In the usual case, where the beam is unpolarized and the three possible values of $m_{S'}$ are indistinguishable, a sum over $m_{S'}=0, \pm1$ for each m_S and then an average over $m_S=0, \pm1$ is performed. The result is:

$$3k^2\frac{d\sigma}{d\Omega}=2|A|^2+|B|^2+\sin^2\theta\{|C|^2+|D|^2\}+\sin^4\theta\{|E|^2\},$$

where

$$A=R+\sum_l \frac{e^{\frac{1}{2}i\alpha_l}}{4i}\{e^{\frac{1}{2}i\alpha_l}P_l[(l+2)U_{ll}^{l+1}+(2l+1)U_{ll}^l+(l-1)U_{ll}^{l-1}-2(2l+1)]-e^{\frac{1}{2}i\alpha_{l+2}}P_{l+2}\times[(l+1)(l+2)]^{\frac{1}{2}}U_{l,\,l+2}^{l+1}-e^{\frac{1}{2}i\alpha_{l-2}}P_{l-2}\times[l(l-1)]^{\frac{1}{2}}U_{l,\,l-2}^{l-1}\},$$

$$B=R+\sum_l \frac{e^{\frac{1}{2}i\alpha_l}}{2i}\{e^{\frac{1}{2}i\alpha_l}P_l[(l+1)U_{ll}^{l+1}+lU_{ll}^{l-1}-(2l+1)]+e^{\frac{1}{2}i\alpha_{l+2}}P_{l+2}[(l+1)(l+2)]^{\frac{1}{2}}U_{l,\,l+2}^{l+1}+e^{\frac{1}{2}i\alpha_{l-2}}P_{l-2}[l(l-1)]^{\frac{1}{2}}U_{l,\,l-2}^{l-1}\},$$

$$C=\sum_l \frac{e^{\frac{1}{2}i\alpha_l}}{2i}\left\{\frac{e^{\frac{1}{2}i\alpha_l}P_l'}{l(l+1)}[l(l+2)U_{l,\,l}^{l+1}-(2l+1)U_{ll}^l-(l^2-1)U_{ll}^{l-1}]+e^{\frac{1}{2}i\alpha_{l+2}}P_{l+2}'\left[\frac{(l+1)}{(l+2)}\right]^{\frac{1}{2}}U_{l,\,l+2}^{l+1}-e^{\frac{1}{2}i\alpha_{l-2}}P_{l-2}'\left(\frac{l}{l-1}\right)^{\frac{1}{2}}U_{l,\,l-2}^{l-1}\right\},$$

$$D=\sum_l \frac{e^{\frac{1}{2}i\alpha_l}}{2i}\left\{e^{\frac{1}{2}i\alpha_l}P_l'[U_{ll}^{l+1}-U_{ll}^{l-1}]-e^{\frac{1}{2}i\alpha_{l+2}}P_{l+2}'\times\left[\frac{(l+1)}{(l+2)}\right]^{\frac{1}{2}}U_{l,\,l+2}^{l+1}+e^{\frac{1}{2}i\alpha_{l-2}}P_{l-2}'\left(\frac{l}{l-1}\right)^{\frac{1}{2}}U_{l,\,l-2}^{l-1}\right\},$$

$$E=\sum_l \frac{e^{\frac{1}{2}i\alpha_l}}{2\sqrt{2}i}\left\{\frac{e^{\frac{1}{2}i\alpha_l}P_l''}{l(l+1)}[lU_{ll}^{l+1}-(2l+1)U_{ll}^l+(l+1)U_{ll}^{l-1}]-\frac{e^{\frac{1}{2}i\alpha_{l+2}}P_{l+2}''}{[(l+1)(l+2)]^{\frac{1}{2}}}U_{l,\,l+2}^{l+1}-\frac{e^{\frac{1}{2}i\alpha_{l-2}}P_{l-2}''}{[l(l-1)]^{\frac{1}{2}}}U_{l,\,l-2}^{l-1}\right\}$$

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Gamma Radiation from Polonium Neutron Sources

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A NaI(Tl) crystal scintillation spectrometer was used to investigate the gamma spectrum from Po-alpha bombardment of Li, Be, B, F, Na, Mg, and Al. The principal gamma energies observed were: Li, 0.483 Mev; Be, 4.45 Mev; B, 2.36 and 3.68 Mev; F, 1.28 and 1.51 Mev; Na, 1.83 and 2.57 Mev; Mg, 1.30, 1.82, and 2.97 Mev; Al, 1.25, 2.28, and 3.55 Mev. The probable origin of the gammas is discussed.

INTRODUCTION

PRIOR to discovery of the neutron, gamma radiation had been observed as a result of the action of alpha particles on some light nuclei.[1,2] Subsequent investigation established the existence of gamma radiation, in addition to neutron emission, from the bombardment of Li, Be, B, F, Na, Mg, and Al by alpha particles.[3]

During preparation of neutron sources by mixture of Po^{210} with various target materials, gamma radiation was observed in addition to that expected from the Po. An investigation of the energy and origin of this radiation would be of assistance in studies of neutron spectra and of efficiency of neutron production by polonium neutron sources.

An investigation of the gamma spectrum from polonium neutron sources was conducted with a NaI(Tl) single-crystal scintillation spectrometer. Data are presented for Po-Li, Po-Be, Po-B, Po-CaF_2, Po-Na, Po-Mg, and Po-Al neutron sources.

EXPERIMENTAL PROCEDURE

The detecting portion of the spectrometer consists of a Harshaw-mounted NaI(Tl) crystal 1.5 inches in diameter by 1 inch thick, coupled through a Lucite light-pipe to an RCA 5819 photomultiplier tube. Pulses from the phototube are amplified by an Atomic Instrument Company Model 205-B preamplifier and a Model 204-B linear amplifier, with an added input delay line for pulse shaping. The high-level output of the linear amplifier is coupled to an Atomic Instrument Company

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‡ Mound Laboratory is operated by Monsanto Chemical Company for the U. S. Atomic Energy Commission.

[1] W. Bothe and H. Becker, Z. Physik **66**, 289 (1930).
[2] H. C. Webster, Proc. Roy. Soc. (London) **A136**, 428 (1932).
[3] H. Slätis, Arkiv Mat. Astron. Fysik **35A**, No. 31, 1 (1948).

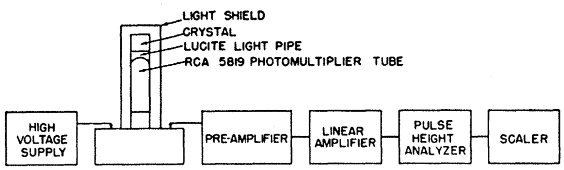

FIG. 1. Schematic diagram of single-crystal scintillation spectrometer.

Model 510 single-channel pulse-height analyzer. Output pulses from the analyzer are counted by a conventional scaling circuit. High voltage (800 v) is supplied to the phototube by an Atomic Instrument Company Model 326 high-voltage supply. A block diagram of the arrangement is shown in Fig. 1.

Excellent stability was obtained by placing the equipment in a cabinet rack with a large exhaust fan arranged to provide adequate ventilation. Results were reproducible over a period of several weeks with negligible change in gain or high-voltage settings. Linearity of the equipment was checked by determining the positions of the photoelectric peaks for Hg^{203}, 0.280 Mev; Cs^{137}, 0.665 Mev; Po^{210}, 0.800 Mev; Co^{60}, 1.17 and 1.33 Mev; and the 4.45-Mev energy level of C^{12} excited in alpha bombardment of Be.

Gamma energies could be determined with less than two percent error up to an energy of 4.5 Mev. With the analyzer set for a channel width of 1 volt, resolutions of approximately 16 percent for Hg^{203} and 10 percent for Po^{210} were obtained. With complex gamma spectra, resolution for lower-energy gamma radiation was considerably reduced because of scattering from higher-energy gamma radiation.

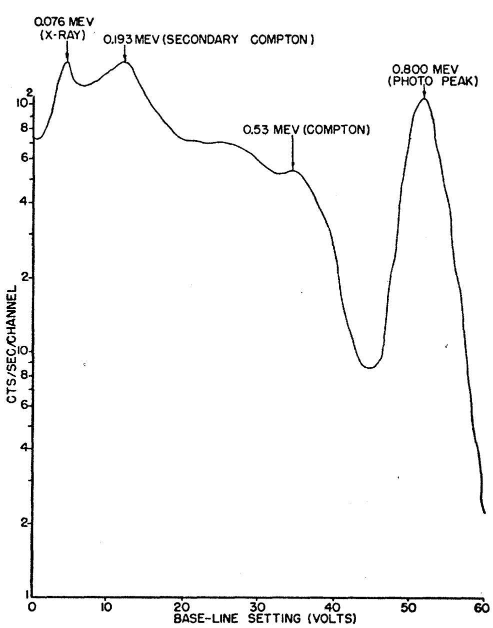

FIG. 2. Gamma spectrum of Po^{210}.

To determine the gamma spectrum, counting rates were observed for one-volt-wide channels at intervals of one volt in pulse height. Results were plotted as counts per second per channel *vs* pulse height in volts. The gamma emitters were positioned on the axis of the tube and crystal at such a distance that the integral counting rate over the entire pulse-height range would be less than 10 000 counts per second. In most cases a total count per channel of at least 5000 was obtained, although this was reduced to 2000 counts when the counting rate was less than 10 counts per second. Backgrounds were negligible in all cases.

The gamma emitters consisted of an intimate mixture of the Po^{210} alpha emitter and the target material. For Po-Li, Po-Be, Po-Na, Po-Mg, and Po-Al neutron sources, the Po was volatilized into an empty nickel container; the pure target material was added, after which the container was closed and coated with nickel by the decompositon of nickel carbonyl. After sealing the container was heated to 600°C to distribute the Po throughout the target material. For the F and B sources, HF and HCl acid solutions of Po, respectively, were poured over the target material and evaporated so that the Po was left in intimate contact with the target material. This was then placed in the container and sealed as described above. Neutron emission and Curie values for the several neutron sources are listed in Table I.

TABLE I. Neutron emission and Curie value for neutron sources.

Type	Po^{210} (Curies)	Neutron emission (neutrons/second)
Po only	2.57	...
Po-Li	2.87	1.06×10^5
Po-Be	0.039	0.86×10^5
Po-B	1.34	7.72×10^5
Po-CaF_2	1.94	2.03×10^5
Po-Na	3.20	1.34×10^5
Po-Al	9.14	1.79×10^5
Po-Mg	6.98	2.07×10^5

RESULTS AND DISCUSSION

The gamma spectrum obtained for Po^{210} is shown in Fig. 2. The only nuclear gamma observed from Po, of energy 0.800 Mev, is shown as a photoelectric peak. The slight rise at 0.53 Mev is principally the maximum of the Compton distribution for the 0.800-Mev gamma, but probably includes a 0.48-Mev gamma from neutron capture by B in the glass of the photomultiplier tube.[4] The peak at 0.19 Mev is interpreted as the result of secondary Compton gammas from 0.800-Mev gammas scattered outside the crystal. The peak at about 80 kev is in good agreement with the energy of the K x-ray of Pb^{206}.

The positions of the peaks in the following neutron source curves (Figs. 3–9) were calculated relative to

[4] Grace, Lemme, and Halban, Proc. Phys. Soc. (London) **A65**, 457 (1952).

the 0.800-Mev peak from Po. A summary of the reactions, reaction energies, thresholds, and observed gamma energies is shown in Table II. The reaction energies were calculated from mass values of Segrè.[5]

Po-Li Sources

Po-alpha bombardment of Li may result in neutrons from the $Li^7(\alpha,n)B^{10}$ reaction and protons from the $Li^7(\alpha,p)Be^{10}$ and $Li^6(\alpha,p)Be^9$ reactions. The threshold for $Li^6(\alpha,n)B^9$ is too large for this reaction to occur with Po alphas. Since Li^6 constitutes only 7.5 percent of the total target material, it is not expected to be the source of a significant portion of the total radiation. In fact, Shepherd *et al.*[6] investigated a RaC$'$($E_\alpha=7.7$ Mev)-Li source for protons and obtained a negative result, which would leave neutrons from the bombardment of Li^7 as the only particle radiation.

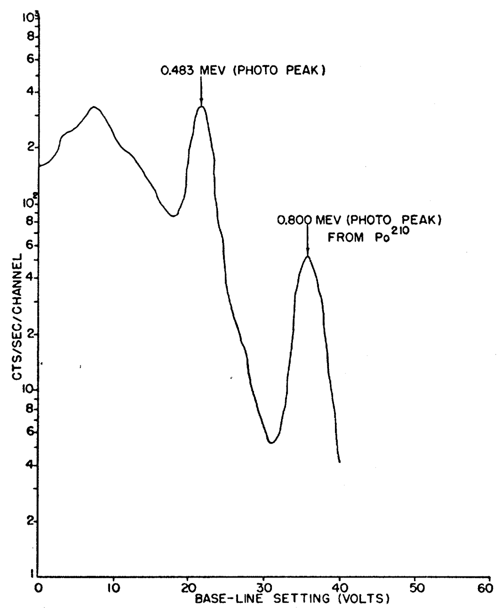

FIG. 3. Gamma spectrum of Po-Li sources.

The gamma spectrum from the Po-Li source is shown in Fig. 3. A single gamma of energy 0.483 Mev was observed. This corresponds to a gamma of 0.462 Mev observed by Siegbahn and Slätis[7] from the excitation of the Li^7 nucleus by inelastic scattering of the alpha particle and that of 0.48 Mev observed by Speh[8] from the same process. In addition, Hornyak *et al.*[9] observed a gamma of 0.476 Mev from inelastic scattering of protons by Li.[7] Gammas of 1.5 and 0.4 Mev observed by Speh from Po-alpha bombardment of Li were not observed in this work.

[5] E. Segrè, Editor, *Experimental Nuclear Physics* (John Wiley and Sons, Inc., New York, 1953), vol. I.
[6] Shepherd, Haxby, and Hill, Phys. Rev. **52**, 674 (1937).
[7] K. Siegbahn and H. Slätis, Arkiv Mat. Astron. Fysik **34A**, No. 14, 1 (1947).
[8] K. C. Speh, Phys. Rev. **50**, 689 (1936).
[9] Hornyak, Lauritsen, and Rasmussen, Phys. Rev. **76**, 731 (1949).

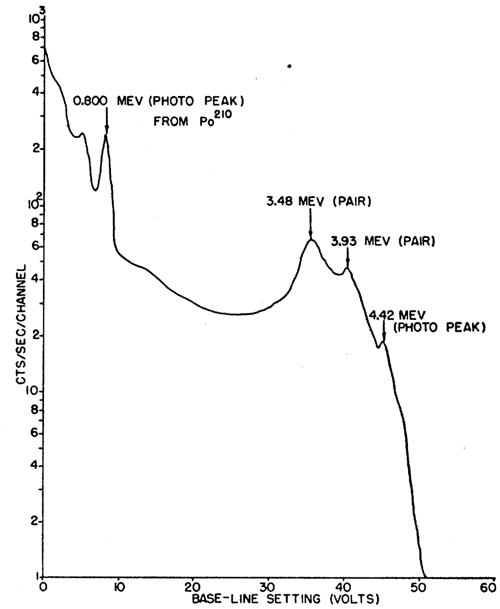

FIG. 4. Gamma spectrum of Po-Be sources.

Po-Be Sources

Neutrons are produced by a Po-Be source from the reaction $Be^9(\alpha,n)C^{12}$. Crussard and Gorodetzky,[10] Giegerl and Broda,[11] Bjerge,[12] and Stuhlinger[13] have

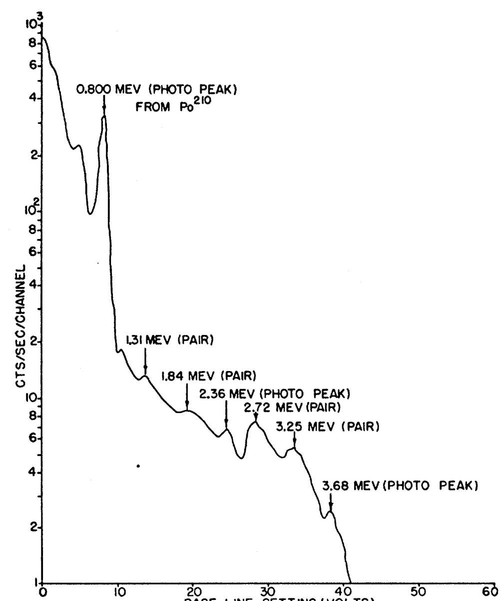

FIG. 5. Gamma spectrum of Po-B sources.

[10] J. Crussard and S. Gorodetzky, Compt. rend. **205**, 1060 (1937).
[11] E. Giegerl and E. Broda, Nature **167**, 399 (1951).
[12] T. Bjerge, Proc. Roy. Soc. (London) **A164**, 243 (1938).
[13] E. Stuhlinger, Z. Physik **114**, 185 (1939).

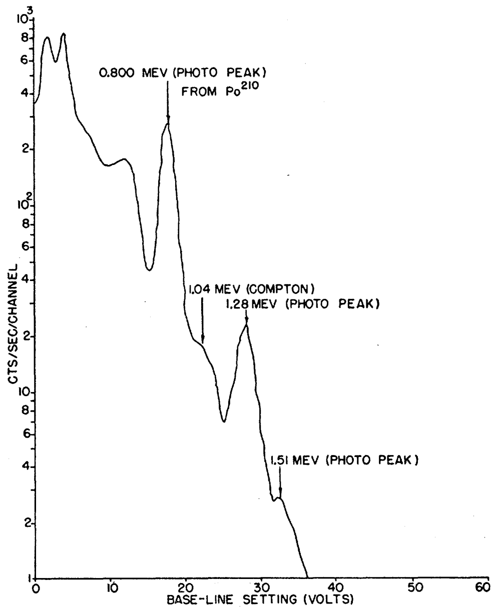

FIG. 6. Gamma spectrum of Po-CaF_2 sources.

detected a neutron group of about 0.1 Mev which they suggest as arising from the reaction $Be^9(\alpha,n)3\alpha$. This process begins at an alpha energy of about 4.8 Mev[11,13]; no gamma radiation has been detected in coincidence with these neutrons. The large threshold energy prevents proton emission from Po-alpha bombardment of Be.

The gamma spectrum obtained from the Po-Be source is shown in Fig. 4. A single gamma was observed with an energy of 4.45 Mev, an average of the photoelectric peak at 4.42 Mev and the pair peaks at 3.93 and 3.48 Mev (adding 0.51 and 1.02 Mev respectively to these last two values). This agrees with a gamma from the excited state of C^{12} found by Bell and Jordan[14] at 4.44 Mev, Terrell[15] at 4.45 Mev, Artenov and Vlasov[16] at 4.37 Mev, and Harries and Davies[17] at 4.4 Mev. In addition to this gamma energy, Pringle *et al.*[18] found indications of a gamma of 7.2 Mev, and neutron spectrum work by Guier *et al.*[19] and Guier and Roberts[20] indicated a neutron group leaving the C^{12} nucleus in an excited state between 7 and 8 Mev; no trace of a gamma higher than 4.45 Mev was found in the experiments described herein.

Po-B Sources

Both neutrons and protons are energetically possible from Po-alpha bombardment of B^{10} and B^{11}. Natural boron contains about 19 percent B^{10}.

The gamma spectrum obtained from the Po-B source is shown in Fig. 5. Interpretation of the curve yields a photoelectric peak at 3.68 Mev with its pair production peaks at 3.25 and 2.72 Mev and a second photoelectric peak at 2.36 Mev with its pair production peaks at 1.84 and 1.31 Mev. Since the pair production peaks are considerably broadened by the Compton distributions, values of 3.68 and 2.36 Mev are taken as the energies of the original gamma rays.

The gamma energy of 3.68 Mev is not far from that of 3.76 Mev attributed to a C^{13} level by Creagan[21] from alpha bombardment of boron. Further confirmation of this gamma arising from the $B^{10}(\alpha,p)C^{13}$ reaction is the Q value of 0.24 Mev for protons attributed to this reaction by Frye and Weidenbeck.[22]

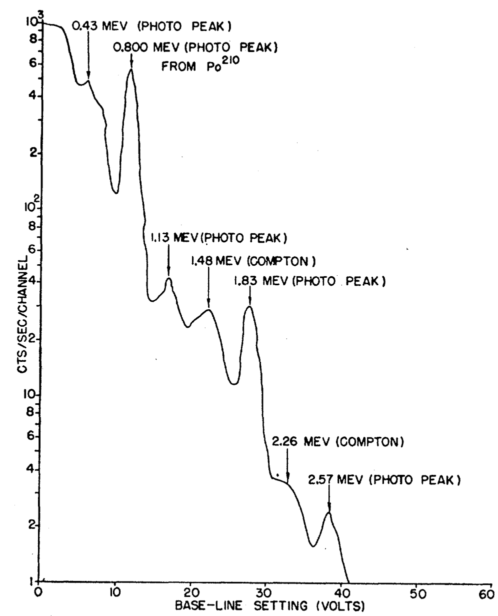

FIG. 7. Gamma spectrum of Po-Na sources.

The value of the 2.36 Mev for a gamma from the $B^{11}(\alpha,n)N^{14}$ reaction is in agreement with the value of 2.2 ± 0.2 Mev observed by Beghian *et al.*[23] from Po-alpha bombardment of B^{11} and is further substantiated by a gamma energy of 2.35 Mev found by Hicks *et al.*[24] with the reaction $C^{13}(p,\alpha)N^{14}$. Also, Cowie *et al.*[25] observed a 2.35-Mev level of N^{14} with proton scattering.

Po-F Sources

Po-alpha bombardment of fluorine may result in neutron emission from the $F^{19}(\alpha,n)Na^{22}$ reaction or proton emission from the $F^{19}(\alpha,p)Ne^{22}$ reaction. Na^{22} is a positron emitter with a half-life of about 2.8 years.

The gamma spectrum of the Po-CaF_2 source is shown

[14] P. R. Bell and W. H. Jordan, Phys. Rev. **79**, 392 (1950).
[15] J. Terrell, Phys. Rev. **80**, 1076 (1950).
[16] K. P. Artenov and N. A. Vlasov, Doklady Akad. Nauk S.S.S.R. **77**, No. 2, 225 (1951).
[17] G. Harries and W. T. Davies, Proc. Phys. Soc. (London) **A65**, 564 (1952).
[18] Pringle, Roulston, and Standil, Phys. Rev. **78**, 627 (1950).
[19] Guier, Bertini, and Roberts, Phys. Rev. **85**, 426 (1952).
[20] W. H. Guier and J. H. Roberts, Phys. Rev. **79**, 719 (1950).
[21] R. J. Creagan, Phys. Rev. **76**, 1769 (1949).
[22] G. M. Frye and M. L. Weidenbeck, Phys. Rev. **82**, 960 (1951).
[23] Beghian, Grace, and Halban, Proc. Phys. Soc. (London) **A63**, 913 (1950).
[24] Hicks, Husain, Sanders, and Beghian, Phys. Rev. **90**, 163 (1953).
[25] Cowie, Heydenburg, and Phillips, Phys. Rev. **87**, 304 (1952).

in Fig. 6. The small peak at 1.51 Mev is probably the result of a gamma from an excited state of Ne^{22} as observed by Jolley and Champion[26] at 1.41 Mev and Speh[8] at 1.51 Mev. The 1.28-Mev photoelectric peak is in good agreement with Alburger's value[27] of 1.277 Mev for the Na^{22} decay gamma and a gamma of the same energy observed by Heydenburg and Temmer[28] from $F^{19}(\alpha,p)Ne^{22}$. It must be assumed, though, that the major part of the 1.28-Mev peak is the result of the (α,p) reaction which leaves the Ne^{22} nucleus at the 1.28-Mev excited state. Since the Po-CaF_2 source was 2 months old when its gamma spectrum was observed, Na^{22}, with a half-life of 2.8 years, could not decay in

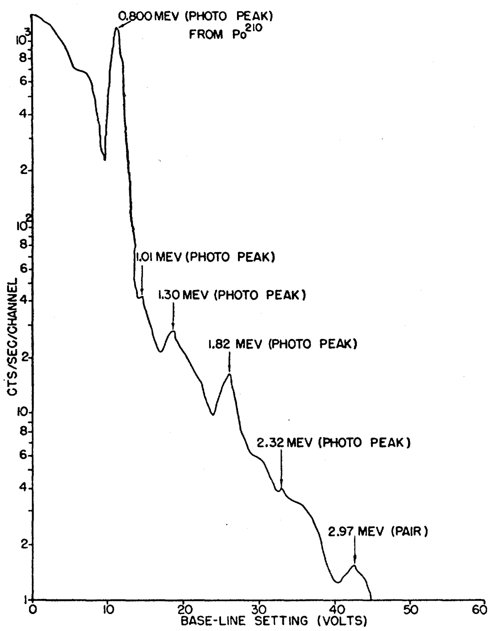

FIG. 8. Gamma spectrum of Po-Mg sources.

sufficient quantities to account for the large peak in Fig. 6. Also, a prominent peak at 0.51 Mev would be expected from the annihilation of positrons from Na^{22} decay. The photopeaks shown at 0.081 and 0.186 Mev probably correspond to those observed by Heydenburg and Temmer at 0.11 and 0.20 Mev from inelastic scattering. The peak at 0.5 Mev may include the 0.6-Mev gamma found by Heydenburg and Temmer from the (α,n) reaction although the peak is no larger than would be expected from Po alone.

Another neutron source with fluorine the major target constituent was two years old when it was studied. The 1.28-Mev peak and a peak at 0.51 Mev from positron annihilation gammas are more intense in this source than the Po peak at 0.800 Mev which tends to confirm the above interpretation of the gamma spectrum of the Po-CaF_2 source.

[26] J. D. Jolley and F. C. Champion, Proc. Phys. Soc. (London) **A64**, 88 (1951).
[27] D. E. Alburger, Phys. Rev. **76**, 435 (1949).
[28] N. P. Heydenburg and G. M. Temmer, Phys. Rev. **94**, 1252 (1954).

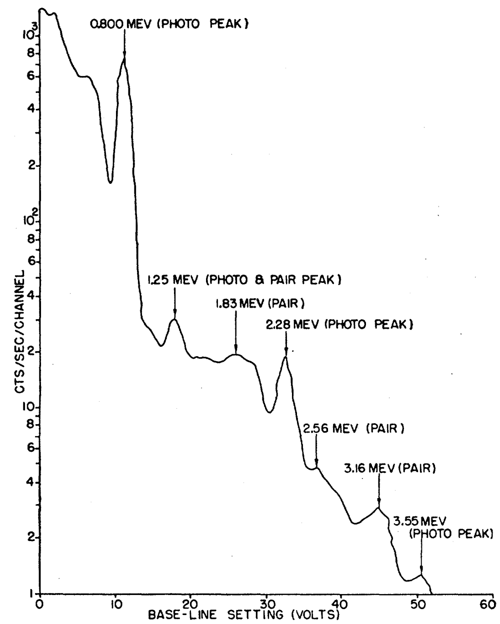

FIG. 9. Gamma spectrum of Po-Al sources.

Po-Na Sources

The two major constituents of the gamma spectrum from the Po-Na source (Fig. 7) are at 1.83 and 2.57 Mev. Assignment of these two gammas to the $Na^{23}(\alpha,p)Mg^{26}$ reaction would be consistent with values of 1.91 and 2.85 Mev for energy levels of Mg^{26} as observed

TABLE II. A summary of the reactions, reaction energies, and threshold energies for each target element.

Target element	Reactions	Reaction energy (Mev)	Threshold energy (Mev)	Observed gamma energies (Mev)
Li	$Li^6(\alpha,n)B^9$	−3.98	6.64	···
	$Li^6(\alpha,p)Be^9$	−2.14	3.57	···
	$Li^7(\alpha,n)B^{10}$	−2.79	4.39	···
	$Li^7(\alpha,p)Be^{10}$	−2.57	4.04	···
	$Li^7(\alpha,\alpha')Li^7$	···	···	0.483
Be	$Be^9(\alpha,n)C^{12}$	5.71	Exothermic	4.45
	$Be^9(\alpha,p)B^{12}$	−6.88	9.93	···
	$Be^9(\alpha,n)3\alpha$	−1.57	2.26	···
B	$B^{10}(\alpha,n)N^{13}$	1.07	Exothermic	···
	$B^{10}(\alpha,p)C^{13}$	4.07	Exothermic	3.68
	$B^{11}(\alpha,n)N^{14}$	0.15	Exothermic	2.36
	$B^{11}(\alpha,p)C^{14}$	0.78	Exothermic	···
F	$F^{19}(\alpha,n)Na^{22}$	−1.84	2.22	···
	$Na^{22}\rightarrow Ne^{22}+\beta^+$	1.82	···	1.28
	$F^{19}(\alpha,p)Ne^{22}$	1.79	Exothermic	1.28, 1.51
Na	$Na^{23}(\alpha,n)Al^{26}$	−3.88	4.55	···
	$Al^{26}\rightarrow Mg^{26}+\beta^+$	3.93	···	···
	$Na^{23}(\alpha,p)Mg^{26}$	1.86	Exothermic	0.43, 1.13, 1.83, 2.57
Mg	$Mg^{24}(\alpha,n)Si^{27}$	−7.24	8.45	···
	$Mg^{24}(\alpha,p)Al^{27}$	−1.60	1.87	1.01?
	$Mg^{25}(\alpha,n)Si^{28}$	2.67	Exothermic	4.0
	$Mg^{25}(\alpha,p)Al^{28}$	−1.20	1.39	1.01?
	$Al^{28}\rightarrow Si^{28}+\beta^-$	4.65	···	1.82
	$Mg^{26}(\alpha,n)Si^{29}$	0.04	Exothermic	···
	$Mg^{26}(\alpha,p)Al^{29}$	−2.93	3.38	···
	$Al^{29}\rightarrow Si^{29}+\beta^-$	3.75	···	1.30, 2.32
Al	$Al^{27}(\alpha,n)P^{30}$	−2.92	3.35	···
	$P^{30}\rightarrow Si^{30}+\beta^+$	4.44	···	···
	$Al^{27}(\alpha,p)Si^{30}$	2.38	Exothermic	1.25, 2.28, 3.55

by Alburger and Hafner[29] with protons from the $Na^{23}(\alpha,p)Mg^{26}$ reaction, levels in Mg^{26} at 1.825 and 2.972 observed by Endt *et al.*[30] with deuteron bombardment of Mg^{25}, and gammas of 1.85 and 2.80 Mev observed by Alburger[31] from 7-Mev alpha bombardment of Na^{23}.

Smaller peaks at 1.12 and 0.43 Mev in Fig. 7 could correspond to a 1.18-Mev level in Mg^{26} given by Humphreys and Pollard[32] and the 0.44-Mev level in Mg^{26} as observed by Alburger and Hafner. Inelastic scattering of the alphas at the 0.44-Mev level of Na^{23} observed by Donahue *et al.*[33] could also account for the 0.43-Mev peak. There is no indication that any gamma radiation arises from the $Na^{23}(\alpha,n)Al^{26}$ reaction.

Po-Mg Sources

Three isotopes of Mg ($A=24$, 25, 26) are present in the natural element in the ratio 78.8:10.1:11.1, respectively. (α,n) reactions with Si^{28} and Si^{29} as residual nuclei and (α,p) reactions with Al^{27}, Al^{28}, and Al^{29} as residual nuclei are possible energetically. Al^{28} and Al^{29} are beta emitters with half-lives of 2.3 and 6.6 minutes.

The gamma spectrum of the Po-Mg neutron source (Fig. 8) has three large peaks at 1.30, 1.82, and 2.97 Mev, a small peak at 1.01 Mev, and a possible peak at 2.32 Mev. The 1.82-Mev peak corresponds to the 1.78-Mev gamma from the decay of Al^{28} as reported by Sheline and Johnson[34] and Motz and Alburger.[35] The 1.30- and 2.32-Mev peaks correspond to the description of Seidlitz *et al.*[36] of Al^{29} decay with 1.25- and 2.35-Mev gammas in the ratio of 3:1. The relative size of these two peaks would be expected from their intensity ratio and a consideration of the energy dependence of the crystal. The photoelectric peak at 1.01 Mev can be attributed to an excited state of either Al^{28} or Al^{29} as reported by Alburger and Hafner.

The low counting rate at 3 Mev prevented investigation past this point. This leaves a question as to the identity of the peak at 2.97 Mev. Considering the size and shape of the peak, it is probable that it is a pair production peak, which would put the gamma energy at about 4 Mev. This is close to the energy of the gamma found by Alburger[31] at 4.3 Mev and assigned to the $Mg^{25}(\alpha,n)Si^{28}$ reaction by Szalay and Csongor.[37]

Po-Al Sources

Proton and neutron radiation from Po-alpha bombardment of Al may arise from the $Al^{27}(\alpha,p)Si^{30}$ and $Al^{27}(\alpha,n)P^{30}$ reactions. P^{30} is a positron emitter with a half-life of 2.5 minutes.

The gamma spectrum curve for the Po-Al source is shown in Fig. 9 and is interpreted as follows: the 3.55-Mev peak—photoelectric peak; the 3.16-Mev peak—pair production from the 3.55-Mev gamma with distortion by the Compton distribution of the same gamma; the 2.56-Mev peak—pair production from the 3.55-Mev gamma; the 2.28-Mev peak—photoelectric peak; the 1.83-Mev peak—pair production from the 2.28-Mev gamma plus the Compton distribution; the 1.25-Mev peak—photoelectric peak broadened by the 2.28-Mev gamma pair production peak.

All the gamma radiation has been assigned to the $Al^{27}(\alpha,p)Si^{30}$ reaction. The 3.55-Mev gamma corresponds to a level in Si^{30} identified as 3.66 Mev by Benson,[38] 3.49 Mev by Brolley *et al.*,[39] 3.54 Mev by Slätis *et al.*,[40] 3.6 Mev by Landon,[41] and 3.66 Mev by Allen *et al.*[42] Alburger[31] observed a gamma of 3.5 Mev from alpha bombardment of Al and assigned it to the $Al^{27}(\alpha,p)Si^{30}$ reaction. The 2.28-Mev gamma in Fig. 9 agrees well with a Si^{30} level at 2.28 Mev as observed by Benson and Brolley *et al.* The 1.25-Mev gamma corresponds to a transition from the 4.9-Mev level to the 3.6-Mev level described by Landon. Allen *et al.* assign a value of 1.28 Mev to the gamma from this transition.

CONCLUSIONS

Since there is little or no gamma radiation from the (α,n) reaction from Po-alpha bombardment of Li, F, Na, and Al, the neutron spectra from these interactions should be relatively simple. Assuming a uniform distribution in the center-of-mass system and a fairly smooth (α,n) excitation function, the neutron spectra from these reactions should have a single maximum[43] since these targets are monoisotopic as far as neutron production is concerned.

The neutron spectrum from Po-alpha bombardment of Be, B, and Mg would be expected to have two or more maxima because of more than one isotope participating in neutron emission as in B and Mg and because of neutron emission occurring from levels of the residual nucleus besides the ground level. Examples of the latter are the 4.45-Mev level in C^{12}, the 2.36-Mev level in N^{14}, and the 4.0-Mev level in Si^{28}.

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