Isomers with Half-Lives in the Range 5–1000 Microseconds Observed in Pulsed 15-MeV Deuteron Beam Bombardment of Natural Elements

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Eighteen new isomers have been observed in a pulsed 15-MeV deuteron beam survey of 72 elements. Gamma-ray transitions were observed using time and energy channels in a two-dimensional 4096-channel analyzer. The new isomers are:

Target	Half-life (μsec)	Gamma-ray energies (keV)	Target	Half-life (μsec)	Gamma-ray energies (keV)
Ca	35	80	Eu	76	40, 82, 178
Sc	11.3	60	Tb	124	43, 115
Ti	12	55	Er	17.5	50, 167
Zr	80	82, 124	Tm	11.8	54
Ag	11.1	217, 273	Yb	115	72
Sn	16.7	22	Hf	36	132, 215, 309
Ba	23	32, 125, 265	W	75	60, 195
La	10.8	518	Re	187	65
Pr	26.6	112		216	156

Eleven isomers previously reported were confirmed, and in some cases, further information on them was obtained.

INTRODUCTION

THE scarcity of isomers known with half-lives in the microsecond and millisecond ranges has initiated systematic searches.[1–7] Since 1955 some 50 isomers have been found in the intermediate lifetime range from 1 to 1000 μsec. Thus it appears that it was instrumentation and not nuclear structures which accounted for the small number of cases compared with the greater numbers in the ranges 10–10^4 and 10^{-11}–10^{-8} sec. Table I is a list of the isomers with half-lives in the range 1–1000 μsec, together with their properties which were known at the beginning of our study.

There are two reasons for continuing the search: (a) while the number of known isomers in this range has increased greatly, there are still only 20 known per decade as compared to 30 known per decade between 10–10^4 sec and somewhat more between 10^{-11} and 10^{-8} sec, and (b) knowledge of the lifetime of transitions between two nuclear levels helps to determine the spin and parity of the levels. Also, the use of the new technique described below should yield new cases.

The techniques used in the references [8–35] of Table I have been primarily gamma-gamma delayed coincidence measurements, and pulsed gamma-ray beam bombardments of targets with the use of counting equipment which measured the time between irradiation and decay.

In the present survey we observe the intermediate

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TABLE I. Known isomers with half-lives in the range 1–1000 μsec.

(1) No.	(2) Isotope	(3) Half-life (μsec)	(4) Energy (keV)	(5) Spins	(6) Transition	(7) Method	(8) Ref.
1	Sc	49	64				6
			78			a	
2	Co	10	53			a	6
3	Zn^{65}	1.65	54			c	9
4	Zn^{67}	9	93	$\frac{3}{2}^-$–$\frac{5}{2}^-$		a, c	1, 4, 7, 8
5	Ge^{73}	4.0	13	$\frac{5}{2}^+$–$\frac{9}{2}^+$		c	10, 11
6	Ge	5	85			a	6
7	As^{73}	6	359	$\frac{9}{2}^+$–$\frac{5}{2}^-$	$M2$	b	12
			66	daughter			
8	As^{77}	116	210	$\frac{9}{2}^+$–$\frac{5}{2}^-$	$M2$	c	13
9	Br^{78}	120	149	3^-–1^+	$M2$	a	2
10	Br^{81}	37	270	$\frac{9}{2}^+$–$\frac{5}{2}^-$	$M2$	d	14
			278	daughter			
11	Y^{88}	300	394	1^+–4^-	$E3$	a, c	1, 4, 15, 16
12	Nb^{92}	5.9	88		$E2$	a	2
13	Mo^{99}	16.5	98		$E2$	a	1, 2
14	Ru	11	165				
15		17.5	217, 307				
16		860	201			a	6
17		1000	70, 160				
18	Pd^{105}	33	189	$11/2^-$–$\frac{7}{2}^+$	$M2$	a	1, 2
			306	daughter			
19	Cd^{109}	12	58	$(\frac{1}{2}^+)$–$(\frac{5}{2}^+)$	$E2$	c	18
20	Cd	11	58				
21		10	199			a	6
			257				
22	Sn^{120}	11	89	7^-–6^+		c	21
23	Sn	165	117			a	1, 2, 40
			163				
			504				
24	Sb^{117}	164				d	19
25	Sb^{122}	1.8	61	3^+–2^-	$E1$		20
26	I	80				d	19
27	Ce	6.5	480			a	6
			1600				
28	Nd	16.5	106				
			515			a	6
			1540				
29	Eu^{149}	2.5	347	$(11/2)^-$–$(\frac{7}{2})^+$	$E3$	c	23
30	Eu^{151}	58	175	$11/2^-$–$\frac{7}{2}^+$	$M2$	c	22
31	Gd	22	198			a	6
			245				
32	Tb	395	172			a	6
33	Dy	115	120				
34		12	380			a	6
			180				
			203				
35	Ho^{165}	1.5	361	$\frac{3}{2}^+$–$\frac{7}{2}^-$		c	24, 25
36	Ho^{166}	200	130		$E2$	e	27
37	Ho	70	136			a	6
38	Tm	218	171			a	6
39	Tm^{171}	2.6	308			b	26
40	Lu^{173}	70	124	?–$\frac{7}{2}^+$		c	28
41	Lu^{174}	75	133		$E2$	a	5, 4
42	Hf	8	495				
43		10	198				
			303			a	6
			720				
			1020				
44		49	125				
45	Ta^{181}	18	133	$\frac{1}{2}^+$–$\frac{5}{2}^+$	$E2$	a	29, 17
46		7	6				
47	W^{181}	14	370	$\frac{7}{2}^-$–$\frac{9}{2}^+$	$E1$, $M2$	a	1, 2, 4, 5
48	Re	70	99			a	6
49	Os	225	157			a	6
50	Hg	21	333				
			580			a	3, 6
51		92	217				
			515				

[a] Pulsed gamma-ray beam. [b] β-γ delayed coincidence. [c] γ-γ delayed coincidence.
[d] Pulsed proton beam. [e] Pulsed neutron beam.

TABLE I. (*continued*)

(1) No.	(2) Isotope	(3) Half-life (μsec)	(3) Energy (keV)	(5) Spins	(6) Transition	(7) Method	(8) Ref.
52	Tl^{204}	62	706	7^+–4^-		a	1, 2
			410	daughter			
53	Tl	530	506			a	1
54	Pb^{206}	123	516	7^-–?		c	30, 31, 32
			202	daughter			
55	Bi^{206}	7	60			c	33
56	Po^{205}	644	160			d	34
57	Po^{207}	45	810		$E3$	d	34
			310		$M1$		
58	U^{234}	33.5	126	?–5^-	$E1$	c	35

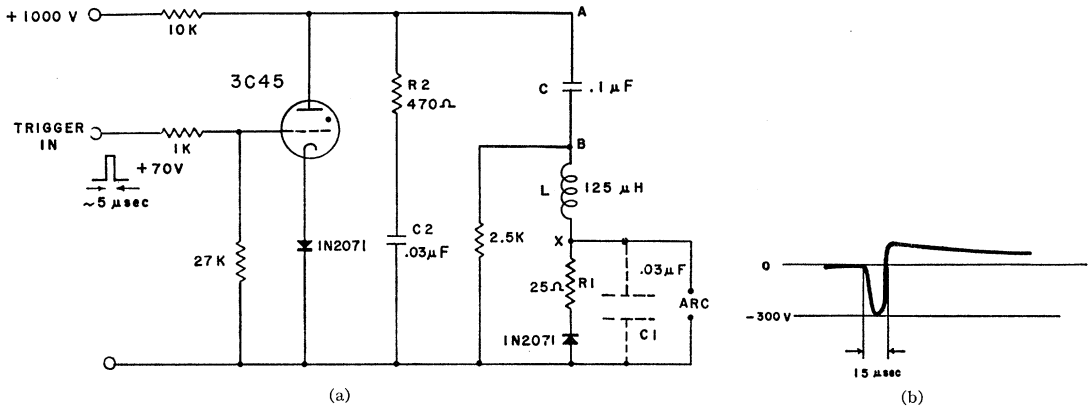


FIG. 1. (a) The circuit used to pulse the arc and produce 15-μsec beam pulses. (b) The voltage pulse shape across the arc.

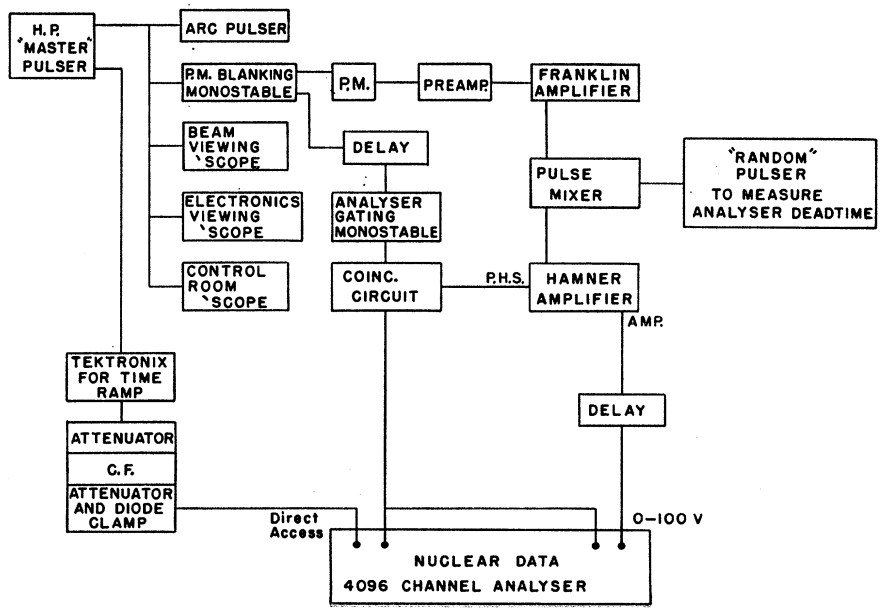


FIG. 2. The block diagram of the circuits used in measuring the energies and half-lives of isomeric transitions.

lifetime gamma-ray spectra from thick natural targets using a pulsed deuteron beam. The reactions with the most favorable cross sections are $(d,2n)$, (d,n), and (d,p). We thus expect to form different isotopes from those formed in the photonuclear reactions where (γ,n) and (γ,p) are the principal ones of interest.

We have measured the lifetimes and gamma-ray energies of 29 isomers found in the bombardment of 72 elements. Eighteen of these are new isomers. Although the longest lived isomer we report is about 200 μsec, we would have expected to see evidence of isomers with half-lives of at least 500 μsec if they had been excited.

EXPERIMENTAL

In this survey the University of Pittsburgh cyclotron was used to give beam pulses of 15 μsec duration at a repetition rate of 500 pulses per second. The pulsed beam was obtained by discharging a capacitor through the arc of an ion source with the aid of a thyratron switch. A pulse-shaping network was used to reverse the polarity on the arc at the end of the pulse; this reversal quenched the discharge. The circuit and pulse shape are shown in Fig. 1.

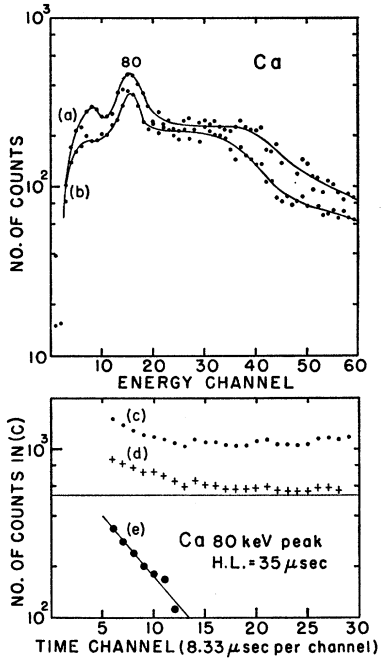


FIG. 3. *Calcium*: (a) Energy spectrum ~40 μsec after bombardment. (b) Energy spectrum ~110 μsec after bombardment. (a) and (b) have been normalized to the same lifetime and may be directly compared. The numbers above the peaks are peak energies in keV. The energy scale is approximately 6.1 keV per channel. (c) The time decay of a peak in the spectrum (labeled by its energy), uncorrected for analyzer losses. Several channels contributing to the peak have been summed. The ordinate scale applies to (c), but not to (d) and (e). (d) The same decay after corrections for losses have been made (ordinate scale is relative). (e) The decay curve after background has been subtracted (ordinate scale is relative). The amount of background subtracted is shown as a horizontal line in the lower part of the diagram.

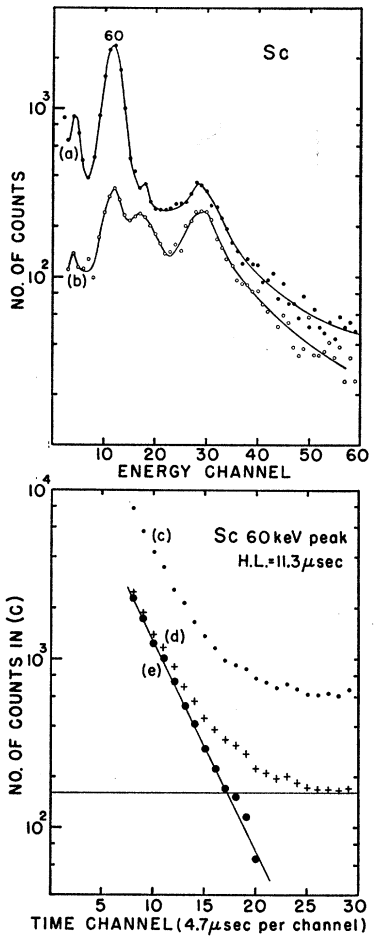
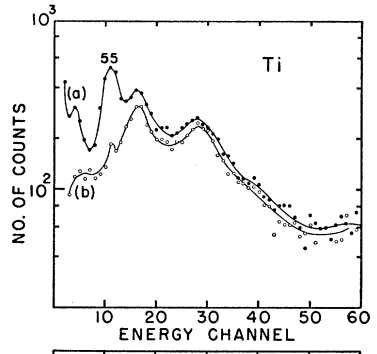


FIG. 4. *Scandium*: As for Fig. 3, except (a) ~20 μsec after bombardment, (b) ~50 μsec after bombardment.

The pulsed beam was extracted and focused to the experimental area in the manner used for the normal beam. The beam was observed on the target using an amplifier and oscilloscope instead of the usual metering and current-integrating circuits. The duration of the beam pulse was measured by observing deuterons elastically scattered from a tantalum foil. The observation showed that residual beam during the counting period was less than one part in 20 000 of the beam in the pulse.

Thick targets which completely stop the beam were bombarded and the gamma-ray spectra observed as a function of time in the periods between beam pulses. The block diagram of the detection apparatus, shown in Fig. 2, is explained below.

The detector was a $\frac{1}{2}$-in.-diam$\times\frac{1}{4}$-in.-high NaI(Tl) crystal mounted on a Dumont-6292 photomultiplier tube, which was blanked off during the actual beam pulses by reducing the potential on the first dynode below that of the photocathode using a monostable multivibrator. This avoids excessively large signals being generated by the prompt high-energy gamma rays produced during the beam pulses. Small pulses are



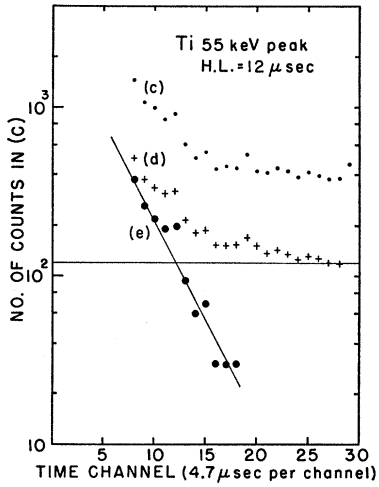
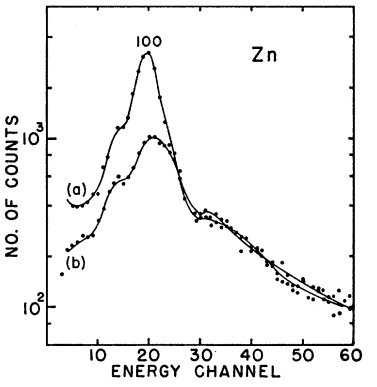


FIG. 5. *Titanium*: As for Fig. 3, except (a) ~20 μsec after bombardment, (b) ~50 μsec after bombardment.



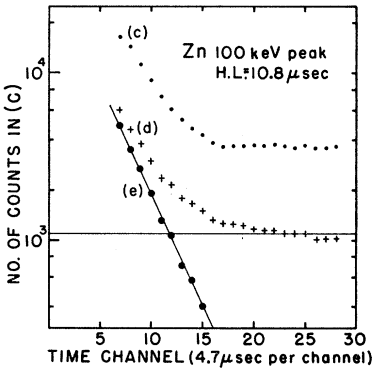


FIG. 6. *Zinc*: As for Fig. 3, except (a) ~20 μsec after bombardment, (b) ~45 μsec after bombardment.

fed through from the blanking pulse to the amplifier because of capacitance between the first dynode and anode. It is arranged not to count these by gating the the analyzer on, some 10 μsec after the phototube becomes unblanked. This limits the minimum half-life observable in this work to about 5–10 μsec.

A Nuclear Data "series one sixty" 4096-channel analyzer is used in a two-dimensional mode to record the energy and time of arrival of each pulse simultaneously. A time ramp triggered by the master pulser provides the time dimension in a simple application of the dc signal analysis mode of this analyzer.

The 64×64 array was used in much of the work to display 64 energy spectra taken at successively later times after bombardments and thus observe the time

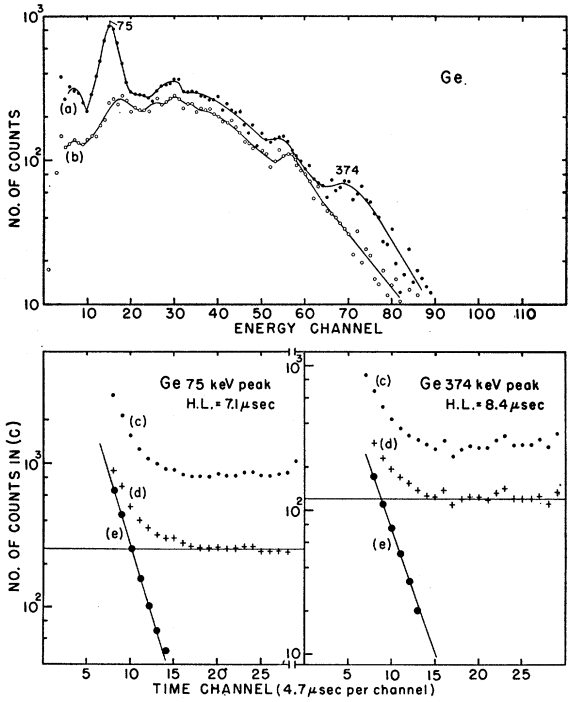


FIG. 7. *Germanium*: As for Fig. 3, except (a) ~20 μsec after bombardment, (b) ~50 μsec after bombardment.

decay of individual gamma rays. Each isomer has been observed two or more times under different time and energy scales. The final data were taken using 128 energy channels for each of the 32 different time channels. In this way the spectrum for each case could conveniently be recorded on the same energy scale of about 6.1 keV per channel. These latter data were taken in one run extending over six days. Drifts of ±3% in energy channel number were observed in the position of the Hg^{203} 279-keV gamma-ray peak. The effects of such drifts have been minimized by frequent calibrations throughout the run using the Cs^{137} 662-keV gamma ray, the Hg^{203} 279-keV gamma ray, and the Co^{60} 59-keV gamma ray.

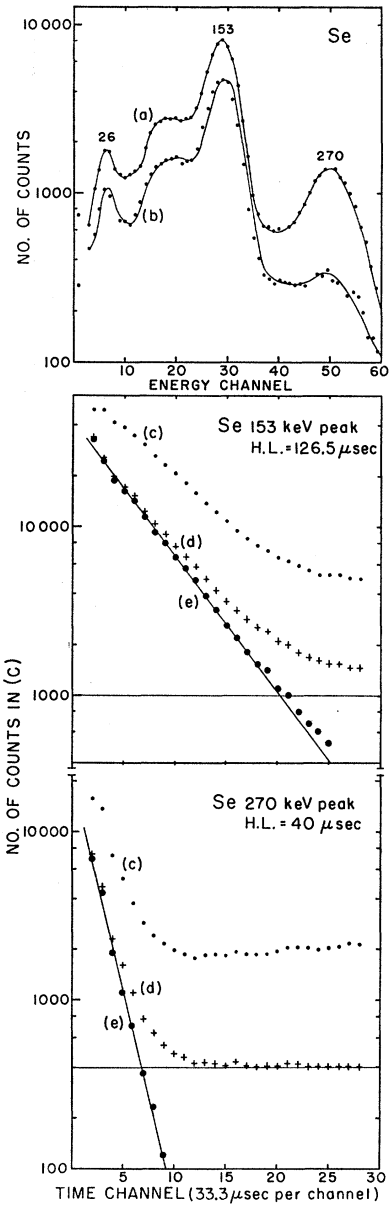


FIG. 8. *Selenium*: As for Fig. 3, except (a) ~60 μsec after bombardment, (b) ~160 μsec after bombardment.

The time scale was chosen to suit the various isomers. Calibration of the time scale was accomplished by using a triggered double pulser with variable delay. The time channel number in which the delayed pulse was recorded and the corresponding delay was measured using an oscilloscope whose time base was checked against a crystal-controlled time mark generator and found to be accurate within 1%. The major source of uncertainty in determining the half-lives is that of choosing the background to be subtracted. The more weakly excited isomers may have errors as large as ±25%, while the strongly excited ones where good statistics have been obtained should be much better than this.

One of the major experimental problems is the fact that in bombardments in which a decay occurs with a half-life in the range of interest, the counting rate is a rapidly varying function of time. Since the analyzer time is about 50 μsec, it is necessary to choose a small NaI crystal, to ensure that it is unlikely that two pulses will occur within 50 μsec. Further, the fraction of pulses being lost at each time channel is measured by feeding in a pulse of fixed pulse height (so that all pulses are in a very few energy channels) and random in time with respect to the master pulser, and observing what fraction of these pulses is not counted in each time channel. A correction is then made to the gamma-ray counts assuming that the same fraction of these is lost.

Figures 3–29 show the data obtained. The parts marked (a) and (b) are energy spectra at two different times; (c) shows the time decay of particular peaks in the energy spectra uncorrected for analyzer losses; (d) shows the same decay after the correction for the losses has been made; and (e) shows the decay curve after the background has been subtracted. The amount of background subtracted is indicated by the horizontal line in the lower part of the diagram. Because the true counting rate for the pulser which is indicating losses could not be conveniently determined for each case, the number-of-counts scale for (d) and (e) is relative while the absolute numbers of counts in (c) refer to the sum over several channels in the energy peak.

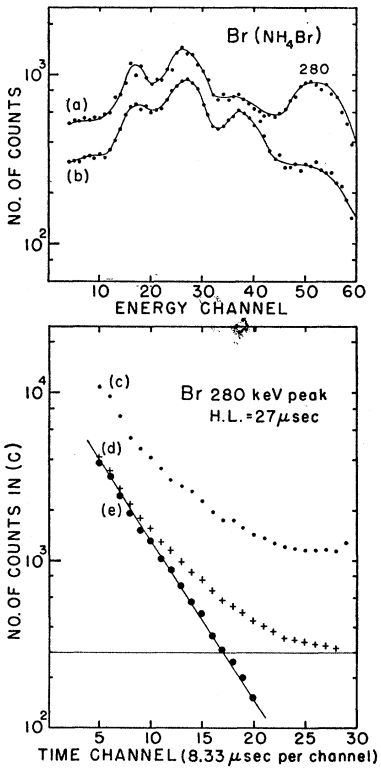


FIG. 9. *Bromine*: As for Fig. 3.

RESULTS AND DISCUSSION

Table II gives the targets, half-lives, and energies of isomers we have observed in this survey. Both new isomers and ones which had already been observed are included. Where assignments have been made, a discussion is given below outlining the justification. Also listed are the x-ray energies for the target elements. In many cases it is noted that the low-energy peak in the spectrum is close to the x-ray energy and is thought to be the x ray following internal conversion. For the cases of Tb, Ho, and Er, estimates of the internal conversion coefficients have been made by comparing the number of counts in the x-ray and gamma-ray peaks; these include corrections for absorption in the walls of the target chamber, detection efficiency of the crystal, fluorescence yield,[36] and background counts. These estimates are discussed below and compared with values

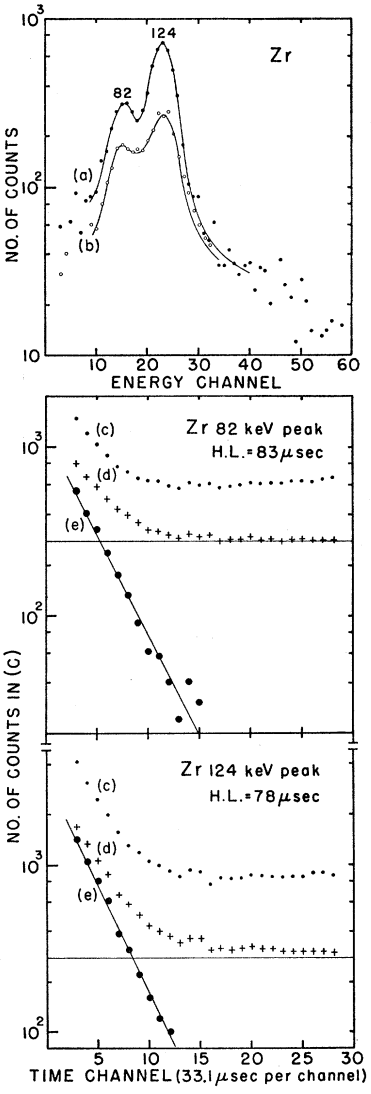


FIG. 10. *Zirconium*: As for Fig. 3, except (a) ~100 μsec after bombardment, (b) ~200 μsec after bombardment.

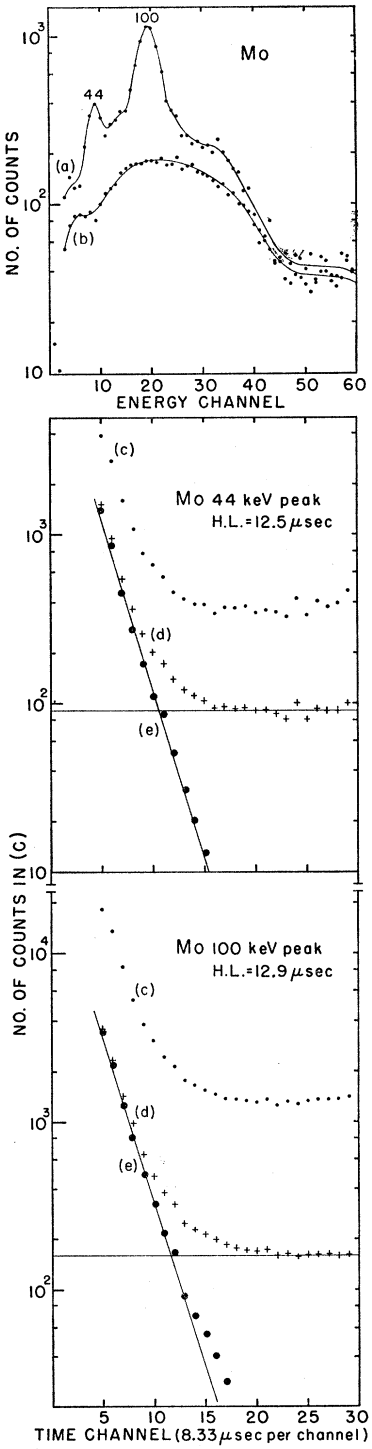


FIG. 11. *Molybdenum*: As for Fig. 3.

[36] H. L. Hagedoorn and A. H. Wapstra, Nucl. Phys. **15**, 146 (1960).

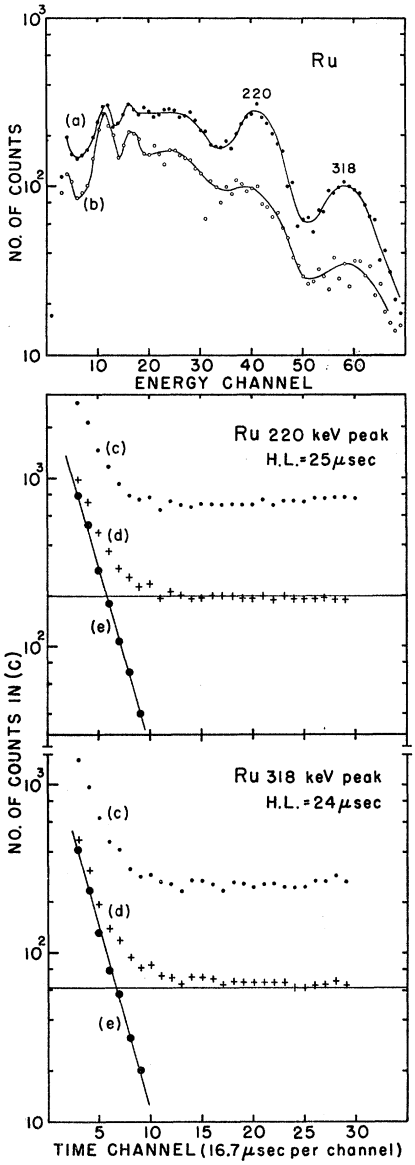


FIG. 12. *Ruthenium*: As for Fig. 3, except (a) ~40 μsec after bombardment, (b) ~100 μsec after bombardment.

obtained from the tables of Rose.[37] In several cases the energy spectra show a peak about 30 keV below the x-ray peak, e.g., in Re and W. It occurs because for some of the x rays detected, the iodine x ray escapes especially when using a NaI crystal as small as the one used here.

Ca, Ti. These are relatively weakly excited cases, but were observed to decay in each bombardment.

Sc. The isomer is quite strongly excited and there can be no confusion with the 78-keV, 49-μsec isomer seen in Ref. 6. The Weisskopf single-particle estimate of the lifetime suggests an *E*2 transition.

Zn. We would expect to observe the Zn^{67} isomer reported by several authors, from the $(d,\dot{p})$ reaction on the 28% Zn^{66} isotope. The half-life and energy are in reasonable agreement.

Ge. Ge is about 8% Ge^{73} and 27% Ge^{72}. Thus the $(d,2n)$ and (d,n) reactions on these two isotopes will form As^{73}. The two gamma-ray energies and the half life are in agreement with the previous report.

Se. Both the Br^{78} isomer of Ref. 2 and the Br^{81} isomer of Ref. 14 are clearly identified and measured.

Br. The data presented was taken using an NH_4Br target. There is little doubt that we are seeing the same Br^{81} isomer excited in Se. The discrepancy in half-life may be due to neutron production in N. A

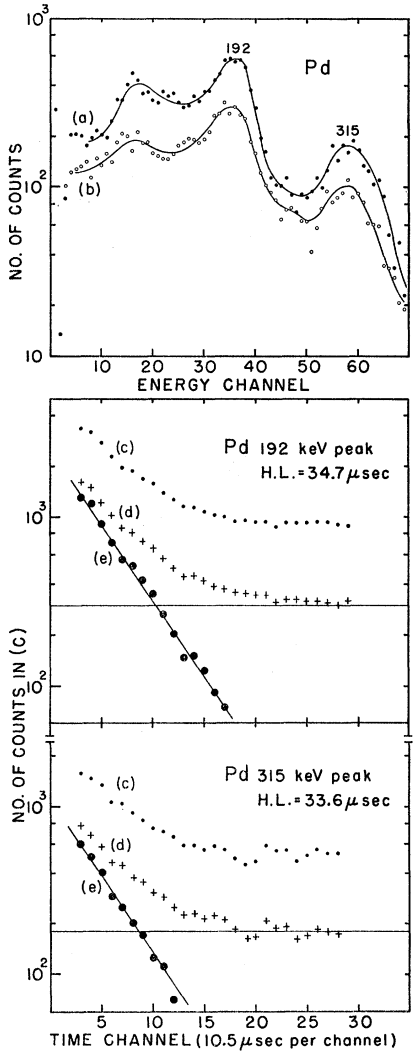


FIG. 13. *Palladium*: As for Fig. 3, except (a) ~40 μsec after bombardment, (b) ~80 μsec after bombardment.

[37] M. E. Rose, *Internal Conversion Coefficients* (North-Holland Publishing Company, Amsterdam, 1958).

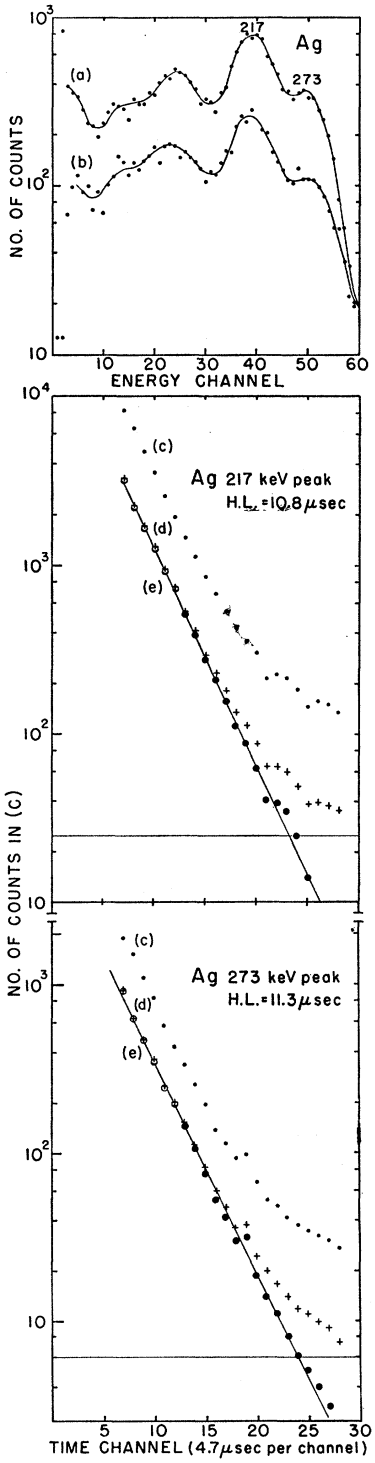


FIG. 14. *Silver*: As for Fig. 3, except (a) ~20 μsec after bombardment, (b) ~40 μsec after bombardment.

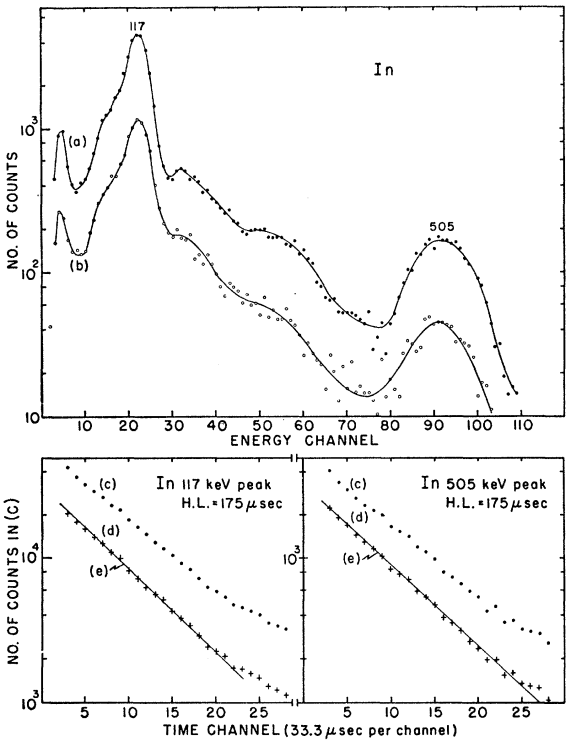


FIG. 15. *Indium*: As for Fig. 3, except (a) ~160 μsec after bombardment, (b) ~500 μsec after bombardment.

better value for the half-life was obtained in the bombardment of NaBr but we present this data because the energy scale is uniform.

Zr. The isomer is fairly strongly excited and the two peaks decay with sensibly the same half-life. The single-particle lifetime estimate suggests an $E2$ transition.

Mo. Duffield and Vegors assign their 98-keV 16.5-μsec isomer to Mo^{99}. We see a 44-keV peak decaying with the same half-life as the 100-keV peak.

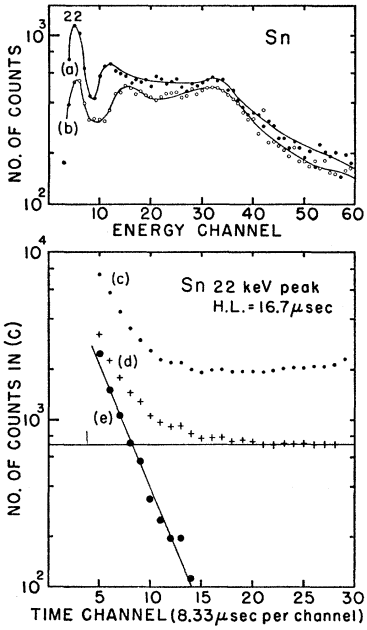


FIG. 16. *Tin*: As for Fig. 3.

Ru. A similar half-life and energies are seen as in the gamma reactions of Krehbiel and Meyer-Berkhout.[6] The isomer must then be in a Ru isotope which can be reached by a (d,p) reaction in our case and a (γ,n) in Ref. 6, from isotopes with reasonable abundances. Ru^{101}

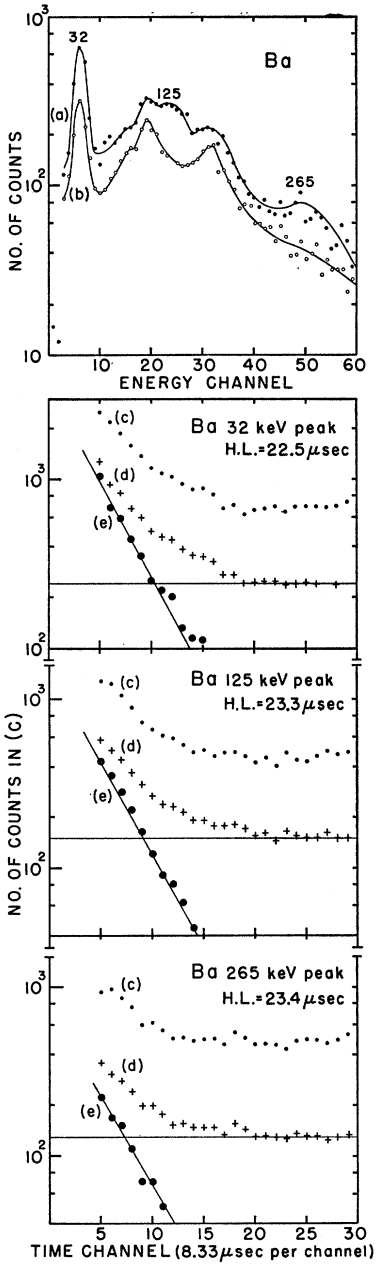


FIG. 17. *Barium*: As for Fig. 3.

has a cascade 307, 235 keV, and fulfills the above criterion. For a 300-keV gamma ray and mass 100, the single-particle lifetime estimate is about 1 μsec for an $M2$ transition. This suggests the assignment of $11/2^-$ as the spin and parity of the 550-keV level. The β transition from the $\frac{9}{2}^+$ Tc^{101} ground state to the 550-keV

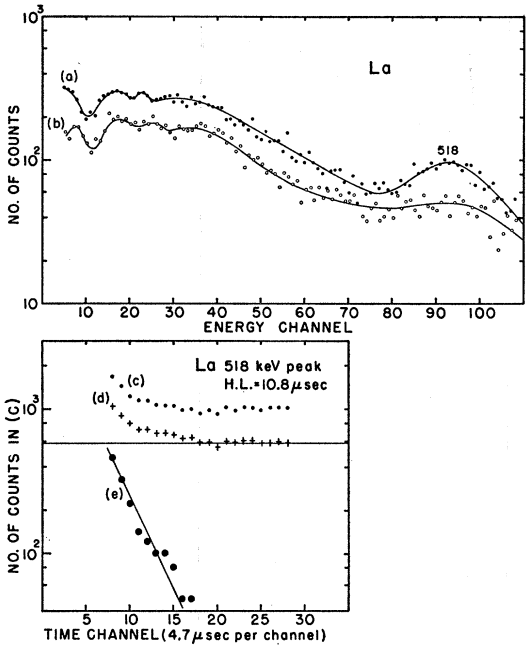


FIG. 18. *Lanthanum*: As for Fig. 3, except (a) ~20 μsec after bombardment, (b) ~50 μsec after bombardment.

level has log $ft=5.6$. This would then have to be a first forbidden transition. These usually have a higher log ft value (7–8) but there are other examples of first forbidden transition with lower ft values, e.g., $Tl^{209} \rightarrow Pb^{209}$ where log $ft=5.3$.

Pd. The results are in good agreement with those of Refs. 1 and 2.

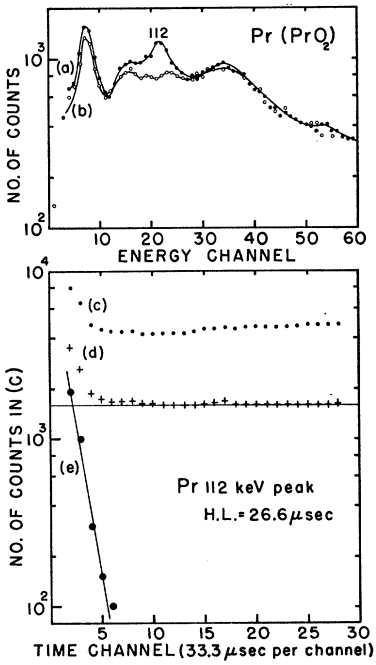


FIG. 19. *Praseodymium*: As for Fig. 3, except (a) ~60 μsec after bombardment, (b) ~500 μsec after bombardment.

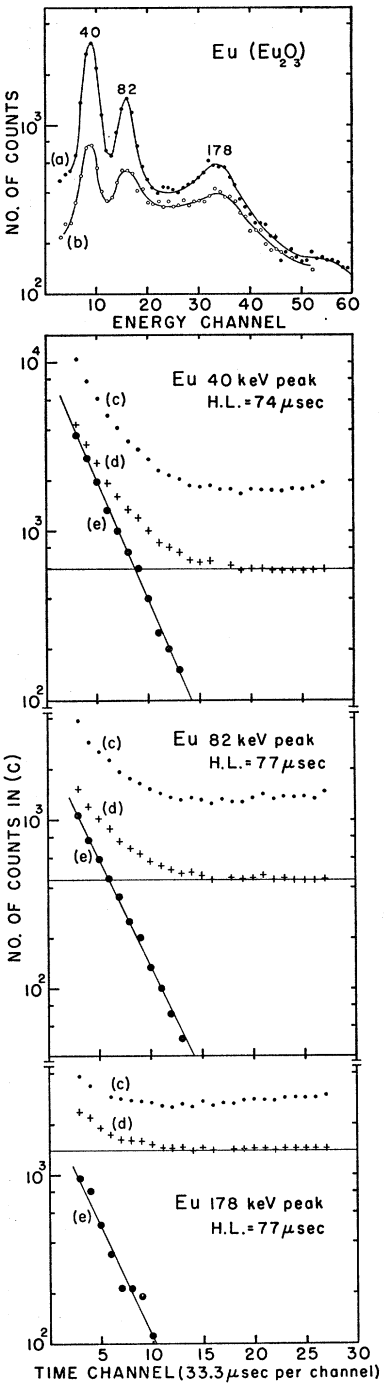


FIG. 20. *Europium*: As for Fig. 3, except (a) ~60 μsec after bombardment, (b) ~260 μsec after bombardment.

Ag. From the shape of the Hg^{203} 279-keV spectrum we deduce that there are just two gamma-ray peaks in the spectrum from the Ag bombardment, at 273 and 217 keV. Because Petroff[18] reports, a 12-μsec 58-keV isomeric transition in Cd^{109}, which can be reached by the $(d,2n)$ reaction on the 48% Ag^{109} isomer, this case is of particular interest. Three separate measurements of the energies yielded the results 215, 217, 220 keV and 271, 273, 275 keV, from which we have given the average value.

The possibility that the 58-keV transition, which Petroff reports to have a conversion coefficient of greater than 5, is a daughter of the isomeric level we observe is not supported by consideration of the energies of the low-lying levels of Cd^{109}. Further evidence that the two isomers are distinct can be inferred from spins and lifetimes. The single-particle lifetime estimate for these energies predicts an $M2$ transition. Using the spin assignments of Nozawa[38] for the low-lying states of Cd^{109}, based on conversion-electron intensity ratios, we can not fit such an energy $M2$ transition into the level scheme in a way which could determine the decay which Petroff observed.

An estimate of the cross section for forming this isomer relative to that for forming the Sn^{115} isomer in

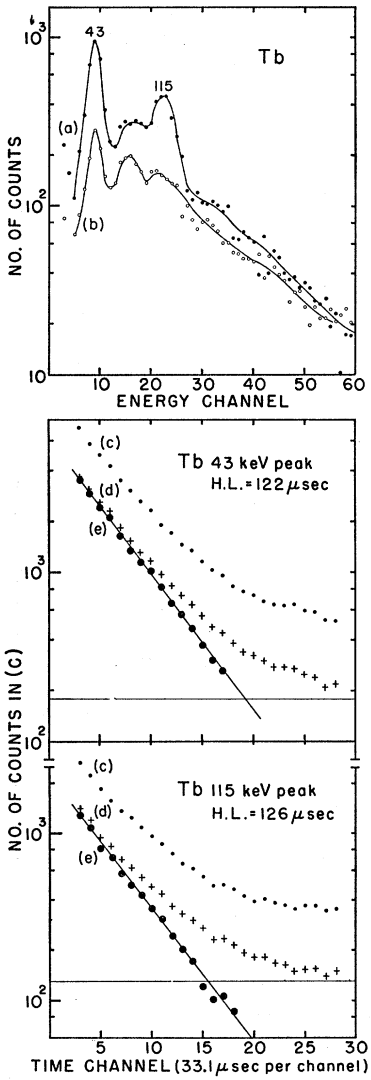


FIG. 21. *Terbium*: As for Fig. 3, except (a) ~220 μsec after bombardment, (b) ~500 μsec after bombardment.

[38] M. Nozawa, Nucl. Phys. **36**, 411 (1962).

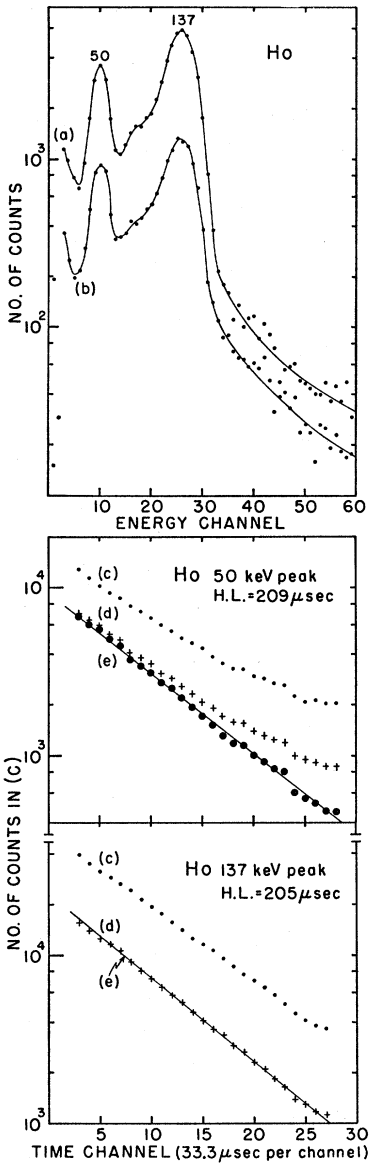


FIG. 22. *Holmium*: As for Fig. 3, except (a) ~50 μsec after bombardment, (b) ~500 μsec after bombardment.

the In bombardment was made from consecutive runs. The result that σ (Ag)$\approx\frac{1}{3}\sigma$(In) gives some indication that the reaction is probably $(d,2n)$. However, it has not been found possible to fit these gamma rays into the level schemes for those isotopes reached by these reactions from the silver isotopes.

In. The 175-μsec half-life of the 117- and 505-keV gamma-rays is determined by the 117-keV transition since this is by far the strongest. Schneid, Cohen, and Prakash[39] report the levels of Sn^{115} from $Sn^{114}(d,p)Sn^{115}$ to be $h_{11/2}$, 0.72 MeV; $g_{7/2}$, 0.60; $d_{3/2}$, 0.49. Since a $(d,2n)$ reaction on the 95% In^{115} isomer leads to Sn^{115} we would expect to observe the $M2$ transition from the 0.72-MeV $h_{11/2}$ to the 0.60-MeV $g_{7/2}$ level and also further 0.12- and 0.49-keV level in cascade. The observed lifetime is close to the single-particle estimate for an $M2$ transition as expected for a transition between relatively pure single-particle states, and the activity is very strong which alone would indicate that a $(d,2n)$ reaction is involved. Vegors and Axel report the same lifetime and spectrum in a γ bombardment of natural Sn. The abundance of Sn^{116} is 14% and the most likely reaction in that bombardment is (γ,n). Ivanov *et al.*[40] have recently reported the same assignment of this isomer which they excited by a (p,n) reaction in a pulsed-beam experiment.

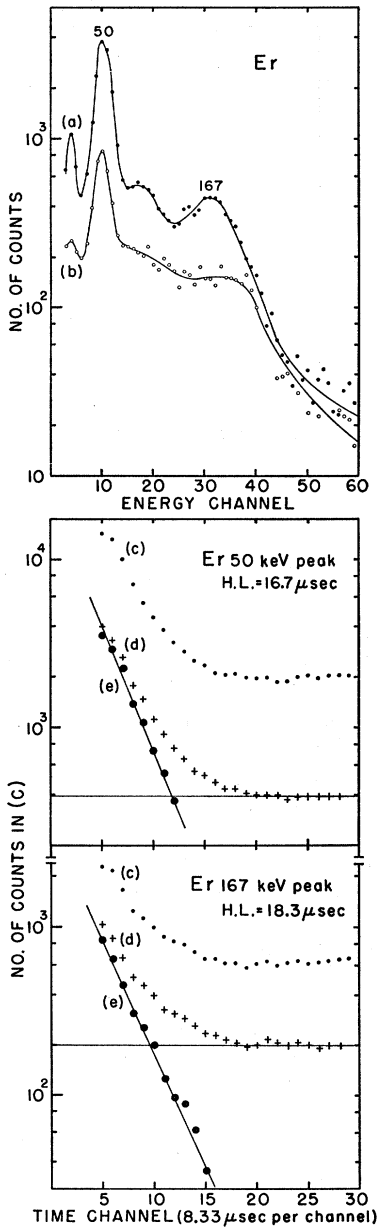


FIG. 23. *Erbium*: As for Fig. 3, except (a) ~20 μsec after bombardment, (b) ~70 μsec after bombardment.

[39] E. J. Schneid, B. L. Cohen, and A. Prakash (to be published).

[40] E. Ivanov *et al.*, Nucl. Phys. **54**, 177 (1964).

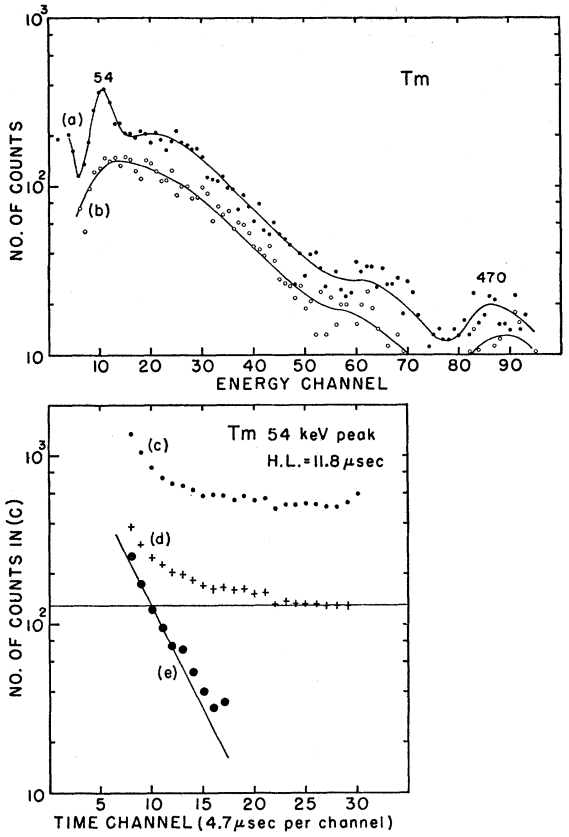


FIG. 24. *Thulium*: As for Fig. 3, except (a) ~20 μsec after bombardment, (b) ~50 μsec after bombardment.

Tb. The estimated value for the conversion coefficient of the 115-keV transition is 0.95±0.40. Rose's tables give 0.86 for $E2$, while the values are 9.2 for $M2$ and 0.17 for $E1$ transitions. It is then probable that the 115-keV transition is $E2$.

Ho. Ho is mono-isotopic and we expect to excite the Ho^{166} isomer reported in Ref. 27 in the $Ho^{165}(d,p)Ho^{166}$ reaction. The half-life and energies are in good agreement with the previous work. Our estimate for the conversion coefficient is 0.27±0.12 while the value obtained previously was ~0.4. Rose's tables give 0.5 for an $E2$ transition, 0.12 for an $E1$ transition, and 6.6 for an $M2$ transition. The transition may be an $E2$ type as suggested in Ref. 27, or a mixture of $E1$ and $M2$ transitions.

Er. Here we estimate the conversion coefficient to be 1.85±0.80. Rose's tables give 3.5 for an $M2$ transition, 0.07 for $E1$ and 0.27 for $E2$. Thus an $E1+M2$ mixture is suggested.

Tm. The 54-keV peak may be the x ray following the internal conversion of the 470-keV transition. The 470-keV peak decays with a half-life which qualitatively is similar to the x-ray peak decay but the number of counts is too small to obtain a measurement of the conversion coefficient.

Yb. The $(d,2n)$ reaction on the 30% Yb^{174} isotope leads to Lu^{174} while the (d,n) reaction on Yb^{173} leads to the same isotope. Further, the $(d,2n)$ reaction on Yb^{173} leads to Lu^{173}. The known isomers in Lu^{173} and Lu^{174} have similar half-lives and energies and we could not expect to resolve these in the present experiment.

We see yet a third isomeric transition with a distinctly longer half-life, and energy 72 keV.

Ta. The three peaks we observe to decay from the Ta bombardments are those of the 14-μsec W^{181} isomer formed by the $(d,2n)$ reaction, and presumably the 134-keV 20-μsec Ta^{181} isomer formed by the (d,pn) reaction. The fact that we do not see the proper half-life for the Ta^{181} isomer is probably due to the small cross section for the (d,pn) reaction compared to the $(d,2n)$ reaction.

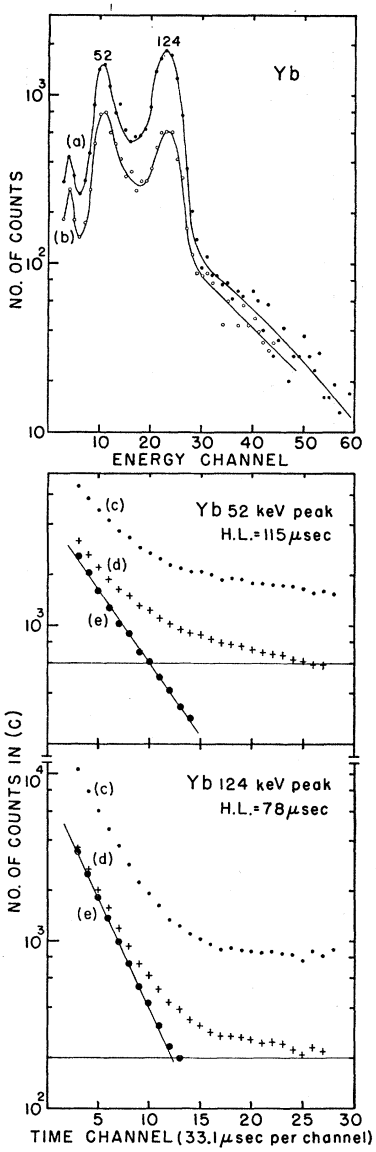


FIG. 25. *Ytterbium*: As for Fig. 3, except (a) ~100 μsec after bombardment, (b) ~200 μsec after bombardment.

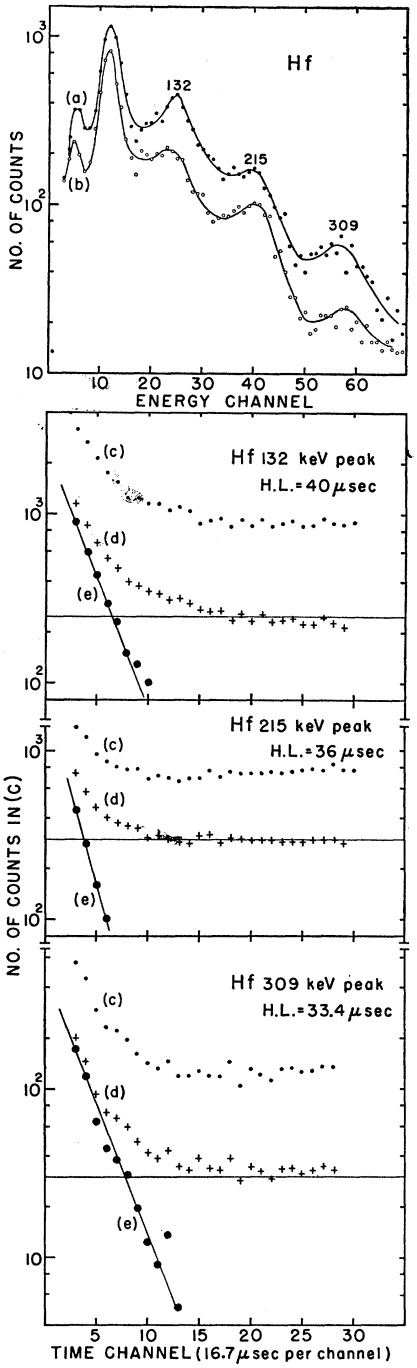


FIG. 26. *Hafnium*: As for Fig. 3, except (a) ~40 μsec after bombardment, (b) ~100 μsec after bombardment.

W. The 60-keV peak is thought to be the x ray following internal conversion of the 195-keV transition which is seen as a weak bump on the early spectrum (a). No numerical estimate of the conversion coefficient has been made but the transition is clearly more highly converted than the Er one discussed above, and is therefore probably an $M2$ transition.

Re. For two decays in a single bombardment where both have good statistics, the error in the relative values of the half-lives is much less than for comparisons between two different runs. The two different half-lives seen in the Re bombardment indicate the presence of two isomeric transitions. The 65-keV peak is probably the x ray and its more rapid decay may indicate that the 187-μsec half-life is a combination of the 216-μsec decay partially converted and some much shorter decay almost completely converted so that the gamma ray is not seen. The possibility that this shorter decay could then be the same one formed in the tungsten bombardment cannot be rejected.

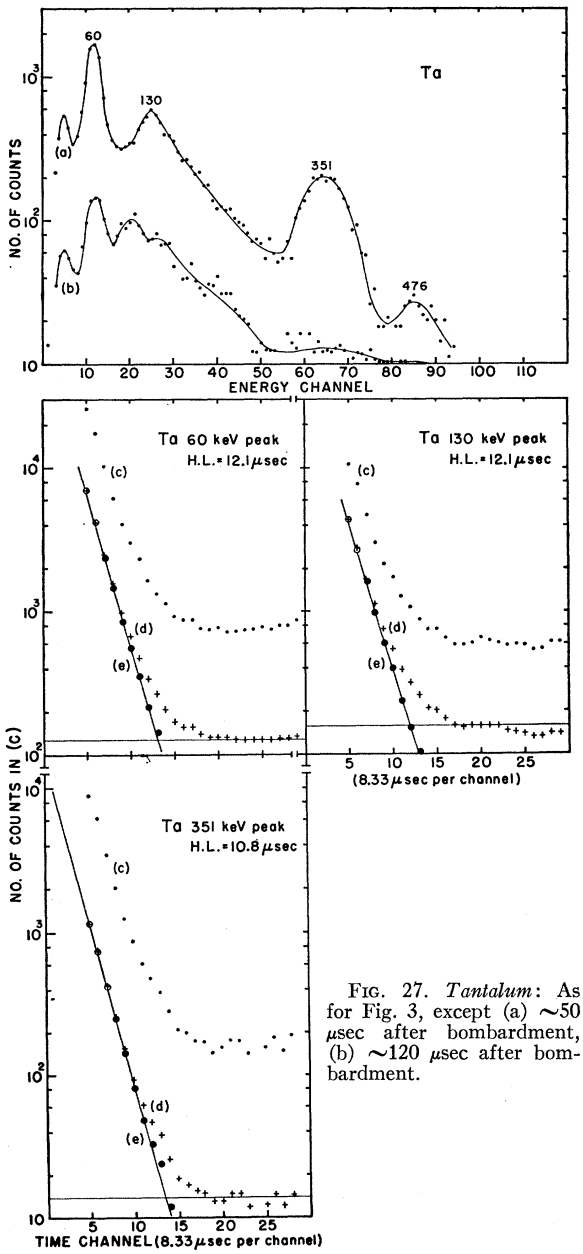


FIG. 27. *Tantalum*: As for Fig. 3, except (a) ~50 μsec after bombardment, (b) ~120 μsec after bombardment.

TABLE II. Isomers observed in this survey.

(1) No.	(2) Target	(3) Half-life (μsec)	(4) Energy (keV)	(5) Assignment	(6) Approx. x-ray energies (keV)	(7) Remarks
1	Ca	35	80	...	...	New
2	Sc	11.3	60	...	...	New
3	Ti	12	55	...	...	New
4	Zn	10.8	100	Zn^{67}	...	Refs. 1, 4
5	Ge	7	75	As^{73}	...	Refs. 1, 12
			374			
6	Se	126.5	153	Br^{78}	...	Ref. 2
7		40	270	Br^{81}	...	Ref. 14
7a	Br	27	280	Br^{81}	...	Ref. 14
8	Zr	80	82	...	...	New
			124			
9	Mo	12.7	44	Mo^{99}	17	Refs. 1, 2
			100			
10	Ru	24.5	220	Ru^{101}	19	Ref. 6
			318			
11	Pd	34	192	Pd^{105}	21	Refs. 1, 2
			315			
12	Ag	11.1	217	...	22	New
			273			
13	In	175	117	Sn^{115}	24	Refs. 1, 40
			505			
14	Sn	16.7	22	...	25	New
15	Ba	23	32			
			125	...	32	New
			265			
16	La	10.8	518	...	32	New
17	Pr	26.6	112	...	35	New
18	Eu	76	40			
			82	...	41	New
			178			
19	Tb	124	43	...	44	New
			115			
20	Ho	207	50	Ho^{166}	47	Ref. 27
			137			
21	Er	17.5	50	...	48	New
			167			
22	Tm	11.8	54	...	50	New
23	Yb	115	72		51	New
24		78	124	Lu^{173}, Lu^{174}		Refs. 5, 4, 28
25	Hf	36	132			
			215	...	55	New
			309			
26	Ta	12	60	W^{181}		
			360		56	Refs. 1, 2, 4,
			130	Ta^{181}		5, 17, 29
27	W	75	60	...	58	New
			195			
28	Re	187	65	...	60	New
		216	156			New

The survey included bombardments of the following targets from which no isomers have been found: C, N, O, F, Na, Mg, Al, Si, P, S, Cl, K, V, Cr, Mn, Fe, Co, Ni, Cu, Ga, As, Rb, Sr, Y, Nb, Rh, Cd, Sb, Te, I, Cs, Ce, Nd, Sm, Gd, Dy, Os, Au, Tl, Pb, Bi. Bombardments of Li, Be, B, and Th gave results which first appeared to be isomeric decays but are now suspected to be the effects of neutron production in these bombardments. The spectra in all four cases were almost identical. In the case of Be it was observed that little change occurred in the spectrum when one-eighth of an inch of lead was placed between the target and the

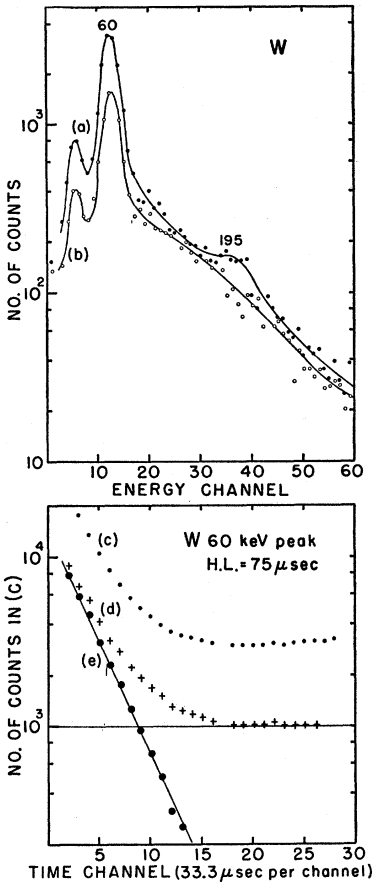


FIG. 28. *Tungsten*: As for Fig. 3, except (a) ~100 μsec after bombardment, (b) ~240 μsec after bombardment.

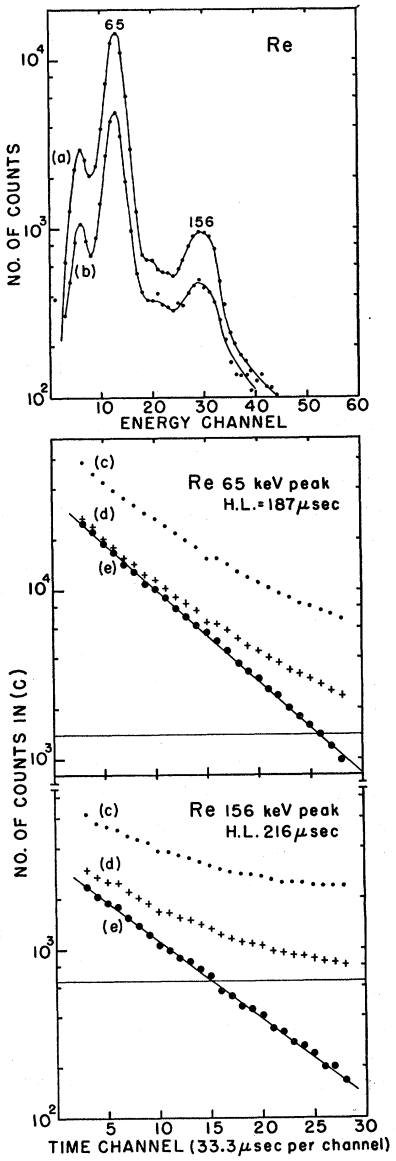


FIG. 29. *Rhenium*: As for Fig. 3, except (a) ~50 μsec after bombardment, (b) ~400 μsec after bombardment.

NaI crystal during the run. In particular a broad peak in the spectrum at about 100 keV is apparently not affected whereas the attenuation of one-eighth of an inch of lead at this energy is very large. Duffield and Vegors[2] experienced difficulty with apparent half-lives from neutron-capture gamma rays. Apart from the cases just discussed this effect was not observed in this experiment.

ACKNOWLEDGMENTS

The authors wish to thank Dr. W. Daehnick and W. McNamee for helpful discussions concerning the electronics used in this work. Members of the staff of the School of Engineering generously offered assistance and equipment for the pressing of thick targets from metallic and oxide powders.

The cooperation of J. Natowitz in the calibration of the crystal efficiency for the estimates of the internal conversion coefficients is gratefully acknowledged.