Gamma-Rays Associated with Selected Neutron-Induced Radioactivities

W. C. RUTLEDGE, J. M. CORK, AND S. B. BURSON
Argonne National Laboratory, Chicago, Illinois, and University of Michigan, Ann Arbor, Michigan
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By means of photographic magnetic spectrometers located close to the heavy water moderated reactor, the following radioactive nuclei have been examined: Se^{77m} (17.5 sec), Se^{79m} (3.5 min), Se^{81m} (58 min), Se^{81} (17 min), Se^{83} (69 sec), Se^{83} (26 min), Nd^{147} (11.9 days), Nd^{149} (1.8 hr), Nd^{151} (12 min), Pm^{149} (50 hr), Pm^{151} (27.5 hr), Sm^{145} (410 days), Sm^{151} (>20 yr), Sm^{153} (46.5 hr), Sm^{155} (23.5 min), Eu^{155} (1.7 yr), Mo^{101} (14 min), Tc^{101} (15 min), and Th^{233} (23.6 min). The 27.5-hour activity assigned to Pm^{151} was discovered in this work. A new vacuum gate for the camera of the spectrometer permits the study of activities with half-lives as short as ten seconds. Energy level schemes for the product nuclei are proposed on the basis of a spectrographic analysis of the gamma-rays and also of coincidence and absorption measurements. Changes in spin and parity between many of the energy levels are determined from measurements of the K/L ratios of the corresponding gamma-rays.

INTRODUCTION

PHOTOGRAPHIC beta-ray spectrometers (called spectrographs hereafter) in close proximity to the heavy water moderated reactor of the Argonne National Laboratory make it possible to carry out investigations of short-lived radioactive nuclei.[1] The pneumatic tube which passes through the shielding of the reactor permits rapid transport of samples to and from the active region. It has been found possible to conduct spectrographic studies of activities having half-lives as short as ten seconds. The energies of the gamma-rays are principally determined by measuring the energies of internal conversion electrons and photoelectrons from various radiators. Additional information is obtained from absorption and coincidence experiments, and from measurements of the intensity of the internal conversion electron lines. From these results several new energy level schemes are proposed.

APPARATUS AND PROCEDURE

The present investigation makes use of the existing magnetic spectrographs of Keller and Cork.[1,2] To facilitate the study of radioactivities with half-lives shorter than one minute, it was necessary to modify the cameras by constructing a faster vacuum gate. This was accomplished by the use of the multiple *O*-ring vacuum seal shown in Fig. 1. The source is placed in a cavity in the brass cylinder which extends through the camera. By the above simplification it is possible to put the source in position in the main chamber by a single continuous motion of the supporting cylinder through its *O*-ring vacuum seals. As the source cavity moves into the region between the first two *O*-rings, it is sealed off from the atmosphere. As the motion continues, the air trapped in the sample cavity is practically all removed by a forepump connected to the vacuum port between the second and third *O*-rings. Two additional *O*-rings on the other side of the main chamber permit the cylindrical tube to extend through the camera so that there is no net thrust due to atmospheric pressure. With this type of vacuum gate the introduction of a source into position in the camera requires about one second.

The sources that were used in the study of internal conversion electrons were usually mounted on a strip of Scotch-tape. They were approximately 0.35 mm wide, 20 mm long, and from 0.5 to 1 mg/cm² thick. The strip of tape was supported on frames made of either Lucite or pure graphite. No disturbing radiation was emitted by the source holder and mounting after irradiation in the reactor. Short-lived sources for studies of photoelectrons were sealed and irradiated in small Lucite tubes. The charged particles emitted by these sources were absorbed by interchangeable copper or aluminum tubes on the source holder; the radiator was 0.35 mm wide, 20 mm long, and approximately 30 mg/cm² thick.

Because of its sensitivity, no-screen x-ray film was used for a qualitative survey of each radioactive nucleus. For quantitative work Kodak NTB nuclear track plates were used. The fine grain and low background of these plates make them far superior to x-ray film for the comparison of intensities of electron lines with a photodensitometer.

The magnetic fields were calibrated and checked at

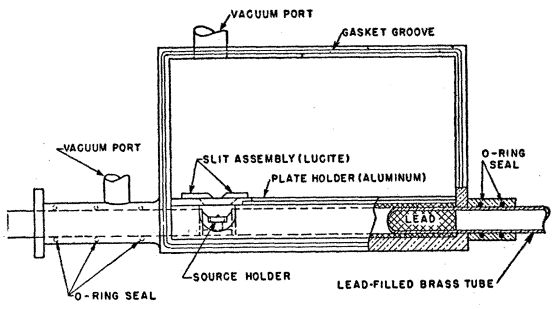

FIG. 1. A fast-entry camera for a magnetic spectrograph.

[1] R. Caldwell, Argonne National Laboratory Report 4408 (1949); Phys. Rev. 78, 407 (1950); H. Keller and J. Cork, Argonne National Laboratory Report 4595 (1951); Phys. Rev. 84 (1952).
[2] J. Cork, Phys. Rev. 72, 581 (1947).

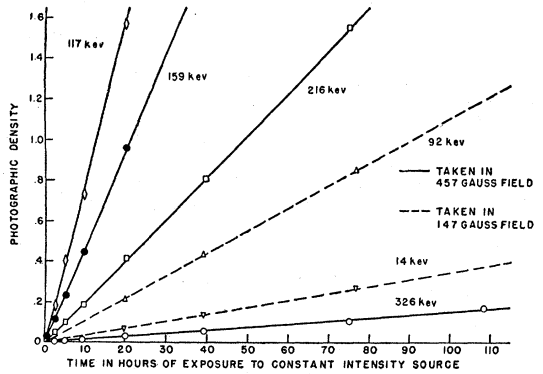

FIG. 2. Variation of density with exposure for NTB plates.

intervals with standard sources of iodine 131, cobalt 60 and radium.[3]

In order to determine the ratio of the electrons that are ejected from the K and L atomic orbits in the process of internal conversion, the relative intensities of the corresponding electron lines on photographic plates are determined by photometric methods. Before these intensities can be obtained, it is necessary to correct the photodensitometer traces of the electron lines for the following factors: background, exposure, attenuation due to the geometry of the camera, and energy sensitivity of the photographic emulsion. It was not feasible to follow the procedure usually used in optical spectroscopy of putting proper calibrating exposures of known relative intensity on every plate. In this work separately exposed plates were used to determine the various corrections in the following manner. For each kind of experiment for the calibration, photographic plates from the same box in the same shipment were used. The plates and developer were stored at a temperature of about 1°C to retard aging processes. Identical conditions of exposure and development of the photographic plates were maintained. Each plate was developed for 2 minutes at 20°C with previously unused D-8 developer from the same batch of stock solution. Instead of varying the intensity of the radioactive source, the time of exposure was varied. That the reciprocity law of equivalence of variation of intensity and time of exposure is valid to better than the accuracy of these measurements for the blackening of the plates by fast electrons has been shown by other workers.[4] The photographic densities ($\log_{10}I_0/I$) of the electron lines were measured with a Leeds and Northrup recording photodensitometer with a scanning beam about 0.02 mm wide and 1.8 mm high.

One set of plates was exposed to the continuous beta-spectrum of scandium 46 with the constant-field spectrograph for times of exposure ranging from 0.5 to 108 hours. The densities at different selected positions, the same position on each plate, were measured to obtain sets of values of density for various times of exposure, each set corresponding to electrons of a particular energy. The results are shown in Fig. 2. It is apparent that for values of density below 1.6 the density is directly proportional to the time of exposure. By the reciprocity law, the density is thus proportional to the intensity of exposure.

The correction for attenuation of the intensities of the electron lines caused by the geometry of the camera was determined by making successive identical exposures of a well-known electron line on different plates at different radii of curvature, ρ. This was accomplished by varying the magnetic field in appropriate steps from 70 to 460 gauss, and by using electron lines at 50, 103, and 139 kev. The variation of the intensity of an electron line with the corresponding radius of curvature is dependent upon a choice of using the density at the peak of the line, or the density integrated over a complete line distribution. The experimentally determined attenuation of the integrated density, or area under the densitometer trace, of a line located on increasing radii of curvature is shown in Fig. 3. The slightly greater attenuation of the intensities of the peaks of the electron lines with radii of curvature is also shown in the same figure. Because of scattering of the electrons from the low energy edge of the metal plate holder, both curves may be relatively inaccurate at values of ρ from 2.75 to 3.25 cm. Additional experiments showed that the intensity of a section of a beta-spectrum was attenuated at various radii of curvature by the same amounts as that of a peak of an electron line.

The sensitivity of various emulsions to electrons of different energy has been considered in detail by several

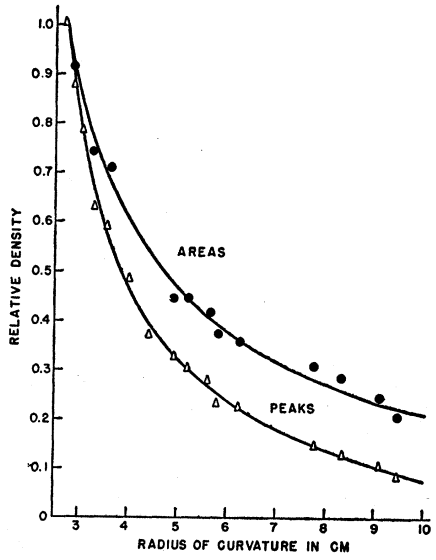

FIG. 3. Variation of photographic density due to geometry.

[3] Lind, Brown, Klein, Muller, and DuMond, Phys. Rev. **75**, 1633 (1949); Lind, Brown, and DuMond, Phys. Rev. **76**, 1838 (1949); Cork, Branyan, Stoddard, Keller, LeBlanc, and Childs, Phys. Rev. **83**, 681 (1951).

[4] W. Bothe, Z. Physik **8**, 243 (1922); C. Ellis and W. Wooster, Proc. Roy. Soc. (London) **A114**, 266 (1927).

authors.[5] In the present investigation the energy sensitivity of the NTB emulsion (25 microns thick) is determined from 14 to 350 kev, as shown in Fig. 4, by comparing the beta-spectrum of scandium 46 obtained[6] by the use of a constant radius beta-spectrometer with that observed in the constant field spectrograph. The photographic data were, of course, corrected for geometrical attenuation before the comparison was made.

Additional experiments were run to check the validity of the correction for attenuation caused by the geometry of the camera when this geometry was varied. Using a range of from 1 mm to 10 mm for the separation of the slits and from 0.20 mm to 1.2 mm for the width of the source, a maximum deviation of ± 10 percent from the average was obtained for the K/L ratio of a prominent gamma-ray. No correlation was observed between the deviations and the parameters that were varied. Taking account of these experiments and the fluctuations of the densitometer traces caused by the size of the grains and defects in the emulsion, it was concluded that it is often possible to obtain K/L ratios within ± 10 percent from the corrected intensities of the electron lines. In a comparison of a K/L ratio determined by the photographic method with that from beta-spectrometer measurements, excellent agreement was obtained.[7] The ratios determined from area measurements and corrected either by the geometrical attenuation curve for areas, or by the one for peaks on a point-to-point basis, are found to agree within experimental error. In this work, however, the K/L ratios are determined from area measurements corrected in the former manner in view of the comparative ease of applying the necessary corrections.

To determine the multipolarity and character (magnetic or electric) of a gamma-ray from its K/L ratio and energy, recently published curves of K/L *versus* Z^2/E were used.[8] In the case of isomeric transitions, the multipolarity and character may also be assigned from lifetime-energy relationships.

In a few cases absorption measurements with GM counters as detectors indicated the presence of weak gamma-rays of over 600 kev that were not observable by the photographic method. More accurate values for these and other unresolved weak gamma-rays were obtained by Dr. B. Hamermesh with a NaI (thallium activated) scintillation spectrometer with a twenty channel pulse-height discriminator.[9]

A standard coincidence circuit with a resolving time of 4.5×10^{-7} second was also used in this research.

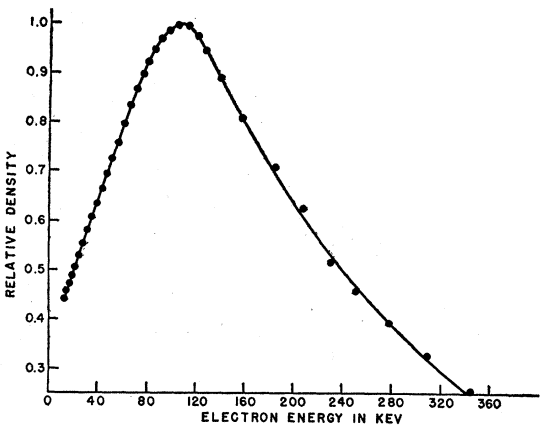

FIG. 4. Sensitivity of Kodak NTB plates to electron energy.

The actual experimental arrangement and techniques have been described previously.[10]

RESULTS

A summary of the significant results is given in Table I, It includes measurements of the half-life, energy of the beta-rays, energy of the electron lines, interpretation of the electron lines, relative intensity of the internal conversion electron lines, energy of the corresponding gamma-rays, and K/L ratio of the prominent gamma-rays. The probable multipolarity and character of these gamma-rays are suggested where data are available. Alternate assignments of the type of the radiation that are less definite are listed in parentheses. Types of radiation classified as mixtures of $M1$ and $E2$ transitions may possibly be either pure $M2$ or $E1$ transitions, depending upon the particular case in question.

A. Selenium

Six stable isotopes of selenium exist in nature with atomic masses and abundances as follows: 74—0.9 percent, 76—9.1 percent, 77—7.5 percent, 78—23.6 percent, 80—49.9 percent, and 82—8.9 percent. For the present study stable isotopes were obtained with the following mass enrichments: 76—57 percent, 78—83 percent, 80—95 percent, and 82—52 percent. Of the eleven radioactivities in selenium that are believed to exist, six short-lived, neutron-induced activities are discussed.

Se^{77m}

The 17.5-second isomer Se^{77m} was first produced[11] by the (η,γ) reaction and later[12] by x-ray excitation. The energy of a single gamma-ray which was reported[13] as

[5] C. Ellis and G. Aston, Proc. Roy. Soc. (London) **A119**, 645 (1928); A. Charlesby, Proc. Phys. Soc. (London) **52**, 657 (1940); B. Barries, Physik. Z. **43**, 190 (1942); Baker, Ramberg, and Hillier, J. Appl. Phys. **13**, 450 (1942); L. Cranberg and J. Halpern, Rev. Sci. Instr. **20**, 641 (1949).

[6] E. Salmi, dissertation, University of Michigan (1950); S. Burson and W. Rutledge, unpublished work at Argonne National Laboratory (1951).

[7] S. Burson and W. Rutledge, (Bull. Am. Phys. Soc. **27**, No. 1, 58 (1952)).

[8] M. Goldhaber and A. Sunyar, Phys. Rev. **83**, 906 (1951).

[9] B. Hamermesh and V. Hummel, Phys. Rev. **83**, 663 (1951).

[10] Burson, Blair, Keller, and Wexler, Phys. Rev. **83**, 62 (1951).

[11] J. Arnold and N. Sugarman, J. Chem. Phys. **15**, 703 (1947); M. Goldhaber and C. Muehlhause, Phys. Rev. **74**, 1248 (1948).

[12] Gideon, Miller, and Waldman, Phys. Rev. **75**, 329 (1949).

[13] A. Flammersfeld and C. Ytheir, Z. Naturforsch. **5a**, 401 (1950); E. der Mateosian and M. Goldhaber, Phys. Rev. **82**, 116 (1951); Canada, Cuffey, Lessor, and Mitchell, Phys. Rev. **82**, 750 (1951).

TABLE I. The electron and gamma-ray energies from selected neutron-induced radioactive nuclei.

Nucleus	Electron energy[a] (kev)	Relative intensity	Interpretation	Energy sum (kev)	Gamma energy (kev)	K/L ratio	Type
Se^{77m}	148.9	100	K^1	161.6	161.6	4.6 ±0.3	$E3$
17.5±0.5 sec	160.0	21.6	L^1	161.6			
I.T.				150[d]			
Se^{79m}	83.2	100	K^1	95.9	95.9	2.9 ±0.5	$E3$
3.5±0.2 min	94.2	34.8	L^1	95.8			
I.T.				85[d]			
Se^{81m}	90.5	100	K^1	103.2	103.1	3.0 ±0.3	$E3$
58±1.5 min	101.4	33.1	L^1	103.0			
I.T.				95[d]			
Se^{81}	none				none		
17±1.5 min							
β=1.5 Mev							
Se^{83}	none				none		
69±1.5 sec							
β=3.4 Mev[b]							
Se^{83}	27.8	100[e]	K^1	41.3	41.3		
26±2.5 min	30.2	100[e]	K^2	43.5	43.5		
β=1.5 Mev	47.5	100[e]	K^3	61.0	61.0		
	160.6		$L_{(Pb)^4}$	175.9	175.9[e]		
				173[d]	950[e]		
				950[d]			
Nd^{147}	31.4		Auger α_1-L_I				
	36.9		Auger α_1-M				
11.9±0.3 days	46.0	100	K^1	91.2	91.2	4.9 ±0.5	$M1+E2$
	75.3	4[e]	K^2	120.5	120.5		
β=0.825 Mev	83.9	20.6	L_{I,II^1}	91.2			
0.598 Mev	89.4	4.0	M^1	91.1			
0.384 Mev	90.7	1.0[e]	N^1	91.0			
	112.9	2.4[e]	$L_I{}^2$	120.4			
			(K)	(168.1)	(168.1)		
	151.9	2.2[e]	K^3	197.1	197.1		
	186.0	0.3[e]	K^4	231.2	231.2		
	214.6	0.06[e]	K^5	259.8	259.8		
	228.0	0.5[f]	K^6	273.2	273.3		
	255.6	0.05[e]	K^7	300.8	300.8		
	266.5	0.12[e]	$L_{II}{}^6$	273.5			
	272.9	1.28[f]	K^8	318.1	318.1		
	311.2	0.2[e]	$L_{II}{}^8$	318.2			
	353.2	0.3[e]	K^9	398.4	398.4		
	396.1	0.3[e]	K^{10}	441.3	441.4		
	434.5	0.04[e]	$L_{II}{}^{10}$	441.5			
	487.0	4.54[f]	K^{11}	532.2	532.3	5.7 ±1.4	$E2$
	525.5	0.79[f]	$L_{II}{}^{11}$	532.5			
				95[d]			
				290[d]			
				540[d]			
Nd^{149}	22.5	4[e]	$L_{II}{}^1$	29.5	29.5		
1.8±0.1 hr	28.0	1[e]	M^1	29.6			
	36.2		Auger α_2-M				
β=1.5 Mev	51.3	14	K^2	96.5	96.5	0.87±0.25	$E2$
1.1 Mev							
0.95 Mev	67.1	30	K^3	112.3	112.3		
	68.9	100	K^4	114.1	114.1	4.8 ±1.6	$E2+M1(M2)$
	78.9	15[e]	K^5	124.1	124.1		
	89.2	16	$L_{I,II}{}^2$	96.4			
	106.7	21	$L_I{}^4$	114.2			
	112.3	3.3	M^4	113.9			
	120.8		$K_{(Pb)^8}$	209.1			
	142.6	3.2	K^6	187.8	187.8		
	150.6		$K_{(Pb)^{10}}$	238.9			
	152.7	1.7	K^7	197.9	197.9		
	165.4	29	K^8	210.6	210.5[e]	6.6 ±1.4	$M1$, $(M2)$
	178.0		$K_{(Pb)^{11}}$	266.3			
	180.9	1.7	K^9	226.1	226.1		
			$(L_{II}{}^6)$	(187.9)			
	181.4		$L_{I(Pb)^7}$	197.3			
	194.8	14.9	K^{10}	240.0	240.0		
	195.0		$L_{II(Pb)^8}$	210.2			
	203.0	4.4	$L_I{}^8$	210.4			
	209.0	0.8	M^8	210.6			
	221.3	4.2	K^{11}	266.5	266.4[e]	(10)	$(M1)$
	250.6		$L_{I(Pb)^{11}}$	266.4			

TABLE I.—*Continued.*

Nucleus	Electron energy[a] (kev)	Relative intensity	Interpretation	Energy sum (kev)	Gamma energy (kev)	K/L ratio	Type
	258.9	0.4[c]	L_I[11]	266.3			
	335.3		$K_{(Pb)}$[12]	423.6	423.5[c]		
	407.0		$L_{I(Pb)}$[12]	422.9			
	449.9		$K_{(Pb)}$[13]	538.2	538[c]		
	561.9		$K_{(Pb)}$[14]	650.2	650[c]		
				110[d]			
				266[d]			
				680[d]			
Nd^{151}	40.2	24[c]	K^1	85.4	85.4		
12±1 min	64.8	17[c]	K^2	110.0	110.0		
	71.9	100	K^3	117.1	117.1	4.1 ±1.7	$(M1+E2)$
$\beta=1.93$ Mev	78.1	21[c]	$L_{I,II}$[1]	85.3			
	83.8	5[c]	M^1	85.4			
	110.0	24.5	$L_{I,II}$[3]	117.2			
	115.5	6[c]	M^3	117.1			
	376.1		K^4	421.3	421[c]		
		By scintillation spectrometer		725±50	725±50[c]		
				1140±25	1140±25[c]		
				995[d]			
Pm^{149}	32.5		Auger α_1-L_{III}				
50±1.5 hr	238.0	100	K^1	284.9	284.9	8.0 ±2.5	$M1(M2)$
	277.6	12.5	$L_{I,II}$[1]	284.9			
$\beta=1.05$ Mev				1300[d]	1300(±200)		
Pm^{151}	17.8	28	K^1	64.7	64.7	0.30±0.15	$E2$
27.5±1.5 hr	18.9	18	K^2	65.8	65.8	0.25±0.15	$E2$
	22.8	13	K^3	69.7	69.6	0.25±0.10	$E2$
$\beta=1.1$ Mev	32.6		Auger α_2-L_{III}				
	37.4		Auger $\beta-L_I$				
	53.1	100	K^4	100.0	100.0	5.0 ±1.7	$M1+E2(M2)$
	57.2	93	$L_{I,II}$[1]	64.7			
	58.3	71	$L_{I,II}$[2]	65.8			
			(K)	(105.2)	(105.2)		
	61.9	50	$L_{I,II}$[3]	69.4			
	63.1	8[c]	M^1	64.8			
	64.1	5.5[c]	M^2	65.8			
	69.2	17.8	K^5	116.1	116.2		
	92.3	20.2	L_I[4]	100.1			
	97.1	23.4	K^6	144.0	144.0	(9)	$(M1)(M2)$
			(L_I)	(104.8)			
	109.0	2.2	L_{II}[5]	116.3			
	116.3	14.7	K^7	163.2	163.1	(7)	$(M1+E2)$
	121.1	14.6	K^8	168.0	168.0	3.3 ±2.2	$M1+E2$
	130.2	22.6	K^9	177.1	177.1	8.7 ±3.0	$M1+E2(M2)$
	136.4	2.5[c]	$L_{I,II}$[6]	143.9			
	155.5	2.0[c]	$L_{I,II}$[7]	163.0			
	160.4	4.4	$L_{I,II}$[8]	167.9			
	161.5	4.7	K^{10}	208.4	208.3	3.6 ±2.5	
	169.4	2.6	L_I[9]	177.2			
	174.9	0.6	M^9	176.6			
	185.0	3.7	K^{11}	231.9	231.9		
	186.5	weak	$K_{(Pb)}$[13]	274.8			
	192.8	2.7	K^{12}	239.7	239.9		
	200.7	1.3	$L_{I,II}$[10]	208.2			
	224.4	0.8	$L_{I,II}$[11]	231.9			
	228.3	5.8	K^{13}	275.2	275.2	(>10)	$(M1)$
	232.6	0.7[c]	$L_{I,II}$[12]	240.1			
	251.7	strong	$K_{(Pb)}$[14]	340.0			
	293.2	39.2	K^{14}	340.1	340.2[c]	9.1 ±2.8	$M1(M2)(E1)$
	324.0		$L_{II(Pb)}$[14]	339.8			
	332.9	4.31	$L_{I,II}$[14]	340.4			
	668.5	weak	K^{15}	715.4	715[c]		
	707.4	weak	$L_{I,II}$[15]	714.9			
				170[d]			
				300[d]			
				700[d]			
Sm^{145}	16.1	100	K^1	61.3	61.3	1.0 ±0.3	$E2+M1$
410 days[b]	31.6		Auger α_2-L_{III}				
K-capture	36.3		Auger α_2-M				
	53.9	98	$L_{I,II}$[1]	61.2			
	59.6	5	M^1	61.3			
				65[d]			
Sm^{151}	none				none		
>20 yr							
$\beta=0.076$ Mev[b]							

TABLE I.—*Continued.*

Nucleus	Electron energy[a] (kev)	Relative intensity	Interpretation	Energy sum (kev)	Gamma energy (kev)	K/L ratio	Type
Sm^{153}	14.5		$K_{(Pb)}^2$	102.8			
46.5±1 hr	21.2	5.5	K^1	69.8	69.8	0.29±0.03	$E2$
	33.5		Auger α_2-L_I				
β=0.820 Mev	39.8		Auger α_2-M				
	54.5		$L_{II(Pb)}^1$	69.7			
	54.7	100	K^2	103.3	103.4	3.5 ±0.6	$E2+M1$
	61.7	18.5	L_I^1	69.8			
	62.9	0.4	L_{III}^2	69.9			
	68.1	2.0	M^1	69.9			
	69.3	0.2	N^1	69.7			
	87.0		$L_{I(Pb)}^2$	102.9			
	88.2		$L_{II(Pb)}^2$	103.4			
	90.5		$L_{III(Pb)}^2$	103.6			
	95.3	28.5	L_I^2	103.4			
	101.5	5.8	M^2	103.3			
	102.9	0.4	N^2	103.3			
	533.7	weak	K^3	582.4	582		
				100[d]			
				600[d]			
Sm^{155}	16.1		$K_{(Pb)}^1$	104.4			
23.5±0.4 min	56.0	100	K^1	104.6	104.6	3.6 ±1.0	$E2+M1(E1)$
	57.3	(4)[a]	$K_{(Sm)}^1$	104.2			
β=1.8 Mev	88.6		$L_{I(Pb)}^1$	104.5			
	89.7		$L_{II(Pb)}^1$	104.9			
	91.9		$L_{III(Pb)}^1$	105.0			
	96.6	27.6	L_I^1	104.7			
	100.6		$M_{(Pb)}^1$	104.4			
	104.4	(3)	M^1	104.8			
	156.2		$K_{(Pb)}^2$	244.5			
	197.2	(100)	K^2	245.8	245.8	(8)	$(M1)(M2)$
	228.6		$L_{I(Pb)}^2$	244.5			
	237.4	(12.5)	L_I^2	245.5			
				100[d]			
				240[d]			
Eu^{155}	10.0	3	K^1	60.4	60.4		
1.7±0.2 yr	36.6	100	K^2	87.0	87.0	8.0 ±2.8	$M1(M2)$
	52.1	31	L_I^1	60.5			
β=0.15[b] Mev	55.3	75	K^3	105.7	105.7	8.3 ±2.8	$M1(M2)$
0.25[b] Mev	58.5	5	M^1	60.4			
	71.1		$L_{I,II(Pb)}^2$	86.7			
	78.9	12.5	$L_{I,II}^2$	87.0			
	82.0	10	K^4	132.4	132.4		
	83.0		$M_{(Pb)}^2$	86.9			
	85.0	1.5	M^2	86.9			
	90.0		$L_{I,II(Pb)}^3$	105.6			
	97.9	9	L_{II}^3	105.7			
	103.9	1[c]	M^3	105.8			
				80[d]			
Mo^{101}	74.6		$K_{(U)}^1$	191.0			
~14 min	103.2		$K_{(Pb)}^1$	191.5			
β=1.2 Mev	168.6		$L_{III(U)}^1$	190.0			
2.1 Mev	170.2	100	K^1	191.2	191.2	6.0 ±2.5	$M1(M2)(E2)$
	175.9		$L_{I,II(Pb)}^1$	191.4			
	188.0	16.7	L_I^1	191.1			
		By scintillation spectrometer		960±50	960±50[e]		
				1100[d]			
				150[d]			
Tc^{101}	190.7		$K_{(U)}^1$	307.1			
~15 min	218.5		$K_{(Pb)}^1$	306.8			
β=1.3 Mev	284.8	100	K^1	306.9	306.9	6.3 ±3.0	$M1(M2)(E2)$
	290.8		$L_{I,II(Pb)}^1$	306.3			
	303.8	16	L_I^1	307.0			
				310[d]			
Th^{233}	none			none			
23.6±0.6 min							
β=1.23 Mev							

[a] The electron energies are measured with an accuracy of ±0.3 percent of the energy.
[b] These measurements were not made in this investigation.
[c] Visual estimates were made of these intensities.
[d] These energies are obtained from absorption measurements.
[e] These values for the energy of the gamma-rays are either checked or obtained with a scintillation spectrometer by Dr. Hamermesh.
[f] These relative intensities are determined from photodensitometer measurements but are not normalized to the same intensity scale as other measurements for the radio nucleus in question.

150–165 kev from various spectrometric and absorption measurements is now shown to be 161.6±0.5 kev. A series of 315 successive irradiations and cumulative photographic exposures failed to show any additional gamma-rays. The K/L ratio of 4.6±0.3, shown in Table I, compares favorably with the value of 4.5 predicted by Goldhaber and Sunyar[8] whose life-time-energy plots indicate that the radiation is electric octopole ($E3$).The photodensitometer trace of the K and L electron lines is shown in Fig. 5 as an example of the results that may be obtained for short-lived activities.

Se^{79m}

A 3.9-minute metastable state in selenium 79 was found to emit a single gamma-ray of 90±10 kev by Flammersfeld and Herr.[14] The existence of this state is confirmed and its half-life is measured as 3.5±0.2 minutes. The energy of the gamma-ray is found to be 95.9±0.3 kev. The lifetime-energy plot indicates that this transition is also $E3$. The K/L of 2.9±0.5 agrees with the value of 2.8 predicted by Goldhaber and Sunyar.

Se^{81m} and Se^{81}

In early investigations of the radionuclei of selenium, a 56–60 minute activity with a gamma-ray of 98–104 kev was associated with Se^{79m} or Se^{81m}.[15–18] Later this activity was assigned to Se^{81m}. A 14–19 minute daughter was found to decay by the emission of a beta-ray of 1.4–1.5 Mev.[16–21] In the present work the assignment of the 58.0±1.5 minute isomer to Se^{81m} is confirmed. An analysis of the internal conversion electrons shown in Table I indicates that the energy of the gamma-ray is 103.1±0.3 kev. From the lifetime-energy plot this transition is also $E3$. The K/L ratio of 3.0±0.3 is appreciably less than that reported by Bergstrom and Thulin,[18] and by Helmholz,[17] but agrees well with the value of 2.8 predicted by Goldhaber. The 17.0±1.5 isomeric state of selenium 81 is found to decay solely by the emission of a beta-ray of 1.5 Mev to Br^{81}.

Se^{83}

It has been proposed[11,16] that two isomeric states exist in selenium 83, with no gamma-transition between them. A 67-second isomeric state was found[11] to emit only a beta-ray of 3.4 Mev. No internal conversion electron or photoelectron lines are associated with this short-lived isomer in the spectrograms of the present study.

A second isomer with a half-life of 25–30 minutes has been assigned to selenium 83.[16,22] Using absorption techniques, Glendenin[20] found that this state decayed via a beta-ray of 1.5 Mev and gamma-rays of 170, 370, and 1100 kev. In the present investigation, a half-life of 26±2.5 minutes is measured after absorbing the softer radiation emitted by contaminations of other radioisotopes of selenium. Scintillation spectrometer and lead absorption measurements confirm the existence of the first and third gamma-rays that were reported by Glendenin, but no evidence is seen for the 370-kev transition. The energy of the beta-ray is also found to be 1.5 Mev from absorption measurements in aluminum. Only one very weak photoelectron line and three weak conversion lines are associated with the 26-minute activity. These internal conversion lines are weaker than several lines that were the result of small contaminations of Se^{79} and Se^{81}. Thus the interpretation of these lines is less definite than is desirable. By the proper selection of bombardment and exposure times, however, it is established that these weak conversion lines are the result of an activity with a half-life less than one hour, and not to any longer-lived contaminates or daughter products.

B. Neodymium

A section of the Segrè chart pertinent to the study of the radioisotopes of neodymium is shown in Fig. 6. Where enriched isotopes have been obtained, the percentages of the enriched masses are listed in parenthesis

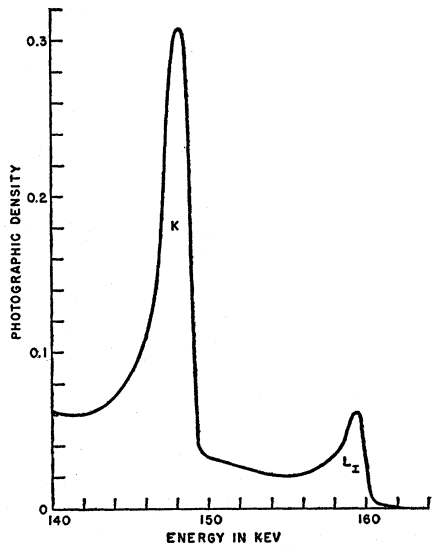

FIG. 5. Photodensitometer trace of K and L electron lines for a gamma-ray of 161.6 kev (17.5 second Se^{77m}).

[14] A. Flammersfeld and W. Herr, Z. Naturforsch. **5a**, 569 (1950).
[15] A. Snell, Phys. Rev. **52**, 1007 (1937).
[16] A. Langsdorf and E. Segrè, Phys. Rev. **57**, 105 (1940).
[17] A. Helmholz, Phys. Rev. **60**, 415 (1941).
[18] I. Bergstrom and S. Thulin, Phys. Rev. **76**, 1718 (1949).
[19] H. Wäffler and O. Hirzel, Helv. Phys. Acta **21**, 200 (1948).
[20] L. Glendenin, *Radiochemical Studies: The Fission Products* (McGraw-Hill Book Company, Inc., New York, 1950), Paper No. 61, National Nuclear Energy Series, Plutonium Project Record, Vol. **9**, Div. IV.
[21] The Plutonium Project, Revs. Modern Phys. **18**, 513 (1946).
[22] Katcoff, Finkle, and Sugarman, *Radiochemical Studies: The Fission Products* (McGraw-Hill Book Company, Inc., New York, 1950), Paper No. 59, National Nuclear Energy Series, Plutonium Project Record, Vol **9**, Div. IV.

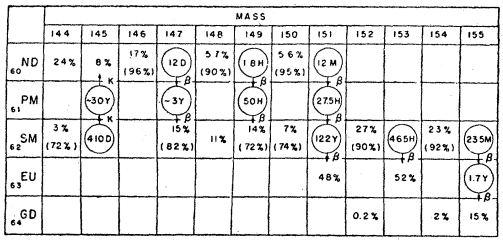

FIG. 6. The radioisotopes from neutron bombardment of neodymium and samarium (enriched by isotope percentages are given in parentheses).

directly under those for the natural abundance. Three neutron-induced neodymium activities are observed.

Nd^{147}

Earlier work on neodymium established[23,24] a 11–12 day activity in neodymium 147 which decayed through three competing beta-branches of 825,600, and 380 kev, each followed by gamma-emission. The energies of the gamma-rays were reported as 91, 309–320, and 520–534 kev; an additional gamma-ray of about 391 kev was also measured, but its association with this activity was not certain. Since the photoelectron spectrum has been thoroughly examined in previous studies, only the internal conversion spectrum is discussed now. In addition to the electron lines for the three strong gamma-rays, many weaker lines shown in Table I are definitely associated with the 11.9-day activity. The accurate spectragraphical determination of the energies of the gamma-rays eliminates the possibility of the sum of the 91.2- and 318.1-kev gamma-rays being equal to the energy of the 398.4-kev gamma-ray, as previously suggested. Besides the coincidences observed between the three strong gamma-rays and the three known beta-rays, weak gamma-gamma coincidences are observed between the 91.2-kev gamma-ray and a gamma-ray of higher energy of about 300–500 kev, which is presumably the newly discovered 441-kev transition. A K/L ratio of 4.9 ± 0.5 for the 91.2-kev gamma-ray agrees within experimental error with a value of 6.5 ± 1.5 reported by Kondaiah. This gamma-ray appears to be a mixture of $E2$ and $M1$ radiation from the measurements. The 532.3-kev gamma-ray is an $E2$ transition on the basis of its K/L ratio of 5.7 ± 1.4. An approximate computation[25] of the $\log(ft)$ values for the beta-transitions indicates[26] a change in parity for each of the three known beta-rays. An energy level scheme for prometheum 147 which incorporates all of the observed beta- and gamma-rays, together with the results of coincidence measurements and K/L ratio determinations, is shown in Fig. 7. Two additional unresolved beta-rays are shown in dotted lines to complete the scheme.

Nd^{149}

A 1.7-to 2.0-hour activity was assigned[24] to Nd^{149}. A 1.5-Mev beta-ray and some evidence of low energy gamma-radiation was observed.[27,28] It is now found that at least 14 gamma-rays are associated with this activity. The 114.1- and 240.0-kev gamma-rays are highly converted, whereas the 423.5-, 538-, and 650-kev gamma-rays show little or no internal conversion and are observed only by photoelectron techniques and by scintillation spectrometer studies. Coincidence measurements show that beta-rays of 0.95, 1.1, and 1.5 Mev are followed by gamma-rays of 650, 210–266, and 114 kev, respectively. At least two of the 210-, 240-, and 266-kev gamma-rays are in coincidence with each other, and one gamma-ray from this group is in coincidence with the 114-kev gamma-ray. The energy level scheme shown in Fig. 8 for prometheum 149 presents these results, together with those obtained from determinations of a few K/L ratios.

Nd^{151}

A 12-minute activity produced by neutron bombardment of neodymium was previously associated[28,29] with

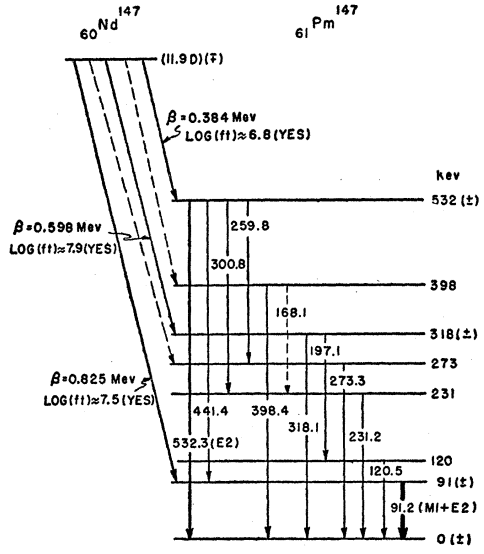

FIG. 7. Proposed energy level scheme for $_{61}Pm^{147}$.

[23] Law, Pool, Kurbatov, and Quill, Phys. Rev. **59**, 936 (1941); C. Muehlhause, Plutonium Project Report, CP-**3750**, 48 (1947); Marinsky, Glendenin, and Coryell, J. Am. Chem. Soc. **69**, 2781 (1947); Cork, Shreffler, and Fowler, Phys. Rev. **74**, 240 (1948); C. Mandeville and E. Shapiro, Phys. Rev. **79**, 391 (1950); E. Kondaiah and K. Siegbahn, Phys. Rev. **81**, 1056 (1951); W. Emmerich and J. Kurbatov, Phys. Rev. **81**, 1062 (1951).

[24] W. Bothe, Z. Naturforsch. **1**, 179 (1946).

[25] S. Moszkowski, Phys. Rev. **82**, 35 (1951).

[26] L. Nordheim, Phys. Rev. **75**, 1894 (1949), **78**, 294 (1950); E. Feenberg and K. Hammach, Phys. Rev. **75**, 1877 (1949); Mayer, Moszkowski, and Nordheim, Argonne National Laboratory Report 4626 (1951).

[27] Marinsky, Glendenin, and Coryell, J. Am. Chem. Soc. **69**, 2781 (1947).

[28] J. A. Marinsky and L. E. Glendenin, *Radiochemical Studies: The Fission Products* (McGraw-Hill Book Company, Inc., New York, 1950), Paper No. 194, National Nuclear Energy Series, Plutonium Project Record, Vol. **9**, Div. IV.

[29] B. Ketelle, Oak Ridge National Laboratory May Quarterly Report (1949).

either Nd^{151} or Pm^{151}. It was known to decay by emitting a beta-ray of 1.9 Mev, followed by a gamma-ray of about 1 Mev. This activity is now assigned[30] to Nd^{151} on the basis of prometheum K-L-M work function differences of the conversion lines of two low energy gamma-rays, and of prometheum K-x-rays. In addition to several low energy gamma-rays which are observed by internal conversion studies, two gamma-rays of higher energy are resolved with a scintillation spectrometer. No energy level scheme is presented, although the beta-ray is in coincidence with one or more gamma-rays having an energy of about 100 kev and the gamma-ray of 1140 kev. This high energy gamma-ray appears to be in coincidence with the low energy group, and it is probably the cross-over transition for gamma-rays of 421.5 and 725 kev.

C. Prometheum

Since no stable forms of prometheum exist in nature, its radioactive nuclei are produced as daughter products. Two of these that are studied in this investigation result from the bombardment of neodymium with thermal neutrons. One activity is observed that was not previously known.

Pm^{149}

A 47–49-hour activity caused by Pm^{149} was reported[24,27,31] to decay via a beta-ray of about 1 Mev and a gamma-ray of about 200–250 kev. The half-life is now measured as 50.0 ± 1.5 hours. The beta-ray has an energy of about 1.05 Mev and a $\log(ft)$ of 6.95, and it is thus accompanied by a change in parity. This beta-ray is in coincidence with an intense magnetic dipole gamma-ray of 284.9 kev. A second, less intense gamma-ray which is associated with the 50-hour activity is found to have an energy of 1300 ± 200 kev by absorption measurements.

Pm^{151}

A newly discovered daughter product of Nd^{151} is found[30] to have a half-life of 27.5 ± 1.5 hours. The assignment of this activity to Pm^{151} is based upon the facts that it is produced by bombarding enriched Nd^{150} with neutrons, and the internal conversion lines associated with the fifteen observed gamma-rays show work function differences of samarium. This agrees with the usual relationship where the half-lives of members of a radioactive chain with odd mass numbers increase successively down the chain. An average energy of 1.1 Mev is obtained for the beta-ray by absorption measurements; its $\log(ft)$ value is 6.8, which indicates a change in parity. Coincidence experiments show that both low and high energy gamma-rays are in coincidence with the 1.1-Mev beta-ray, but no other beta-ray is resolved. One experiment to determine the attenuation of beta-electron coincidence rates as a function of absorber thickness is done with aluminum absorbers in front of one counter and nothing in front of the other. This shows that the beta-ray is in coincidence with x-rays and with conversion electrons which correspond to prominent gamma-rays of about 100, 165, 275, 340, and 715 kev. No gamma-gamma coincidences are observed. This probably means that the 715 and 340 kev are not in coincidence. The gamma-rays of lower energy are highly converted, so that it is impossible to conclude anything further about the sequences of the gamma-rays from this type of experiment. However, additional information is obtained from an experimental arrangement of filters and Geiger counters that allows only x-rays and gamma-rays to pass into the gamma-counter, and beta-rays, conversion electrons, and gamma-rays to pass into the beta-counter. The hard components are found to be in coincidence with conversion electron groups corresponding to gamma-rays of about 65, 169, and 340 kev. No coincidences are observed between x-rays or gamma-rays and conversion electrons associated with the 715-kev gamma-ray. An energy level scheme for Sm^{151} based upon these data and results from K/L ratio determinations is shown in Fig. 9. This diagram is in good agreement with energy determinations, coincidence measurements, and changes in spin and parity indicated by the K/L ratios. An alternate scheme based primarily upon identities of mathematical sums that requires two unobserved beta-rays is shown in Fig. 10.

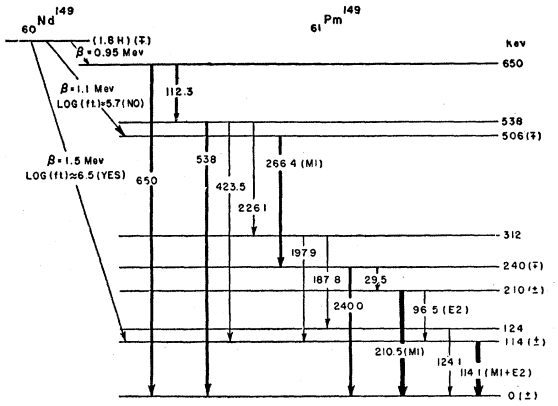

FIG. 8. Proposed energy level scheme for $_{61}Pm^{149}$.

D. Samarium

Because of the high activation cross section and presence of an europium contaminate in amounts from 0.3 to 0.6 percent in all of the enriched isotopes of samarium, the predominate electron lines of the 9-hour and 5-year europium activities are often as intense as

[30] Rutledge, Cork, and Burson, Bull. Am. Phys. Soc. **26**, No. 6, 38 (1951).

[31] B. Ketelle, Oak Ridge National Laboratory Report **229**, 34 (1948); C. Mandeville and M. Scherb, Phys. Rev. **76**, 186 (1949); J. Marinsky and L. Glendenin, *Radiochemical Studies: The Fission Products* (McGraw-Hill Book Company, Inc., New York, 1950), Paper No. 193, National Nuclear Energy Series, Plutonium Project Record, Vol. **9**, Div. IV.

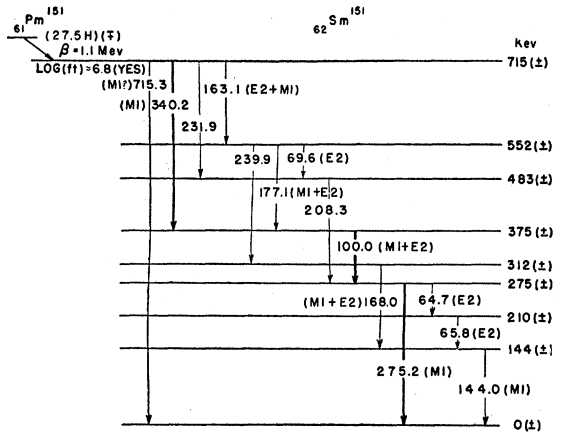

FIG. 9. Proposed energy level scheme for $_{62}Sm^{151}$.

the lines associated with the samarium activities. This contaminate prevented the observation of reliable coincidence measurements on the longer-lived activities of samarium. Four different activities are studied, and several new gamma-rays are observed. The results are summarized in Table I.

Sm^{145}

Values of the half-life of Sm^{145} have been reported[32] ranging from 60 to 410 days, with the latter value currently favored. Neither of the previously reported gamma-rays are found to be associated with this activity; that they are undoubtedly the result of an europium contaminant is known from K-L work function differences and energy values. A single gamma-ray of 61.3 kev is now observed with K-L-M work function differences of prometheum, which implies that it is emitted following K-electron capture. From the K/L *versus* Z^2/E curves, this gamma-ray with a K/L ratio of 1.0 ± 0.3 appears to be either $E1$, $M3$, or a mixture of $E2$ and $M1$. The choice of $E1$ may be ruled out by the observation[33] that in odd nuclei gamma-transitions between low-lying states appear never to be $E1$, although this is sometimes not valid in the rare earth region. Since an $M3$ transition has a measurable lifetime, the 61.3-kev gamma-ray is probably a mixture of $E2$ and $M1$ radiation.

Sm^{151}

An activity in Sm^{151} with a half-life reported[34,35] as 20 to 1000 years, and currently as 122 years, is known[35,36] to emit a soft beta-ray of about 76 kev. A single gamma-ray of 21 kev was detected[37] by a proportional counter. In the present investigation no internal conversion electrons or photoelectrons are associated with this activity. The half-life is found to be greater than 20 years.

Sm^{153}

An excited state of Sm^{153} is known[24,32,38] to decay with a half-life of 47 hours by the emission[39] of beta-rays of 680 and 800 kev followed by gamma-radiation reported[40] as 69.5, 102 to 110, and 570 to 610 kev. It is now observed that the half-life of 46.5 ± 1 hours, and that the energies of the gamma-rays are 69.8, 103.4, and 582 kev. The K/L ratios for the more intense low energy gamma-rays are slightly lower than shown in previous results. The 69.8-kev gamma-ray appears to be an $E2$ transition on the basis of its energy and its K/L ratio of 0.29 ± 0.03. Both the K/L ratio and the conversion coefficient of the 103.4-kev gamma-ray indicate that it is probably a mixture of $M1$ and $E2$ radiation. From coincidence measurements, these two intense gamma-rays appear to be in cascade. Since the less energetic of the two radiations is also much less intense, it is assumed that the 800-kev beta-ray proceeds directly to the ground state of Eu^{153}, that the 680-kev beta-ray precedes the 103.4-kev gamma-ray, and that another unresolved beta-ray is followed by the 69.8-kev gamma-ray. No definite coincidences are established between the very weak high energy gamma-ray and other radiations.

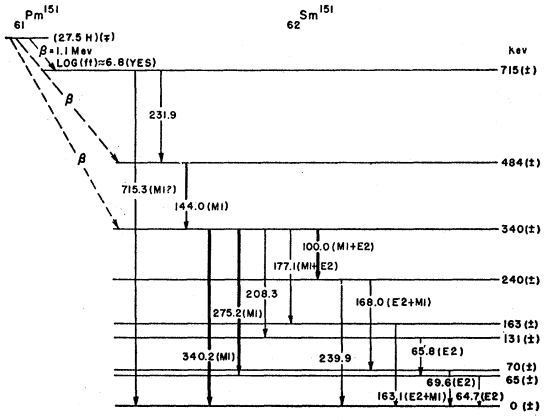

FIG. 10. An alternate level scheme for $_{62}Sm^{151}$.

[32] Kurbatov, MacDonald, Pool, and Quill, Phys. Rev. **61**, 106 (1942); Inghram, Hayden, and Hess, Phys. Rev. **71**, 643 (1947); Cork, Shreffler, and Fowler, Phys. Rev. **74**, 240 (1948); F. Butement, Nature **167**, 400 (1951).

[33] M. Mayer, Phys. Rev. **78**, 16 (1950).

[34] Parker, Lantz, Ruch, and Hebert, Oak Ridge National Laboratory Report 65, 105, and Atomic Energy Commission Declassified Report 2160 (1948).

[35] B. Ketelle and G. Parker, Phys. Rev. **76**, 1416 (1949); J. Marinski, thesis, MIT, and Progress Report Laboratory Nuclear Science Engineering July (1949); M. Inghram, *et al.*, Atomic Energy Commission Declassified Report 2759 (1950).

[36] H. Agnew, Phys. Rev. **77**, 655 (1950).

[37] Scharff-Goldhaber, der Mateosian, McKeown, and Sunyar, Phys. Rev. **78**, 325 (1950).

[38] L. Winsberg, *Radiochemical Studies: The Fission Products* (McGraw-Hill Book Company, Inc., New York, 1950), Paper No. 195, National Nuclear Energy Series, Plutonium Project Record, Vol. **9**, Div. IV.

[39] J. Hill and L. Shepherd, Proc. Phys. Soc. (London) **A63**, 126 (1950).

[40] L. Miller and L. Curtiss, Phys. Rev. **70**, 983 (1946); R. Hill, Phys. Rev. **74**, 78 (1948); S. Burson and C. Muehlhause, Phys. Rev. **74**, 1264 (1948).

Sm^{155}

A short-lived activity in samarium of 21–25 minutes half-life was first assigned[41] to Sm^{155} by Pool. It was found[42] by absorption techniques to decay via a beta-ray of 1.8–1.9 Mev and a gamma-ray of 300 kev. The value of 1.8 Mev for the energy of the beta-ray is confirmed in this study. This determination, together with a measured half-life of 23.5±0.4 minutes, enables one to compute its log(ft), as 6.0, which implies a change in parity. Two gamma-rays of equal intensity of 104.6 and 245.8 kev are measured on the internal conversion electron and photoelectron spectrograms. A K/L ratio of 3.6±1.0 for the 104.7-kev gamma-ray implies that it is probably a mixture of $E2$ and $M1$ radiations. The relatively high beta-background prevents an accurate determination of the K/L ratio for the gamma-ray of higher energy, but it is estimated as 8. Because of the fact that this activity is much shorter-lived than the 9-hour europium contaminate, it is possible to make reliable coincidence measurements. These measurements show that the 1.8-Mev beta-ray is in coincidence with x-rays and each of the gamma-rays, which are in coincidence with each other. These data are used to construct the energy level scheme for Eu^{155}, as shown in Fig. 11.

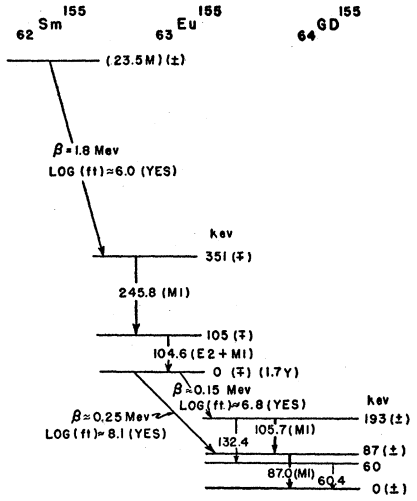

FIG. 11. Proposed energy level scheme for $_{64}Gd^{155}$ and $_{63}Eu^{155}$.

E. Some Additional Radioactivities

In the study of short-lived activities, four miscellaneous radioactive emitters are also examined. The information that is obtained is summarized in Table I.

Eu^{155}

The daughter product of 23.5-minute Sm^{155} is known[43] to be a long-lived radioactive nucleus, Eu^{155}. Two beta-rays of 0.15 and 0.24 Mev and two gamma-rays of 85 and 100 kev have been associated[35,44] with this activity. It is now found that the half life is 1.7±0.2 years, and that two weak gamma-rays are emitted in addition to the two intense ones. The latter are measured as 87.0 and 105.7 kev and appear to be $M1$ (or $M2$) transitions on the basis of respective K/L ratios of 8.0±2.8 and 8.3±2.8. These results are added to the previously discussed decay scheme of Sm^{155}, shown in Fig. 11.

Mo^{101}

A radioisotope of molybdenum with a half-life of 14 minutes has been ascribed[45] to mass 101. It was reported from absorption studies[45] to decay by the emission of two beta-rays of 1.0 and 1.9 to 2.2 Mev, and two gamma-rays of 900 and 150 to 300 kev. The complex beta-decay is now confirmed, and the corresponding energies are measured as 1.2 and 2.1 Mev. A low energy gamma-ray of 191.2 kev is found in the study of the internal conversion electron and photoelectron spectra emitted by this excited nucleus. Thus the previously reported values of 150 and 300 kev appear to be measurements of the same gamma-ray and not of other unconverted ones. The energy of the other gamma-ray is measured as 960 kev with the scintillation spectrometer. The K/L ratio of 6.0±2.5 indicates that the 191.2-kev gamma-ray may be interpretated as $M1$, $M2$, or $E2$ radiation. According to results reported[46] by Mihelich and Church, $M1$ transitions are converted predominantly in the L_I shell, whereas $E2$ radiation is converted predominantly in the L_{II} shell. This is confirmed in this research in all of the cases where definite assignments can be made. Since the low energy gamma-ray is converted predominantly in the L_I shell, it is assumed that it is a $M1$ transition. Coincidence measurements indicate that the high energy gamma and the low energy beta-rays are in coincidence, and that the two gamma-rays are probably in cascade. A tentative energy level scheme for Tc^{101} is proposed in Fig. 12.

Tc^{101}

This 15-minute daughter product of Mo^{101} is known[45,47] to emit a beta-ray of about 1.3 Mev, and gamma-rays of 260–300 and 560 kev. No evidence for the gamma-ray of higher energy is now found with either the magnetic spectrographs or the scintillation

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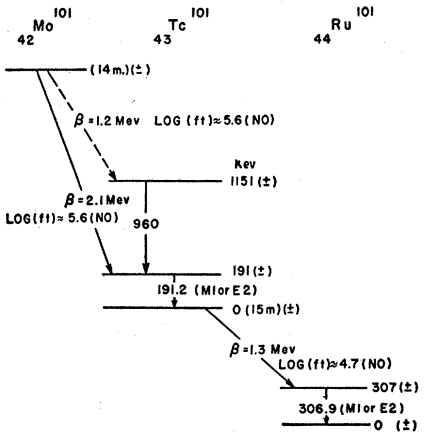

FIG. 12. Proposed energy level scheme for $_{44}Ru^{101}$ and $_{43}Tc^{101}$.

spectrometer. A single gamma-ray of 306.9 kev is found in the study of the internal conversion electron and photoelectron spectra. High coincidence rates are obtained between the beta-ray and this intense gamma-ray. The K/L ratio of 6.3±3.0 implies that the gamma-ray may be interpretated as $M1$, $M2$, or $E2$. Since it is predominantly converted in the L_I shell, it is probably an $M1$ transition on the basis of the argument given for Mo^{101}. The probable energy levels in Ru^{101} are also shown in Fig. 12.

Th^{233}

In a study of Th^{233}, a beta-ray of 1.23 Mev that decays with a 23.6±0.6-minute half-life is measured. These results agree with previously reported data.[48] No gamma-rays are associated with this activity.

CONCLUSIONS

It is possible to obtain the K/L ratios for many prominent gamma-rays to an accuracy of ±10 percent, after correcting the observed electron line intensities for attenuation due to the geometry of the camera and for the energy sensitivity of the photographic emulsion. This method is probably the best means of obtaining K/L ratios of gamma-rays that are associated with short half-lives. Where check points are possible, the experimental results agree closely with the recently published curves of Goldhaber and Sunyar of K/L ratios for gamma-radiation of a specific type. Also, in a comparison of the results of the photographic method with those of a constant radius beta-spectrometer using a G-M counter for the detector, excellent agreement is obtained.

In general, the predominant internal conversion of $M1$ and $E2$ transitions occurs in the L_I and L_{II} subshells, respectively. This is in agreement with the recently proposed rules of Mihelich and Church. Only one exception is noted; a transition associated with the decay of Sm^{153} appears to be converted mostly in the L_I shell and is assumed to be electric quadrupole radiation on the basis of its energy and K/L ratio. It is also observed that all of the $E3$ transitions are predominantly converted in the L_I shell in this work. A further confirmation of the fact that $M1$ transitions are converted predominantly in L_I shell is that the theoretical K/L_I ratios for $M1$ transitions at various values of Z^2/E are nearly identical to the corresponding K/L ratios given by Goldhaber and Sunyar, the theoretical K/L_I ratios being computed from the relativistic K conversion coefficients of Rose, *et al.*[49] and the L_I coefficients of Gellman, *et al.*[50] for $M1$ radiation.

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