Mev state and the ground state. The first alternative is unlikely because of the rather high energy of the first excited state directly populated in the decay. This would not be in accord with the pattern suggested by the other odd-mass gallium and copper nuclides. The second alternative would require a 1.05-Mev transition with an intensity equal to that of the 0.67-Mev transition. Such a transition was not observed. These observations are summarized in two alternative decay schemes given in Fig. 5. The difference between them is in the position of the second excited state.

The decay energy of Ge^{65} is 4.7±0.4 Mev. This value may be compared with a value predicted from beta-decay energy systematics as suggested by Way and Wood.[10] In Fig. 6 the most recent values[2] of the energy differences between the odd-mass gallium and germanium isotopes are plotted. The extrapolated decay energy of Ge^{65} is 5.5±0.4 Mev. The measured decay energy, while considerably lower, is compatible with this value within the limits of error.

ACKNOWLEDGMENTS

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[10] K. Way and M. Wood, Phys. Rev. **94**, 119 (1954).

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Five New Isomers with Half-Lives between 10^{-6} and 10^{-1} Second*

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Isomers with half-lives greater than approximately 5 μsec were sought between the 180-cps, 1-μsec x-ray pulses of a 22-Mev betatron. The following new activities were observed:

Isotope	Half-life (μsec)	Gamma-ray energy (kev)	Production reaction	Production threshold (Mev)
$Br^{78,80}$	127±5	149±6	(γ,n)	11.0±0.3
$Br^{79,81}$	37±3	268±4	(γ,γ')	···
Nb^{92}	5.9±0.5	88±5	(γ,n)	9.1±0.7
In^{114}	(42±5)×10^3	311±5	(γ,n)	9.9±0.2
Sn	165±15	117±5 163±5 504±6	(γ,n)	~11

Excitation functions and cross sections for the production of the above isomers are also given for some cases. The properties of all the isomers investigated are summarizes in this paper. Additional results include improved values for half-lives and gamma-ray energies, plus some measurements on production thresholds, excitation functions, and cross sections for the isomers listed in a previous paper.

INTRODUCTION

THIS paper gives a report on continued success in the search for isomeric transitions with half-lives in the microsecond and millisecond range. The experimental arrangement used was a modified and improved version of that discussed in an earlier publication.[1] The isomeric states were produced by irradiation of various target materials in the x-ray beam from the University of Illinois 22-Mev betatron. The x-ray yield pulses had a duration of approximately 1 μsec and a repetition rate of 180 cps. The irradiated targets were viewed by a scintillation spectrometer, gated on during the 5555-μsec interval between x-ray pulses. The repetition rate was reduced by factors of 2, 4, or 8 during experiments with some of the longer-lived cases. The isomeric states were produced by the (γ,n) or (γ,γ') reactions.

Since the previous report[1] on the detection of isomers with half-lives in the microsecond and millisecond range, 24 additional elements have been surveyed. These elements are Si, Ca, V, Co, Ge, Se, Br, Rb, Sr, Nb, Rh, Ag, Cd, In, Sn, Cs, La, Pr, Nd, Sm, Gd, Pt, Au, and Hg. New isomers were found in Br (2), Nb, In, and Sn. The possible existence of isomeric transitions in this half-life region in the elements Co, Ge, Sr, Cd, Gd, and Hg cannot be definitely excluded by this

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‡ Present address: Atomic Energy Division, Phillips Petroleum Company, Idaho Falls, Idaho.
[1] S. Vegors and P. Axel, Phys. Rev. **101**, 1067 (1956).

TABLE I. Summary of experimental data.

Isotope	Half-life (μsec)	Gamma-ray energy (kev)	Internal conversion coefficient[a]	Relative gamma-ray intensity	Production reaction	Production threshold[b] (Mev)
$_{33}As^{75}$	$(17\pm1)\times10^3$	284±5[c]	...	...	(γ,γ')	...
$_{35}Br^{78,80}$	127±5	149±6	...	...	(γ,n)	11.0±0.3
$_{35}Br^{79,81}$	37±3	268±4	...	...	(γ,γ')	...
$_{41}Nb^{92}$	5.9±0.5	88±5	...	...	(γ,n)	9.1±0.7
$_{42}Mo^{99}$	16.3±1	98±5	...	...	(γ,n)	8.4±0.6
$_{46}Pd^{105}$	37±3	189±7 306±10[d]	...	$\left[\frac{I_\gamma(189\text{ kev})}{I_\gamma(306\text{ kev})}\right]$ =0.86±0.15	(γ,n) and (γ,γ')	11.9±0.7
$_{49}In^{114}$	$(42\pm5)\times10^3$	311±5	<0.18	...	(γ,n)	9.9±0.2
$_{50}Sn$	165±15	117±5 163±5 504±6[d]	...	...	(γ,n)	~11
$_{74}W^{181}$	14.7±0.5	368±5	0.35±0.05	...	(γ,n)	8.36±0.35
$_{81}Tl^{202}$	585±25	475±25[c]	0.25±0.1	...	(γ,n)	~10
$_{81}Tl^{202,204}$	62±5	419±5 703±10[d]	<0.20	$\left[\frac{I_\gamma(419\text{ kev})}{I_\gamma(703\text{ kev})}\right]$ =1.14±0.2	(γ,n)	11.4±0.4
$_{83}Bi^{208}$	$(2.7\pm0.25)\times10^3$	509±10 921±15[d]	0.3±0.15	$\left[\frac{I_\gamma(509\text{ kev})}{I_\gamma(921\text{ kev})}\right]$ =0.9±0.15	(γ,n)	11.4±0.4

[a] Where more than one gamma ray is present, the value of the internal-conversion coefficient given is the ratio of the number of K electrons to the intensity of the highest energy gamma ray listed for that nucleus.
[b] In order to allow for any uncertainties in the absolute energy calibration of the betatron, 100 kev was added to the statistical error in the threshold measurement. Therefore, the values given here, taken with the quoted errors, should be considered as absolute energy measurements.
[c] The 284±5 kev line in As^{75} may be an unresolved 305–280 kev doublet. This possibility is discussed in the section of this paper on results.
[d] Gamma-gamma coincidences have been observed with a resolving time $\tau=2\times10^{-8}$ sec for the 419–703 kev gamma rays in $Tl^{202,204}$ and for the 509–921 kev gamma rays in Bi^{208}. Gamma-gamma coincidences have been observed with a resolving time $\tau=10^{-7}$ sec for the 189–306 kev gamma rays in Pd^{105} and also between the 504–117 kev gamma rays in Sn. No coincidences were observed between the 504–163 kev gamma rays in Sn.
[e] Data in reference 34 show that there are two gamma rays, of energy 459.8 and 490.4 kev, for Tl^{202}.

survey. All the other elements studied gave negative results.

Table I lists the results of the work done on the five isomers particular to this report, plus improved results for the seven isomers previously reported.[1] An improved value for the half-life of Y^{88m} (not listed) is 300±10 μsec.

EXPERIMENTAL PROCEDURE

Geometry

Figure 1 shows a scale drawing of the experimental arrangement. The x-rays were produced at the betatron target (1). A nickel target was used in order to reduce the neutron flux originating in the target. An iron, instead of a lead, collimator was used to decrease the number of neutrons produced by (γ,n) reactions due to x-rays stopping in the collimator. In order to minimize air scattering into the NaI scintillation crystals, the x-ray beam traveled much of the distance to the sample through an evacuated tube (3). The collimated x-ray beam was $1\frac{3}{4}$ in. in diameter at the location of the sample, and the distance from the betatron target to the sample was 11.3 ft. The front face of the NaI crystal was $1\frac{1}{4}$ in. from the center of the x-ray beam in most of the measurements. At a betatron energy of 22 Mev, the flux of radiation at the sample position was 4.3 r/min. In general, the samples used were 2×2 in. and were placed at an angle of 45° with respect to the axis of the x-ray beam. Sample thickness depended upon the activity being observed. The monitor used was an aluminum-walled ionization chamber with a sensitive area 4 in. in diameter. This was substantially larger than the area of the x-ray beam at the position of the monitor.

The large iron collimator, the earth-filled wall, and the combination of iron, borax, and paraffin immediately around the evacuated tube served to attenuate the neutron flux generated by the betatron target and the collimator by a factor of approximately 4000. However, the sample itself was also a large source of neutrons. A minimum amount of shielding was used around the NaI crystals to keep the neutrons produced by the sample, plus those which leaked through the wall, from being captured in the vicinity of the phototube. Thus neutron-capture gamma rays, one of the main sources of background, were reduced. This shielding consisted only of a $\frac{1}{16}$-in.-thick layer of lead wrapped around the sides of the large crystals ($1\frac{3}{4}$ in. diameter ×2 in. long). Smaller crystals had no shielding.

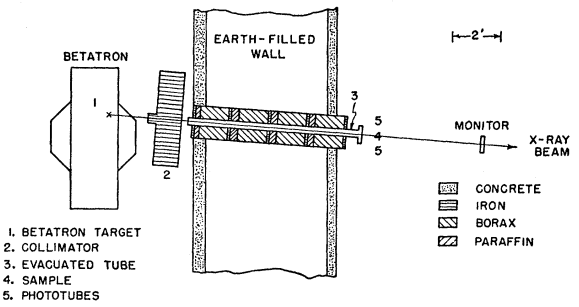

FIG. 1. Scale drawing of the experimental apparatus.

Electronics

A block diagram of the electronics is shown in Fig. 2. The entire system was triggered by the "betatron expander trigger" which preceded the x-ray yield pulse by approximately 5 μsec. The phototube gating network gated the photomultiplier off during the 1-μsec x-ray yield pulse. This was necessary to avoid overloading the electronics because of the large amount of radiation which was scattered by the sample into the NaI crystal during the x-ray yield pulse. Two different methods of gating were used. One was to gate the photomultiplier photocathode (and the aluminum can covering the NaI crystal) to a more positive voltage than that on the first dynode. Normally the photocathode was at ground. The other method was to gate the first dynode to a negative voltage. Both methods seemed to be satisfactory and each was used during part of the experiment. However, there was less capacitative feed-through of the gating pulse when the first dynode was gated. DuMont 6292 photomultipliers with NaI(Tl) crystals were used as the scintillation detectors. The preamplifier, amplifier, and pulse-height selector were of conventional design.

The gray-wedge pulse-height analyzer[2] used had the property that it could be made to display only pulses in coincidence with an external gate, if desired. The gate for this purpose was generated by the single-channel time discriminator. This gate could be varied continuously in length from 1 to 2000 μsec and the front edge of the gate could be delayed continuously from 5 to 5000 μsec after the x-ray yield pulse.

The 5-channel time discriminator, 5-channel coincidence circuit, and 5-channel scaler made it possible to count simultaneously in each of 5 preset time bins. The 5-channel time discriminator generated 5 contiguous gates, the length of each gate being independently and continuously variable from 20 to 5000 μsec. The front edge of the first gate could be delayed continuously from 10 to 10 000 μsec after the x-ray yield pulse. The longest delays and gate lengths were used only when the repetition rate of the betatron had been reduced by a factor of either 2, 4, or 8. The front edge of all the gates, except the first, followed the back edge of the preceding gate within 0.2 μsec. Any output pulse from the pulse-height selector, which was in coincidence with any one of the gates from the 5-channel time discriminator, would pass through the 5-channel coincidence circuit and be recorded in the corresponding channel of the 5-channel scaler. The 5-channel scaler was simply 5 independent scalers mounted on a single chassis.

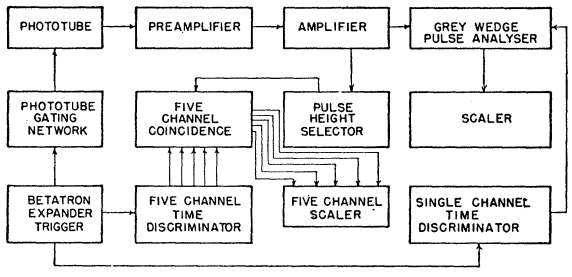

FIG. 2. Block diagram of the electronics.

[2] R. L. Chase, Coincidence Grey Wedge Pulse-Height Analyzer, Brookhaven National Laboratory Model EHI-501, BNL-263 (T-42).

In addition to the electronics shown in the block diagram in Fig. 2, provision was also made for coincidence work. Two different coincidence circuits were used: one with a resolving time τ of 10^{-7} sec, and the other with a resolving time τ of 2×10^{-8} sec. The 10^{-7}-sec coincidence circuit was contained in the gray-wedge pulse-height analyzer[2] while the other circuit was external to the gray wedge. In both cases, however, the events which were in coincidence were displayed on the gray wedge. The restrictions which could be placed on the events displayed were that they had to be in fast coincidence with events in a preset pulse-height channel and also had to occur during a preset time gate.

TABLE II. Delay and duration of time channels.

Delay (μsec)	Length of time channel (μsec)
30	30
100	100
200	200
500	500
1000	1000
2000	2000

Searching for New Isomers

The search for new isomers was made by using the gated, gray-wedge pulse-height analyzer. A series of delays and their corresponding time channels was worked out to minimize background effects and, simultaneously, at least 20% of the isomeric decays with half-lives between 8 μsec and approximately 5 sec would appear in at least one of the time channels. The schedule of delays and time channels is shown in Table II. At each delay and its corresponding time channel, two pictures were taken: one with the amplifier gain set so the energy range displayed on the gray wedge was approximately 0 to 600 kev, and the other with a range 0 to 2.5 Mev. For each setting of the amplifier gain and the delay-time channel, a 200-sec exposure was taken. Because of the high noise level in the photomultiplier, it was usually impossible to observe any gamma rays with energies less than 25 kev. However, gamma rays in the energy range from 25 kev to 2.5 Mev should have been observable, provided that the cross section for production of the activity was large enough. In the search for new isomers the betatron was operated at an energy of 19.5 Mev.

Sensitivity of the Method Used to Search for New Isomers

By means of a calibration using the 7-sec β^+ activity of Al^{26}, it was determined that 5.5 Mev mb was approximately the minimum integrated cross section necessary for the formation of an isomeric level, if transitions from this level were to be detected using the technique outlined above for searching for new isomers.[3] This value held for samples 1 g/cm² thick. Because this value was determined for a 510-kev activity in Al, several approximations were necessary to have it apply for other nuclei and other gamma-ray energies. For increasing gamma-ray energy the efficiency of the crystal decreased. However, the background also decreased with increasing gamma-ray energy, making higher energy gamma-ray lines more easily detectable, and it was felt that these two effects roughly compensated for each other. Therefore, the approximation was made that the value obtained for 510-kev gamma rays was applicable to all gamma-ray energies between 30 kev and 2.5 Mev. Also, the value of the minimum cross section observable for nuclei other than Al would depend on the shape of the cross section for the particular nucleus. For nuclei with higher values of Z than Al, the cross section is relatively greater for lower energies. This would have the effect that for a given integrated cross section up to 19.5 Mev, nuclei of higher Z would give a greater yield and thus be more easily detectable. As all of the elements surveyed had higher Z values than Al, it was felt that the cross section necessary for observation in Al would represent a minimum value. There is, however, one thing which may increase the minimum isomeric production cross section necessary for observation. This is the presence of other intense activities which are generated in the sample while it is being surveyed. The worst offenders are the relatively short-lived (several seconds) β^+ activities which occur especially in the low-Z elements. Experimental values of the (γ,n) cross sections up to 19.5 Mev were taken from the work of Montalbetti *et al.*,[4] and the fraction of the (γ,n) reactions which must lead to an isomeric state, in order for its decay to be detectable, was computed assuming no masking transitions. The results of this calculation for several nuclei are shown in Fig. 3 as dark circles. The smooth curve drawn through these points is a "best curve" through these discrete points and serves as a guide to obtain estimates for other nuclei. To allow for possible errors and to make a conservative estimate, the values plotted in Fig. 3 have been multiplied by a "safety factor" of 2. Because only gamma rays were detected, the intensity of any transition which goes partially by internal conversion would have to be $1+\alpha_K$ times as strong as a transition which is unconverted in order for the converted transition to be observed. Thus it is possible that the low-energy, highly converted lines could have been missed in this survey. In the course of the present work and the previous research paper,[1] no isomeric states were found in nuclei of the following 37 elements: O, Na, Mg, Al, Si, Cl, K, Ca, Ti, V, Cr, Mn, Fe, Co, Ni, Ge, Se, Rb, Sr, Zr, Rh, Ag, Cd, Sb, I, Cs, Ba, La, Ce, Pr, Nd, Sm, Gd, Pt, Au, Hg, and Th.

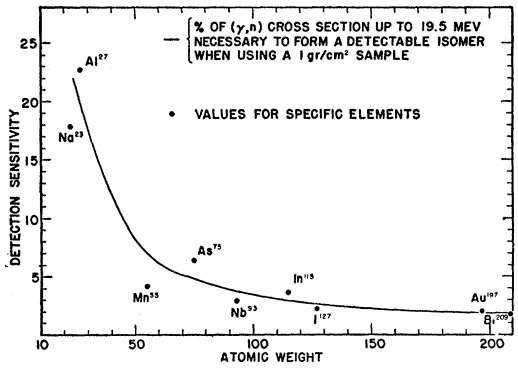

FIG. 3. Graph of calculated detection sensitivity. The point for Al^{27} was measured experimentally. The points for other nuclei were calculated using the experimental value for Al^{27} and the (γ,n) cross-section data of reference 4. The smooth curve is drawn through the points.

Half-Life Measurements

A very difficult problem in the measurement of the half-lives was the determination of the background. One very large component of the background was due to neutron-capture gamma rays and had an apparent half-life of approximately 200 μsec. As the sample itself was an important source of neutrons, it was not possible to measure separately the neutron background and the desired activity from the sample. To obtain an approximation to the neutron background, a measurement of the activity as a function of time was made for a pulse-height channel set just above the gamma-ray line being studied. The counting rate in this channel was then normalized to the counting rate with the pulse-height selector set on the gamma ray at large values of time delays. Figure 4, which shows a typical measurement of the Sn half-life, illustrates the technique used. In general the statistical errors in the half-life measurements were much greater than the errors due to calibration of the time discriminator. By taking several sets of data, it was felt that the errors in calibration of the time discriminator could be made small compared to statistical errors, so the calibration errors were usually neglected in stating experimental errors.

Measurement of Gamma-Ray Energies

Gamma-ray energies were measured using the gray-wedge pulse-height analyzer. The positions of the

[3] S. Vegors, Ph.D. thesis, University of Illinois, July, 1955 (unpublished).
[4] Montalbetti, Katz, and Goldemberg, Phys. Rev. **91**, 659 (1953).

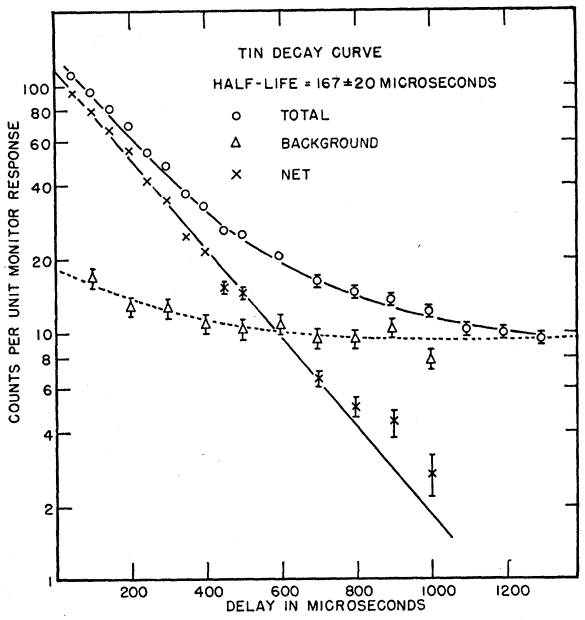

FIG. 4. Decay curve of tin isomer. This measurement gives 167 ±20 μsec. The best value including other data is 165±15 μsec.

photoelectric peaks were measured from Polaroid camera pictures upon which were simultaneously recorded both the unknown gamma rays and several gamma rays of known energy from long-lived sources placed near the sample.

Relative Gamma-Ray Intensities

The relative gamma-ray intensities were obtained by measuring the area under the photopeaks on 5×7-in. prints of 35-mm photographs of the spectrum taken using the gray-wedge pulse-height analyzer.[2] It was then necessary to correct the measured area (or intensity of the gamma ray) for absorption of the gamma ray in the sample and for the efficiency of the crystal. In order to reduce any uncertainty in the correction for the self-absorption in the sample, several thicknesses of sample were used. The correction for self-absorption in the sample was then made for each sample thickness and the results compared. The greatest difficulty, however, was in measuring the intensities of the gamma-ray lines from the photographs. It was somewhat difficult to judge the shape of the line exactly because of the finite contrast on the film. Also, to reduce the correction for absorption in the sample as much as possible, thin samples were used; and as a result the gamma-ray lines often did not stick out prominently from the background.

Calibration of the Crystal

The proper crystal calibration for the $1\frac{3}{4}$-in. diameter ×2-in.-thick NaI(Tl) crystal used in this experiment was assumed to be identical to the case of a point source of radioactivity located 1.18 in. (3 cm) away from the front face of the crystal on its extended central axis. This distance approximates very closely the actual distance from the center of the source to the crystal, which was 1.25 in. Because calculations and measurements have been made[5] which relate the number of events in the gamma-ray photopeak to the number of disintegrations per second in the source, this allowed a relative calibration of the crystal to be made.

Due to the $\frac{1}{8}$-in.-thick lead shield which surrounded the crystal, a small amount of lead x-ray fluorescence radiation was created. The amount of this fluorescence radiation produced as a function of gamma-ray energy was studied using point sources of radioactivity. A correction was made, where necessary, for this effect.

Method of Measuring Thresholds and Excitation Functions

The thresholds and excitation functions were determined by measuring the net amount of activity in a pulse-height channel centered on a convenient gamma ray in the spectrum of the activity being studied. To correct for background effects, two channels of the 5-channel time discriminator were used; one to measure the activity plus background, and one to measure background only. The difference between these two readings was assumed to be due only to the activity. This method had the advantage that it automatically corrected for backgrounds which changed slowly with time (e.g., long-lived radioactivity building up in the sample). However, it did not necessarily compensate for backgrounds which decayed quickly (e.g., the neutron-capture gamma-ray background).

In some cases where the half-lives were quite long (As, In, and Bi), it was impractical to use the techniques just described. In these cases the background associated with each energy of the betatron was measured as soon as possible after the bombardment. These background counts usually started within 30 sec after the betatron went off and sometimes lasted for as long as 10 min. To determine the effectiveness of the background cancellation, several points were taken at energies below the threshold of the activity being measured. In general these procedures seemed quite satisfactory.

For activities having very short half-lives (less than 50 μsec), a correction was made for the fact that the time, with respect to the betatron "expander pulse," at which the x-ray yield pulse occurs varied with the betatron energy. A calibration of the vibrating reed against an r thimble as a function of energy was made to convert the data into counts/r. An attempt was made to obtain absolute values for the activation curve in disintegrations/100 r-mole. This was not completely successful and it is felt that the absolute values obtained are only good to within ±40%.

[5] Vegors, Marsden, and Heath (to be published).

RESULTS

The experimental data on each of the isomers are presented in the following section. Reference is made to previous experiments on the same nuclei, but not in complete detail. Some of the isomers observed first by the present technique have subsequently been identified in the decay of long-lived parent nuclei. The more accurate gamma-ray energies so obtained have been included.

$_{33}As^{75}$

The activity observed in arsenic has been assigned to As^{75}, as the activation curve for this activity (not shown) indicated that it was produced by a (γ,γ') reaction. This assignment is verified by the fact that this isomeric state has been observed in the Se^{75} decay.[6] An improved value of the half-life, 17 ± 1 msec, is in good agreement with the value of 17 ± 0.7 msec reported by Schardt.[7] The value of 18 ± 2 msec has been reported by Campbell and Stelson.[8] The 305- and 280-kev gamma rays reported by Schardt and Welker[9] were not resolved in our experiment, but the value of 284 ± 5 kev measured in this work for the gamma ray is in good agreement with a composite photopeak of 85% 280 kev and 15% 305 kev.[9] Unfortunately, because of the high noise level and probable high internal-conversion coefficient, it was impossible to observe the 25-kev line which should be in coincidence with the 280-kev transition.

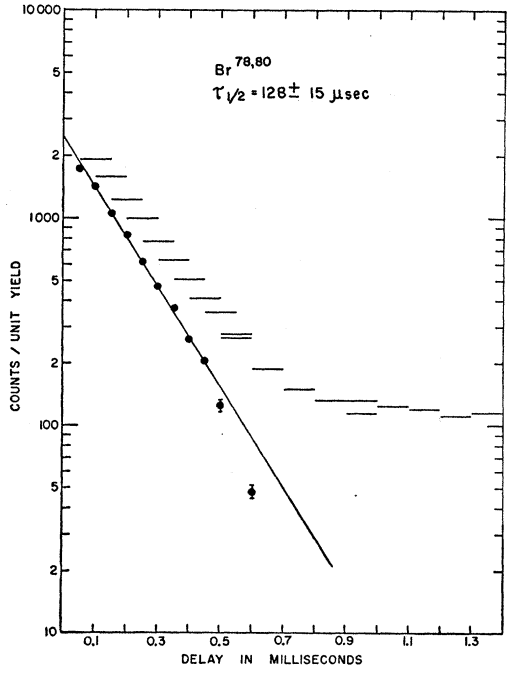

FIG. 5. Decay curve of $Br^{78,80}$ isomer. This measurement gives 128 ±15 μsec. The best value including other data is 127 ± 5 μsec.

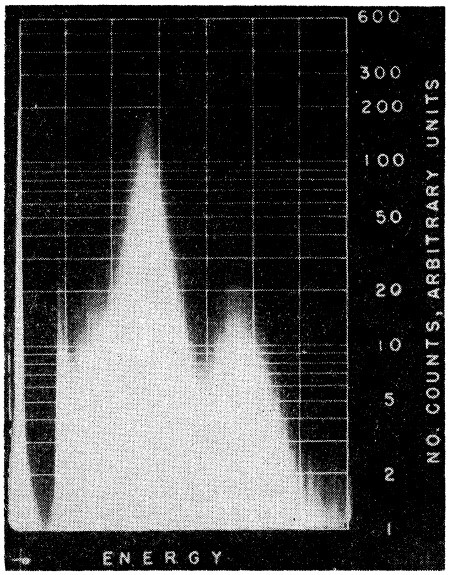

FIG. 6. Pulse-height spectrum of gamma rays from both $Br^{78,80}$ and $Br^{79,81}$ isomers.

The identification of the levels in As^{75} from studies of the decay schemes of the neighboring nuclei, Se^{75} and Ge^{75}, has been discussed at length by Schardt and Welker.[9,10] The ground state of As^{75} is $p_{3/2}$, and from Schardt's work it can be deduced that the isomeric level is at 305 kev. The latter decays approximately 10% by a 305-kev transition to the ground state and approximately 90% by a 2-step transition of 25 kev plus 280 kev to the ground state. From the lifetime-energy correlations of Goldhaber and Sunyar,[11] it can be deduced that the 25-kev transition is probably $M2$ and the 305-kev transition is probably $E3$ or $M3$. A classification as $E3$ is favored by an internal-conversion measurement made by Schardt.[7] These multipolarities then indicate that the 305-kev level is $g_{9/2}$ and the 280-kev level is $f_{5/2}$. These assignments are consistent with the shell model and with Coulomb excitation data.[12] The present work sheds no light on the identification of the 402-kev level.

$_{35}Br^{78,80}$

This 127-μsec, 149-kev activity in bromine is produced by a (γ,n) reaction with a threshold at 11.0 ± 0.3 Mev (see Figs. 5, 6, and 14). Measurements of the (γ,n) thresholds for the reactions $Br^{81}(\gamma,n)Br^{80}$ and $Br^{79}(\gamma,n)Br^{78}$, using the 18-min and 6-min residual activities, have been made with the University of

[6] A. W. Schardt, Bull. Am. Phys. Soc. Ser. II, **1**, 85 (1956).
[7] A. W. Schardt, Phys. Rev. **108**, 398 (1957).
[8] E. C. Campbell and P. H. Stelson, Oak Ridge National Laboratory Report ORNL-2302 (unpublished).
[9] A. W. Schardt and J. P. Welker, Phys. Rev. **99**, 810 (1955).
[10] A. W. Schardt (private communication).
[11] M. Goldhaber and A. W. Sunyar, *Beta- and Gamma-Ray Spectroscopy* (North-Holland Publishing Company, Amsterdam, 1955), Chap. XVI.
[12] G. M. Temmer and N. P. Heydenburg, Phys. Rev. **104**, 967 (1956).

Illinois betatron.[13] Values for these thresholds are 9.95±0.1 and 10.55±0.1 Mev, respectively. Adding the energy of the isomeric level to these values gives 10.1±0.1 and 10.7±0.1 Mev, respectively, as the thresholds for the production of the isomeric level. The value of the $Br^{79}(\gamma,n)Br^{78m}$ threshold is in better agreement with the measured threshold for the 127-μsec isomer, but the result is not considered to be conclusive.

There is not sufficient information available to construct a decay scheme for this isomer. The half-life and energy indicate that the transition is probably $M2$, but a slow $E2$ is not excluded.[11] The ground states of both Br^{78} and Br^{80} are 1+ and longer-lived isomers of each are known with probable spins of 5−.

$_{35}Br^{79,81}$

The 37-μsec, 268-kev transition in bromine is produced by a (γ,γ') reaction, as it was observed at betatron energies down to 4 Mev (see Figs. 6, 7, and 14). This indicates that the isomeric state must be assigned to either Br^{79} or Br^{81}. The lifetime is consistent with an $M2$ transition. No other gamma rays of energy greater than 50 kev were observed in comparable intensity (our sensitivity below 50 kev was very poor). Consequently, because of the short lifetime, it is probable that the 268-kev transition is the rate-controlling one.

The ground-state spins of Br^{79} and Br^{81} are both $\frac{3}{2}-$. The single-particle states available for the 35th proton are $p_{3/2}$, $f_{5/2}$, $g_{9/2}$, and $p_{1/2}$. Levels excited by Coulomb excitation[14] have been seen at 278 kev in Br^{81} and at 219 kev in Br^{79}; these probably have spins of $\frac{1}{2}-$ and $\frac{5}{2}-$, respectively. There are insufficient data to assign the mass number of the 37-μsec state or to construct a decay scheme. Thulin[15] has investigated the large number of levels in Br^{79} formed by the decay of Kr^{79}. There is no evidence in his work that the 37-μsec isomer is formed by the Kr^{79} decay. All of the nuclei As^{75}, Br^{77}, and Br^{79} appear to have a large number of low-spin levels within 500 kev of the ground state. This indicates that the extreme single-particle model cannot account for all of them.

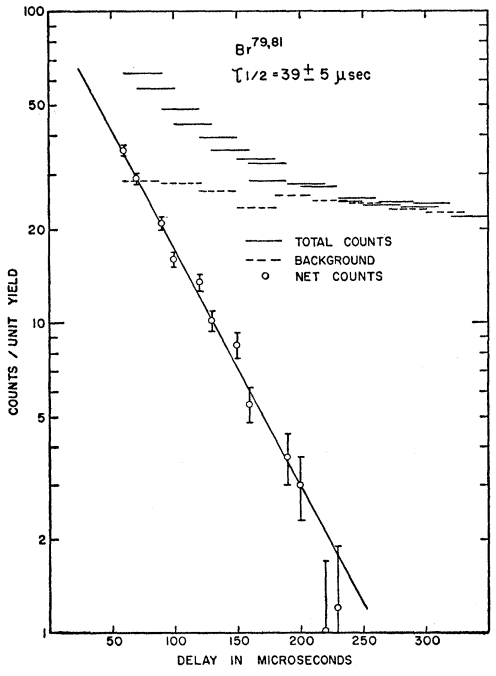

FIG. 7. Decay curve of $Br^{79,81}$ isomer. This measurement gives 39±5 μsec. The best value including other data is 37±3 μsec.

In As^{73}, As^{75}, and As^{77}, $M2$ transitions between 9/2+ and $\frac{5}{2}-$ levels have been observed.[7] The nuclei Br^{79} and Br^{81} might be expected to show similar transitions and the 37-μsec isomer may be one of these. We were not able to detect a gamma ray corresponding to the decay from the $\frac{5}{2}-$ state to the $p_{3/2}$ ground state. A possible explanation is that the ground-state transition coincides in energy with the 268-kev isomeric transition so closely that we were unable to resolve them.

$_{41}Nb^{92}$

The 5.9-μsec activity in niobium was assigned to Nb^{92}, because it was formed by a (γ,n) reaction with a threshold of 9.1±0.7 Mev (see Figs. 8, 9, and 14). Subtracting 88 kev for the energy of the isomeric level gives an implied ground-state threshold of 9.0±0.7 Mev. This is in agreement with the previous value of 8.7±0.2 Mev.[16] The half-life energy data are in good agreement with an $E2$ transition, although a slow $E1$ or $M1$ transition is possible.

In Nb^{92}, the available single-particle proton states are $p_{1/2}$ and $g_{9/2}$ while the lowest available single-particle neutron state is $d_{5/2}$ (the $g_{7/2}$ state appears to be much higher). Combining the $p_{1/2}$ and $d_{5/2}$ states will give resultant states of 2− and 3−; and combining $g_{9/2}$ and $d_{5/2}$ will give 2+, 3+, 4+, 5+, 6+, and 7+. The beta decay of the ground state of Nb^{92} goes 97% to the 2+ state of Zr^{92}, thus indicating that the Nb^{92} ground state is 2+, 2−, or 3+.[17] The nucleus Nb^{94}, which is expected to be similar, has a ground state of 6 or 7+. Nordheim's rules predict a ground state for Nb^{92} of 2− or 7+ (possibly 6+, 5+). An isomeric state in Nb^{92} of half-life 13 hours which decays by electron capture to the very high-energy levels of Zr^{92} has been reported.[18] This is probably the high-spin state (7+, 6+, 5+).

[13] J. Fox (private communication).

[14] Wolicki, Fagg, and Geer, Phys. Rev. **105**, 238 (1957).

[15] S. Thulin, Arkiv Fysik **1**, 132 (1955).

[16] National Academy of Sciences, National Research Council Report NAS–NRC 336 (unpublished).

[17] *Nuclear Level Schemes, A=40—A=92*, compiled by Way, King, McGinnis, and van Lieshout, Atomic Energy Commission Report TID-5300 (U. S. Government Printing Office, Washington, D. C., 1955).

[18] R. A. James, Phys. Rev. **93**, 288 (1954).

There is not sufficient information to establish a decay scheme for the 5.9-μsec, 88-kev isomeric state. The transition may end on either the ground state or the 13-hr isomeric state. A transition from a 3+ state to the 2− ground state is possible.

$_{42}Mo^{99}$

The half-life energy data for this isomer are in good agreement with an $E2$ transition, and are in much poorer agreement with an $E1$ or $M2$ transition.[11] This activity has been tentatively assigned to Mo^{99} on the basis of the following arguments: Because the spin change between the ground state and the isomeric level is 2 or less, the isomer should be formed by a (γ,γ') reaction if it is in any of the stable Mo isotopes. However, data taken while measuring the threshold of the isomeric level failed to indicate any activity below the (γ,n) threshold, thus ruling out the (γ,γ') process. This indicates that the isomer must be in either Mo^{91}, Mo^{93}, or Mo^{99}. The threshold for production of Mo^{91} is 12.5 Mev,[19] and that for Mo^{93} is $\geq 9.33\pm 0.15$ Mev.[16] (The measured threshold of 8.4 ± 0.6 Mev excludes Mo^{91} and Mo^{93}.) The shell model predicts a ground state of $g_{7/2}$ or $d_{5/2}$ for Mo^{99}. However, analysis of the beta-decay data shows that the ground state is probably $\frac{1}{2}+$.[20,21] Therefore, it is quite possible that the $d_{5/2}$ level is a first-excited state.

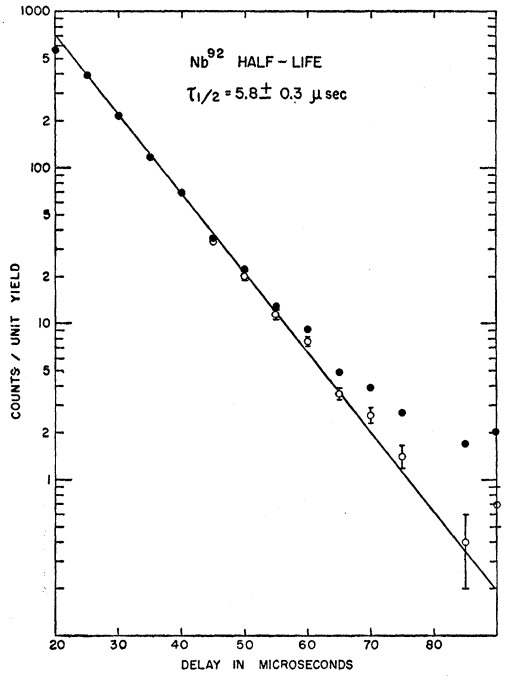

FIG. 8. Decay curve of Nb^{92} isomer. This measurement gives 5.8 ± 0.3 μsec. The best value including other data is 5.9 ± 0.5 μsec.

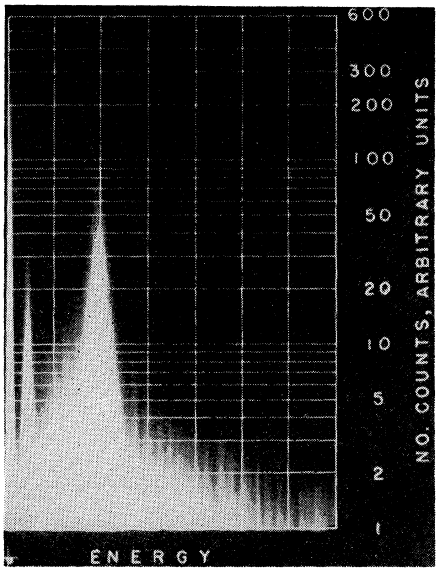

FIG. 9. Pulse-height spectrum of gamma rays from Nb^{92} isomer.

$_{46}Pd^{105}$

Two gamma rays of energies 189 and 306 kev decaying with a half-life of 37 μsec were observed in palladium. Coincidences were obtained between the two gamma rays using a circuit with a resolving time of 10^{-7} sec, indicating that the intermediate state has a half-life of less than 10^{-6} sec. No experiments were done to establish the order of emission of the two gamma rays.

The shape of the activation function for the formation of this isomer (see Fig. 15) shows that it is probably being made by both the (γ,n) and (γ,γ') reactions. This is possible only if the isomer is in Pd^{104} or Pd^{105}. However, as Pd^{104} is an even-even nucleus with a Coulomb-excited state at 560 kev[22,23] (presumably its first excited state), it is quite unlikely that the isomer is in this nucleus. Therefore, the 37-μsec activity is assigned to Pd^{105}.

From half-life energy relations, the rate-determining transition may be 189-kev $E2$ or $M2$, or 306-kev $M2$. The upper limit of 10^{-6} sec on the lifetime of the intermediate state indicates that the total spin change between isomeric level and the ground state is 3 or 4. The ground state is known to be[24] $d_{5/2}$; therefore, the isomeric level probably has a spin of 11/2 (13/2 being inadmissible from shell theory).

The energy levels in Pd^{105} excited in the decay of both Rh^{105} and Ag^{105} have been studied by several

[19] Axel, Fox, and Parker, Phys. Rev. **97**, 975 (1955).
[20] C. Levi and L. Papineau, Compt. rend. **239**, 1782 (1954).
[21] U. Cappeller and R. Klingelhöfer, Z. Physik **139**, 402 (1954).
[22] G. M. Temmer and N. P. Heydenburg, Phys. Rev. **98**, 1308 (1955).
[23] P. H. Stelson and F. K. McGowan, Phys. Rev. **99**, 112 (1955).
[24] Way, Kundu, McGinnis, and van Lieshout, *Annual Review of Nuclear Science* (Annual Reviews, Inc., Palo Alto, 1956), Vol. 6, p. 129.

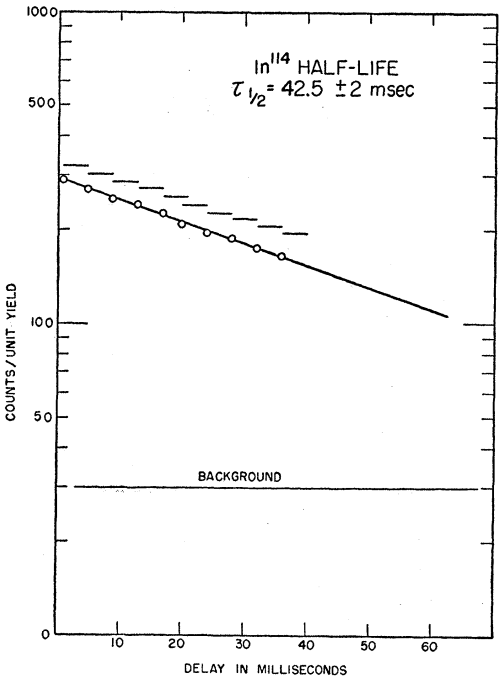

FIG. 10. Decay curve of In^{114} isomer. This measurement gives 42.5 ±2 msec. The best value including other data is 42±5 msec.

investigators,[25–28] but the order and identity of the levels are still not established. Gamma rays of energy 319 and 181 kev have been observed and these may be the ones involved in the isomer decay. A possible assignment for this decay is

$$h_{11/2} \xrightarrow{189\text{-kev } M2} g_{7/2} \xrightarrow{306\text{-kev } M1} d_{5/2}.$$

$_{49}In^{114}$

A single gamma ray of 311 kev which decayed with a 42-msec half-life was observed in indium targets. The internal-conversion coefficient was measured to be less than 0.18. The threshold for production was found to be 9.9±0.2 Mev (see Figs. 10, 11, and 16). The assignment of the activity to In^{114} is based on the following intensity argument: At a betatron energy of 19.5 Mev, the number of 311-kev gamma rays was measured to be 1.2×10^8/100 roentgen-mole from a natural indium target. The corresponding number of photoneutrons has been measured to be 7×10^8/100 roentgen-mole from natural indium.[4] If the isomeric activity were in In^{112} formed from the 4% abundant In^{113}, the number of activations would be 30×10^8/100 roentgen-mole of In^{113}. Therefore, assignment of the activity to In^{114} is indicated. Confirmation by bombardment of separated isotopes would be desirable.

Half-life energy correlation indicates that the isomeric transition is $E3$ or, less likely, $M3$. The expected value of α_K is 0.30 for $M3$ and 0.08 for $E3$. The ground state of In^{114} is 1+ and the 50-day isomeric level is probably 5+.[29] A level scheme in agreement with the experimental data and with shell structure is shown in Fig. 12.

$_{50}Sn$

The spectrum of delayed gamma rays produced in tin targets is shown in Fig. 13. Lines were observed at 117 kev, 163 kev, 504 kev, and possible additional lines at lower energies. A half-life of 165 μsec was measured for the 504-kev gamma ray. The 504-kev and 117-kev gamma rays were observed to be in coincidence (resolving time 10^{-7} sec). No information was obtained on which to base an isotopic assignment. The threshold for production was approximately 11 Mev.

$_{74}W^{181}$

Improved measurements on the characteristics of the tungsten isomer reported earlier[1] have given the energy as 368±5 kev and the half-life as 14.7±0.5 μsec. These numbers are in satisfactory agreement with the later values of Bureau and Hammer.[30] We have measured α_K to be 0.35±0.05 and the threshold for production to be 8.36±0.35 Mev. The assignment of the activity to W^{181} follows from the work[30] in which separated isotopes were used. More recently, the activity has been observed in the Re^{181} decay.[31]

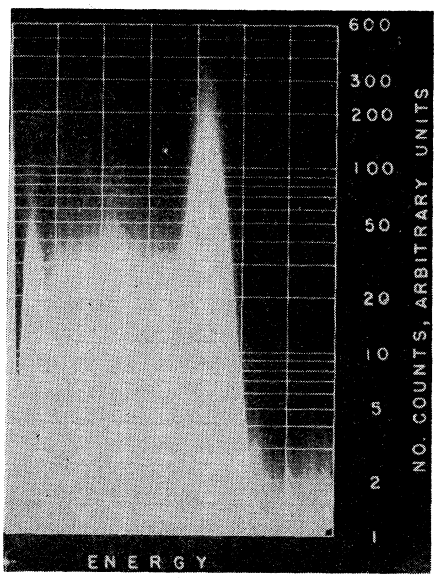

FIG. 11. Pulse-height spectrum of gamma rays from In^{114} isomer.

[25] F. A. Johnson, Can. J. Phys. **31**, 1136 (1953).
[26] J. Laberrique-Frolow, Compt. rend. **240**, 287 (1955).
[27] R. W. Hayward and D. D. Hoppes, Bull. Am. Phys. Soc. Ser. II, **1**, 42 (1956).
[28] R. W. Hayward (private communication).
[29] M. Goldhaber and R. D. Hill, Revs. Modern Phys. **24**, 179 (1952).
[30] A. J. Bureau and C. L. Hammer, Phys. Rev. **105**, 1006 (1957).
[31] Gallagher, Sweeney, and Rasmussen, Phys. Rev. **108**, 108 (1957).

Bureau and Hammer[30] have proposed, on the basis of their value of α_K, that the isomeric transition is probably a mixture of 28% $E1$ and 72% $M2$ between 2 Nilsson states,[32] $7/2- \rightarrow 9/2+$. Gallagher *et al.*[31] have shown that if one uses Sliv's K-shell internal conversion coefficients,[33] the experimental limits of error do not exclude a pure $M2$ transition. Furthermore, they point out that the Nilsson calculations show a low-lying $\frac{5}{2}-$ state from which a pure $M2$ transition could lead to the $9/2+$ ground state.

$_{81}Tl^{202}$ (585 μsec)

An isomeric state with a half-life of 585 μsec was produced by a (γ,n) reaction on thallium with a threshold of approximately 10 Mev. Figure 16 shows the excitation function and cross section for this activity. The threshold for the reaction $Tl^{203}(\gamma,n)Tl^{202}$ leading to the ground state is 8.8±0.2 Mev. A gamma-ray energy of 475 kev was observed in our experiments. Our work does not establish the mass number of the isomer.

After our measurements were made, a report on the decay scheme of Tl^{202} has been published by McDonell *et al.*[34] They propose that the decay involves the following levels:

$$(7+) \xrightarrow{\text{460-kev } E3} (4-) \xrightarrow{\text{490-kev } E2} (2-).$$

Their work shows that the isomer is to be assigned to Tl^{202}, as it is formed in the electron-capture decay of Pb^{202} and that there are really two gamma rays which were unresolved by our equipment. From their decay scheme, values of the internal-conversion coefficients as follows would be expected[33]: for the 460-kev gamma ray, $\alpha_K=6\times10^{-2}$; and for the 490-kev gamma ray, $\alpha_K=2\times10^{-2}$. These would give a value of the total conversion coefficient for the two gamma rays, $[N_e(460 \text{ kev})+N_e(490 \text{ kev})]/[N_\gamma(460 \text{ kev})+N_\gamma(490 \text{ kev})]$, equal to 0.04. Our measurements gave 0.25±0.1 for this number. If the isomeric transition were $M3$ rather than $E3$, the expected total conversion coefficient would be 0.28. This is a difficult measurement to make, however, and our experimental result may be in error. Arguments in favor of the $E3$ assignment are given in reference 34.

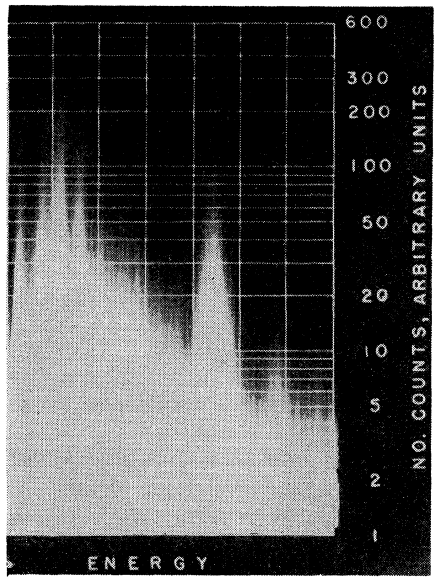

FIG. 13. Pulse-height spectrum of gamma rays from tin isomer.

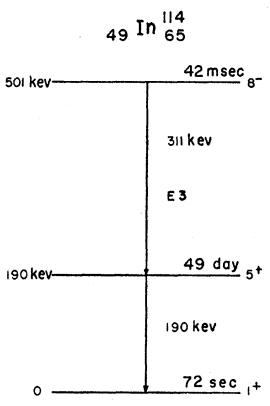

FIG. 12. Suggested decay scheme of In^{114} isomer.

$_{81}Tl^{202,204}$ (62 μsec)

Two gamma rays of energies 419 and 703 kev and half-life 62 μsec were produced by a (γ,n) reaction on thallium. The threshold was found to be 11.4±0.4 Mev and the activation function and cross section are shown in Fig. 16. The two gamma rays were observed to be in prompt coincidence and an upper limit of 6×10^{-9} sec was set on the half-life of the intermediate state. It was not established which gamma ray was emitted first. It was experimentally observed (by measuring relative Tl x-ray and gamma-ray intensities) that $[N_e(703 \text{ kev})+N_e(419 \text{ kev})]/N_\gamma(419 \text{ kev}) \leq 0.2$ and that the intensity ratio of the 419-kev gamma ray to the 703-kev gamma ray was 1.14±0.2.

It is probable that this isomer is to be assigned to Tl^{204}, as it has not been observed in the Tl^{202} research which has been done.[34] No evidence on this point was obtained in the present work.

The above observations and the lifetime-energy relations indicate that the isomeric transition involves a spin change of 2 or 3 units and the decay of the intermediate state a spin change of 1 or 2 units.

Several different possible combinations of pure multipole radiations for the two transitions would be expected to give a total conversion coefficient within

[32] S. G. Nilsson, Kgl. Danske Videnskab. Selskab, Mat.-fys. Medd **29**, No. 16 (1955).
[33] L. A. Sliv and I. B. Band, Leningrad Physico-Technical Institute Report, 1956 [translation: Report 57ICCK1, issued by Physics Department, University of Illinois, Urbana, Illinois (unpublished)].
[34] McDonell, Stockendal, Herrlander, and Bergstrom, Nuclear Phys. **3**, 513 (1957).

TABLE III. Summary of experimental conditions for measurement of activation functions.

Isomer	Gamma-ray pulse-height channel Width (kev)	Center (kev)	Time channel Width (μsec)	Delay (μsec)	Background channel Width (μsec)	Delay (μsec)	Sample (g/cm²)	Threshold (Mev)
As^{75}(17 msec)	60	284	3000	1200	Betatron off[a]		7.15	<7
$Br^{78,80}$(127 μsec)	60	149	350	150	1000	3000	Liquid Br_2, ~3	11.0±0.3
$Br^{79,81}$(37 μsec)	70	268	120	60	500	300	Liquid Br_2, ~3	<5
Nb^{92}(5.9 μsec)	50	88	30	25	300	145	0.87	9.1±0.7
Pd^{105}(37 μsec)	125	306	120	50	1200	500	3.08	11.9±0.7
In^{114}(42 msec)	115	311	3000	1200	Betatron off[a]		4.6	9.9±0.2
Sn(165 μsec)	100	504	340	60	1000	3000	2.64	~11
W^{181}(14.7 μsec)	100	368	50	35	500	305	2.86	8.36±0.35
Tl^{202}(585 μsec)	160	475	2000	600	2000	2600	2.06	~10
$Tl^{202,204}$(62 μsec)	200	703	200	100	2000	1000	2.06	11.4±0.4
Bi^{208}(2.7 msec)	160	921	3000	1200	Betatron off[a]		9.05	11.4±0.4

[a] The background was taken to be that observed in the same time and energy channels immediately after the betatron was turned off.

the experimental error of the measured value. The fact that the threshold for production of the isomeric level is considerably higher than the threshold for formation of the ground state by the (γ,n) reaction shows that the isomeric level has a high spin (Tl^{203} and Tl^{205} are both $\frac{1}{2}+$).

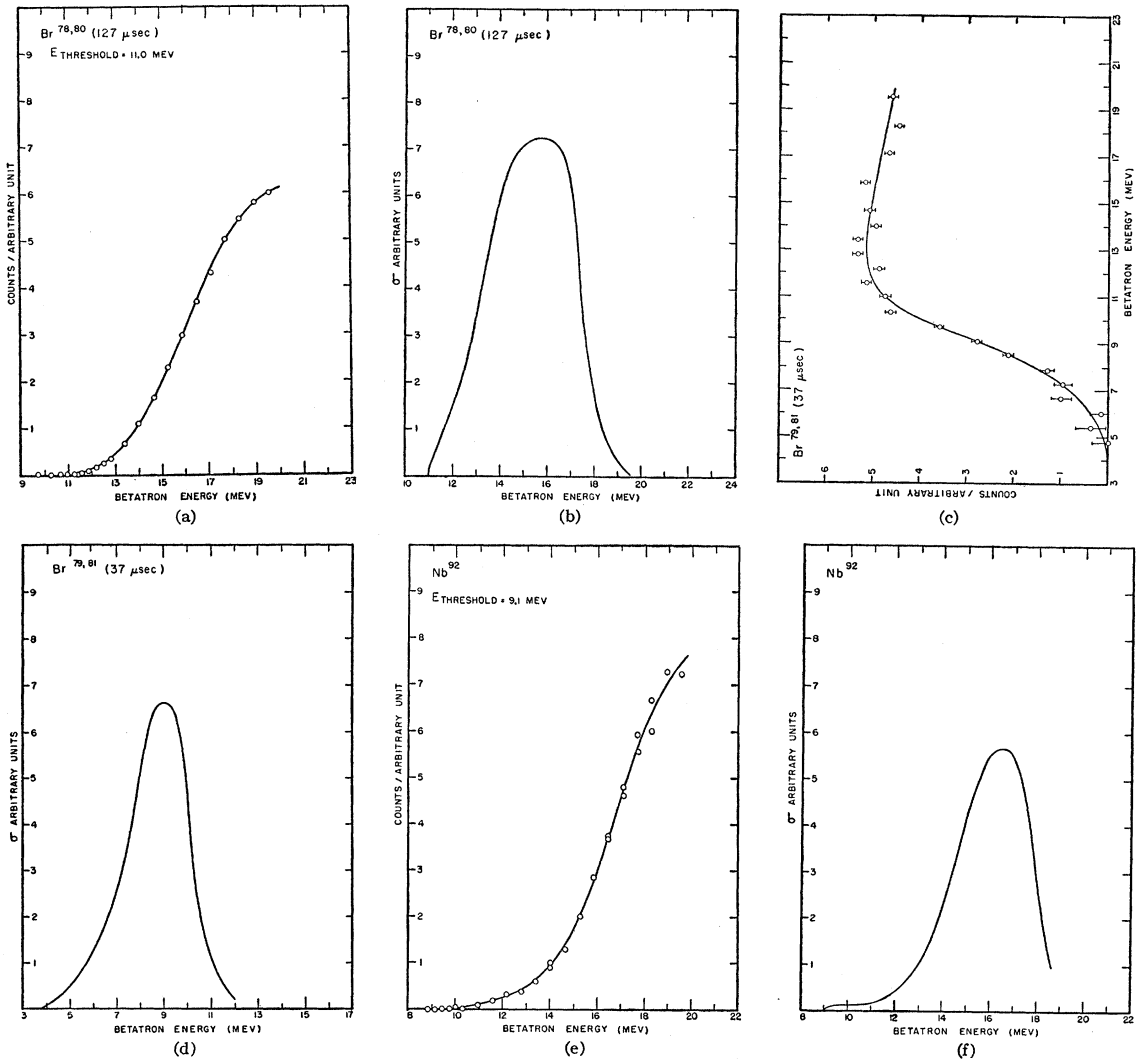

FIG. 14. Activation functions and cross sections for formation of bromine and niobium somers.

$_{83}Bi^{208}$

The isomeric state produced by irradiation of bismuth decayed with a half-life of 2.7 msec and the emitted radiation was found to consist of 2 gamma rays of energies 921 and 509 kev. The threshold for production was observed to be 11.4±0.4 Mev; and for this reason the activity is assigned to Bi^{208}. Coincidence measurements established that the half-life of the intermediate state was less than 8×10^{-9} sec. The total K-shell conversion coefficient, $[N_e(509\text{ kev})+N_e(921\text{ kev})]/N_\gamma(921\text{ kev})$, was measured to be 0.3±0.15. The intensity ratio, $I_\gamma(509\text{ kev})/I_\gamma(905\text{ kev})$, was measured to be 0.9±0.15. It was not established which of the gamma rays was emitted first.

In a publication recently made available to us, Iampol'skii *et al.*[35] report the observation in 1953 of a 2-msec state produced by fast-neutron irradiation of bismuth. A later publication by Leipunskii *et al.*[36] reports the production of this activity by bombardment of bismuth and lead with 20-Mev protons and gives the half-life as 3±1 msec.

This isomer has also been observed by De Benedetti *et al.*[37] Their publication gives an excitation function for its production by the $Bi^{209}(\gamma,n)Bi^{208}$ reaction.

The discovery of the activity of the ground state of Bi^{208} has recently been reported by Roy, Eastwood, and Hawkins.[38] It decays by electron capture to Pb^{208} and the expected 2.61-Mev gamma-ray transition in Pb^{208} was observed. The half-life is given as approximately 3×10^4 years. This decay is consistent with the predicted ground-state spin for Bi^{208} of 4+ or 5+, as follows:

The levels of Pb^{206} were calculated quite successfully by Pryce.[39,40] A similar procedure has been used by Wahlborn[41] to predict the levels in Bi^{208} and other heavy nuclei. The input data were the levels of Pb^{207} (one neutron hole in the shell which closes at 126) and the levels of Bi^{209} (one proton outside the shell which closes at 82). The ground state of Bi^{208} is expected to be 4+ or 5+ corresponding to a $p_{1/2}$ neutron hole and the 83rd proton in the $h_{9/2}$ level. A possible decay scheme[41] for the 2.7-msec isomer is:

$$\underline{\qquad}\quad (10-)\xrightarrow{E_3}(7+)\xrightarrow{E_2}(5+).$$

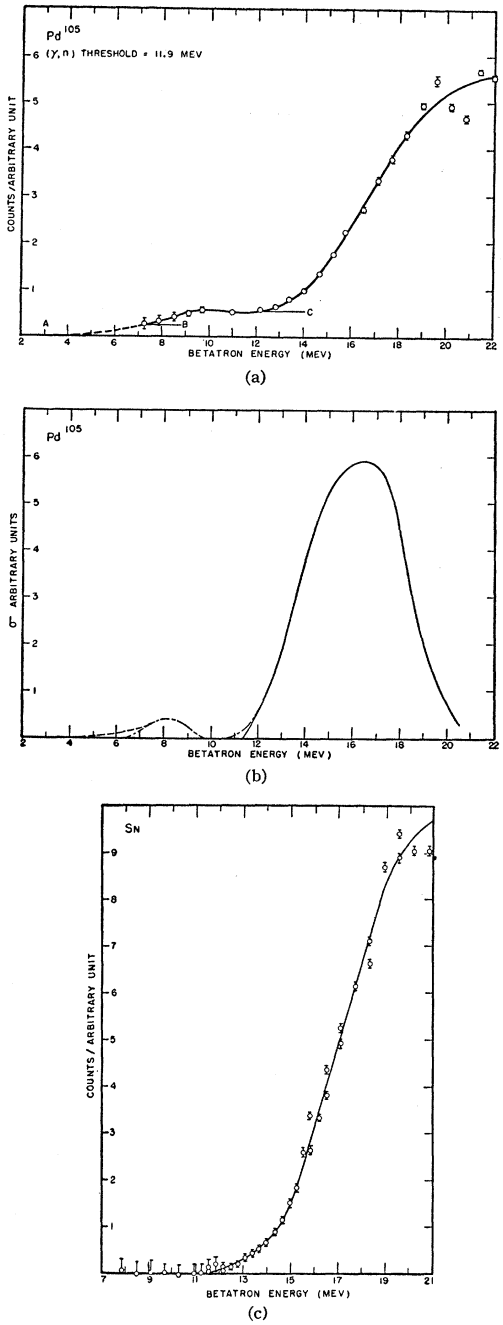

FIG. 15. Activation functions and cross sections for formation of palladium and tin isomers. The solid line on the graph of the palladium excitation function was drawn through the experimental points. The dashed-line extrapolation at low energies was drawn to follow the shape of the 37-μsec bromine activity. In the calculation of the corresponding cross-section curve, a constant background (C) was assumed above 12.2 Mev; this procedure gave the solid-line portion of the cross-section curve. Below 12.2 Mev, use of the background levels (B) and (A) gave the two dashed curves on the palladium cross-section plot.

Low-lying levels having these spins and parities can be formed from the available single-particle states.

A high spin for the isomeric level is indicated by the

[35] Iampol'skii, Leipunskii, Gen, and Tikhomirow, Bull. acad. sci. U.S.S.R. Phys. Ser. **19**, 338 (1955) (Columbia Technical Translation, p. 312).

[36] Leipunskii, Miller, Morozov, and Iampol'skii, Doklady Akad. Nauk S.S.S.R. **109**, 935 (1956) [translation: Soviet Phys. Doklady **1**, 505 (1956)].

[37] De Benedetti, Farinelli, Ferrero, Malvano, Pelli, and Tribuno, Nuovo cimento **6**, 682 (1957).

[38] Roy, Eastwood, and Hawkins, Can. J. Phys. **36**, 18 (1958).

[39] M. H. L. Pryce, Proc. Phys. Soc. (London) **A65**, 773 (1952).

[40] D. E. Alburger and M. H. L. Pryce, Phys. Rev. **95**, 1482 (1954).

[41] S. Wahlborn, Nuclear Phys. **3**, 644 (1957). Also discussion by S. Wahlborn, in *Proceedings of the International Conference on Nuclear Structure at Weizmann Institute of Science, Rehoveth, Israel, September 8–14, 1957* (North-Holland Publishing Company, Amsterdam, 1958).

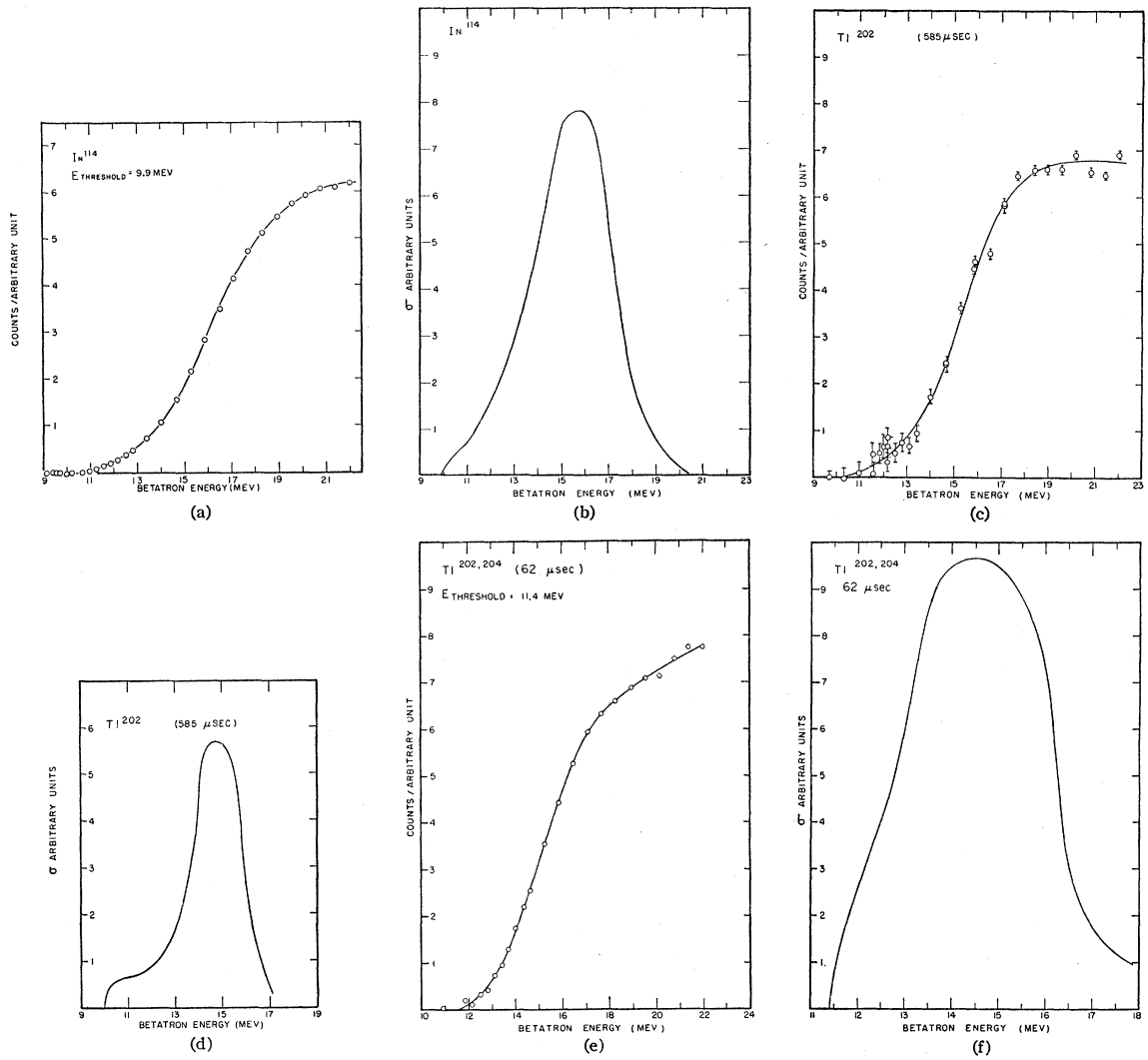

FIG. 16. Activation functions and cross sections for formation of indium and thallium isomers.

high threshold for its production. The energetically possible threshold is 7.28+0.921+0.509=8.71 Mev. This is 2.7 Mev below the experimental value.

THRESHOLD MEASUREMENTS, ACTIVATION FUNCTIONS, AND CROSS SECTIONS

Summary of Results

Threshold measurements were made for all of the isomeric states listed in the previous sections of this paper. The experimental conditions used, and the results obtained, are summarized in Table III. Activation functions up to 20 Mev were obtained for some of the isomers. A modification of the photon difference method of analysis developed by Leiss and Penfold[42] was used to extract cross sections from the experimental data. The results are shown in Figs. 14, 15, and 16 and the characteristics of the cross sections are summarized in Table IV. The absolute values of peak and integrated cross sections depend on the detection efficiency which in turn depends on the decay scheme. It is possible that there are unknown complications in any of the decay schemes which would lead to errors in the cross sections.

Details of the Measurements

The activation function and threshold measurements were made using energy and time channels chosen to maximize the signal-to-background ratio. In general, the energy channel was centered on the photopeak of the gamma ray to be measured and the width set to include all of the photopeak. The background was measured in a second time channel, delayed sufficiently after the betatron pulse that most of the desired activity had decayed. For half-lives in the millisecond

[42] J. Leiss and A. Penfold, University of Illinois (private communication).

range, the background was measured with the betatron off.

The energy and time channels used for each measurement are shown in Table III. The sample thickness used for each target is shown in column 8 of this table. Additional comments concerning certain of the activation functions follow:

As^{75}—Photographs taken with the gray-wedge pulse-height analyzer at a betatron energy of 9.7 Mev [0.5 Mev below the $As^{75}(\gamma,n)$ threshold] showed the characteristic As^{75m} spectrum.

Pd^{105}—Using an energy channel centered at 306 kev with a width of 125 kev and a betatron energy of 12 Mev, two runs were made with time channels of (a) delay 50 μsec, duration 120 μsec; and (b) delay 170 μsec, duration 120 μsec. In each case the background channel had a delay of 500 μsec and a duration of 1200 μsec. If the net counting rate were due entirely to neutron-capture gamma-ray background, the ratio of (b) to (a) would be expected to be 0.66; and if it were due entirely to 37-μsec Pd^{105}, the ratio of (b) to (a) would be expected to be 0.11. The measured value of 0.25 ± 0.15 indicates that most of the net activity was Pd^{105}. This was taken as evidence that the isomeric state was produced at an energy of 12 Mev.

DISCUSSION OF THE CROSS-SECTION DATA

Isomeric states produced by (γ,n) reactions.—Energies at peak of resonance and half-width of resonance have been measured for many elements.[43] The values for both of these quantities obtained in the present measurements fit well with the systematics previously pointed out. The peak cross sections and the integrated cross sections listed in Table IV are all considerably smaller (by a factor of 10 to 100) than the expected total photodisintegration cross sections. This indicates that only a fraction of cascades to the ground state of the product go through the isomeric levels.

Isomeric states produced by (γ,γ') reactions.—The production of the isomeric states of $Br^{79,81}$ and of Pd^{105} is clearly shown at energies below the neutron binding energy in Figs. 14 and 15. There are fewer data on (γ,γ') reactions with which to compare the present results. Bogdankevich, Lazareva, and Nikolaev[44] have measured the cross section for the reaction $In^{115}(\gamma,\gamma')In^{115m}$ and have summarized the previous measurements. They report a peak energy of 8.6 Mev, an integrated cross section (to 18 Mev) of 11.2 Mev-millibarns, and a half-width of 2.6 Mev. Their data indicate a very strong rise in the cross section above 20 Mev. None of our measurements was carried to energies high enough to detect this effect.

TABLE IV. Summary of cross-section data.[a]

Isomer	Production reaction	Half-width of resonance (Mev)	Peak cross section (millibarns)	Energy at peak cross section (Mev)	Integrated cross section (Mev-millibarns)
$Br^{78,80}$(127 μsec)	(γ,n)	4.4	5.6	15.8	26
$Br^{79,81}$(37 μsec)	(γ,γ')	2.8	0.32	9.0	1.0
Nb^{92}	(γ,n)	3.6	29	16.5	110
Pd^{105}	(γ,γ')	1.9	0.1	8.2	0.2
Pd^{105}	(γ,n)	5.1	1.3	16.5	6.6
In^{114}	(γ,n)	3.8	28	15.8	120
Tl^{202}(585 μsec)	(γ,n)	2.4	13	14.7	37
$Tl^{202,204}$(62 μsec)	(γ,n)	3.5	3.7[b]	14.5	15

[a] In all calculations, α_k was taken to be zero in view of the uncertainty of its value for the various cases considered.
[b] No correction for isotopic abundance has been made for this case; 100% isotopic abundance is assumed in lieu of an isotopic identification.

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The search for short-lived isomers using the Illinois betatron was initiated by P. Axel and S. Vegors as reported in reference 1. The present work benefited greatly from the earlier contributions of P. Axel.

[43] Montalbetti, Katz, and Goldemberg, Phys. Rev. **91**, 659 (1953); R. Nathans and J. Halpern, Phys. Rev. **93**, 437 (1954).

[44] Bogdankevich, Lazareva, and Nikolaev, Physica **22**, 1137 (1956).

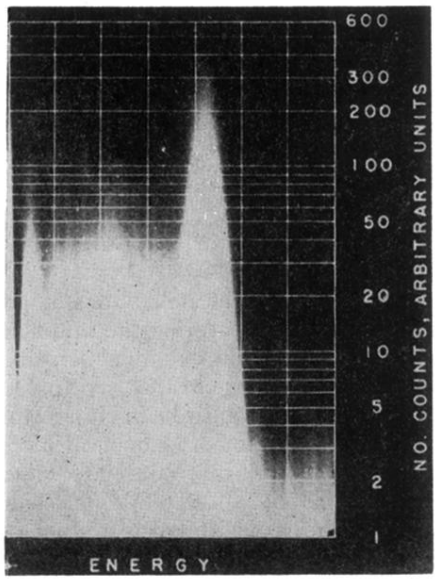

FIG. 11. Pulse-height spectrum of gamma rays from In^{114} isomer.

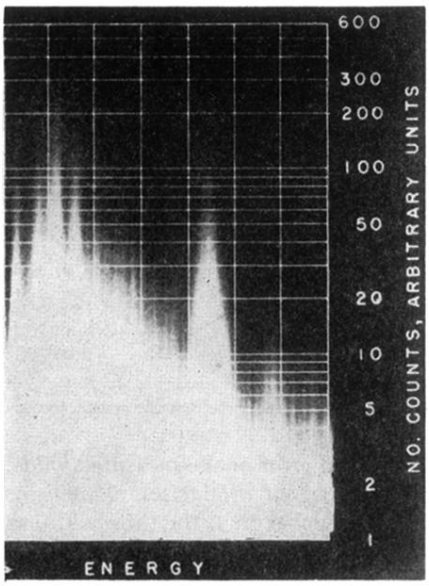

FIG. 13. Pulse-height spectrum of gamma rays from tin isomer.

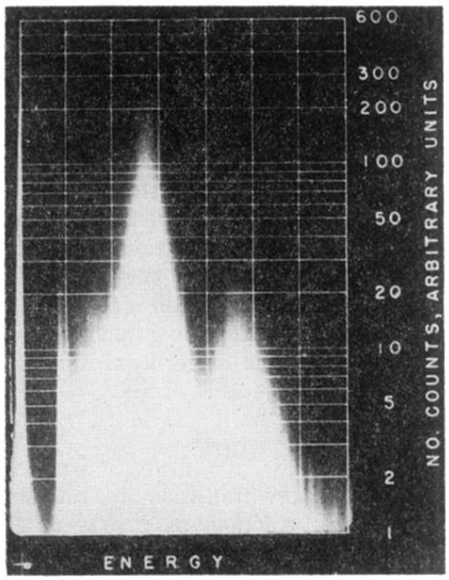

FIG. 6. Pulse-height spectrum of gamma rays from both $Br^{78,80}$ and $Br^{79,81}$ isomers.

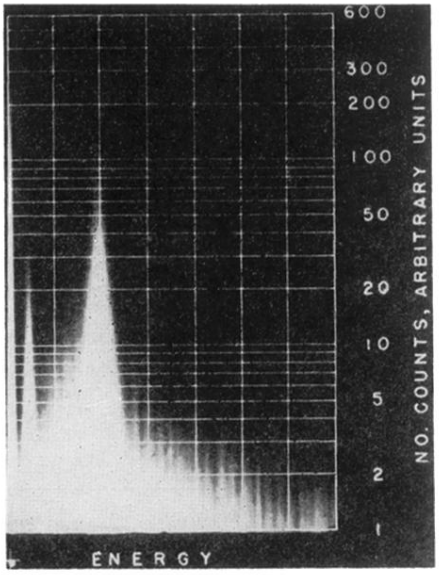

FIG. 9. Pulse-height spectrum of gamma rays from Nb^{92} isomer.