SNO-STR-90-111

α-Particle Induced High Energy γ-Rays from Light Elements

R. Heaton, H. Lee, and B. C. Robertson

September 12, 1990

The γ-ray yield induced by α-particles on infinitely thick targets has been measured at the Lawrence Berkeley 88" Cyclotron. Targets of aluminum, beryllium, boron nitride, silicon, magnesium, sodium fluoride and mylar were exposed to α-particles of 10, 8.8, 7.7, 7.0, 6.3, and 5.6 MeV. The resulting γ-rays were observed in two HPGE detectors positioned at 30.6° and 109.9°, and recorded in 8K channel spectra on an Ortec MCA/PC based system.

The preliminary analysis of the spectra uses a simple centroid and peak area calculation in the Ortec MCA program. The goals of the preliminary analysis are to quickly obtain estimates of the γ-ray yield from each target, to check for systematic problems and to identify any analytical problems. The source reaction for γ-rays down to 3 MeV are identified in each detector, and the γ-ray yield is obtained by fitting to Legendre polynomials P_0 and P_2 after correcting the net peak area for detector efficiency and dead time.

A preliminary analysis of the $A\ell$ and Be targets has been completed for all α-particle energies. A preliminary analysis of the data from the Si, BN and Mg targets have been completed for 10 MeV α-particles. Because of the low yield from the Si, no further data was taken below 10 MeV for this target. No analysis has been completed on the NaF or mylar targets.

The results of the analysis to date are summarized in Tables 1 and 2. Table 1 lists the highest energy γ-ray observed from each reaction in the targets. Table 2 gives the calculated γ-ray yield for each beam energy for γ-ray energies above 6 MeV and between 4 to 6 MeV.

A comparison of the γ-ray yields in $A\ell$ and Be suggests a systematic suppression of the yield by 7% at 8.8 MeV and 11% at 7.0 MeV. This is possibly due to a loss of beam on the target holder or target chamber.

Analysis of the BN target data at 10 MeV shows that both the $^{11}B(\alpha,n)^{14}N$ and the $^{14}N(\alpha,\alpha')^{14}N$ reactions contribute to the γ-ray yield from this target. This is seen from

Table 1: γ-Ray Source Reactions

Target	Reaction	Q-value (MeV)	γ-Ray (keV)
$A\ell$	$^{27}A\ell(\alpha,p)^{30}Si$	2.373	6915
Be	$^{9}Be(\alpha,n)^{12}C$	5.701	4439
BN	$^{11}B(\alpha,p)^{14}C$	0.784	6728
	$^{11}B(\alpha,n)^{14}N$	1.059	5832
	$^{10}B(\alpha,p)^{13}C$	4.063	3854
	$^{14}N(\alpha,\alpha')^{14}N$	—	4915
Si	$^{29}Si(\alpha,n)^{32}S$	-1.525	5798
	$^{28}Si(\alpha,p)^{31}P$	-1.916	4783
Mg	$^{25}Mg(\alpha,n)^{28}Si$	2.653	7933
	$^{26}Mg(\alpha,n)^{29}Si$	0.035	4840
	$^{25}Mg(\alpha,p)^{28}Al$	-1.207	4598
	$^{24}Mg(\alpha,p)^{27}Al$	-1.600	3210

the observed Doppler shifts in the short lived ($<$ 7fs) states of ^{14}N given in Table 3. The observed shift in the 5690 keV level is consistent with the (α,n) reaction populating the level, while the Doppler shift in the 4915 and 3948 keV levels is consistent with population via the (α, α') reaction. Notice that in the latter case, the observed peak energy falls outside the maximum doppler shift value in detector #2. This is attributed to interference from the 4410 keV single escape peak in that detector.

Following the preliminary analysis of the data, a more in-depth analysis will be performed which will include a more elaborate fit of the peak shapes and background subtraction. A parameterization of the escape peaks in each detector based on an EGS modelling of each detector will enable the removal of the escape peaks from each spectrum. The neutron background at high energy in each spectrum will be estimated by scaling the region to that of the Be spectrum. This will provide a test for low intensity high-energy γ-rays.

Table 2a:> 6 MeV γ-Ray Yields per α-Particle†

α-Particle Energy	$A\ell$	BN	Mg
10	$(8.9 \pm 0.7)^{-7}$	$(5.5 \pm 0.4)^{-7}$	$(1.9 \pm 0.2)^{-6}$
8.8	$(1.5 \pm 0.1)^{-8}$	—	—
7.7	$(9.0 \pm 1.1)^{-8}$	—	—
7.0	$(1.2 \pm 0.2)^{-8}$	—	—
6.3	$(9.6 \pm 6.2)^{-10}$	—	—
5.6	—	—	—

† γ-rays above 6 MeV not found in the Berylium and Silicon spectra.

Table 2b: 4-6 MeV γ-Ray Yields per α-Particle

α-Particle Energy	$A\ell$	Be	BN†	Si	Mg
10	$(3.3 \pm 0.2)^{-6}$	$(1.05 \pm 0.01)^{-4}$	$(4.9 \pm 0.1)^{-6}$	$(4.5 \pm 0.2)^{-7}$	$(4.0 \pm 0.2)^{-6}$
8.8	$(9.0 \pm 0.3)^{-7}$	$(7.50 \pm 0.06)^{-5}$	—	—	—
7.7	$(5.8 \pm 0.3)^{-7}$	$(6.71 \pm 0.04)^{-5}$	—	—	—
7.0	$(2.4 \pm 0.1)^{-7}$	$(4.93 \pm 0.03)^{-5}$	—	—	—
6.3	$(1.6 \pm 0.1)^{-7}$	$(4.98 \pm 0.04)^{-5}$	—	—	—
5.6	$(4.0 \pm 0.1)^{-8}$	$(3.44 \pm 0.02)^{-5}$	—	—	—

† Yields include both $^{11}B(\alpha,n)^{14}N$ and $^{14}N(\alpha,\alpha')^{14}N$ reactions. For a conservative estimate of the HEγ yield from boron, divide the target yield by 0.433 (stopping power contribution of boron in the target).

Table 3: Doppler Shifts of ^{14}N Levels

Level (keV)	Detector #1			Detector #2		
	Maximum Doppler $^{11}B(\alpha,n)^{14}N$ (keV)	Maximum Doppler $^{14}N(\alpha,\alpha')^{14}N$ (keV)	Observed Peak Energy (keV)	Maximum Doppler $^{11}B(\alpha,n)^{14}N$ (keV)	Maximum Doppler $^{14}N(\alpha,\alpha')^{14}N$ (keV)	Observed Peak Energy (keV)
5690	5786	5770	5783 ± 23	5651	5658	5652 ± 30
4915	4998	4984	4983 ± 21	4882	4887	4889 ± 15
3948	4015	4004	3983 ± 65	3921	2926	3915 ± [illegible]