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DECAY CHARACTERISTICS OF ^{84}Se

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Abstract—The nuclide ^{84}Se has been identified among the fission products of ^{235}U. The selenium fraction was obtained by solvent extraction from HBr into 2,6-dimethyl-4-heptanone. The radiations were studied by β- and γ-ray scintillation spectroscopy, by γ-ray spectroscopy with a Ge(Li) detector, and by coincidence measurements. The decay of ^{84}Se shows a half life of $3{\cdot}1 \pm 0{\cdot}2$ min and involves a single β transition of $1{\cdot}4 \pm 0{\cdot}05$ MeV and a coincident γ ray of $407{\cdot}7 \pm 0{\cdot}5$ keV.

INTRODUCTION

THE NUCLIDE ^{84}Se has received the attention of previous workers [1–3], whose studies were confined to measurements of its half life and to identification through its radioactive descendent, 31·8-min ^{84}Br. No spectroscopic studies have been reported, perhaps due to the lack of a fast radiochemical technique for isolation of radiochemically pure selenium samples from fission products. A modified version of the solvent extraction procedure developed by Kuroda [4] makes it possible to obtain radiochemically pure selenium samples from fission products in about 5 min. This paper summarizes a study of the decay characteristics of ^{84}Se isolated by this technique.

EXPERIMENTAL PROCEDURES

Sample preparation

The fission products were prepared by irradiating $UO_2(NO_3)_2.6H_2O$ or a solution of enriched (90% ^{235}U) uranium in dilute nitric acid. Irradiations were made in the pneumatic tube facilities of the Ford Nuclear Reactor at the University of Michigan. A typical procedure involved 100 μg of ^{235}U irradiated for 5 min at a thermal neutron flux of $2{\cdot}10^{12}$ n cm^{-2} sec^{-1}. Selenium samples were prepared as follows:

1. The target material was transferred to 20 ml of conc. HBr containing 5 mg each of Te(IV) and Se(IV) carriers. Selenium was extracted by shaking for 30 sec with 20 ml of 2,6-dimethyl-4-heptanone.
2. The organic phase was washed with 10 ml of 1 M NaOH.
3. A few milligrams of iodine (dissolved in the ketone) were added to the organic phase. The phase was washed with 20 ml of an aqueous solution 5% in EDTA (disodium salt), 5% in sodium tartrate, and containing several drops of 3 M $NaHSO_3$.
4. Step 3 was repeated.
5. Selenium was stripped into 10 ml of 6 M HCl and 0·1 g $NaBiO_3$.
6. The HCl phase was diluted to 20 ml, and selenium metal was precipitated by saturating the solution with SO_2.
7. The metal was collected by filtration, yielding a sample 1 cm dia. and 3–4 mg cm^{-2} in thickness.

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1. L. E. Glendenin, *USAEC Rep.* No. CN-2839, cited in Paper 58 of *Radiochemical Studies—The Fission Products*, (Edited by C. D. Coryell and N. Sugarman), National Nuclear Energy Series, Div. IV, Vol. 9. McGraw Hill, New York (1951).
2. R. C. Fix, U. Schindewolf, and C. D. Coryell, *USAEC Rep.* No. AECU-3377 (1956).
3. J. E. Sattizahn, J. D. Knight, and M. Kahn, *J. inorg. nucl. Chem.* **12**, 206 (1960).
4. R. Kuroda, *USAEC Rep.* No. TID-17272 (1962).

Spectroscopic procedures and results

The samples thus prepared contain ^{84}Se plus 18·6-min ^{81}Se, 25-min ^{83}Se, and the bromine daughters 2·41-hr ^{83}Br and 31·8-min ^{84}Br. The activities of the selenium samples from 5 experiments were followed in an end window, gas flow detector, and the decay curves were resolved by least squares analysis. The component assigned to ^{84}Se showed a half period of 3·1 ± 0·2 min. The error quoted includes the standard deviation derived from statistical considerations and an estimate of the systematic errors, the latter being the dominant term.

Gamma-ray spectra were obtained with a 7·6 cm × 7·6 cm NaI(Tl) crystal and with a 10 cm^3 Ge(Li) detector. Figure 1 shows the γ-ray spectra taken at various times with the NaI(Tl) detector.

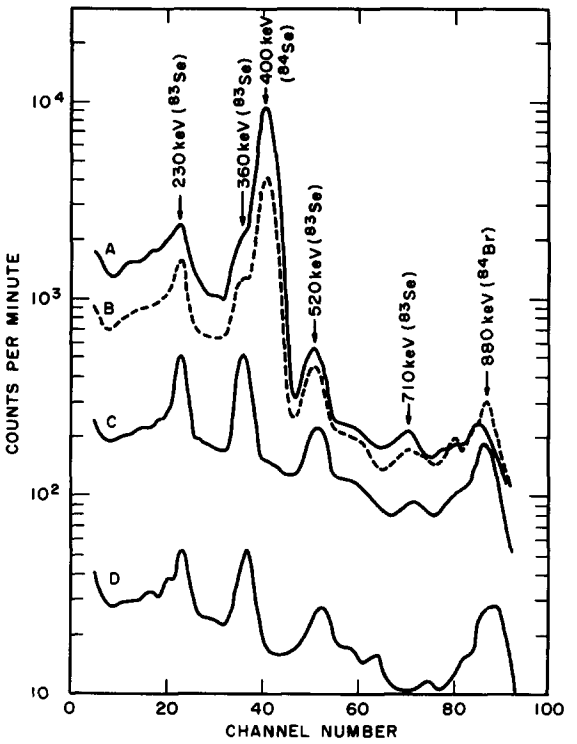

Fig. 1. Gamma-ray spectra of the selenium sample. The source was 5 cm from the face of a 7·6 cm × 7·6 cm NaI(Tl) detector. A 0·9-g cm^{-2} polythylene β absorber was used. The spectra correspond to the following average times after the end of the irradiation: A – 5·5 min, B – 9·5 min, C – 32·5 min, and D – 110 min.

A peak corresponding to 399 ± 5 keV followed a half period of 3·1 min plus a longer lived component due to other γ rays. No other peaks showed a 3·1-min component other than that associated with the 399-keV peak. The spectra obtained with the Ge(Li) detector showed a peak corresponding to 407·7 ± 0·5 keV and which followed a 3·1-min half period. No other features in the vicinity of 400 keV were seen. The Ge(Li) spectra were calibrated with internal standards of ^{203}Hg, ^{198}Au, and ^{137}Cs, and included corrections for nonlinearities in the electronics.

A hollow plastic scintillator[5] was used to obtain β-ray spectra. Time dependent spectra were recorded in order to correct for contributions from the other species present in the samples. The net spectra were analyzed by Fermi-Kurie plots (See Fig. 2). These measurements yielded an end-point energy of 1·4 ± 0·1 MeV. Samples of ^{113}Sn (e^-), ^{137}Cs (e^-), ^{32}P(β) were used for calibrations.

Beta-gamma coincidence measurements were made with the NaI detector, the hollow scintillator,

5. D. G. Gardner and W. W. Meinke, *Int. J. appl. Radiat. Isotopes* **3**, 232 (1958).

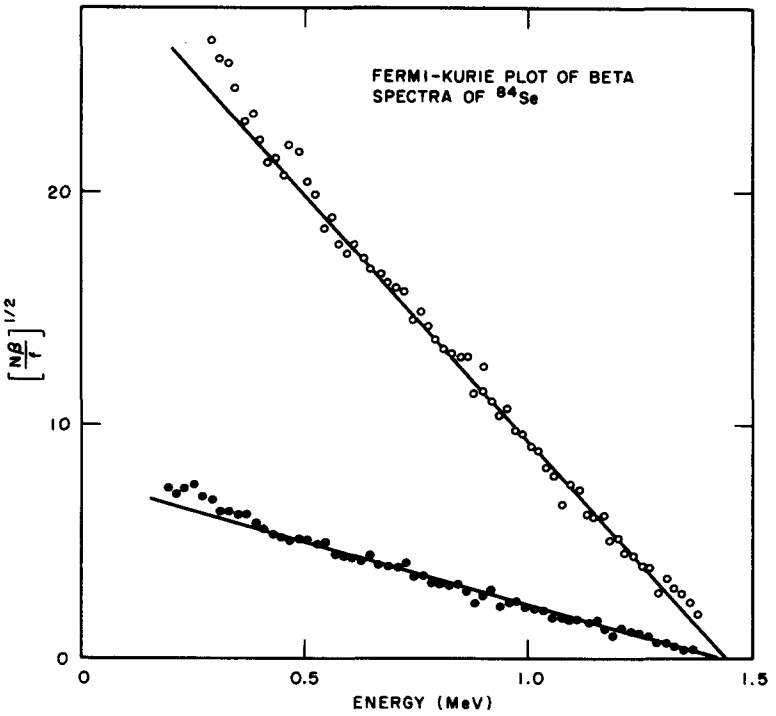

Fig. 2. The open circles show the Fermi-Kurie plot of the net spectrum due to ^{84}Se. The closed circles show the F-K plot of the net spectrum coincident with the 407·7 keV γ ray.

and a coincidence circuit with a resolving time of 3 μsec. Beta spectra coincident with the peak corresponding to 399 keV were obtained as a function of time, and corrections were made as noted above. The net spectra were analyzed (See Fig. 2), and 2 such experiments gave endpoint values of 1·41 and 1·42 MeV.

Gamma-gamma coincidence measurements were performed in a similar manner. No coincidences were observed for a 3·1-min component.

CONCLUSIONS

The data obtained show that ^{84}Se has a half life of 3·1 ±0·2 min and decays predominantly by a (1·41 ± 0·05 MeV beta transition to a (407·7 ± 0·5)-keV level[6] in ^{84}Br. This excited state has a half life of less than 10^{-5} sec and decays to the ground state by a single gamma transition.

The logft value for the 1·41-MeV beta transition is 4·1 ±0·2[7] and indicates that the transition is allowed. If as expected the ground state of ^{84}Se is 0^+, the excited state of ^{84}Br is 0^+ or 1^+. Systematics of γ-ray transition rates[7] indicate that the γ ray is dipole or quadrupole and limit the ground state of ^{84}Br to a spin of 3 or less. The ground state is known[8] to decay to 0 and 2 states of ^{84}Kr with logft values for each transition of 7·7 or log frt values of 8·3. These results limit the assignment for the ground state of ^{84}Br to 0^-, or $1^\pm$ or 2^-.

6. It is not known which of the isomers of ^{84}Br is the true ground state. Here we assume that the 31·8-min state is the ground state, since it does serve as the ground state for this decay chain. The arguments do not depend on this assumption.
7. A. H. Wapstra, G. J. Nijgh, and R. Van Lieshout, *Nuclear Spectroscopy Tables*. North-Holland, Amsterdam (1959).
8. C. M. Lederer, J. M. Hollander, and I. Perlman, *Table of Isotopes*, 6th Edn. Wiley, New York (1967).

Since this is not considered to be a region of deformed nuclei, the conventional (spherical potential) shell model[9] can be used to indicate probable configurations. For neutrons the most probable configurations are $(p_{1/2})^2(g_{9/2})^{-1}$ and $(p_{1/2})(g_{9/2})^{10}$. The last seven protons probably occupy the $2p_{3/2}$ and $1f_{5/2}$ subshells. With these configurations Brennen and Bernstein's coupling rules[10] predict states of spins and parities 1^+, 2^-, $3^\pm$, 4^-, 5^-, and 6^-.

Combining the above model considerations with our experimental results, we conclude that the most probable assignments are 1^+ for the 407·7-keV state of ^{84}Br and 2^- for the 31·8-min ground state of ^{84}Br.

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9. M. G. Mayer and J. H. D. Jensen, *Elementary Theory of Nuclear Shell Structure*. Wiley, New York (1957).
10. M. H. Brennen and A. M Bernstein, *Phys. Rev.* **120**, 927 (1960).