gions probably occurs with dosages in excess of 5×10^{15} fissions per cm^3, so greater accuracy is obtained when less than 50% of the material has been transformed. By this analysis it is seen that $\sim10^6$ atoms are affected by each fission fragment in inducing the phase transition. In the original observation of the irradiation-induced phase transition,[1] the particle size of the transformed crystallites was ~100A radius as determined from x-ray diffraction line breadths. Particles of this size would contain about 3.5×10^5 atoms, lower by a factor of three from the 10^6 atoms estimated in the present work. The discrepancy is not unreasonable, however, since the x-ray line breadth determination did not consider the strain contribution to the line broadening. If the true particle size was as much as 140A radius, no discrepancy would exist and both cases would give 10^6 atoms affected by each fission fragment. Other irradiation-induced phase transitions in reactor fuel materials[6,7] have been reported, and it is interesting to note that estimates[7] of the number of atoms affected in a U-Mo alloy by a single fission event is fairly close to the number proposed here for the insulator ZrO_2. Calculations using the method of Seitz[8] show that a pair of fission fragments in a material like ZrO_2 would produce about 10^4 displaced atoms as a result of elastic collisions. It does not seem likely that a single displaced atom could affect 200 surrounding atoms to produce a phase transition, and this is supported by the stability of the material under fast neutron bombardment, solely. It is more likely that the process under which the transition occurs is a "fission spike" mechanism with a rapid, high-temperature quench.

The results of this investigation indicate that monoclinic ZrO_2 is stable under fast neutron bombardment but that it transforms into the cubic phase under the action of fission fragments. In this material it appears that $\sim2\times10^6$ atoms are quenched into the high-temperature modification as a result of the energy dissipated by a pair of fission fragments.

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PROTON CAPTURE GAMMA RAYS IN THE GIANT RESONANCE REGION

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Measurements of the 90° yield of gamma rays resulting from the capture of protons, with energies up to 11 Mev, in B^{11} and Al^{27} have been made using the Chalk River Tandem Accelerator.[1] In both cases the gamma rays investigated were those leading to the ground and first excited states (4.43 and 1.78 Mev) of the appropriate residual nucleus, C^{12} and Si^{28}, respectively. In addition, the angular distributions of these gamma rays with respect to the incident proton beam were measured at several proton energies. This Letter reports principally the results of the reaction $B^{11}(p,\gamma)C^{12}$ ($Q=15.949$ Mev).

The gamma rays were detected in a 5-inch diameter by 6-inch long unshielded NaI(Tl) crystal.[2] For the angular distribution measurements a second 5-inch diameter by 4-inch long NaI(Tl) detector was used at a fixed angle as a monitor.

Both the aluminum and boron targets were thin self-supported films through which the beam passed to be stopped in a lead plate behind shielding blocks about 16 feet from the target. The boron targets were prepared by mixing finely powdered boron of normal isotopic abundance with a colloidal graphite suspension in alcohol. This mixture was spread on a glass plate and the dried films were floated off in water. The resulting targets were about 20 kev thick for 10-Mev protons. Equivalent thicknesses of aluminum foil were used.

Figure 1 shows the 90° yield of the ground-state proton capture gamma rays (γ_0) from the $B^{11}(p,\gamma)C^{12}$ reaction as a function both of the incident proton energy in the laboratory system and of the excitation energy in C^{12}. The points shown represent several runs with different targets and the fluctuations are partly due to the normalization required and partly because of target nonuniformity. The yield of gamma rays leading to the first excited state of C^{12} (these gamma rays will be referred to hereafter as γ_1) shows a general rise between proton energies of 5.5 to 11.4 Mev with some evidence for two or three broad resonances. At proton energies corresponding to the peak of the giant resonance for γ_0 the yield of γ_1 is appreciably lower than that for γ_0. Consequently a detailed yield curve of γ_1 awaits the determination of the spectrum line shape of high-energy gamma rays in the 5-inch by 6-inch NaI(Tl) crystal. A careful search, in approximately 20-kev steps, has been made between proton energies of 5.5 to 7.8 Mev for one of the breaks observed[3] in the integral yield of neutrons, from bremsstrahlung irradiation of C^{12}, at 21.72-Mev excitation (this corresponds in the present experiment to a laboratory proton energy of 6.3 Mev). This break can be interpreted[3] as a resonance at this energy with a total width of 170 ± 70 kev. Neither the yield of γ_0 nor γ_1 showed any variation from a fairly uniform rise greater than ± 10% over the region in question. As seen from Fig. 1 the yield of γ_0 shows a pronounced broad peak with a maximum at approximately 22.5-Mev excitation energy in C^{12} and a width at half maximum of about 3 Mev in the center-of-mass system. This is consistent with photonuclear giant resonance observations[4] and measurements of the $B^{11}(p,\gamma_0)C^{12}$ reaction over a limited energy range by Gemmell et al.[5] The yield of γ_1, on the other hand, is quite different showing no pronounced maximum in the yield up to the highest proton energy of 11.4 Mev at which measurements were made.

Angular distributions of γ_0 in the $B^{11}(p,\gamma)C^{12}$ reaction at three energies on the giant resonance and one below it are shown in Fig. 2. The three measurements on the resonance can be fitted within the experimental uncertainties (± 10%) by an expression of the form $W(\theta) = 1 - 0.5P_2(\cos\theta)$ while that at the lower energy is spherically symmetric. Distributions of γ_1 at the same four energies are all spherically symmetric within the experimental uncertainties (± 25%). The observed ground-state distribution is that expected for the case of d-wave spinless particles captured by a spinless nucleus and then dropping to a p shell with the emission of electric dipole radiation. It can also, of course, be accounted for by one of the terms in conventional angular correlation theory. The former interpretation corresponds to direct capture and has been predicted for giant-resonance transitions by Courant.[6]

The situation for the $Al^{27}(p,\gamma)Si^{28}$ reaction ($Q = 11.588$ Mev), which is quite different, will be

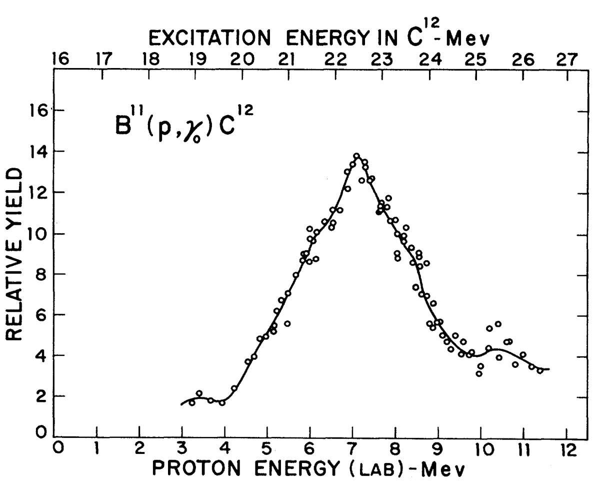

FIG. 1. The 90° yield of gamma rays leading to the ground state of C^{12} from the $B^{11}(p,\gamma)C^{12}$ reaction.

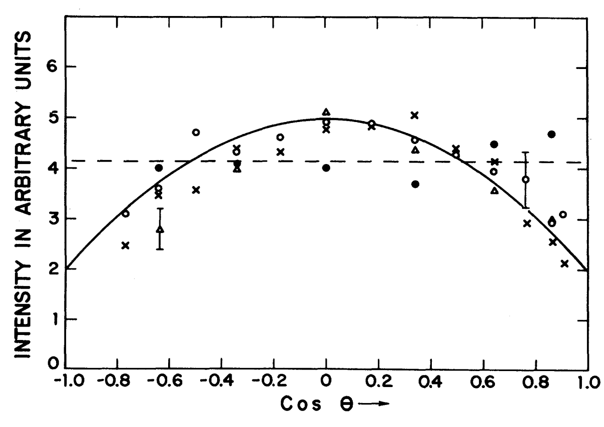

FIG. 2. The angular distribution of gamma rays leading to the ground state of C^{12} from the $B^{11}(p,\gamma)C^{12}$ reaction at a number of proton energies; closed circles 3.55 Mev, open circles 6.09 Mev, crosses 7.21 Mev, and triangles 8.45 Mev. The solid line is the function $W(\theta) = 1 - 0.5P_2(\cos\theta)$ and the dashed line is the mean of the values for 3.55 Mev.

summarized briefly here. The 90° yields of both γ_0 and γ_1 in this case show considerable, though dissimilar, sharp resonance structure. The envelope of this structure for γ_1 rises steadily for proton energies from 4.0 to 10.4 Mev while that for γ_0 rises and stays relatively constant from 6.0 to 10.4 Mev. If, indeed, the ground state gamma-ray yield falls off at energies above the range presently covered to give a giant resonance envelope, the present measurements indicate that the width of the envelope is at least 4.5 Mev.

Angular distributions of both γ_0 and γ_1 in the $Al^{27}(p,\gamma)Si^{28}$ reaction have been measured at proton energies of about 6.9, 7.2, and 8.4 Mev. All three distributions for γ_0 are fitted by $W(\theta)=1+a_2P_2(\cos\theta)$ where a_2 is slightly greater than zero, while those for γ_1 are spherically symmetric within experimental uncertainties. Direct capture processes give rise to a coefficient of $P_2(\cos\theta)$ which is less than or equal to zero and hence the observed positive coefficient for γ_0 suggests that the process cannot be described in this way.

* Seconded from the Atomic Weapons Research Establishment, Aldermaston, England.

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NEUTRON ASYMMETRY FROM MU CAPTURE IN MAGNESIUM*

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It has been pointed out by many authors[1-4] that a measurement of the angular distribution of neutrons emitted after the capture of polarized μ^- mesons by complex nuclei may give information on the nature of the coupling constants in the process

$$\mu^- + p \rightarrow n + \nu. \qquad (1)$$

A spatial asymmetry with respect to the μ spin direction would also be evidence for parity nonconservation in reaction (1). Until now no such violation has been experimentally observed. A calculation by Primakoff suggests that an asymmetry parameter as large as -0.4 could be expected.[2] In addition to the neutrons from (1), evaporation neutrons would be emitted. Since these would mask an asymmetry, they were discriminated against in the present experiment by detecting only those neutrons with an energy > 5.5 Mev.

A previous attempt to measure this asymmetry was hindered by a large contamination of nuclear de-excitation γ rays.[5] A large number of such γ rays per μ capture has been observed.[6-8] In order to reject these γ rays in this experiment, the neutrons were detected with a sandwich counter consisting of 15 6-in. by 3-in. sheets of 1/8-in. thick plastic scintillator. The adjacent layers were viewed alternately by two phototubes [6 and 7 of Fig. 1 (a)]. Electrons of energy above a certain threshold produced by gamma rays crossing the counter have in general a range sufficient to penetrate more than one layer thus causing a (67) coincidence. It is therefore possible to reject such events because most of the neutrons from μ^- capture produce counts either in 6 only or in 7 only, the range of the proton recoil being short compared to the thickness of a single layer (see Fig. 2).

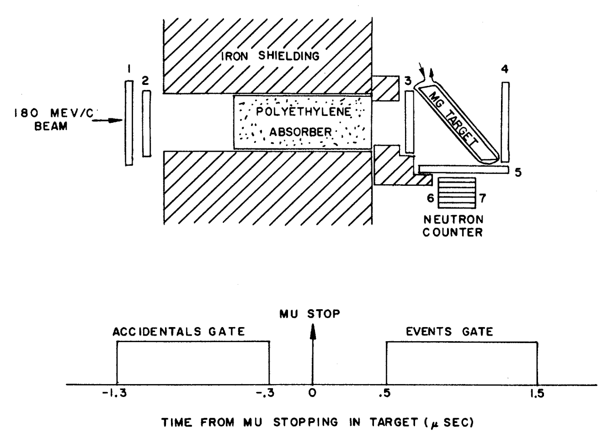

FIG. 1. (a) Experimental arrangement. (b) Timing diagram.