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An Examination of Uranium-233 Fission-Yield Data

The uranium-233 thermal-neutron fission-yield data as found in the literature are incomplete, unverified, and not very well organized. The reported fission yields are the extensive early radiochemical determinations in Canada⁽¹⁾ and the United States;⁽²⁾ and the recent limited mass-spectrometric determinations of Steinberg, Glendenin, Inghram, and Hayden;⁽³⁾ Fleming, Tomlinson, and Thode;⁽⁴⁾ and Melaika, Parker, Petruska, and Tomlinson.⁽⁵⁾ Where data from both old and new studies are available, the disagreement is often considerable. Usually the old values are low, even though certain of the old values are used to normalize the relative yields found in the newer work.

The results of these investigators are given in Table 1 and in Figure 1. Estimates of the yields of the chains not reported can be made by drawing a smooth curve through the points representing the best data. Such a curve is the solid line in Figure 1. However, this is unsatisfactory. If one sums the yields obtained this way, the light fraction adds up to 100.5, the heavy to 91.7. It appears that the light mass peak is rather well defined by the work of Steinberg, et. al.,⁽³⁾ but good data are rather incomplete for the heavy fraction.

The high-yield portion of the heavy-mass peak is determined largely by the mass spectrometric determinations of Fleming, et. al.⁽⁴⁾ on the isotopes of xenon and cesium. The dip at 135 and sharp peak at 136 are probably not real; no correction has been made for burnout of Xe^{135} during the irradiation. These investigators irradiated two samples at different (unmonitored) fluxes in the NRX. The values used here are from the low-flux sample; the effect is more exaggerated in the other sample. Because of the high probability of fine structure in this region (reflected in the low-mass peak) it is impossible to smooth out the curve in this region; it

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Table 1
Summary of U²³³ Fission Yields

Mass No.	Yield Values (%) Reported in Reference					Recommended Mass Yield
	(1)	(2)	(3)	(4)	(5) Normalized	
77		0.018				0.018
78						0.03
79						0.12
80						0.3
81						0.5
82						0.7
83		0.70		1.20		1.20
84				1.96		1.96
85						2.7
86				3.33		3.33
87						4.0
88						4.7
89	4.1	5.6	6.5			6.5
90	3.7					6.5
91	4.1		6.5			6.5
92			6.7			6.7
93			7.1			7.1
94			6.8			6.8
95	3.9	5.7	6.1			6.1
96			5.6			5.6
97			5.3			5.3
98			5.1			5.1
99		4.7	5.1			5.1
100			4.4			4.4
101			3.0			3.0
102		0.85	2.5			2.5
103	0.21		1.6			1.6
104			1.0			1.0
105						0.6
106	0.064	0.24				0.24
107						0.1
108						0.07
109		0.047				0.047
110						0.035
111		0.022				0.022
112		0.014				0.014
113						0.015

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Table 1 (Cont.)

Mass No.	Yield Values (%) Reported in Reference					Recommended Mass Yield
	(1)	(2)	(3)	(4)	(5) Normalized	
114						0.015
115		0.017				0.017
116						0.015
117						0.015
118						0.015
119						0.01
120						0.01
121		0.018				0.01
122						0.01
123	0.0025					0.0025
124						0.03
125	0.060	0.054				0.24
126						0.6
127	0.067	0.094				1.0
128						1.6
129	0.22					2.5
130						3.0
131	2.4	2.7		3.59		3.6
132	4.9					4.9
133				5.93		5.9
134				6.28		6.3
135				4.74		4.7
136		1.7		8.51		8.5
137	1.8			6.87		6.9
138						6.8
139						6.8
140	6.7	6.0				6.7
141						6.5
142						6.5
143					4.6	4.6
144	2.2	3.4				3.4
145					2.7	2.7
146					2.1	2.1
147	0.6				1.46	1.46
148					1.04	1.04
149					0.52	0.52
150					0.41	0.41
151					0.22	0.22
152					0.145	0.145
153		0.078				0.078
154					0.032	0.032

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- Grummitt and Wilkinson⁽¹⁾
- NRES-IV-9⁽²⁾
- Steinberg, et. al.⁽³⁾
- Fleming, et. al.⁽⁴⁾
- Melaika, et. al.⁽⁵⁾ normalized
- Curve through data
- Suggested revision

Fig. 1 MASS YIELDS OF U²³³ THERMAL-NEUTRON FISSION PRODUCTS

appears possible, however, to take the sum of the yields cited for 135 and 136 as correct. These data are normalized by the value of Grummitt and Wilkinson⁽¹⁾ for I^{132} ; the yields obtained reflect the light-mass peak reasonably well except for the 135-136 discrepancy.

The use of the data of Melaika, et. al.⁽⁵⁾ for filling out the high-mass end of the distribution requires some explanation. These authors obtained yields, given in Table 2, for the neodymium isotopes relative to Nd^{143} and the samarium isotopes relative to Sm^{149} . They refuse to normalize their yields on the rather reasonable ground that the absolute yields available are not good enough. There are early conflicting radiochemical yields in this region at 144 and 147 reported by the Canadians⁽¹⁾ and at 144 and 153 by the U. S. workers.⁽²⁾ The latter have been used to normalize the relative yields for Table 1 and Figure 1 for two reasons. The ratio of the two Canadian values does not check the ratio of the mass spectrometric value at 144 to the interpolated value for 147 in a plot of the mass spectrometric neodymium yields, and the somewhat higher U. S. yields give a good match to the complementary portion of the low-mass curve.

If the remainder of the high-mass curve is filled out by connecting the available points with a smooth curve as in Figure 1, the yields, as already pointed out, add up to only 91.7%. The discrepancy can be explained if the two peaks are compared. If the sum of the masses of the complementary products is 231 (this assumes $\nu = 3$), the curves match within the accuracy of the data except at masses 125-130 and 141-142. It is very probable that the early measurements in the 125-130 region gave only a part of the mass yield, since the decay is rather complex, involving long-lived isomeric states of tin and tellurium isotopes. For this reason, it is probably better to use in this region the yield of mass 231-A for the yield of mass A. At masses 141 and 142 there are no experimental yield values. The smooth-curve values are low, since there is a shoulder at 6.5% at the complementary masses 89 and 90 in the low-mass fraction. Thus, it

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Table 2

Yields Obtained by Melaika, et. al. (5)

Mass No.	Relative Nd Yields	Relative Sm Yields	Normalized % Yield
143	1.00		4.6
144	0.779		3.4 ^x
145	0.587		2.7
146	0.441		2.1
147	0.32 [*]	2.81	1.46
148	0.224		1.04
149		1.000	0.52
150	0.089		0.41
151		0.422	0.22
152		0.278	0.145
153		0.15 [*]	0.078 ^x
154		0.061	0.032

* Interpolated value read from smooth curve.

^x Early radiochemical value (2) used to normalize.

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is better to use 6.5% as the estimated yields of mass 141 and 142 rather than the smooth-curve values. These suggested estimated yields for these two regions are given in the recommended mass yields in Table 1 and by the broken line in Figure 1. These yields then sum to 99.8% for the high-mass group. The proximity of the sum to 100% confirms the reasonableness of the estimates made.

Some other results of value can be obtained from the fission yield studies. Fleming, et. al.,⁽⁴⁾ find that the long-lived Kr^{85} has a yield of 0.583% and a half life of 10.27 years. This is less than the mass yield because most of the mass 85 chain bypasses this nuclide. If it is assumed that all of the 85 mass fission products decay through the 4.4 hour isomeric state of Kr^{85} and the known fraction (23%) of this decays through the long-lived state, a mass yield of 2.6% is obtained, in good agreement with the smooth-curve value.

Melaika and coworkers were able to observe the burnup of Sm^{149} , since Sm^{150} is shielded and is formed to little or no extent in fission. In their samarium abundances, the sum of masses 149 and 150 measured the yield of 149; the amount of 150 measured the neutron capture in 149. Using a boron monitor, they found $66,200 \pm 2,500$ barns for the capture cross section of Sm^{149} . For Sm^{151} they find a 12,000 barn cross section and a 93 year half life.

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