316
140-Ce	5.648	5.491	5.570	0.095
141	5.272	5.171	5.222	0.287
142-Ce	4.897	4.851	4.874	0.084
143-Nd	4.614	4.687	4.651	0.057
144-Nd+Ce	4.046	4.102	4.074	0.049
145-Nd	3.185	3.220	3.203	0.038
146-Nd	2.615	2.629	2.622	0.031
147-Sm	2.161	2.232	2.196	0.043
148-Nd	1.819	1.822	1.820	0.024
149-Sm	1.352	1.333	1.343	0.018
150-Nd	1.098	1.090	1.094	0.016
151-Sm	0.858	0.841	0.849	0.011
152-Sm	0.657	0.635	0.646	0.014
153	0.486	0.466	0.476	0.054
154-Sm	0.314	0.298	0.306	0.009
155-160	0.50	0.50	0.50	0.116
Σ			99.969	

TABLE VIII (Cont'd)

SUMMARY OF ^{240}Pu FAST REACTOR FISSION YIELDS

LIGHT MASS PEAK

Mass No.	CAPSULE 8	CAPSULE 15	$\bar{X}$	σ
75-82		0.51	0.51	0.11
83-Kr		0.227	0.227	0.002
84-Kr		0.390	0.390	0.004
85-Kr+Rb		0.437	0.437	0.009
86-Kr		0.630	0.630	0.006
87-Rb		0.863	0.863	0.019
88-Sr	1.002	0.957	0.979	0.023
89	1.407	1.379	1.393	0.106
90-Zr+Sr	1.811	1.802	1.807	0.030
91-Zr	2.184	2.214	2.199	0.029
92-Zr	2.690	2.699	2.694	0.034
93-Zr	3.566	3.484	3.525	0.046
94-Zr	3.945	3.964	3.954	0.048
95-Mo	4.421	4.520	4.470	0.068
96-Zr	4.746	4.774	4.760	0.060
97-Mo	5.146	5.264	5.205	0.076
98-Mo	5.458	5.623	5.541	0.092
99	6.124	6.297	6.210	0.363
100-Mo	6.789	6.971	6.880	0.103
101-Ru		6.617	6.617	0.249
102-Ru		6.822	6.822	0.257
103		6.929	6.929	0.616
104-Ru		7.031	7.031	0.265
105		6.192	6.192	0.564
106-Ru		5.346	5.346	0.275
107	3.32	3.29	3.31	0.97
108	2.07	2.04	2.06	0.61
109	1.22	1.20	1.21	0.36
110	0.70	0.69	0.69	0.22
111	0.37	0.37	0.37	0.11
112	0.16	0.16	0.16	0.05
113	0.09	0.09	0.09	0.02
114-119	0.22	0.22	0.22	0.12

V. PLUTONIUM-242 FAST REACTOR FISSION YIELDS

Two encapsulated samples of $^{242}PuO_2$ were irradiated in EBR-II and analyzed. The location of these samples in the irradiation assembly is shown in Figure 1. The irradiation conditions and the neutron environment are given in Table I.

V-A. Determination of Number of Fissions

V-A-1. Total Fissions by Summation Technique

The total number of fissions for each of the ^{242}Pu capsules was determined using the summation method. For both capsules, the number of fissions is based on the sum of the atoms in the heavy mass peak. The same techniques for estimation of the unmeasured masses as detailed for the ^{240}Pu capsules in Section IV-A-1 were applied to the ^{242}Pu capsules.

Th fractions of the heavy mass peak determined by measurement, interpolation, and estimation, and the uncertainties associated with each value for both ^{242}Pu capsules are given in Table IX.

V-A-2. Corrections for Extraneous Fissions

The fraction of extraneous fissions in the ^{242}Pu target material was estimated based on a calculation involving the quantity and initial isotopic composition of the target material, the neutron spectra based on data derived from the spectrum monitor capsules, and the spectrum-averaged fission and capture cross sections for the minor isotopes. For the ^{242}Pu samples, it is estimated that approximately 4.5% of the total fissions occurred in the ^{239}Pu component in the original target material. Less than 1% of the total fissions was contributed by the other minor isotopes. The uncertainty assigned to the fraction of extraneous fissions was 10% relative. The total measured number of fissions for each capsule was corrected for the fraction of extraneous fissions to arrive at a net value for the number of fissions attributable to ^{242}Pu.

TABLE IX

COMPONENTS AND ERRORS RELATIVE
TO DETERMINING THE TOTAL NUMBER OF FISSIONS, ^{242}Pu CAPSULES

	CAPSULE			
	9		22	
	% Total Fissions	Relative Error, %	% Total Fissions	Relative Error, %
Measured Atoms				
Sb	0.062	11.2	0.054	11.2
Xe	22.197	0.6	21.970	0.6
Cs	20.236	0.2	20.161	0.4
Ba	6.167	1.4	6.263	1.4
La	6.150	2.7	5.932	2.7
Ce	10.148	1.4	10.238	1.4
Nd	18.486	0.5	18.417	0.3
Sm	6.119	0.3	6.123	0.3
Σ Measured Atoms	89.565	0.3	89.158	0.3
Linear Interpolation Mass 141	5.074	5.3	5.119	5.3
Linear Interpolation Mass 153	0.592	10.2	0.593	10.2
Interpolation Mass 130-126	3.80	8.6	4.12	8.6
Extrapolation Mass 155-160	0.82	20.0	0.88	20.0
Estimation, Mass 124-121	0.15	50.0	0.14	50.0
TOTAL	100.001	0.6	100.010	0.6

The measured number of total atoms of each individual mass was corrected for the number of atoms produced from ^{239}Pu fission using the following relationship:

$$\text{Net atoms } i = G_i - (G_T F^{239} FY_i^{239})$$

where

G_T = total number of atoms in heavy mass peak

G_i = measured number of total atoms of the individual nuclide

F^{239} = fraction of the total fissions from ^{239}Pu

FY_i^{239} = fast reactor fission yield of the individual nuclide, i, for ^{239}Pu.

The measured total number of atoms, the net number of atoms after correction for ^{239}Pu fission, and the net fast reactor fission yield for the individual mass numbers for the two ^{242}Pu capsules are given in Tables XI and XII. The total propagated errors include those associated with the correction procedure.

V-B. Isotopic Composition of Fission Product Elements

The isotopic composition of each fission product element measured is given in Table X. These values are after correction for ^{239}Pu fission and correlative with the fission yield data in Tables XI and XII. The errors are the random measurement errors obtained from the analysis prior to correction for ^{239}Pu fissioning. In all cases, except for krypton and xenon for which only one sample was collected and analyzed, the isotopic values are based on four individual sample analyses.

The differences in the isotopic data between the two capsules are small and no definite trend is shown. This is reasonable, because both samples were in a similar neutron environment and hence, no neutron energy effect is expected.

TABLE X

ISOTOPIC COMPOSITION OF ELEMENTS FOR ^{242}Pu FAST FISSION HEAVY MASS PEAK

	CAPSULE			CAPSULE	
	9	22		9	22
Xenon			**Neodymium**		
131	0.1406	0.1401	143	0.2478 ±0.0002	0.2478 ±0.0001
132	0.2045	0.2038			
134	0.3408	0.3411	144	0.2307 ±0.0001	0.2310 ±0.0001
136	0.3140	0.3149			
131/136	0.4478	0.4449	145	0.1837 ±0.0001	0.1835 ±0.0001
Cesium			146	0.1576 ±0.0001	0.1573 ±0.0001
133	0.3393 ±0.0001	0.3377 ±0.0002			
135	0.3465 ±0.0001	0.3466 ±0.0001	148	0.1087 ±0.0001	0.1089 ±0.0001
137	0.3135 ±0.0001	0.3157 ±0.0002	150	0.0716 ±0.0001	0.0715 ±0.0001
133/137	1.082	1.070	150/143	0.2889	0.2885
Cerium			**Samarium**		
140	0.5448 ±0.0013	0.5458 ±0.0007	147	0.3857 ±0.0004	0.3848 ±0.0004
142	0.4552 ±0.0013	0.4542 ±0.0007	149	0.2595 ±0.0001	0.2593 ±0.0001
140/142	1.197	1.202	151	0.1614 ±0.0001	0.1615 ±0.0001
			152	0.1247 ±0.0001	0.1247 ±0.0002
			154	0.0695 ±0.0001	0.0697 ±0.0001
			154/147	0.1802	0.1811
			152/147	0.3233	0.3241

TABLE X (Cont'd)

ISOTOPIC COMPOSITION OF ELEMENTS FOR ^{242}Pu FAST FISSION LIGHT MASS PEAK

	CAPSULE	
	9	22
Krypton		
83	0.1684	0.1682
84	0.3218	0.3244
86	0.5098	0.5074
83/86	0.3303	0.3315
Rubidium		
85	0.3465 ±0.0001	0.3363 ±0.0001
87	0.6535 ±0.0001	0.6637 ±0.0001
85/87	0.5302	0.5067
Strontium		
88	0.3794 ±0.0022	0.3811 ±0.0008
90	0.6206 ±0.0025	0.6189 ±0.0009
88/90	0.6113	0.6158
Zirconium		
91	0.1268 ±0.0006	0.1271 ±0.0015
92	0.1540 ±0.0002	0.1521 ±0.0004
93	0.1969 ±0.0005	0.1993 ±0.0009
94	0.2225 ±0.0009	0.2180 ±0.0008
96	0.2998 ±0.0004	0.3035 ±0.0013
91/96	0.4229	0.4188
Molybdenum		
95	0.1915 ±0.0006	0.1903 ±0.0006
97	0.2338 ±0.0009	0.2341 ±0.0011
98	0.2562 ±0.0008	0.2529 ±0.0007
100	0.3185 ±0.0010	0.3227 ±0.0016
95/100	0.6012	0.5854
Ruthenium		
101	0.2398 ±0.0001	0.2395 ±0.0002
102	0.2572 ±0.0001	0.2577 ±0.0001
104	0.2722 ±0.0001	0.2720 ±0.0001
106	0.2309 ±0.0186	0.2308 ±0.0037
104/101	1.135	1.136
106/101	0.9629	0.9637

V-C. Absolute Fission Yields

The following data are presented in Tables XI and XII for each of the two analyzed ^{242}Pu capsules: a) the total number of atoms for each mass, b) the net number of atoms after correction for the contribution from ^{239}Pu fissioning for each measured mass, c) the number of estimated atoms or fission yields for each unmeasured mass number, d) the net number of ^{242}Pu fissions based on the sum of the net ^{242}Pu fission product atoms in the heavy mass peak, e) the fission yield for each mass number obtained by dividing the measured and estimated number of net fission product atoms of that mass number by the sum of the net number of atoms in the heavy mass peak, and f) the propagated uncertainty associated with each value.

The fission yields for the two capsules are summarized in Table XIII where the yields have been combined.

V-C-1. Heavy Mass Peak

V-C-1-a. Mass Region 121-124. The number of atoms in this region was estimated based on the measured number of ^{125}Sb atoms and limited radiochemical data.[6] A 50% relative uncertainty was assigned to this value.

V-C-1-b. Mass 125. The atoms of mass 125 were determined from a radiochemical measurement of ^{125}Sb.

V-C-1-c. Mass Region 126-130. The number of atoms for the mass numbers in this mass region for each of the two ^{242}Pu capsules was obtained by interpolation. A smooth function was assumed between the measured values for ^{125}Sb and ^{131}Xe. The sum of the atoms in this mass region is $\sim$4.0% of the total atoms in the heavy mass peak. The uncertainty of 8.6% relative given in Table IX was obtained by assuming a 15% relative systematic error for each individual mass number estimate and includes the error for the measured atoms of ^{125}Sb and ^{131}Xe.

V-C-1-d. Xenon (Mass 131,132,134,136). The isotopic data for xenon for the two capsules are given in Table X. The small differences (less than 0.5% relative) in these data confirm that the two capsules were irradiated in very similar neutron spectra (Table I). Normally, the abundance of mass 131 is strongly correlated with neutron energy, because being on the light side of the heavy mass peak, it is under the influence of changing peak to valley ratios which are highly correlated with neutron energy.

V-C-1-e. Cesium (Mass 133,135,137). The absolute number of mass 137 atoms was obtained by summing the measured atoms of ^{137}Cs and ^{137}Ba.

V-C-1-f. Barium (Mass 138). The atoms of mass 138 were determined from an analysis of barium.

V-C-1-g. Lanthanum (Mass 139). The atoms of mass 139 were determined from an analysis of lanthanum. The large error associated with the measured number of mass 139 atoms results from the difficulty in performing a reliable correction for natural lanthanum. This occurs because there are only two natural occurring lanthanum isotopes; mass 138 and 139, and the abundance of mass 139 is 99.91%.

V-C-1-h. Cerium (Mass 140, 142). Three isotopes of cerium were measured, mass 140, 142, and 144. The atoms of ^{144}Ce were summed with the atoms of ^{144}Nd to give the total atoms of mass 144.

V-C-1-i. Neodymium (Mass 143,144,145,146,148,150). The isotopic composition of the neodymium isotopes is given in Table X. The value for 144 is based on the sum of the net atoms of ^{144}Nd plus ^{144}Ce. The fact that there is no significant difference in the isotopic data for the two samples adds further evidence that the two capsules were irradiated in similar neutron spectra. Previously[2,3], the $^{150}Nd/^{143}Nd$ isotopic ratio was shown to be highly correlated with the energy of the fissioning neutrons. For these two capsules, the difference in this ratio is $\sim$0.15%, which is not considered significant.

V-C-1-j. Samarium (Mass 147,149,151,152,154). The isotopic composition for fission product samarium for the two capsules is given in Table X. The measured atoms of ^{147}Sm and ^{151}Sm were corrected using half-life corrections of 2.623y and 93y, respectively. The differences in the isotopic values between the two capsules is less than 0.5%.

V-C-1-k. Mass 153. The atoms of mass 153 were obtained by linear interpolation between the measured atoms of ^{152}Sm and ^{154}Sm. The number of net mass 153 atoms represents ~0.6% of the heavy mass peak. The propagated uncertainty in the number of mass 153 atoms is 10.2% relative, which includes an assigned 10% relative systematic error, and the error associated with the measured number of samarium atoms.

V-C-1-ℓ. Mass Region 155-160. The number of atoms in this mass region was obtained by extrapolation of the measured number of atoms in the 150-154 mass region to mass 160. This mass region comprises ~0.85% of the heavy mass peak for ^{242}Pu fast fission. A relative uncertainty of 20% has been assigned to this value.

V-C-2. Light Mass Peak

The yields for all measured isotopes in the light mass peak were obtained by dividing the net number of atoms of each measured mass by the sum of the net number of atoms in the heavy mass peak.

V-C-2-a. Mass Region 75-82. The number of atoms in the mass region 75-82 was obtained by extrapolation of the measured number of atoms of the krypton isotopes to mass 75. A 20% relative uncertainty was assigned to this value.

V-C-2-b. Krypton (Mass 83, 84, 86). The isotopic composition of the krypton isotopes for both capsules is given in Table X. Krypton-85 data are not included with the other krypton isotopes because ~80% of mass 85 exists in the form of ^{85}Rb. The measured atoms of ^{85}Kr are summed with those of ^{85}Rb and given with the rubidium data.

A significant departure from a smoothly changing function and definite evidence for fine structure is noted in the mass region 84, 85, and 86. For ^{242}Pu fast fission, the yield of mass 84 is slightly greater than that for mass 85 which, in turn, is considerably less than

expected when compared to mass 86 (Table XIII). We believe this results from an abnormally high independent yield for ^{85}As which subsequently decays by delayed neutron emission, and that the fraction of ^{85}As formed is correlated with the energy of the fissioning neutron. For those cases where the target nucleus is fissionable at all neutron energies (i.e., ^{235}U, ^{239}Pu, ^{241}Pu), little fine structure is evident. However, for those cases in which fast neutrons in excess of a given energy are required for fission, the fine structure is very evident. Plutonium-240, ^{238}U, and ^{237}Np also exhibit fine structure in this region of the mass yield curve. The most pronounced is that for ^{238}U, followed in order by ^{242}Pu, ^{240}Pu, and ^{237}Np. The yield of mass 84 is greater than mass 85 for both ^{238}U (ref. 2) and ^{242}Pu fast fission and less than mass 85 for ^{240}Pu and ^{237}Np (ref. 4) fast fission.

V-C-2-c. Rubidium (Mass 85, 87). The relative isotopic data for both capsules are given in Table X. The abundance of mass 85 relative to mass 87 was obtained by summing the measured atoms of ^{85}Kr and ^{85}Rb.

V-C-2-d. Strontium (Mass 88, 90). The isotopic composition for strontium for the two capsules is given in Table X. The amount of mass 90 is based on the measured sum of the net atoms of ^{90}Sr plus ^{90}Zr.

V-C-2-e. Mass 89. The atoms of mass 89 were obtained by linear interpolation between the measured atoms of ^{88}Sr and ^{90}Sr plus ^{90}Zr. A 7% relative systematic error was assigned to this value.

V-C-2-f. Zirconium (Mass 91,92,93,94,96). The isotopic composition of fission product zirconium for the two ^{242}Pu capsules is given in Table X. The larger relative errors associated with the zirconium yields result from large correction for natural zirconium (70-80%) in the samples. The source of the natural zirconium contamination is believed to be the quartz glassware used in the capsule dissolution process. In many cases, quartzware is fired in zirconia lined furnaces in the fabrication process.

V-C-2-g. Molybdenum (Mass 95,97,98,100). The isotopic data for ^{242}Pu fission product molybdenum for the two capsules are given in Table X.

V-C-2-h. Mass 99. The number of atoms of mass 99 was determined by linear interpolation between the measured atoms of ^{98}Mo and ^{100}Mo. A 5% relative systematic error was assigned to this value.

V-C-2-i. Ruthenium (Mass 101,102,103,104,105,106). The isotopic composition of ^{242}Pu fission product ruthenium for both capsules is given in Table X. The large uncertainty in the fractional abundance and absolute fission yields for ^{106}Ru results from large decay corrections and that mass 106 was a minor component at the time of measurement. A half-life of 369d was used for the decay correction.

The atoms of each ruthenium isotope were determined by the combined measurement-calculational method detailed in Section IV-C-2-i. The agreement in the yields for the two ^{242}Pu capsules using this technique is $\sim$1% relative, indicating no significant systematic errors in the measured number of atoms in the heavy and/or light mass peaks.

The values for mass 103 and 105 were obtained by linear interpolation between the measured values for ^{102}Ru and ^{104}Ru, and between ^{104}Ru and ^{106}Ru, respectively. A systematic error of 7% relative was assigned to those values.

V-C-2-j. Mass 107,108,109,110,111,112,113. The fission yields for these values were obtained by reflection of the yield values of the corresponding masses on the heavy mass peak. A systematic uncertainty of 25% relative was assigned to each value.

V-C-2-k. Mass 114-120. The number of atoms in this mass region was estimated and a 50% relative uncertainty was assigned.

TABLE XI

MEASURED TOTAL ATOMS, CORRECTED NET ATOMS, AND FISSION YIELDS FOR ^{242}Pu-CAPSULE 9

	HEAVY MASS PEAK			
Mass No.	Measured Total Atoms $x10^{17}$	Corrected Net Atoms $x10^{17}$	Fission Yield	σ
121-124	0.10 ±0.005	0.09 ±0.05	0.15	0.08
125-Sb	0.041±0.005	0.037±0.005	0.059	0.007
126	0.09 ±0.02	0.08 ±0.02	0.13	0.03
127	0.18 ±0.03	0.16 ±0.03	0.26	0.05
128	0.36 ±0.06	0.33 ±0.06	0.53	0.10
129	0.67 ±0.10	0.62 ±0.10	1.00	0.16
130	1.18 ±0.18	1.10 ±0.18	1.77	0.28
131-Xe	2.053±0.014	1.936±0.019	3.111	0.021
132-Xe	2.978±0.019	2.817±0.025	4.525	0.036
133-Cs	4.484±0.017	4.272±0.027	6.863	0.047
134-Xe	4.919±0.028	4.694±0.036	7.541	0.055
135-Cs	4.583±0.011	4.355±0.025	6.995	0.044
136-Xe	4.538±0.029	4.325±0.036	6.948	0.055
137-Cs+Ba	4.140±0.019	3.940±0.030	6.330	0.045
138-Ba	4.025±0.055	3.840±0.058	6.168	0.090
139-La	4.014±0.107	3.848±0.108	6.181	0.165
140-Ce	3.602±0.050	3.442±0.053	5.529	0.075
141	3.311±0.175	3.159±0.176	5.075	0.267
142-Ce	3.021±0.042	2.876±0.045	4.621	0.063
143-Nd	3.000±0.017	2.868±0.021	4.608	0.036
144-Nd+Ce	2.783±0.014	2.671±0.019	4.291	0.032
145-Nd	2.217±0.011	2.126±0.014	3.416	0.025
146-Nd	1.898±0.009	1.824±0.012	2.930	0.021
147-Sm	1.542±0.007	1.482±0.010	2.381	0.018
148-Nd	1.308±0.009	1.258±0.010	2.021	0.017
149-Sm	1.036±0.003	0.997±0.005	1.602	0.011
150-Nd	0.859±0.007	0.829±0.008	1.332	0.014
151-Sm	0.643±0.002	0.620±0.003	0.996	0.007
152-Sm	0.497±0.002	0.479±0.003	0.770	0.006
153	0.386±0.039	0.373±0.039	0.600	0.063
154-Sm	0.275±0.002	0.267±0.002	0.429	0.004
155-160	0.54 ±0.11	0.52 ±0.11	0.84	0.17
Σ	65.266±0.373	62.250±0.466	100.002	

TABLE XI (Cont'd)

MEASURED TOTAL ATOMS, CORRECTED NET ATOMS,
AND FISSION YIELDS FOR ^{242}Pu-CAPSULE 9

LIGHT MASS PEAK

Mass No.	Measured Total Atoms x10^{17}	Corrected Net Atoms x10^{17}	Fission Yield	σ
75-82	0.28 ±0.06	0.27 ±0.06	0.43	0.09
83-Kr	0.122±0.001	0.112±0.001	0.180	0.002
84-Kr	0.229±0.001	0.214±0.002	0.344	0.003
85-Kr+Rb	0.220±0.003	0.202±0.004	0.324	0.006
86-Kr	0.363±0.002	0.339±0.003	0.545	0.005
87-Rb	0.412±0.007	0.381±0.008	0.612	0.013
88-Sr	0.559±0.004	0.519±0.006	0.834	0.009
89	0.735±0.052	0.697±0.052	1.099	0.084
90-Sr+Zr	0.910±0.008	0.849±0.009	1.364	0.014
91-Zr	1.210±0.049	1.135±0.049	1.824	0.079
92-Zr	1.469±0.058	1.378±0.059	2.214	0.095
93-Zr	1.877±0.075	1.762±0.075	2.831	0.121
94-Zr	2.120±0.084	1.991±0.085	3.199	0.137
95-Mo	2.411±0.025	2.269±0.028	3.645	0.046
96-Zr	2.829±0.113	2.683±0.114	4.310	0.183
97-Mo	2.933±0.028	2.771±0.033	4.451	0.053
98-Mo	3.208±0.030	3.036±0.035	4.877	0.056
99	3.592±0.186	3.405±0.187	5.470	0.301
100-Mo	3.976±0.040	3.775±0.045	6.064	0.075
101-Ru	3.940±0.220	3.739±0.222	6.006	0.347
102-Ru	4.215±0.235	4.010±0.237	6.442	0.371
103	4.329±0.389	4.127±0.390	6.629	0.621
104-Ru	4.445±0.248	4.244±0.250	6.818	0.391
105	4.089±0.376	3.922±0.377	6.300	0.600
106-Ru	3.732±0.217	3.600±0.219	5.783	0.343
107			5.10	1.31
108			4.58	1.16
109			3.19	0.82
110			2.02	0.51
111			1.19	0.30
112			0.67	0.17
113			0.33	0.08
114			0.12	0.03
115-120			0.20	0.10

TABLE XII

MEASURED TOTAL ATOMS, CORRECTED NET ATOMS, AND FISSION YIELDS FOR ^{242}Pu-CAPSULE 22

	HEAVY MASS PEAK			
Mass No.	Measured Total Atoms x10^{17}	Corrected Net Atoms x10^{17}	Fission Yield	σ
121-124	0.10 ±0.05	0.09 ±0.05	0.13	0.07
125-Sb	0.040±0.004	0.035±0.004	0.051	0.006
126	0.10 ±0.02	0.09 ±0.02	0.13	0.03
127	0.23 ±0.04	0.21 ±0.04	0.30	0.06
128	0.45 ±0.07	0.42 ±0.07	0.60	0.11
129	0.83 ±0.13	0.78 ±0.13	1.11	0.18
130	1.40 ±0.21	1.32 ±0.21	1.88	0.30
131-Xe	2.268±0.016	2.142±0.021	3.067	0.027
132-Xe	3.289±0.019	3.115±0.026	4.461	0.034
133-Cs	4.972±0.024	4.743±0.033	6.792	0.051
134-Xe	5.457±0.035	5.214±0.042	7.467	0.060
135-Cs	5.114±0.020	4.867±0.032	6.969	0.049
136-Xe	5.044±0.034	4.814±0.041	6.894	0.058
137-Cs+Ba	4.650±0.024	4.434±0.033	6.349	0.049
138-Ba	4.578±0.063	4.378±0.066	6.269	0.092
139-La	4.336±0.115	4.156±0.117	5.952	0.159
140-Ce	4.077±0.056	3.904±0.059	5.591	0.075
141	3.742±0.198	3.577±0.199	5.122	0.268
142-Ce	3.406±0.047	3.249±0.049	4.653	0.063
143-Nd	3.347±0.014	3.205±0.020	4.589	0.033
144-Nd+Ce	3.109±0.011	2.988±0.017	4.279	0.029
145-Nd	2.472±0.008	2.373±0.012	3.399	0.023
146-Nd	2.116±0.007	2.035±0.011	2.914	0.020
147-Sm	1.726±0.008	1.661±0.011	2.379	0.019
148-Nd	1.461±0.008	1.408±0.010	2.016	0.016
149-Sm	1.160±0.004	1.119±0.006	1.602	0.011
150-Nd	0.957±0.007	0.925±0.008	1.324	0.013
151-Sm	0.722±0.003	0.697±0.004	0.997	0.007
152-Sm	0.557±0.003	0.538±0.003	0.770	0.006
153	0.433±0.044	0.419±0.044	0.601	0.063
154-Sm	0.310±0.002	0.301±0.002	0.431	0.004
155-160	0.64 ±0.13	0.63 ±0.13	0.90	0.18
Σ	73.093±0.430	69.833±0.525	99.988	

TABLE XII (Cont'd)

MEASURED TOTAL ATOMS, CORRECTED NET ATOMS, AND FISSION YIELDS FOR ^{242}Pu-CAPSULE 22

LIGHT MASS PEAK

Mass No.	Measured Total Atoms x10^{17}	Corrected Net Atoms x10^{17}	Fission Yield	σ
75-82	0.33 ±0.07	0.31 ±0.07	0.44	0.09
83-Kr	0.135±0.001	0.125±0.001	0.179	0.002
84-Kr	0.257±0.001	0.241±0.002	0.345	0.003
85-Kr+Rb	0.243±0.004	0.224±0.004	0.321	0.006
86-Kr	0.402±0.002	0.377±0.003	0.540	0.005
87-Rb	0.476±0.008	0.442±0.009	0.633	0.013
88-Sr	0.628±0.004	0.585±0.006	0.838	0.008
89	0.822±0.055	0.767±0.055	1.099	0.079
90-Sr+Zr	1.015±0.007	0.950±0.009	1.360	0.014
91-Zr	1.330±0.033	1.250±0.034	1.789	0.049
92-Zr	1.595±0.035	1.496±0.036	2.143	0.052
93-Zr	2.084±0.046	1.960±0.048	2.806	0.068
94-Zr	2.283±0.050	2.144±0.052	3.070	0.074
95-Mo	2.680±0.022	2.526±0.027	3.617	0.039
96-Zr	3.143±0.070	2.985±0.072	4.274	0.103
97-Mo	3.282±0.026	3.107±0.031	4.449	0.046
98-Mo	3.542±0.024	3.357±0.030	4.807	0.045
99	4.022±0.207	3.820±0.208	5.471	0.299
100-Mo	4.501±0.038	4.284±0.044	6.134	0.067
101-Ru	4.443±0.239	4.225±0.241	6.050	0.335
102-Ru	4.767±0.256	4.546±0.258	6.510	0.359
103	4.890±0.433	4.671±0.434	6.688	0.615
104-Ru	5.016±0.270	4.799±0.272	6.871	0.379
105	4.613±0.418	4.433±0.419	6.347	0.595
106-Ru	4.214±0.237	4.071±0.239	5.829	0.333
107			5.09	1.31
108			4.57	1.16
109			3.19	0.82
110			2.01	0.51
111			1.19	0.30
112			0.67	0.17
113			0.33	0.08
114			0.12	0.03
115-120			0.20	0.10

TABLE XIII

SUMMARY OF ^{242}Pu FAST REACTOR FISSION YIELDS

HEAVY MASS PEAK

Mass No.	CAPSULE 9	CAPSULE 22	$\bar{X}$	σ
121-124	0.15	0.13	0.14	0.08
125-Sb	0.059	0.051	0.055	0.006
126	0.13	0.13	0.13	0.03
127	0.26	0.30	0.28	0.06
128	0.53	0.60	0.56	0.10
129	1.00	1.11	1.06	0.17
130	1.77	1.88	1.83	0.29
131-Xe	3.111	3.067	3.089	0.024
132-Xe	4.525	4.461	4.493	0.035
133-Cs	6.863	6.792	6.827	0.046
134-Xe	7.541	7.467	7.504	0.051
135-Cs	6.995	6.969	6.982	0.043
136-Xe	6.948	6.894	6.921	0.051
137-Cs+Ba	6.330	6.349	6.340	0.044
138-Ba	6.168	6.269	6.219	0.069
139-La	6.181	5.952	6.067	0.124
140-Ce	5.529	5.591	5.560	0.068
141	5.075	5.122	5.098	0.263
142-Ce	4.621	4.653	4.637	0.057
143-Nd	4.608	4.589	4.598	0.032
144-Nd+Ce	4.291	4.279	4.285	0.028
145-Nd	3.416	3.399	3.407	0.022
146-Nd	2.930	2.914	2.922	0.019
147-Sm	2.381	2.379	2.380	0.017
148-Nd	2.021	2.016	2.018	0.016
149-Sm	1.602	1.602	1.602	0.010
150-Nd	1.332	1.324	1.328	0.013
151-Sm	0.996	0.997	0.997	0.007
152-Sm	0.770	0.770	0.770	0.006
153	0.600	0.601	0.600	0.062
154-Sm	0.429	0.431	0.430	0.004
155-160	0.84	0.90	0.87	0.18

TABLE XIII (Cont'd)

SUMMARY OF ^{242}Pu FAST REACTOR FISSION YIELDS

LIGHT MASS PEAK

Mass No.	CAPSULE 9	CAPSULE 22	$\bar{X}$	σ
75-82	0.43	0.44	0.44	0.09
83-Kr	0.180	0.179	0.179	0.001
84-Kr	0.344	0.345	0.344	0.002
85-Kr+Rb	0.324	0.321	0.323	0.005
86-Kr	0.545	0.540	0.542	0.004
87-Rb	0.612	0.633	0.623	0.011
88-Sr	0.834	0.838	0.836	0.007
89	1.099	1.099	1.099	0.081
90-Sr+Zr	1.364	1.360	1.362	0.012
91-Zr	1.824	1.789	1.807	0.048
92-Zr	2.214	2.143	2.178	0.056
93-Zr	2.831	2.806	2.819	0.072
94-Zr	3.199	3.070	3.134	0.081
95-Mo	3.645	3.617	3.631	0.036
96-Zr	4.310	4.274	4.292	0.110
97-Mo	4.451	4.449	4.450	0.041
98-Mo	4.877	4.807	4.842	0.043
99	5.470	5.471	5.471	0.296
100-Mo	6.064	6.134	6.099	0.059
101-Ru	6.006	6.050	6.028	0.335
102-Ru	6.442	6.510	6.476	0.360
103	6.629	6.688	6.659	0.614
104-Ru	6.818	6.871	6.844	0.378
105	6.300	6.347	6.324	0.587
106-Ru	5.783	5.829	5.806	0.328
107	5.10	5.09	5.10	1.31
108	4.58	4.57	4.57	1.16
109	3.19	3.19	3.19	0.82
110	2.02	2.01	2.01	0.51
111	1.19	1.19	1.19	0.30
112	0.67	0.67	0.67	0.17
113	0.33	0.33	0.33	0.08
114	0.12	0.12	0.12	0.03
115-120	0.20	0.20	0.20	0.10

VI. ERROR ANALYSIS

The standard deviation associated with each reported fission yield is given in Tables VI-VIII and XI-XIII and includes allowances for known sources of systematic errors. The standard deviation was calculated by first approximating the functions used to calculate the fission yields, by the linear terms of the Taylor series expansion, and then applying the usual method of calculating the standard deviation of a linear sum of random variables. The procedure consisted of five distinct steps.

1) The propagated standard deviation of the measured number of total atoms of each element was calculated. This computation included the systematic effect of uncertaintyin the spike concentrations, the random mass spectrometer errors in the spike, natural, fission product, and mixed spike-fission product isotopic fractions, and the Kr and Xe spike volume uncertainties. One recognized uncertainty not included is the systematic error in the element concentration resulting from systematic errors in the mass spectrometer.

2) The standard deviation of the total number of atoms in the heavy peak was calculated using the above standard deviations for the measured total atoms and estimated total atoms.

3) For each capsule, the standard deviations were calculated for a) the <u>total</u> and <u>net</u> number of atoms of each fission product isotope, b) the total number of net fissions, and c) each fission yield. This included using the standard deviations of the total number of fissions, the atoms of each fission product element, and the fractional isotopic composition of the specific element. Also included, were the estimated uncertainties in the fraction of the total fissions resulting from ^{239}Pu and ^{241}Pu, and the uncertainties in the individual fission yields of ^{239}Pu and ^{241}Pu. The standard deviation of the isotopic fractions includes the random mass spectrometer errors and the estimated systematic uncertainty in the mass spectrometer.

4) The standard deviations of the total number of fissions, atoms of each element, atoms of each fission product isotope, and the fission yields for each capsule, were calculated using the observed random error in the element yields.

5) Finally, the standard deviation of the average fission yield from all capsules was calculated considering the effects of these systematic and random errors.

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