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†Work supported in part by a grant from the National Science Foundation.

‡Operated by Union Carbide Corporation for the U. S. Atomic Energy Commission.

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PHYSICAL REVIEW C VOLUME 5, NUMBER 1 JANUARY 1972

Identification of ^{94}Kr and ^{143}Xe, and Measurement of γ-Ray Spectra and Half-Lives of Nuclides in the Mass Chains 93, 94, and 143*

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(Received 16 September 1971)

Fission-produced nuclides ^{94}Kr and ^{143}Xe have been measured directly using on-line mass separation. The half-lives derived from the β-decay curve are 0.20 ± 0.01 and 0.3 ± 0.03 sec, respectively. γ-ray spectra in the mass chain 93 have been measured and various γ peaks were assigned to the individual nuclides.

Identification of short-lived nuclides produced in fission and knowledge of their nuclear properties are essential for determining independent fission yields and for a better understanding of the fission process. So far only those fission-produced krypton and xenon isotopes having half-lives longer than 1 sec have been identified.[1-4] The shorter-lived ones have escaped measurement because of the difficulty of achieving the extreme rapidity required in separating them from the fissioning source and transporting them to the counting assembly. The shortest-lived (and thus heaviest) ones measured directly so far were ^{93}Kr and ^{142}Xe.[2,5]

By using gas sweeping over a short distance between a fissioning ^{235}U source and the ion source

of a separator, the detection of shorter-lived noble-gas isotopes was possible. The krypton and xenon produced in fission of ^{235}U were extracted from an emanating source containing a mixture of 9 g U_3O_8 (93.3% enriched in ^{235}U) and barium stearate, covered by a particle filter (stainless steel, 400 mesh). The target was swept by a steady current of helium (containing 2–3% of either Kr or Xe, according to the element being investigated) which transferred the gaseous fission products through a connecting tube 2.8 cm in diameter and 9 cm long, into the plasmatron ion source (modified Nielsen type) of the Soreq On-Line Isotope Separator.[6] The target was irradiated in a thermal-neutron flux of approximately 2×10^8 $n\,cm^{-2}\,sec^{-1}$ from an external beam tube of the Israel Research Reactor-1. The irradiation time was controlled by a neutron shutter operated by compressed air. The time required for full opening or closing of the shutter was about 100 msec. The beam of a single separated isotope was collected on a conducting (to eliminate electrostatic-charge buildup) moving tape, with adjustable velocity in the range 0–6 cm/sec.

The mass assignment was obtained by fixing a stable isotope between two stabilizing pins, at a calculated distance from the measuring position where the desired mass beam should hit. The distances between masses were calibrated using a photographic film and verified by counting individual isotopes. The mean transfer time between the target and collector was about 0.7 sec, as calculated from the rate of accumulation of activity, using a computer program which takes into account the half-lives in question.[7]

The half-lives were determined by analyzing the β-decay curves. In order to reduce the background, the β rays were counted by a telescopic counter consisting of a 20- and a 40-mm plastic scintillator (NE-102), and the coincidence pulses were multiscaled. The γ-ray spectrum was taken simultaneously using a 30-cm^3 Ge(Li) detector connected to a 4096-channel pulse-height analyzer working either in 8×512 or 16×250 sections.

The system was operated in cycles of irradiation and decay, and the tape was moved at the end of each cycle in order to remove the residual activity. At the end of each irradiation, the ion beam was cut off. The system was programmed electronically to operate automatically, the times of irradiation and counting being reproducible within ±0.01 sec.

The half-lives were determined by resolving the β-decay curve of the separated isotope and its radioactive daughters using a computer program QMBLSQ.[8] The results are summarized in Table I. The principal γ rays detected are summarized in Table II. The assignment of the γ-ray peaks was made by following the decay of the spectrum for short time periods. Figure 1 is an example of γ-ray spectra obtained for mass chain 93.

^{94}Kr has not been observed previously, but a

TABLE I. Half-lives of noble-gas isotopes and their daughters of masses 93, 94, 141, and 143.

Isotope	This work	Half-life (sec) Previous direct measurements	Previous indirect measurements
^{93}Kr	1.2 ± 0.1	1.19 ± 0.05 [a] 1.289 ± 0.012 [c]	1.17 ± 0.04 [b]
^{93}Rb	5.8 ± 0.1	5.86 ± 0.13 [c] 5.89 ± 0.04 [e] 5.60 ± 0.05 [a]	5.1 ± 0.3 [d]
^{94}Kr	0.20 ± 0.01	···	≤1 [b]
^{94}Rb	2.8 ± 0.1	2.67 ± 0.04 [e]	2.9 ± 0.3 [f]
^{141}Xe	1.81 ± 0.10	1.720 ± 0.013 [c] 1.8 ± 0.2 [g]	1.70 ± 0.05 [b]
^{143}Xe	0.30 ± 0.03	···	0.96 ± 0.02 [b] 1.1 ± 0.3 [b]
^{143}Cs	1.7 ± 0.1	1.69 ± 0.13 [h]	2.0 ± 0.4 [i]

[a] See Ref. 5.
[b] See Ref. 9.
[c] See Ref. 2.
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TABLE II. γ-ray energies and relative intensities for nuclides of mass 93.

Isotope	This work E_γ (keV)	This work Relative intensity	Previous measurements E_γ (keV)	Previous measurements Relative intensity
Kr	182 ± 2	0.10		
	253 ± 2	1.00	257 [a]	
	267 ± 2	0.29		
	323 ± 2	0.49		
Rb	215 ± 2	0.30		
	431 ± 2	1.00		
Sr	169 ± 2	0.29	178 [b]	0.17 [b]
	260 ± 2	0.15	255	0.13
	590 ± 2	1.00	600	1.00
	710 ± 3	0.58	710	0.35
	876 ± 3	0.55	880	0.76
	889 ± 3	0.39		

[a] See Ref. 14. [b] See Ref. 13.

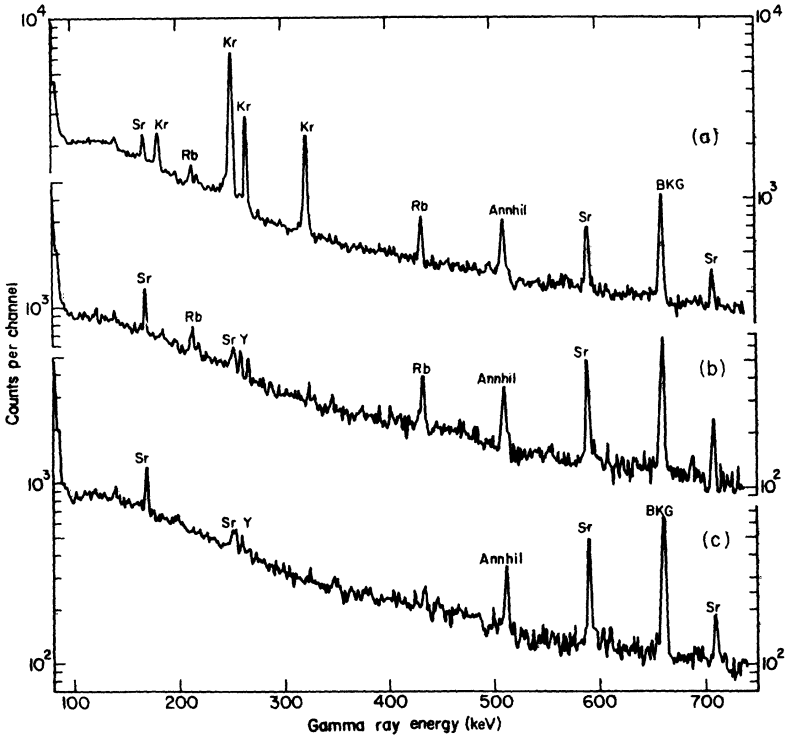

FIG. 1. Time-dependent γ-ray spectra of mass 93: (a) at end of irradiation; (b) 12 sec after end of irradiation; and (c) 24 sec after end of irradiation.

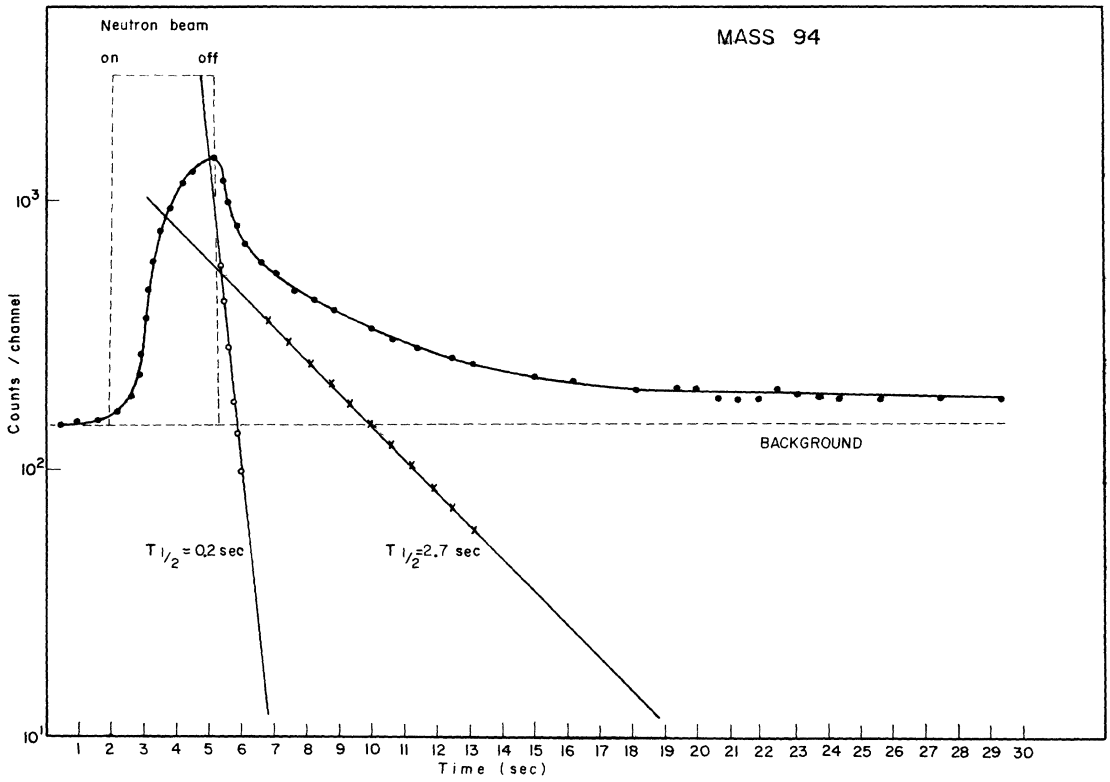

FIG. 2. Growth and decay of β activity at $A = 94$ using pulsed (3-sec) irradiations.

half-life of less than 1 sec was estimated from the distribution of the 20-min ^{94}Y[9] deposited along a charged collector from the noble gases swept from a fission source. Our direct β measurement and resolution of the resulting decay curve permit unambiguous determination of the half-life (Fig. 2). The initial activities of Kr and its Rb daughter, as deduced by extrapolation of the experimental data, fit the genetic relationship calculated on the basis of the irradiation time and the ratio of the half-lives. Predictions based on the semiempirical linear dependence[10] of $\ln T_{1/2}$ on the mass number, for odd and even masses separately, give a value of about 0.12 sec, which is quite close to the experimental value. The half-life of ^{94}Rb agrees well with the previously reported value.[11]

Inspecting the γ-ray spectrum in mass chain 94, we found a prominent γ peak of energy 833 keV, which is in good agreement with the value predicted for the $2^+ \rightarrow 0^+$ transition in ^{94}Sr based on the systematics for even-even nuclei.[12] However, due to rather poor counting statistics, the half-life of that transition has not been followed.

The γ spectrum of ^{93}Kr has not been published previously, but the half-life of ^{93}Kr has been evaluated by multiscaling γ energy bands[2] which, in general, fit the peaks identified in our spectrum. The spectrum of ^{93}Sr agrees (within ± 10 keV) with that published,[13] but the 880-keV peak[13] is clearly a doublet of 876 and 889 keV (Fig. 1). The most prominent γ ray observed in the ^{93}Kr spectrum, at 253 keV, is identified with the 57-μsec isomeric transition of ^{93}Rb.[14] The half-lives of ^{93}Kr and ^{93}Rb are in good agreement with the published values.

In the decay of mass chain 143 a short-lived component of half-life 0.3 ± 0.03 sec is clearly observed and has been assigned to ^{143}Xe. However, from the ratios of the ^{143}Cs/^{143}Xe activities, it seems as if another Xe isomer might exist with a half-life close to that of ^{143}Cs, which accounts for about 80% of the ^{143}Xe produced directly in fission. This undetected isomer, if it exists, would have a half-life in better agreement with the 0.96-sec value obtained from indirect measurements.[9] Such a half-life could not be resolved from the β-decay curve, because its value is too close to the other genetically related component. X-ray and γ-ray multiscaling may solve this problem but higher intensities are needed.

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*Part of a study carried out by Mrs. H. Feldstein towards a Ph.D. degree, Hebrew University, Jerusalem.

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