[11]$Z_A - Z$ is the distance from the line of β stability along an isobaric chain.
[12]R. Brandt, in *Proceedings of the Symposium on the Physics and Chemistry of Fission, Salzburg, 1965* (International Atomic Energy Agency, Vienna, Austria, 1965), Vol. 2, p. 329; Radiochim. Acta 16, 148 (1972).
[13]V. P. Crespo, J. B. Cumming, and A. M. Poskanzer, Phys. Rev. 174, 1455 (1968).
[14]E. Hagebø and H. Ravn, J. Inorg. Nucl. Chem. 31, 2649 (1969).
[15]K. Bächmann and J. B. Cumming, Phys. Rev. C 5, 210 (1972).
[16]L. P. Remsberg, F. Plasil, J. B. Cumming, and M. L. Perlman, Phys. Rev. 187, 1597 (1969).
[17]K. Bächmann, J. Inorg. Nucl. Chem. 32, 1 (1970).
[18]N. Sugarman, M. Campos, and K. Wielgoz, Phys. Rev. 101, 388 (1956); N. T. Porile and N. Sugarman, Phys. Rev. 107, 1410 (1957).
[19]J. B. Niday, Phys. Rev. 121, 1471 (1961).
[20]For a general review, see J. M. Alexander, in *Nuclear Chemistry*, edited by L. Yaffe (Academic, New York, 1968), Vol. I, p. 273.
[21]V. P. Crespo, J. B. Cumming, and J. M. Alexander, Phys. Rev. C 2, 1777 (1970).
[22]N. Sugarman, H. Münzel, J. A. Panontin, K. Wielgoz, M. V. Ramaniah, G. Lange, and E. Lopez-Menchero, Phys. Rev. 143, 952 (1966).
[23]J. B. Cumming, unpublished.
[24]L. C. Northcliffe and R. F. Schilling, Nucl. Data A7, 233 (1970).
[25]J. J. Hogan and N. Sugarman, Phys. Rev. 182, 1210 (1969).
[26]J. R. Nix and W. J. Swiatecki, Nucl. Phys. 71, 1 (1965).
[27]L. P. Remsberg, F. Plasil, J. B. Cumming, and M. L. Perlman, Phys. Rev. C 1, 265 (1970).
[28]J. A. Panontin and N. T. Porile, J. Inorg. Nucl. Chem 32, 1775 (1970).
[29]A. M. Poskanzer, G. W. Butler, and E. K. Hyde, Phys. Rev. C 3, 1 (1971).
[30]N. T. Porile, Phys. Rev. 120, 572 (1960).
[31]N. Metropolis, R. Bevins, M. Storm, A. Turkevich, J. M. Miller, and G. Friedlander, Phys. Rev. 110, 185 (1958).
[32]N. Metropolis, R. Bevins, M. Storm, J. M. Miller, G. Friedlander, and A. Turkevich, Phys. Rev. 110, 204 (1958).
[33]In Ref. 21 the constant term in Eq. (10) appears on the opposite side of the equation due to an error.
[34]N. T. Porile, private communication as quoted in Ref. 21.
[35]K. Chen, Z. Fraenkel, G. Friedlander, J. R. Grover, J. M. Miller, and Y. Shimamoto, Phys. Rev. 166, 949 (1968).
[36]J. B. Cumming, R. J. Cross, Jr., J. Hudis, and A. M. Poskanzer, Phys. Rev. 134, B167 (1964).
[37]D. Perry and L. P. Remsberg, unpublished.

PHYSICAL REVIEW C VOLUME 6, NUMBER 4 OCTOBER 1972

Positron Branching in the Decay of ^{143}Sm, ^{141}Nd, and ^{140}Pr

J. L. Evans, J. R. Cooper, D. M. Moore, and W. L. Alford
Physics Department, Auburn University, Auburn, Alabama 36830
(Received 22 May 1972)

The nuclides ^{143}Sm, ^{141}Nd, and ^{140}Pr were prepared by the $(n, 2n)$ reaction using energetic neutrons produced by deuteron bombardment of tritium and lithium targets. A comparison of K x rays and annihilation radiation from each nuclide was made by means of a thin-window NaI detector. Using theoretical ratios of K electron capture to total electron capture, percentages of positron emission for ^{143}Sm, ^{141}Nd, and ^{140}Pr were found to be 40.0 ± 2.0, 2.72 ± 0.20, and 48.7 ± 2.2, respectively.

INTRODUCTION

For a number of $(n, 2n)$ reactions, neutron deficient nuclides are produced for which positron emission is a possible mode of decay. Since it is quite common practice to determine cross sections for such reactions by measuring the induced positron activities, a knowledge of the ratio of electron capture to positron emission in the decay of the product nucleus is essential. Our interest in certain rare earth isotopes has led us to measure the percentages of positron emission in the decay of ^{143}Sm, ^{141}Nd, and ^{140}Pr. The purpose of this paper is to describe briefly these measurements.

EXPERIMENTAL PROCEDURE AND RESULTS

Deuterons from the Auburn University dynamitron accelerator were used to produce energetic neutrons by the T$(d, n)^4$He and ^{7}Li$(d, n)^8$Be reactions. Samples subjected to neutron irradiation consisted of 0.0971 g of 99.9% pure powdered Pr_6O_{11}, 0.233 g of Nd_2O_3 enriched to greater than

90% ^{142}Nd, and 0.0488 g of Sm_2O_3 enriched to greater than 90% ^{144}Sm. The latter two samples were purchased from the Isotopes Development Center of Oak Ridge National Laboratory. Typical irradiation times varied from 15 min to $2\frac{1}{2}$ h. Except for ^{16}N and short-lived isomers, the dominant activities produced were attributable to the ground-state decay of ^{140}Pr, ^{141}Nd, and ^{143}Sm. Each of these nuclides, which are products of $(n, 2n)$ reactions, decays by electron capture and positron emission. A 1-in.-diam by 1-in.-thick thallium-activated sodium-iodide detector with a 0.005-in. beryllium window was chosen to detect both K x rays due to electron capture and 0.511-MeV γ rays due to positron annihilation. Because of its low noise characteristics, the photomultiplier utilized was an RCA 8575. Each activated sample was counted for annihilation radiation with both front and back absorbers to ensure local annihilation of all emitted positrons. Also, each sample was counted for K x rays at the same geometrical position but without absorbers. Spectra were recorded on a multichannel analyzer.

The photopeak efficiencies of the NaI detector were calculated theoretically in the x-ray region by the method of Grosjean[1] and were determined experimentally at 0.511 MeV by using a standard ^{22}Na source obtained from the National Bureau of Standards, U.S. Department of Commerce. Since the ^{22}Na standard was a point source and the activated samples were disk shaped, the experimental efficiencies were multiplied by the theoretically determined ratio of absolute disk source efficiency to absolute point source efficiency. Grosjean's method was again followed in obtaining the theoretical efficiencies at 0.511 MeV.

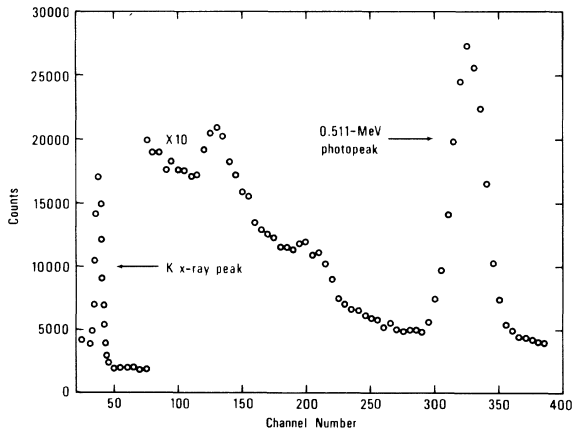

FIG. 1. A typical spectrum showing the K x-ray and 0.511-MeV photopeaks due to the decay of ^{143}Sm. Other structure in the spectrum near channels 130 and 200 may be attributed to backward scattering and to the Compton edge for the annihilation radiation photons.

A typical spectrum is shown in Fig. 1. The counts under the respective photopeaks were determined and corrected for background and for decay between counting intervals. Mass absorption coefficients necessary to correct for self-absorption effects were taken from the report by Storm and Israel.[2] The calculations of Axel[3] were used in adjusting the x-ray counts for the iodine x-ray escape from the NaI detector. Pertinent decay scheme information was taken from Lederer, Hollander, and Perlman,[4] except that the results of Borman, Behrend, Riehle, and Vogel[5] were used for ^{143}Sm. After making each of the indicated corrections, the K x-ray intensity to the annihilation-radiation photon-intensity ratios were found to be 0.579, 13.7, and 0.405 for ^{143}Sm, ^{141}Nd, and ^{140}Pr, respectively. With K fluorescent yields of 0.912 for ^{143}Pm, 0.903 for ^{141}Pr, and 0.899 for ^{140}Ce from the report by Storm and Israel, ratios of K capture to positron decay, K/β^+, were obtained. The derived ratios are given in Table I.

Since a comparison of the total electron capture to positron emission was desired, the theoretical calculations of Brysk and Rose[4,6] were used for the relative intensities of capture from the K shell and from higher shells. An allowed β decay, in which a single dominant transition takes place, was assumed for each of the three cases treated. The ratio of the total electron capture to positron decay, EC/β^+, was obtained in this manner. From these ratios the percentages of positron branching in the decay of ^{143}Sm, ^{141}Nd, and ^{140}Pr were found to be 40.0 ± 2.0, 2.72 ± 0.20, and 48.7 ± 2.2, respectively. These results, along with those of other workers,[7-17] are presented in Table I. The errors

TABLE I. Values for the positron branching, expressed as a percentage of the total number of decays, and the K capture to positron ratio.

Nuclide	β^+ (%)	K/β^+	Reference
^{140}Pr	48.7 ± 2.2	0.90 ± 0.08	Present result
	50		7
	54		8
	54		9
		0.74 ± 0.03	10
^{141}Nd	2.72 ± 0.20	30.4 ± 2.3	Present result
	2.73 ± 0.27		11
	1.9		12
	4.3		13
	4		14
		28 ± 1	10
	2		15
^{143}Sm	40.0 ± 2.0	1.27 ± 0.11	Present result
	37	1.7	16
		0.945 ± 0.05	17
		0.92 ± 0.09	10

shown for the present results are our estimate of the standard errors based on counting statistics and uncertainties in the various quantities entering the branching ratio calculation. The major contributors to these errors are the uncertainties in detector efficiencies and absorption corrections. For improvement in the measurements, sources of higher specific activity are needed to permit the use of better counting geometry and to reduce the uncertainties due to self-absorption corrections.

ACKNOWLEDGMENTS

The authors wish to thank the personnel of the Auburn University Computer Center for assistance in processing the experimental data. The experimental work was made possible by the staff and facilities of the Edmund C. Leach Nuclear Science Center at the University.

[1]C. C. Grosjean, Nucl. Instr. Methods 17, 289 (1962).
[2]E. Storm and H. I. Israel, Los Alamos Scientific Laboratory Report No. LA-3753, 1967 (unpublished).
[3]P. Axel, Rev. Sci. Instr. 25, 391 (1954).
[4]C. M. Lederer, J. M. Hollander, and I. Perlman, *Table of Isotopes* (Wiley, New York, 1967), 6th ed.
[5]M. Borman, A. Behrend, I. Riehle, and O. Vogel, Nucl. Phys. A115, 309 (1968).
[6]H. Brysk and M. E. Rose, Oak Ridge National Laboratory Report No. ORNL-1830, 1955 (unpublished).
[7]V. Brabec, B. Kracík, and M. Volecký, Czechoslov. J. Phys. 10, 885 (1960).
[8]E. I. Biryukov, O. I. Grigor'ev, B. S. Kuznetsov, and N. S. Shimanskaya, Izv. Akad. Nauk SSSR, Ser. Fiz. 24, 1135 (1960) [transl.: Bull. Acad. Sci. USSR, Phys. Ser. 24, 1138 (1960)].
[9]C. I. Browne, J. O. Rasmussen, J. P. Surls, and D. F. Martin, Phys. Rev. 85, 146 (1952).
[10]E. I. Biryukov and N. S. Shimanskaya, Yad. Fiz. 11, 246 (1970) [transl.: Sov. J. Nucl. Phys. 11, 138 (1970)].
[11]J. T. Grissom, D. R. Koehler, and W. L. Alford, Phys. Rev. 142, 725 (1966).
[12]H. L. Polak, W. Shoo, B. L. Schram, R. R. Girgis, and R. van Lieshout, Nucl. Phys. 5, 271 (1958).
[13]D. B. Beery, W. H. Kelly, and W. C. McHarris, Phys. Rev. 171, 1283 (1968).
[14]E. I. Biryukov and N. S. Shimanskaya, Izv. Akad. Nauk SSSR, Ser. Fiz. 27, 1402 (1963) [transl.: Bull. Acad. Sci. USSR, Phys. Ser. 27, 1377 (1963)].
[15]G. Wilkinson and H. G. Hicks, Phys. Rev. 75, 1687 (1949).
[16]I. Gratot, M. LePage, J. Olkowsky, and G. Ranc, Nucl. Phys. 13, 302 (1959).
[17]G. Di Caporiacco, M. Mandò, and F. Ferrero, Nuovo Cimento 13, 522 (1959).

PHYSICAL REVIEW C VOLUME 6, NUMBER 4 OCTOBER 1972

Reaction-Spectroscopy Studies of the Actinide Elements. III. Levels in ^{241}Pu and ^{243}Pu†

T. H. Braid, R. R. Chasman, J. R. Erskine, and A. M. Friedman
Argonne National Laboratory, Argonne, Illinois 60439
(Received 24 April 1972)

Properties of levels in ^{241}Pu and ^{243}Pu were determined by (d,p) and (d,t) reactions on targets of ^{240}Pu and ^{242}Pu. The reactions ^{240}Pu$(n,\gamma)^{241}$Pu and ^{241}Pu$(d,d')^{241}$Pu were also studied. On the basis of these data, single-particle assignments are made for levels in ^{241}Pu and ^{243}Pu. Single-particle spectra, extracted from the data by means of a pairing-force calculation, are compared both with those of the isotonic nuclides and with the single-particle spectra calculated from a deformed Woods-Saxon potential.

I. INTRODUCTION

This paper is the third in a series of studies of the single-particle states of actinide nuclei populated in single-neutron transfer reactions. In Paper I of this series,[1] we presented the results of a detailed study of ^{235}U and developed the theoretical framework for these studies. In Paper II,[2] we dealt with the Cm isotopes. Some preliminary results of our studies of ^{241}Pu and ^{243}Pu were reported earlier,[3] but the detailed analysis is presented here.

Section II is a brief discussion of the theoretical basis for our analysis of the single-nucleon transfer data. Our experimental results for ^{241}Pu and ^{243}Pu are presented in Sec. III, and our assign-