Transcurium Isotopes Produced in the Neutron Irradiation of Plutonium

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We have succeeded in producing isotopes of three transcurium elements by the irradiation of the starting material Pu^{239} in the Materials Testing Reactor. The heaviest elements were separated completely from plutonium, fission products, americium, and curium by methods involving combinations of precipitation and ion exchange.[1–4] In the element 97 (berkelium) fraction, soft beta particles were observed. In the californium fraction, alpha particles of three different energies were observed, namely, about 6.15 Mev, 6.05 Mev, and 5.8 Mev. In the fraction just preceding the californium in elution from the hot Dowex-50 resin column, specifically the element 99 fraction,[5] alpha particles of 6.6-Mev energy were observed. The amount of activity observed in this fraction was extremely small; nevertheless, its assignment to element 99 is regarded as certain. All of these isotopes have half-lives longer than one week.

The berkelium isotope which decays by the emission of soft beta particles is probably Bk^{249}. Other work[6] has indicated that Bk^{247} is probably a relatively short-lived isotope which decays by electron capture to Cm^{247} which is beta stable. Therefore the lightest curium isotope which decays to berkelium would be Cm^{249}. The assignment to Bk^{249} is also reasonable since its radiations should be very soft whereas Bk^{248} or Bk^{250} (both odd-odd isotopes) would be expected to emit energetic radiation. On the basis of this assignment, it is interesting to note that there are no beta-stable berkelium isotopes.

The californium isotope or isotopes emitting the above-mentioned alpha particles must be heavier than 248. From alpha systematics, the alpha half-lives corresponding to the measured energies should range from a few years to several hundred years.[7]

The isotope of element 99 emitting 6.6-Mev alpha particles is logically assigned as 99^{253}. A reasonable half-life estimated from systematics, assuming a hindrance factor of ten, would be very roughly a month.

The isotopes mentioned here were all produced as a result of combinations of successive neutron captures and beta decays. A possible sequence leading to the production of 99^{253} might be the following:[8]

$$\begin{array}{l} Pu^{239}(n,\gamma)Pu^{240}(n,\gamma)\ Pu^{241}\ (n,\gamma)\ Pu^{242}\ (n,\gamma)\ Pu^{243} \\ \qquad\qquad\qquad\quad \downarrow \qquad\quad \uparrow \qquad\quad \downarrow \\ \qquad\qquad\qquad Am^{241}(n,\gamma)Am^{242}(n,\gamma)Am^{243}(n,\gamma)Am^{244} \\ \qquad\qquad\qquad\qquad\qquad \downarrow \qquad\qquad\qquad\quad \downarrow \\ \qquad\qquad\qquad\qquad\quad Cm^{242}(n,\gamma)Cm^{243}(n,\gamma)Cm^{244}, \end{array}$$

$$\begin{array}{r} Cm^{244}(n,\gamma)Cm^{245}(n,\gamma)Cm^{246}(n,\gamma)Cm^{247}(n,\gamma)Cm^{248}(n,\gamma)Cm^{249} \\ \downarrow \\ Bk^{249}, \end{array}$$

$$\begin{array}{l} Bk^{249}(n,\gamma)Bk^{250} \\ \downarrow \qquad\quad \downarrow \\ Cf^{249}(n,\gamma)\ Cf^{250}(n,\gamma)Cf^{251}(n,\gamma)Cf^{252}(n,\gamma)Cf^{253} \\ \qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad \downarrow \\ \qquad\qquad\qquad\qquad\qquad\qquad\qquad\quad 99^{253}. \end{array}$$

There is unpublished information relevant to element 99 at the University of California, Argonne National Laboratory, and Los Alamos Scientific Laboratory. Until this information is published, the question of the first preparation should not be prejudged on the basis of this paper or the preceding one.[5]

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"*V* Dinucleons"*

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In a previous paper[1] (hereafter referred to as A) we have suggested the possibility of the existence of "V deuterons": particles involving a nuclearly stable structure of a proton bound to a neutral V.[2] These V deuterons are subject to nonmesonic and mesonic decay according to the schemes:

$$V \text{ deuteron} \equiv [V^0+p] \rightarrow \begin{cases} p+n+\approx 175\text{-Mev K.E.} & (1) \\ p+p+\pi^-+\approx 35\text{-Mev K.E.} & (2) \\ p+n+\pi^0+\approx 35\text{-Mev K.E.} & (3) \\ d+\pi^0+\approx 35\text{-Mev K.E.} & (3') \\ n+n+\pi^+ +\approx 35\text{-Mev K.E.} & (4) \end{cases}$$

Schemes (3′) and (4) were not mentioned in A; on the basis of charge symmetry, scheme (4) should obviously occur if scheme (2) occurs, while scheme (3′) is an alternative to (3) since the n and p may on occasion be produced in a bound (deuteron) state. The relative probabilities of the nonmesonic decay scheme (1) and of the mesonic decay schemes (2), (3), (3′), (4) have been shown in A to be of the same order of magnitude; the mean life of the V deuteron has been shown in A to be of the same order as the mean life (for the mesonic decay) of a free V^0 ($\approx 3\times 10^{-10}$ sec).

We now wish to point out that an alternative structure of the V deuteron is also possible, namely $[V^+ + n]$, i.e., a nuclearly stable structure of a neutron bound to positively charged V; this alternative V deuteron will also be capable of decay according to schemes (1) through (4) but with a considerably larger kinetic energy release, since the rest energy of the $V^\pm$ is some 85 ± 40 Mev larger than the rest energy of the $V^0[M(V^0)\approx(2185\pm 10)m_e$; $M(V^\pm)\approx(2350\pm 80)m_e]$.[3]

In addition, particles which might be called "negative V deuterons," "V diprotons," and "V dineutrons" can be nuclearly stable even if the "specifically nuclear" attractive forces between nucleons and V's in various angular momentum states are no stronger than the corresponding forces between nucleons and other nucleons. For unlike ordinary dinucleons, all of these "V dinucleons" can exist in $^3S_1$ states (Pauli exclusion inoperative between a V and a nucleon); moreover the relatively greater mass of the V will tend to increase the binding energy of a V dinucleon relative to that of a deuteron. Having postulated the