SPONTANEOUS FISSION IN VERY NEUTRON-RICH ISOTOPES*

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Par, a test of a nuclear explosive designed to produce transuranic nuclides, was fired underground at the Atomic Energy Commission's Nevada test site on 9 October 1964, and gave an explosive yield of 30 kilotons. The debris was recovered by drilling, and samples were analyzed for isotopes produced by multiple neutron captures in the U^{238} target. The radiochemical analysis, following techniques described previously,[1] was done concurrently by Argonne National Laboratory, Los Alamos Scientific Laboratory, Lawrence Radiation Laboratory (Berkeley), and Lawrence Radiation Laboratory (Livermore). The mass yields listed in Table I are derived from the total measured atoms of nuclides, each of which may be unambiguously described as a product of multiple neutron capture in the U^{238} target. Yields of species with masses in the range $A = 239$-244 also were measured; the interpretation of these yields is more difficult since corrections must be made for nuclides produced in the device in regions of lower neutron flux and for residual nuclides, e.g. Pu^{241}, which are identical to the observed products of multiple neutron capture in the U^{238} target.

Neutron-capture cross sections deduced from previous experiments[2] were used in mass-yield calculations similar to those carried out for the Mike[3] experiment. Two assumptions, different from previous calculations, were made: (1) No fission occurs during the capture process, and (2) no spontaneous fission occurs during the subsequent β decay. The experimental yield curve (Fig. 1) lies between calculated yield curves for fluxes of 7 and 8 moles n/cm^2. The flux obtained in Par is a factor of 1.5 to 3 better than previous experiments.[1,3,4]

The assumption that no fission takes place during the capture process is apparently a good

Table I. Relative yields of heavy elements from Par device.

Mass number	Nuclide measured	Method	Laboratory[a]	Relative number of atoms[b]
245	Cm^{245}	Mass spectrometry	ANL	1.000
	Pu^{245}-Am^{245}	Beta counting	LASL, LIV	
246	Cm^{246}	Mass spectrometry	ANL	$(8.5\pm0.4)\times10^{-1}$
	Pu^{246}-Am^{246}	Beta counting	LASL, LIV	
247	Cm^{247}	Mass spectrometry	ANL	$(1.1\pm0.05)\times10^{-1}$
248	Cm^{248}	Mass spectrometry	ANL	$(5.1\pm0.2)\times10^{-2}$
249	Bk^{249}-Cf^{249}	Alpha counting	LASL, BERK	$(9\pm4)\times10^{-3}$
250	Cm^{250}	Mass spectrometry	ANL	$(4.1\pm0.2)\times10^{-3}$
251	Cf^{251}	Alpha counting	BERK	$\leq1.3\times10^{-3}$
252	Cf^{252}	Alpha counting	BERK, LASL, ANL, LIV	$(2.2\pm0.2)\times10^{-4}$
253	Cf^{253}-Es^{253}	Alpha counting (Es)	BERK, LASL, ANL, LIV	$(1.1\pm0.1)\times10^{-4}$
254	Cf^{254}	Fission counting	BERK, LASL, ANL, LIV	$(1.2\pm0.1)\times10^{-5}$
255	Es^{255}-Fm^{255}	Alpha counting (Fm)	BERK, LASL, ANL, LIV	$(4.3\pm0.2)\times10^{-6}$
256	Cf^{256}	Fission counting[c]	ANL	$(2.6\pm0.4)\times10^{-7}$
257	Fm^{257}	Alpha counting	LASL, ANL, BERK	$(5.6\pm1.0)\times10^{-8}$

[a]These data were collected by groups of scientists at four laboratories. The laboratories are abbreviated as follows: ANL, Argonne National Laboratory; LASL, Los Alamos Scientific Laboratory; BERK, Lawrence Radiation Laboratory, Berkeley; LIV, Lawrence Radiation Laboratory, Livermore.
[b]The relative yields are normalized to the abundance of Cm^{245}.
[c]Cf^{256} is a new nuclide discovered by the group at ANL who will report its properties in a later publication.

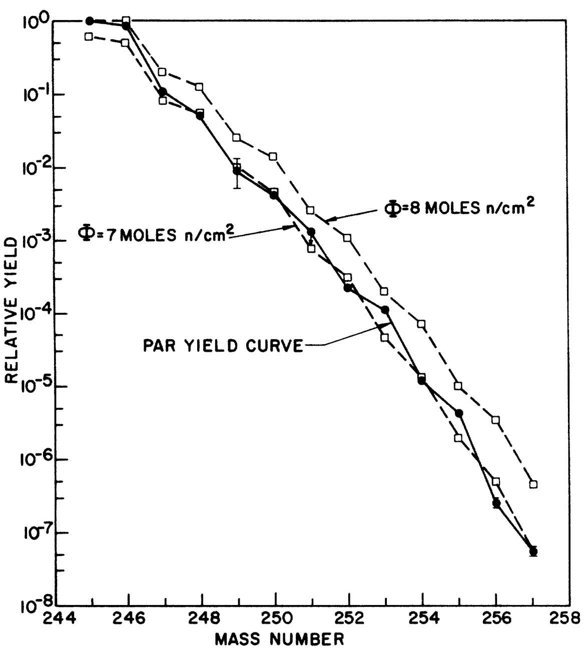

FIG. 1. Mass-yield data for Par experiment. Theoretical mass-yield calculations were done with capture cross sections deduced from previous experiments[2] and assumed fluxes of seven and eight moles of neutrons per square centimeter.

one, since the odd-mass isotopes are well represented. The even masses starting with $A = 248$, however, appear to be depleted. One possible explanation for this depletion is that some spontaneous fission takes place in the β-decay chain. Table II shows implied spontaneous fission half-lives assuming[3] all β decays in the chain are allowed transitions with a $\log(ft_{1/2}|M|^2) = 4.2$. For example, in the mass-252 chain, if all the fission takes place while the isobar is U^{252}, its half-life is 11 sec, while Pu^{252} and Cm^{252} do not fission at all. Similarly, if the Pu isobar is the one which fissions, it has a half-life of 70 sec, and U^{252} and Cm^{252} do not fission. In all likelihood, each element in a given mass chain contributes to the apparent depletion. If this interpretation is correct, comparison of Par with a subsequent experiment using Pu as a target would experimentally determine the spontaneous-fission half-lives for U^{248}, U^{250}, U^{252}, U^{254}, and U^{256}.

Diamond and Fields of Argonne National Laboratory have proposed another possible explanation for the reversal of the odd-even effect, postulating that a proton may be either gained or lost early in the neutron-capture chain, and that further capture then takes place in an odd-Z element. This would have the effect of reversing the ratios as observed.

A more complete treatment of this subject, as well as other results of the Par experiment, will be published later. It should be emphasized that Par is the first experiment on which a continuous mass-yield curve has been obtained. Such a continuous curve is essential both for cross-section estimates[2] and for spontaneous-fission estimates. The authors wish to acknowledge the efforts of many co-workers at the participating laboratories in collecting the data shown in Table I.

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[1]R. W. Hoff and D. W. Dorn, Nucl. Sci. Eng. 18, 110 (1964).

[2]J. S. Ingley, to be published.

[3]D. W. Dorn, Phys. Rev. 126, 693 (1962).

[4]D. W. Dorn, in Proceedings of the Third Plowshare Symposium, 21-23 April 1964, U. S. Atomic Energy Commission Technical Information Division Report No. TID 7695, Vol. I, pp. 11-20 (unpublished).

Table II. Implied spontaneous fission half lives (sec).

Element \ Mass chain	248	250	252	254	256
Apparent depletion (%)	30	35	65	65	80
U	⩾160	⩾70	⩾11	⩾7	⩾2
Pu	⩾3000	⩾670	⩾70	⩾30	⩾7
Cm			⩾5800	⩾750	⩾20