ten-minute Pa^{237} and in the fact that very little is known about the radiation characteristics of Pa^{237}.

† This work was performed under the auspices of the U. S. Atomic Energy Commission.

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Isotopes of Curium, Berkelium, and Californium†

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SEVERAL new isotopes of curium, berkelium, and californium have been produced by charged-particle bombardments of pile-produced transplutonium isotopes, and their nuclear properties studied. The chemical procedures and counting methods used were essentially the same as those used in prior work of this nature at Berkeley.[1,2]

The existence of Cm^{245} was first proved by mass spectrographic analysis[3] of samples of curium subjected to long neutron irradiations in the Chalk River reactor. However, the electron capture decay of Bk^{245}, produced by helium ion bombardment of Cm^{242}, results in the formation of pure but small samples of Cm^{245}. This nuclide was found to decay by emitting alpha particles of 5.36 ± 0.05 Mev as measured by alpha-particle pulse-height analysis.[4] The energy measured probably does not represent the transition to the ground state of Am^{241}, but higher-energy alpha-particle groups were undetected in the samples of such low counting rates. The best approximation for the half-life of Cm^{245} is 20 000 years. This value is based on the counting of K and L x-rays arising from orbital electron capture by Bk^{245}, the use of approximate Auger conversion factors,[5,6] and the measurement of the alpha disintegration rate of the daughter. Elution of the material emitting 5.36-Mev alpha particles in the curium position (with Cm^{242}) from a cation exchange column with buffered ammonium citrate eluant proved that this new alpha-particle emitter is an isotope of curium.

A previously unknown isotope of californium, Cf^{248}, was made by helium ion bombardment of curium containing a small percentage of Cm^{245}.[3] This isotope decays by emission of 6.26 ± 0.03 Mev alpha particles with a half-life of 250 ± 20 days. Decay of the alpha radioactivity of the above energy was followed through two half-lives. A spontaneous fission half-life of about 7000 years was also measured, but this value is rather uncertain because of the extremely slow spontaneous fission rate of the sample. Observation of the growth of the 5.80-Mev alpha particles of Cm^{244} in the above sample proved the mass assignment of the Cf^{248}.

The bombardment of various mixtures of Am^{241} and Am^{243} with 27-Mev helium ions is believed to have produced a 1.8-day electron-capture isotope of berkelium which is tentatively assigned to Bk^{246}. The 1.8-day period was observed in the berkelium fraction from three different bombardments. A different chemical separation procedure was used in each case. This intermediate period was resolved from the 4.5-hour Bk^{243} (and Bk^{244}) and the 4.95-day Bk^{245} periods after following the decay in a windowless proportional counter. An 820 ± 10-kev gamma ray decaying with a 1.7-day half-life was observed in the berkelium fraction by means of a sodium iodide crystal scintillation counter connected to a 50-channel pulse-height analyzer.[7] It appeared that between 20 and 50 percent of the Bk^{246} electron-capture disintegrations passed through this 820-kev excited state of Cm^{246}, based on the total disintegration rate from the estimated counting yield of the windowless proportional counter and the best value[8,9] for the photoelectric yield from the sodium iodide crystal. K x-rays resulting from the berkelium decay were followed for decay with the sodium iodide scintillation counter and the L x-rays with a small xenon-filled proportional counter (90 percent xenon and 10 percent methane, at 1 atmos. connected to the 50-channel pulse-height analyzer. The approximate Bk^{246} decay period could be resolved from the 4.95-day component in both the K and L x-ray decay curves. A total disintegration energy of approximately 1.4 Mev is estimated from energy balances within closed decay cycles[10] to be available for orbital electron capture by Bk^{246}. The half-life thought to be associated with Bk^{246} seems reasonable for either a highly forbidden ground-state transition or if a large percentage of the disintegrations are forced to pass through a high-energy level of Cm^{246}.

Helium ion bombardment of curium containing a high percentage of Cm^{244} followed by a fast chemical separation of the californium fraction resulted in the detection of an orbital electron capture isotope of californium, Cf^{247}. This isotope was also observed in the products from nitrogen ion bombardments of U^{238} metal foils.[11] Decay of the K x-rays of this nuclide (followed in the presence of interfering Cf^{246} alpha radioactivity) with the aforementioned sodium iodide crystal scintillation spectrometer gave a half-life of 2.5 hours. A rough 3-hour half-life was obtained by resolving the decay curve of the L x-rays associated with the orbital electron capture of Cf^{247} and the alpha decay of Cf^{246}. The measured energies of the L x-rays ($L_\alpha=15.1$, $L_\beta=19.7$, and $L_\gamma=24.1$ kev) agree well with those expected from berkelium. No radioactivity could be detected from the daughter of Cf^{247}, namely Bk^{247}.

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Disintegration of Bismuth by 2.2-Bev Protons*

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THE irradiation of bismuth with 2.2-Bev protons from the Brookhaven Cosmotron produces a large number of radioactive species. We report here on the cross sections for the formation of some of them.

Foils of bismuth metal were exposed in the circulating proton beam of the Cosmotron. During most of the irradiations, the beam intensity was approximately 10^{10} protons per pulse and the repetition rate was 1 pulse per 5 seconds. The number of protons striking the target was determined from the Na^{24} activity produced in a 0.003-inch aluminum monitor foil adjacent to the bismuth target. The cross section for the production of Na^{24} is approximately 9 millibarns at 2.2 Bev.[1]

Table I lists the products for which cross sections have been determined. After isolation from the target, the radioactivity of each species was measured by a calibrated proportional counter or a NaI scintillation counter. The alpha activity was measured directly in thin target foils.

The variation of cross section with mass number is strikingly different from that observed in the hundred-Mev range. Though only a few products have been measured at 2.2 Bev, there appears to be a monotonic decrease of cross section with decreasing Z of the product.[2] This is in contrast to the results obtained in the irradiation of bismuth with 190-Mev deuterons[3] or 340–450 Mev protons.[4] At the lower energies, there is a hump in the cross section curve centered at mass 95–100 with a total cross section of about 200 millibarns. This group of products, attributed to fission, is well separated from the spallation products. The present experiments at the higher energy indicate that, first, spallation with the emission of a large number of nucleons has become more probable, while, second, the division of the target nucleus into two fragments of approximately equal mass has become less probable, so that it is no longer possible to see in the yield *vs* mass curve a sharp division between the two processes. For example, the cross section for the production of Sr^{89} at 2.2 Bev is about 1/5 of that found with 190-Mev deuterons or ~400-Mev protons, while that for the production of mass number 149 is at least 100 times as large at 2.2 Bev as at 190 Mev. The absence, at 2.2 Bev, of a trough in the yield curve between spallation and fission regions has already been reported in preliminary work on reactions with lead.[5] Here a gross rare earth fraction (approximately representing mass numbers 130 to 180) was found to contain about 70 percent of the total x and γ activity of an irradiated lead target, while in a 380-Mev proton bombardment the corresponding fraction was of the order of one percent. The cross section for the formation of Ce^{141} from lead is about 100 times larger at 2.2-Bev than at 380-Mev proton energy.

A few very preliminary experiments have been done to determine the recoil momenta of the radioactive products. It has been found that the ranges in aluminum (mg/cm^2) at 0° to the proton beam of some products are as follows: $Br^{80,82}$, ~3.2; $Sr^{91,92}$, ~3.3; $Ba^{128,129}$, ~1.5; Tb^{149}, ~1. From a thick bismuth target, approximately 5 times as many Tb^{149} recoils were found on a catcher foil in the forward direction as compared to the backward direction to the proton beam. The corresponding ratio in thick targets for $Ba^{128,129}$ was 3.8, and for $Sr^{91,92}$, 1.2. This would appear to mean that the cen-

TABLE I. Formation cross sections from 2.2-Bev protons in bismuth. All values are based on a cross section of 9 mb for the reaction $Al^{27}(p,3pn)Na^{24}$.

Product observed	σ(mb)	Product observed	σ(mb)
Pb^{203}	26	Ba^{129}	1.9
Tl^{202}	3	Ba^{128}	4.3
Tl^{201}	20	Sr^{91}	0.48
Tl^{200}	12	Sr^{89}	1.4
Tl^{199}	27	Br^{82}	0.22
Tl^{198}	15	Br^{80m}	0.67
Tb^{149}	0.95[a]	Ge^{75}	0.53
$Dy^{149-153}$ (19 min)	0.62[a]	Ge^{69}	0.65
$Dy^{149-153}$ (7 min)	1.77[a]	Ge^{66}	0.17
Ba^{131}	5.5		

[a] These nuclei were detected by their alpha activity. The cross sections are for the alpha branch only; the decay branching ratio is not accurately known. For this reason and also because these particular isotopes are highly neutron-deficient, the cross sections given represent only lower limits for the formation cross sections for these mass numbers.