Br^{86}—A New Nuclide*

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The nuclide Br^{86} has been identified by chemical separation following neutron bombardment of enriched Kr^{86}. A half-life of 54±2 sec was observed. β- and γ-scintillation counting with multichannel pulse-height analysis indicate a complex beta spectrum with an end point of 7.1±0.5 MeV for the most energetic component and prominent γ rays at 1.57 and 2.76 MeV. The effect of Br^{86} on the interpretation of previous data on short-lived bromine fission products is discussed. Rough values for the relative (n,p), (n,pn), and (n,α) reactions on Kr^{86} were determined as 1:1:0.05, respectively. The ratio of Se^{83} isomers formed by the (n,α) reaction is 3:1 in favor of the metastable state.

I. INTRODUCTION

ALTHOUGH several studies of the isotopes of bromine produced in nuclear fission have been made,[1–3] Br^{86} has not been identified. A number of possibilities may be suggested to account for its apparent absence: (1) Its fission yield may be diminished as a result of neutron emission associated with the 50-neutron shell closure; (2) its half-life may be too short to have been observed; or (3) it may have a half-life close to that of other bromine fission products, and the decay curves observed may, in fact, be unresolved composites.

The expected fission yield of Br^{86}, estimated from the known cumulative yield (2.02%)[4] and the independent yield (~0.01 of the chain) of Kr^{86}, is about 2%. Delayed or prompt neutron emission related to the shell of 50 neutrons (which would feed Kr^{86}, but bypass Br^{86}) is estimated as $\leq 0.3\%$ expressed as a fission yield. Thus, the cumulative yield at Br^{86} should be $\geq 1.7\%$. An empirical regularity observed for bromine isotopes[5] implies a half-life of about 3 min for Br^{86}; however, the decay characteristics observed for 3-min Br^{85} (a single 2.5-MeV β and no γ's)[6] are too simple to be the plausible result of a mixture of Br^{85} and Br^{86}. A prediction of the properties of Br^{86} on the basis of beta-decay systematics and shell-model considerations indicates a half-life of the order of 0.5–1 min and a Q_β of about 8 MeV; an extremely short half-life appears to be unlikely. It would thus seem that the most likely explanation for the failure to observe Br^{86} among the fission products is a close similarity of its half-life to that of another isotope—most likely 56-sec Br^{87} or 15.5-sec Br^{88}.

Sattizahn, Knight, and Kahn[3] observed a 16-sec Se isotope in fission decaying to a 1-min bromine. Although a tentative assignment to Se^{87} was made on the basis of fission yield considerations and the known 56-sec Br^{87}, these authors pointed out that an assignment to Se^{86} with about a 1-min Br^{86} daughter was not ruled out.

An attempt to observe Br^{86} from the (n,p) reaction on normal krypton was made by Yellin.[7] Although a component of about 1-min half-life was observed in the decay curve of the products, no chemical separations were performed and no identification of the activity was made.

In the present work Br^{86} was produced by the (n,p) reaction on enriched Kr^{86} (>99.8%) as well as on normal krypton. The reaction Kr^{86} (n,p) Br^{86} should produce the Br^{86} without interference from Br^{87} or Br^{88}. Some production of 3-min Br^{85} by the (n,pn) reaction and the 6.0- and 31.8-min Br^{84} isomers by the (n,t) reaction may be expected, however. Chemical isolation of the bromine from the bombardment products was carried out, and β- and γ-ray spectrometry were employed to help establish a decay period which could be ascribed to Br^{86}.

II. EXPERIMENTAL

Bombardment of a thick beryllium target with 21.5-MeV deuterons at the Argonne 60-in. cyclotron produced neutrons with a maximum energy of about 25 MeV and maximum intensity at about 7.5 MeV. The neutron flux at the surface of the beryllium in the forward direction was typically of the order of 7×10^{10}/sec/cm², of which 15 to 20% had energies in excess of the 13 MeV estimated for the combined threshold and potential barrier energies for the Kr^{86} (n,p) Br^{86} reaction. For irradiation, the krypton was frozen into the tip of a quartz tube close to the beryllium, and it was necessary to recover the induced bromine activities outside of the shielded cyclotron area in order to avoid the high radiation background which remained for some time after bombardment. Provision for recovery of the enriched samples of Kr^{86} was also an important consideration in the design of the experiment.

In preliminary stages of this work, the krypton was volatilized and flushed with helium through a long length of tubing to a trap where the bromine carried in the gas stream was recovered. However, erratic results

* Based on work performed under the auspices of the U. S. Atomic Energy Commission.
[1] N. Sugarman, J. Chem. Phys. **17**, 11 (1949).
[2] A. F. Stehney and N. Sugarman, Phys. Rev. **89**, 194 (1953).
[3] J. E. Sattizahn, J. D. Knight, and M. Kahn, J. Inorg. Nuclear Chem. **12**, 206 (1960).
[4] See, e.g., S. Katcoff, Nucleonics **18**, No. 11, 201 (1960).
[5] A. F. Stehney and G. J. Perlow, *Proceedings of the Second United Nations International Conference on the Peaceful Uses of Atomic Energy* (United Nations, Geneva, 1958), Vol. 15, p. 384.
[6] D. Strominger, J. M. Hollander, and G. T. Seaborg, Revs. Modern Phys. **30**, 585 (1958).
[7] E. Yellin, Massachusetts Institute of Technology Progress Report, November 1, 1959 (unpublished), p. 24.

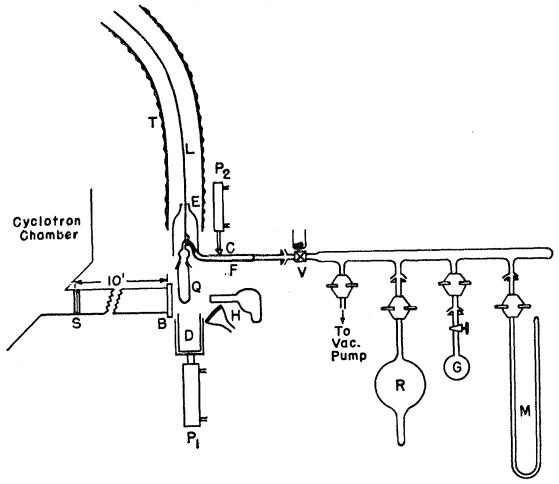

FIG. 1. Schematic diagram of apparatus.

were obtained, and it was found that most of the bromine activity remained on the walls of the quartz tube when no bromine carrier was added. Since we wished to avoid bromine activities induced by neutrons on bromine, this flow technique was replaced by a combination of automatic and manual techniques, in which the krypton was pumped off after bombardment, and the quartz tube was quickly transferred to another room where the bromine activities were recovered by rinsing the tube with an acid solution.

Figure 1 is a schematic diagram of the experimental arrangement finally adopted for this work. The quartz tube (Q) of about 50 cc volume was supported close to the beryllium target (B) and connected to a manifold through a small length of soft Tygon tubing (F) and a mechanical valve (V). A flexible tube (T), 4 in. in diameter, was mounted above Q and extended a distance of 40 ft through the wall of the cyclotron room to provide a guide for pulling Q to a low background area. In operation, Q and the manifold were evacuated and krypton gas from the sample bulb (G) was admitted to the line. A cooling bath of liquid nitrogen (D) was then raised by means of a piston (P_1) so as to freeze the krypton into the tip of the quartz tube. After closing V, the evacuated 2-liter flask (R) was opened and cooled with liquid nitrogen. The bath (D) was lowered by means of a remote switch at the same time that the cyclotron shutter (S) was opened to start the bombardment. After 20 sec, two infrared lamps and a hot-air blast were turned on to warm the krypton, volatilization being completed at the end of a 40-sec bombardment. Valve V was then opened long enough to allow the krypton to be drawn into the 2-liter flask. After V closed, the Tygon tube was cut by a razor blade (C) mounted on a piston (P_2), freeing the quartz tube from the line about 6 sec after the end of bombardment. This sequence of heating, valve operation, and cutting was done automatically by means of a control timer and solenoid valves. The string (L) was then pulled, bringing Q up into the protective polyethylene envelope (E) and on through T to a position where the ground-glass joint was opened by hand to provide access to the activities retained on the walls of the lower portion of Q. For subsequent runs, the gas in R was reused with a small amount of krypton added from the original supply bulb as needed to make up for losses.

The chemical procedure was designed primarily to obtain the bromine in a form suitable for counting and free of selenium activities derived from the (n,α) reaction on krypton. A hot solution of $4M$ HNO_3 and $0.25M$ $NH_2OH \cdot H_2SO_4$ containing 5 mg of selenium holdback carrier was poured into the quartz tube, and 8 mg of Br^- carrier was added. After swirling the solution to dissolve bromine activities from the walls, 20 mg Ag^+ was added to precipitate AgBr and the slurry was filtered with suction to provide a disk 0.6 in. in diameter on the filter paper. The precipitate was washed with water, alcohol, and acetone, then air-dried briefly, mounted on cardboard and covered with a rubber hydrochloride film ~ 0.7 mg/cm^2 thick. In preliminary tests of this procedure, about 0.1% of Se^{75} tracer, added to the original solution, was found in the AgBr precipitates. The amount of selenium activity derived from cyclotron bombardments of enriched Kr^{86} was measured by adding selenium carrier to the quartz tube, then hydroxylamine and Br^- in $6M$ HCl, and boiling to precipitate metallic Se which was mounted for counting in the same manner as for the AgBr samples. The initial counting rate (at 3 min after the end of bombardment) thus obtained was only 3% of that from AgBr mounts at the same time, and it was concluded that selenium activities could not interfere significantly with the more prominent activities obtained by the bromine chemistry. The selenium activity was readily identified as the 69-sec and 25-min isomers of Se^{83}.

The amount of krypton and the time sequence of operations were maintained the same for runs with normal krypton and the enriched (99.8%) Kr^{86}, partly to provide for easy comparison of activity levels and partly because of experimental limitations. A maximum pressure of less than one atmosphere was needed to ensure tightness of the ground-glass joint on the quartz irradiation tube and 40 cc (STP) was regularly used. An irradiation time of 40 sec was used to avoid buildup of long-lived activities, and starting the heaters at 20 sec resulted in full volatilization of this amount of krypton just prior to the end of bombardment so that the krypton could be transferred immediately to the collection reservoir. More than 95% of the krypton was recovered with this procedure, and the time required from the end of bombardment to the start of counting was typically 1.0 to 1.2 min. Vapor-pressure measurements showed that about 20% of the krypton had volatilized at the start of heating and that 50% had volatilized 10 sec later. These changes from solid krypton to gas resulted, of course, in a change of bombardment

geometry, and a precise "end of bombardment time" could not be established. We simply used the time of closing the cyclotron shutter in obtaining approximate values of the relative intensities of the activities from decay curves.

Decay measurements of the beta-particle activity were made with an end-window proportional counter having a window thickness of 1 mg/cm^2. The decay data were recorded by means of a traffic counter which printed the number of counts accumulated during preset periods of time, usually 0.2 min at the start of counting. A transistorized 256-channel analyzer was used with a Pilot B crystal for energy measurements of beta particles and with a NaI crystal for gamma rays. The decay rates of various energy groups were studied by taking successive spectra at known time intervals. In addition, the analyzer was used as a traffic counter with a variable energy gate to obtain decay data for selected energy regions of the beta- or gamma-ray spectra. The time base of the analyzer was calibrated for use in this "scaler preset time" mode of operation.

Beta-particle energies were studied with a cylindrical Pilot B crystal 2.5 in. in diameter and 1.5 in. thick mounted on a Dumont 6363 multiplier phototube. The samples were placed $\frac{1}{16}$ of an inch below a 3-mil aluminum foil which covered the crystal face. Energy calibrations were made by means of conversion electrons from Bi^{207} at 0.976 MeV and Kurie plots of the beta-ray spectra of P^{32} (1.71 MeV) and Rh^{106} (3.53 MeV for the most energetic group). The energy scale was first set for about 8 MeV over the full scale and then the gain was increased fourfold to correspond to about 8 MeV over each of the 64-channel quadrants of the analyzer. This allowed four successive spectra to be taken for decay analysis before printing out the data. The linearity of the analyzer and the accuracy of the relative gain settings were verified by means of a precision pulse generator, but the condensed energy scale could be checked only with the Rh^{106} source, since pulses from Bi^{207} electrons and most of the beta-ray spectra from P^{32} fell into the first few channels of the analyzer which were not usable. Thus, calibration of the energy scale was considered reliable to only about 5%; however, this was sufficient for the present work in which the energy measurements were used primarily to help establish the presence of a new nuclide and to obtain an approximate value of the decay energy.

Gamma-ray spectra were measured by means of a 3-×3-in. cylindrical NaI crystal and Dumont 6363 multiplier phototube. An energy scale of 4 MeV over 255 channels was calibrated by gamma rays from Na^{22} (0.511 and 1.277 MeV), Bi^{207} (0.57 and 1.06 MeV), Cs^{137} (0.662 MeV), Co^{60} (1.17 and 1.33 MeV), and sum peaks from Bi,^{207} Na,^{22} and Co^{60}. Beta particles from the calibration samples were absorbed in 3.7 g/cm^2 of aluminum. The samples were placed close to the face of the crystal (usually 0.6 in.) in order to obtain sufficient counting rates for spectral analysis. Resolution (full energy width at half-maximum intensity) for the Cs^{137} was 10%.

Background runs for each type of counting measurement were made to correspond to the same time sequence of cyclotron operation and chemistry as used in the experiments. The quartz bombardment tubes had radiation levels of ~1 R/h soon after the end of bombardment, and it was necessary to shield them at a distance in order to prevent interference with the counters (especially from the 1.8 MeV gamma rays of 2.3-min Al^{28}). The possibility that some of this activity could be leached from the quartz and carried on the AgBr precipitates was tested by irradiation of an empty quartz cell and separation of bromine carrier with the standard procedure. An initial activity of only 100 counts/min was obtained compared with about 10^5 counts/min when samples of Kr^{86} were run under identical conditions. A single sample of Kr^{86} was repeatedly irradiated at frequent intervals, and long-lived bromine isotopes might have built up in the gas. However, no activity was observed in a AgBr sample prepared in the usual manner when this krypton was frozen into a quartz tube and volatilized without a bombardment. A standard run in which Kr^{86} was present in the quartz tube during the normal cyclotron tune up with the shutter closed, also resulted in no activity in the AgBr mount, and it was evident that only the time during which the shutter was open need be considered in evaluating the relative activities of the various bromine isotopes.

III. RESULTS

The beta decay data for the bombardment of normal krypton and enriched (99.8%) Kr^{86} were analyzed graphically, using the known half-lives of the bromine isotopes expected from the (n,p) and (n,pn) reactions on krypton. These data were consistent with the known half-lives, and the shorter lived components remaining after subtraction of the longer lived species are shown in Fig. 2. In both cases a short-lived component of about 0.9-min half-life was observed after subtraction of the known decay periods. The increase in relative abundance of this component in the case of the 99.8% Kr^{86} bombardment is consistent with the change in isotopic abundance from normal krypton (Kr^{86}=17.3%), clearly establishing the decay period as a product of the bombardment of Kr^{86}. Arguments presented below suggest that it is most likely the decay period of Br^{86}. The 3.0-min Br^{85} is also seen to increase in the same proportion, indicating it is being formed by the (n,pn) reaction on Kr.^{86}

A comparison of the initial activities of the various components from the normal and enriched krypton bombardment is given in Table I. The conditions for these bombardments were very nearly identical, and the ratios of activities observed should be directly compa-

TABLE I. Comparison of initial activities of bromine isotopes

Isotope	Initial activity at end of bombardment (counts/min) 99.8% Kr^{86}	Normal Kr	Normal isotopic abundances of Kr	Remarks
36-h Br^{82}	2.8	72	Kr^{82}=11.6%	$Kr^{82}(n,p)Br^{82}$; $Kr^{83}(n,pn)Br^{82}$
4.4-h Kr^{85m} 4.4-h Br^{80m}	110	380	Kr^{80}= 2.27%	Daughter of 3.0-min Br^{85}; $Kr^{80}(n,p)Br^{80m}$
2.3-h Br^{83}	165	2140	Kr^{83}=11.5%	$Kr^{83}(n,p)Br^{83}$ $Kr^{84}(n,pn)Br^{83}$
31.8-min Br^{84}	340	8800	Kr^{84}=57.0%	$Kr^{84}(n,p)Br^{84}$; $Kr^{86}(n,t)Br^{84}$
17.6-min Br^{80}	...	1800	Kr^{80}= 2.27%	$Kr^{80}(n,p)Br^{80}$
6.0-min Br^{84m}	(1160)[a]	30,000	Kr^{84}=57.0%	$Kr^{84}(n,p)Br^{84m}$; $Kr^{86}(n,t)Br^{84m}$
3.0-min Br^{85}	32,000	10,300	Kr^{86}=17.3%	$Kr^{86}(n,pn)Br^{85}$
0.9-min Br^{86}	120,000	35,500	Kr^{86}=17.3%	$Kr^{86}(n,p)Br^{86}$

[a] Assumed intensity from observed Br^{84} and ratio of Br^{84m}/Br^{84} in normal krypton bombardment.

rable with the isotopic abundance of the krypton isotopes. In the case of the enriched krypton, a 6-min component (Br^{84m}) was not actually seen in what was felt to be the best analysis of the decay data. However, 1160 counts/min of such a component could easily have been present and obscured. This intensity [shown as a dashed line in Fig. 2(b)] would be consistent with the observed activity of the 31.8-min Br^{84} isomer and the ratio observed in the normal krypton bombardments.

The difficulty of analyzing these complex decay curves was such that little confidence could be placed on the value of the half-life obtained for the shortest-lived component. Energy discrimination techniques were employed to observe this component free from the interference of the other bromine isotopes formed in bombardments of enriched Kr.[86] Since it was expected from beta-decay systematics that the Q_β of Br^{86} would be 7–8 MeV, it should be easily separable from the 2.5-MeV β of 3.0-min Br^{85}. Decay data were obtained using the Pilot B scintillator with the multichannel-analyzer lower level discriminator set to accept pulses $\geq$3 MeV. Figure 3 illustrates that, within the statistical errors, the decay curve obtained under these conditions shows a single component of 56±2-sec half-life.

In another set of experiments, the multichannel analyzer was adjusted to give ~8 MeV full scale for 64 channels. A complete beta spectrum was obtained every 30 sec for 2 min, the data were printed out during the third minute, and the cycle repeated. Subsequent cycles of 1- and 2-min counts were run, and a final background spectrum also obtained. A channel-by-channel analysis

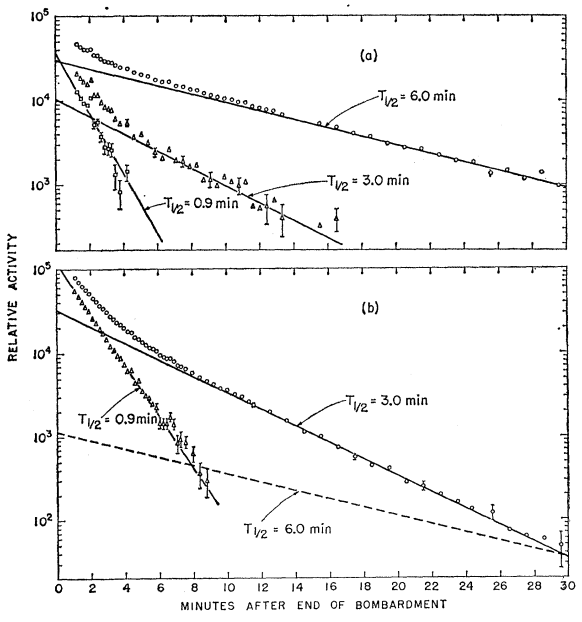

FIG. 2. Beta decay of short-lived bromine activities. (a) Normal krypton target; (b) enriched Kr^{86} target. See Table I for the mass assignments of the components.

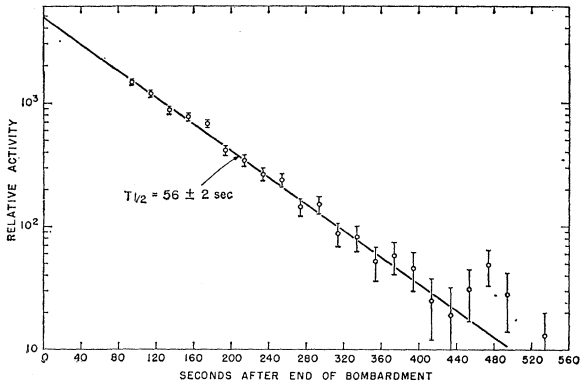

FIG. 3. Decay of beta rays $\geq$3MeV.

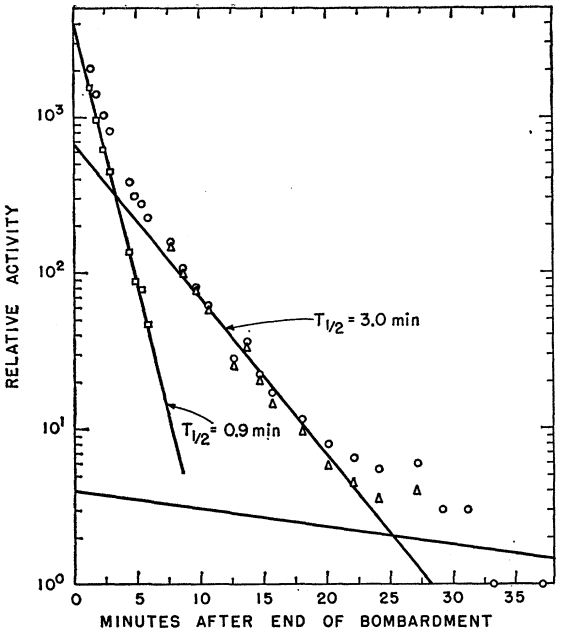

FIG. 4. Typical decay curve for a single channel (channel 12) of beta spectrum of short-lived bromine from Kr^{86} target.

of the decay data after the subtraction of a low intensity, long-lived component, indicated the presence of two components in the lower channels and a single component above channel 17 (about 2.5 MeV). Typical data are shown in Fig. 4. An average half-life of 53.7 ±2.6 sec was obtained for 17 decay curves from channels 18–34 (2.5–4.0 MeV). Subtraction of a 3.0-min component in the data of channels 7–17 gave an average half-life of 49.8±1.8 sec. Although the average deviation in the latter case is somewhat less, the accuracy of the value of the half-life is probably lower, owing to the possible error introduced on subtraction of the 3.0-min component.

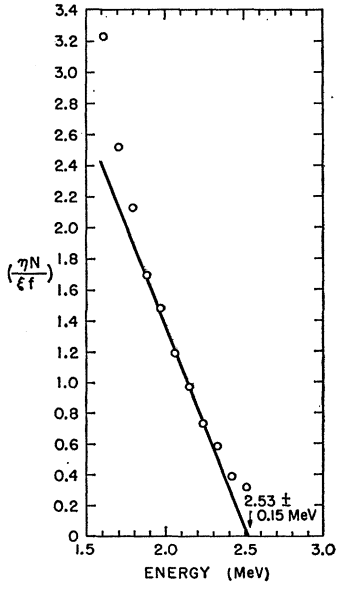

FIG. 5. Kurie plot of 3.0-min beta component.

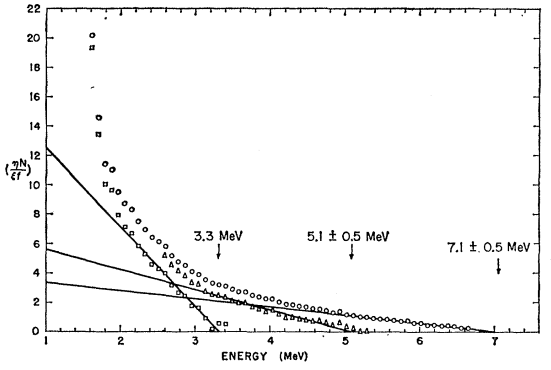

FIG. 6. Kurie plot of 54-sec beta component.

The data from the first two minutes of decay were combined to give isochrones, and Kurie plots were constructed to obtain the beta end-point energies. An end-point energy of 2.5 MeV was obtained for the 3.0-min component, establishing it as Br^{85} (Fig. 5). The 54-sec component showed a complex beta spectrum (Fig. 6) with an end point of 7.1±0.5 MeV for the most energetic component. The further analysis into 5- and 3-MeV components shown in Fig. 6 should be considered as very preliminary since the escape of high-energy beta rays from the Pilot B crystal is such that the lower energy groups cannot be determined reliably under the conditions of our measurement. Coincidence spectrometry would be required to identify these clearly. For the present analysis, the abundances of any lower energy beta-ray groups were included with that of the tentative 3-MeV group, giving relative abundances of 1:1:3 for the 7.1-, 5-, and 3-MeV groups, respectively.

Gamma spectra were obtained with the 3-×3-in. NaI crystal detector. In order to achieve reasonable statistical accuracy, the results of two 6-min counts (each starting 1.25 min after bombardment) were combined. The spectrum, shown in Fig. 7, exhibits several

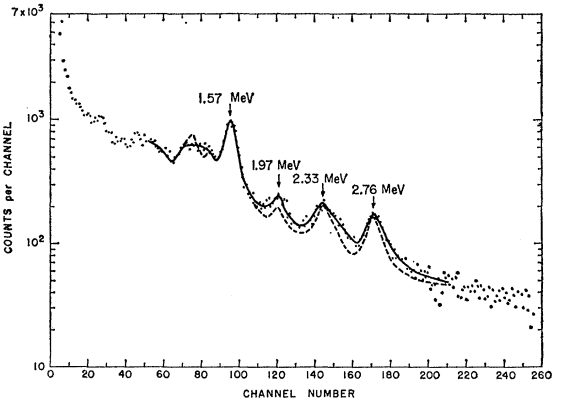

FIG. 7. Gross gamma spectrum of short-lived bromine activities. (Solid line represents data taken with a sample-to-detector distance of 0.60 in.; dashed line, 1.20 in.)

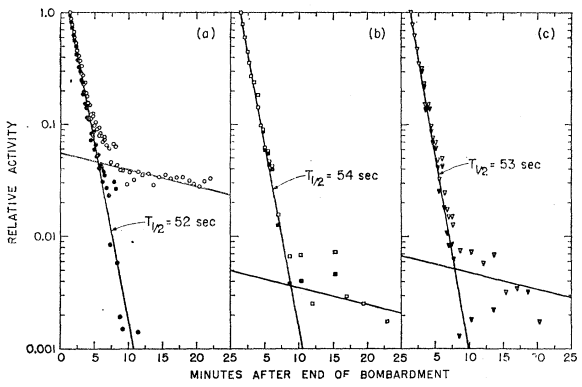

FIG. 8. Gamma decay data. (a) Decay of all energies >0.2 MeV. (b) Decay of energies >1.8 MeV. (c) Decay of 1.4–1.7 MeV region.

clearly-defined peaks. These data were obtained at a sample-to-crystal distance of 0.60 in., and in order to ascertain whether any of the peaks may be sum-peaks, data were also taken at a sample-to-crystal distance of 1.20 in. The changes observed under the latter condition, shown by the dotted line in Fig. 7, indicate that the 1.97-MeV peak may be a sum-peak. A complete analysis of the complex γ-spectrum will require coincidence spectrometry; however, a preliminary attempt to apply the method of Miller and Snow[8] to the observed spectrum indicates that the 1.26- and 2.33-MeV peaks may be, in large part, Compton and/or pair-escape peaks. The 1.57- and 2.76-MeV peaks appear to be true γ peaks associated with the Br^{86}.

Gamma-decay data were observed in several ways: (1) total γ-ray decay for all energies above 0.2 MeV; (2) decay of γ rays >1.8 MeV; and (3) decay of the 1.57-MeV peak (for which the energy range from 1.4 to 1.7 MeV was accepted). In each case, a low intensity component (probably a mixture of Br^{84} and Br^{84m}) was subtracted from the decay data giving half-lives of 52, 54, and 53 sec, respectively. The data are illustrated in Fig. 8.

The various experiments performed to establish the half-life of Br^{86} are summarized in Table II, and an average value of 54±2 sec is indicated.

IV. DISCUSSION

The data of Table I clearly establish the 54-sec and 3.0-min activities as resulting from the bombardment of Kr^{86}. Identification of the 3.0-min activity as Br^{85} indicates that it was formed by the (n,pn) reaction on Kr^{86}. The assignment of the 54-sec activity to Br^{86} produced by the (n,p) reaction on Kr^{86} is made on the basis of the following argument:

(1) It cannot be Br^{87}, since the formation of Br^{87} by neutron bombardment of Kr would require double neutron capture.

(2) It is a new nuclide, differing in half-life and decay energy from other bromine products of the neutron bombardment of krypton.

(3) The Q_β observed is consistent with that expected for Br^{86}.

(4) It is probably not an isomer of Br^{85} since isomerism in this region is very unlikely. Moreover, an experiment in which the deuteron beam was reduced in energy by ~5 MeV (by degradation through a 5-mil gold foil before impinging on the Be target) produced essentially the same ratio of 54-sec to 3.0-min activities. The calculated Q value to produce Br^{85} in the ground state from Kr^{86} is about 11.6 MeV, and taking a Coulomb barrier for proton emission of 6.5 MeV, one would expect that neutrons of about 18-MeV kinetic energy would be required to produce Br^{85} in good yield. If the 54-sec bromine activity were an isomer of Br^{85}, an additional 4.5 MeV of excitation energy would be required. The total of about 22.5 MeV is close to the maximum energy available for the neutrons produced in our bombardments. A reduction of 5 MeV in this maximum should have reduced the ratio of the 54-sec to 3.0-min activities appreciably. Since no such reduction was observed, we conclude that the 54-sec activity cannot be an isomer of Br^{85}.

Although it is not possible from the present data to establish a decay scheme for Br^{86}, the maximum β energy and rough branching ratio are consistent with an assignment of 0− or 1− for the Br^{86} ground state, the latter being somewhat more likely. Further experiments involving coincidence spectrometry must be carried out to establish the decay scheme of Br^{86}.

From the observed abundance of the 4.4-h component (Kr^{85}) in Table I, column 2, one would expect only about $\frac{1}{3}$ of the observed activity for the 3.0-min Br^{85} parent. The "excess" of 3.0-min activity could be the result of counting efficiency differences, escape of Kr^{85} from the sample, errors in the analyses of the complex decay curves, and/or the existence of a 3-min isomer of Br^{86}. The latter possibility is very doubtful since no β rays of energy >2.5 MeV or gamma rays were observed with a 3.0-min half-life. Moreover, the experiment

TABLE II. Half-life of Br^{86}

Method	Value (sec)
β-decay curve analysis	54
β's>3MeV	56 ±2
β spectrum (1.5–2.5 MeV)	49.8±1.8
β spectrum (2.5–4 MeV)	53.7±2.6
γ's>0.2 MeV	52
γ's>1.8 MeV	54 ±2
γ peak (1.4–1.7 MeV)	53.5±1.5
Average	54 ±2

[8] W. F. Miller and W. J. Snow, Rev. Sci. Instr. **31**, 39 (1960); Argonne National Laboratory Report ANL-6318, 1961 (unpublished).

in which the bombarding deuterons were degraded through a 5-mil gold foil should have altered the abundance of a 3.0-min Br^{86} isomer, and hence the ratio of 3.0-min to 54-sec activities, but no such change was observed. An attempt to observe Br x rays was made, but it was unsuccessful.

The establishment of a 54-sec Br^{86} raises a number of questions regarding previous investigations of short-lived bromine isotopes in nuclear fission. The close similarity in nuclear properties with 56-sec Br^{87} would, of course, confuse the observations. Since a half-life of 56 sec was established by Sugarman[1] from observations of the 78-min Kr^{87} daughter, there is no reason to suspect interference from the Br^{86} on this value. However, measurements of the characteristics of Br^{87} observed directly[2] are questionable, since in these experiments Br^{86} would also be contributing to the observed activity.

Sattizahn, Knight, and Kahn[3] report the presence of prominent gamma rays of 1.42 and 1.56 MeV and less abundant gammas of 2.0, 2.4, 2.7, and 3.2 MeV, the intensities of which all decayed with a half-life ≤ 1 min. No evidence of the 5-MeV gamma ray reported by Stehney and Sugarman[2] for Br^{87} was observed. The present investigation of Br^{86} indicates gamma rays corresponding to four of the above peaks, but no evidence for prominent 1.42- or 3.2-MeV peaks (Fig. 7). In all probability, the latter are associated with Br^{87}.

A preliminary experiment,[9] carried out on fission-produced bromine, indicated γ-ray peaks at 0.76, 1.42, 1.57, 2.0, 2.3, and 2.7 MeV, all of which decayed with somewhat less than 1-min half-life. Although activity above background was observed at higher energies it was not possible to resolve clear peaks. Larger crystals and higher intensity sources would be required to clarify the high energy gamma region.

Data obtained in the present experiment permit some rough evaluations of the relative cross sections for the (n,p), (n,pn), and (n,α) reactions for neutrons produced from 22-MeV deuterons on Be. The data of Table I indicate that, for this spectrum of neutron energies, the (n,p) and (n,pn) cross sections are approximately equal. Figure 9 shows a decay curve for Se isolated from a bombardment of enriched Kr^{86}. The 69-sec Se^{83m} and 25-min Se^{83} which decay to 2.3-h Br^{83} are easily seen.

[9] Performed in collaboration with M. N. Namboodiri and Dr. Kenneth Rind.

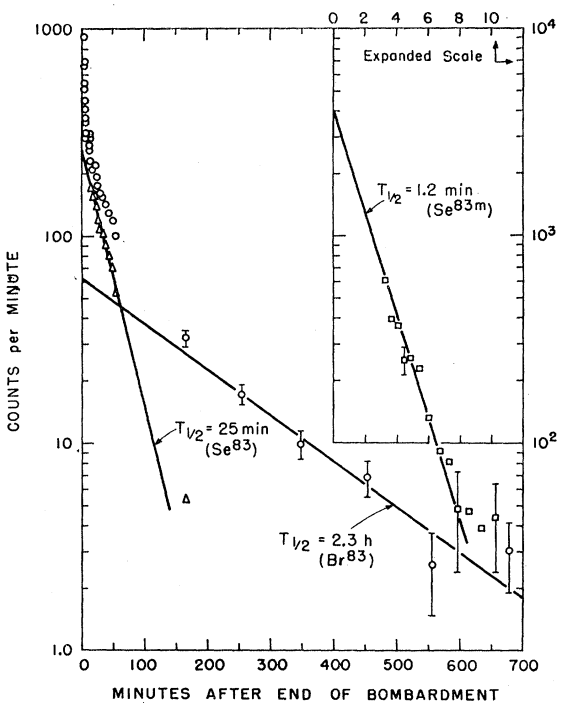

FIG. 9. Gross beta decay curve of selenium activities isolated from a bombardment of enriched Kr^{86}.

Since the selenium was not counted on the same apparatus as the bromine activities, it was necessary to apply an empirical correction factor of 1.14 to compare the Se^{83m} and Se^{83} activities with the Br^{86} and Br^{85}. These data indicate that the (n,α) cross section is about 5% that of the (n,p) or (n,pn). Moreover, the (n,α) production of the Se isomers is about 3 to 1 in favor of the Se^{83m}.

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