is therefore $(7.9\pm1.3)\times10^{-11}$ sec. The $E2$ transition probability is thus 20 times the single-proton value.

It is interesting to note that the enhancement of the transition probability from the first excited rotational level of Sm^{152} is three times larger. In Fig. 2 the present measurement is added to a plot of mean life values as presented by Sunyar.[12] Thus, in passing from neutron number 90 to 88 with the decrease in deformation of the nucleus as exhibited in the abrupt change of the sequence of levels and their relative energies, we see a corresponding change in reduced transition probabilities from the first excited states.

[12] A. W. Sunyar, Phys. Rev. 98, 653 (1955).

Perlman[13] has recently indicated that a similar case appears in the other region of strongly distorted nuclei, that of the heavy elements where A is greater than 220. For Em^{218}, which is outside the deformed nuclei region as shown by its sequence of levels, the transition probability from its first excited state[14] is correspondingly reduced.

ACKNOWLEDGMENT

The authors would like to thank Professor S. G. Cohen for valuable discussions and interest.

[13] I. Perlman, *Proceedings of the International Conference on Nuclear Structure, Kingston,* (University of Toronto Press, Toronto, 1960), p. 547.

[14] R. E. Bell, S. Bjornholm and J. C. Severiene, *Proceedings of the International Conference on Nuclear Structure, Kingston,* (University of Toronto Press, Toronto, 1960), p. 927 (KCRC 31).

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Decay of Cd^{119} and In^{119} Isomers*

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The isomers 9.5-min Cd^{119} and 2.7-min Cd^{119m} are formed in the fission of natural uranium induced by 14-Mev deuterons and fast neutrons, with the latter reaction favoring the production of the low-spin 9.5-min isomer. The decay of 18-min In^{119m}, the daughter of 9.5-min Cd^{119}, is characterized by β rays with a maximum energy of 2.7 Mev and γ rays of 0.024, 0.30, and 0.91 Mev. Some ($\sim$5%) isomeric transition is observed. The decay of 2.0-min In^{119} is characterized by 1.6-Mev β rays and 0.82-Mev γ rays.

INTRODUCTION

IN 1949 Duffield and Knight prepared (17.5 ± 1)-min In^{119} by the reaction $Sn^{120}(\gamma,p)In^{119}$ employing isotopically enriched tin and 23-Mev x rays.[1] Beta rays with a maximum energy of 2.7 ± 0.2 Mev were found to be associated with this nuclide. No γ rays were observed. More recently, Nussis reported 10-min Cd^{119} and a (3.5 ± 0.5)-min Cd isotope.[2,3] The 3.5-min Cd, tentatively assigned mass number 121, was stated to be the parent of two indium daughters, (11 ± 1)-min In associated with 1.2- and 3.8-Mev β-ray groups and 850-kev γ rays, and (32 ± 2)-min In associated with 1.7-Mev β rays and 740- and 520-kev γ rays.

Earlier studies in our laboratory of neutron-rich isotopes of Cd and In formed in fission revealed several short-lived species that could not be ascribed to the known 115, 117, and 118 chains.[4,5] This study is an extension of this work employing similar irradiation and chemical procedures.

EXPERIMENTAL RESULTS

Cadmium produced by the fission of natural uranium (U^{238}) with 14-Mev deuterons, bombarded 1 to 3 min and separated 3 min after irradiation, showed an apparent 3.1-min period for gross β decay and longer periods due mainly to 49-min Cd^{118}, 50-min Cd^{117}, and 3-hr Cd^{117m}. In a series of 11 experiments in which In was separated from the Cd within 3 min after the initial Cd separation β-decay periods of 2.0 ± 0.2 and 18 ± 1 min were apparent when measured on a proportional counter. Extracts of In taken at times greater than 15 min after the initial Cd separation displayed only the 18-min half-life. Analysis of the apparent 3.1-min period showed it to be a composite of the decay of Cd

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[1] R. B. Duffield and J. D. Knight, Phys. Rev. 75, 1967 (1949).

[2] N. Nussis, J. Pahissa, and E. Ricci, Z. Naturforsch. 12a, 520 (1957).

[3] N. Nussis *et al., Proceedings of the Second United Nations International Conference on the Peaceful Uses of Atomic Energy, Geneva, 1958* (United Nations, Geneva, 1958), Vol. 14, p. 209.

[4] C. E. Gleit and C. D. Coryell, Phys. Rev. 122, 229 (1961).

[5] C. E. Gleit, Ph.D. thesis in Chemistry, Massachusetts Institute of Technology, 1958 (unpublished); Semiannual Progress Report, Laboratory for Nuclear Science, Massachusetts Institute of Technology (November 30, 1958) (unpublished), p. 34; also Atomic Energy Commission Report AECU-3908 (1959) (unpublished).

parent and a 2.0-min In daughter initially growing and then decaying. The true Cd half-life was calculated from a series of 14 experiments to be 2.7 ± 0.3 min. The presence of a species with a half-life <1 min, presumably Cd^{120}, was detected but could not be quantitatively analyzed.

Separating Cd from the products of fast-neutron induced fission of natural uranium reveals apparent β-decay periods of 3 and 11 min. Extracting In from Cd produced by neutron-induced fission shows that the 18-min In has a (10 ± 2)-min parent. The high value of In activity in the initial extractions of freshly formed Cd indicates some formation of 18-min In from the newly characterized 2.7-min Cd. Correcting the decay data for the growth of In, the half-life of the longer period Cd was calculated to be 9.5 ± 1 min.

Experiments in which In was extracted from Cd produced by deuteron-induced fission yielded similar results as to the genetic relationship of the Cd and In isotopes. The parent of 2.0-min In has a half-life of (2 ± 1.5) min. The In extracts also indicate that 18-min In arises from both the 2.7- and 9.5-min parents in this situation, where 2.7-min Cd heavily outweighs the 9.5-min species.

A 256-channel pulse-height analyzer coupled to a 3-in.$\times$3-in. NaI(Tl) crystal was used for γ-ray measurements. Spectral analysis of the short-lived Cd isotopes is rendered difficult by the complex spectra of 50-min Cd^{117} and 3.0-hr Cd^{117m} which are present in appreciable quantities. The most prominent photopeak in the γ-ray spectrum of Cd rapidly separated from fission products or In rapidly extracted from Cd is a 0.82-Mev γ ray. A 0.73-Mev γ ray with an intensity of 0.05 relative to the 0.82-Mev γ ray has a similar decay characteristic, namely a rapid decay of ~2 min and a slowly decaying ~15-min component (Fig. 1).

All the γ rays associated with 18-min In are in low abundances. Photopeaks of 0.024, 0.30, and 0.91 are apparent in In samples 10–60 min old. These decay with ~20-min half-periods. As the 0.024-Mev γ rays are obscured by competing phenomena and the 0.30-Mev γ rays appear only as a weak shoulder on the more intense isomeric transition γ rays of In^{115} (0.335 Mev) and In^{117} (0.316 Mev) measurements of their intensities are difficult to make. The ratios of the 0.024, 0.30, and 0.91-Mev γ rays, corrected for counter efficiency, relative to the total β decay of 18-min In, are evaluated as approximately 0.4, 0.03, and 0.05, respectively. The 0.82-Mev γ ray and the 0.91-Mev γ ray are about equally intense after the 2.0-min In initially present has been removed by decay.

In addition to the short-period γ rays found in In, photopeaks of 0.43, 0.61, and 1.8 (very weak) Mev are associated with 9.5-min Cd. On the basis of its great intensity in freshly separated Cd, it is possible that γ rays of about 0.82 Mev occur in the decay of both 2.7-min Cd and 2.0-min In.

By judicious choice of timing of extractions, the 18-min In can be obtained with high purity, the β-decay curve showing no deviation over a period of seven half-lives. An Al absorption analysis yields a maximum β-ray energy of 2.7 ± 0.2 Mev. Beta-ray scintillation spectrometry employing a hollow-well plastic crystal reveals that In rapidly extracted from freshly formed Cd is richer in low-energy β rays. Absorption analysis and spectrometry reveal a β-ray end-point energy of approximately 3.5 Mev for the 2.7-min Cd and nearly the same value for 9.5-min Cd.

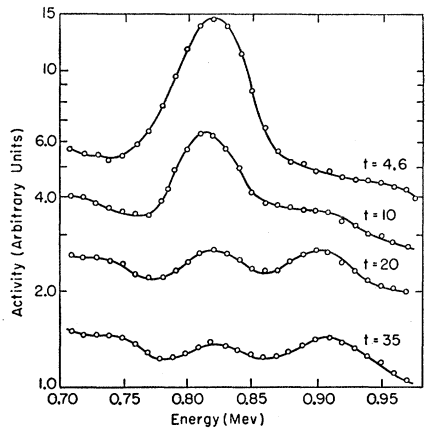

FIG. 1. Partial γ spectra of In separated from Cd produced by deuteron-induced fission of U. Time t represents minutes elapsed since end of irradiation.

DISCUSSION OF RESULTS

The identification of the 18-min In, emitting 2.7-Mev β rays, is in good agreement with the previously reported[1] 17.5-min In^{119}. As 18-min In grows mainly from 9.5-min Cd, this latter nuclide must also be a member of the 119 chain. The 2.7-min Cd appears a parent of both 18-min In and 2.0-min In and is tentatively identified as Cd^{119m}. The decay characteristics of the 0.73- and 0.82-Mev γ rays associated with 2.0-min In^{119} indicating growth of 2.0-min In^{119} from 18-min In^{119m} tend to confirm the mass assignment of the shorter lived In species.

Figure 2 illustrates the suggested decay scheme for the 119 chain. The $s_{1/2}$ ground state, 18-nsec $(d_{3/2})$ level, and ~245-day $(h_{11/2})$ level of Sn^{119} have been observed in previous studies and their spin assignments confirmed through measurements of conversion ratios.[6] The 0.907-Mev level of Sn^{119} has been produced by Coulomb excitation.[7] Assuming it to be an $E2$ transition an assignment of $\frac{3}{2}+$ is tentatively made. An assignment of $g_{7/2}$ to the 0.82-Mev level is consistent with the single-particle model and a similar level[6] in Sn^{117}.

Designations of $p_{1/2}$ and $g_{9/2}$ are given to 18-min

[6] K. Way *et al.*, *Nuclear Data Sheets*, National Research Council, NRC-58-6-11 (National Academy of Sciences, Washington, D. C.).

[7] D. G. Alkhazov, D. S. Andreev, K. I. Erokhina, I. Kh. Lemberg, Zhur. Eksptl. i Teoret. Fiz. 33, 1346 (1957).

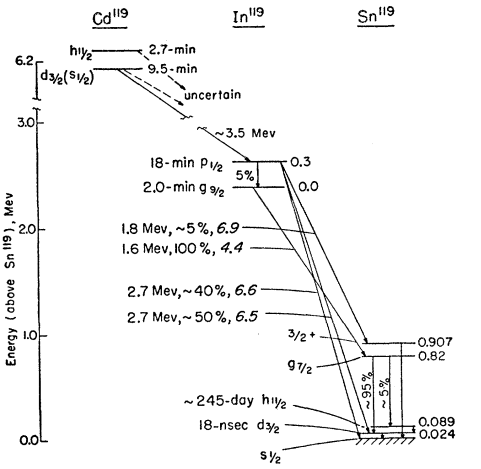

FIG. 2. Decay schemes for 9.5-min Cd^{119}, 2.7-min Cd^{119m}, 2.0-min In^{119}, and 18-min In^{119m}.

In^{119m} and 2.0-min In^{119} respectively, on the basis of the single-particle model and by analogy to the lighter odd-A isotopes of In. The energy of the observed 0.30-Mev γ ray of In^{119m}, ascribed to the isomeric transition between In levels, agrees well with similar energy differences in the lighter odd-A In isotopes. The 1.8-Mev β-ray transition of 18-min In^{119m} is calculated from the measured 2.7-Mev β ray and the 0.91-Mev γ ray.

The abundance of the isomeric transition $\sim 5\%$, based on the relative intensities of the 0.82- and 0.91-Mev γ rays in old In, agrees with a calculated abundance based on the intensity of the 0.30-Mev γ ray and a theoretical value for α_K of 1.2. The branching ratios for the β transitions to the $\frac{3}{2}+$ level, $d_{3/2}$ level, and $s_{1/2}$ ground state based on the observed γ/β ratios are 5%, 40%, and 50% respectively. The log ft values of these β transitions, 6.9, 6.6, and 6.5, are consistent with their first forbidden assignment.

The prominent 0.82-Mev γ ray is associated with 2.0-min In^{119}. On the basis of a value of 2.7 Mev for the energy difference between In^{119m} and the ground state of Sn^{119} and a separation of 0.3 Mev between the In isomers, a value of 1.6 Mev is calculated for the β rays associated with the 0.82-Mev γ rays. If this path accounts for the entire decay of In^{119}, the log ft for this transition is 4.4, within the normal range for allowed transitions. The 0.73-Mev γ ray associated with 2.0-min In^{119} arises from a transition from the $g_{7/2}$ level of Sn^{119} to 250-day Sn^{119m} ($h_{11/2}$). The expected energy of this transition, 0.82−0.09 Mev, is in good agreement with the 0.73 Mev observed. The abundance of the 0.73-Mev γ rays relative to those of 0.82 Mev ($\sim 5\%$) is within theoretical limits.

Level assignments of $h_{11/2}$ for the metastable level and $d_{3/2}$ (or possibly $s_{1/2}$) for the ground state of Cd^{119} are predicted on the basis of the single-particle model and the energetics of lighter odd-A Cd isotopes. As the 9.5-min Cd appears to be the parent of 18-min In^{119m} ($p_{1/2}$) and 2.7-min Cd is mainly the parent of 2.0-min In^{119} ($g_{9/2}$), 9.5-min Cd^{119} is taken to be the low-spin ground state.

The low yield of 9.5-min Cd^{119} relative to 2.7-min Cd^{119m} in deuteron-induced fission can be explained in terms of these assignments. In neutron-induced fission chain-lengths are appreciably longer. If isomerism inherited from the Ag and Pd precursors favors the 9.5-min isomer ($d_{3/2}$), as appears true for lighter Cd species,[8] whereas the short-lived isomer of Cd^{119} ($h_{11/2}$) is favored among the primary products of near-symmetric fission, the observed greater relative abundance of 2.7-min Cd^{119} in deuteron-induced fission is expected.

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[8] J. M. Alexander, U. Schindewolf, and C. D. Coryell, Phys. Rev. 111, 228 (1958).