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NEUTRON-INDUCED GAMMA-RAY PRODUCTION FROM CARBON AND NITROGEN

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ABSTRACT

Gamma-ray production cross sections and angular distributions were measured with five 7.6 cm diameter x 7.6 cm long BGO detectors at the high-energy white neutron source of the WNR facility at Los Alamos for targets of C $^{14}NH_3$ and $^{15}NH_3$. Gamma rays were measured in the energy range from 1.4 to 25 MeV. The incident neutron energies spanned the range from 2 to over 100 MeV. The detectors were positioned at angles of 39°, 55°, 90°, 125°, and 144° with respect to the neutron beam. We have extracted angular distributions and cross sections for the 4.44 and 15.1 MeV γ rays from inelastic excitation of C for $4 < E_n < 150$ MeV. In ENDF-B/VI these γ-rays are treated as being isotropic. Our angular distributions show that this is not the case. For the nitrogen isotopes we have extracted angular distributions and cross sections for several γ rays in the neutron energy range, $2 < E_n < 20$ MeV.

I. INTRODUCTION

One or more of the elements, C, N, and O can be found almost everywhere, in water, air, biological tissues, conventional explosives, and the solar corona. Thus in addition to studying nuclear reactions on these elements for fundamental nuclear physics, there are many applications in a wide variety of areas of science and technology where a knowledge of such cross sections is useful. In this paper we report on measurements of neutron induced γ-ray production on C and N. A new experiment is planned to acquire similar data on O.

Previous studies (e.g. Ref. 1) have generally been limited to two angles and neutron energies below 20 MeV. In some applications, however, a detailed knowledge of the angular distribution of the γ rays is necessary, and higher incident neutron energies are required.

Our measurements are performed with the WNR white neutron source at Los Alamos. A general description of the facility is given in by Lisowski, et al.[2] Because of the continuous neutron energy coverage, and the wide neutron energy range available, this facility is well-suited for such measurements. Preliminary results of data taken earlier on C(n,n'γ) at our facility have been presented.[3] Since that time, many improvements have been made in determining the absolute normalization of our data, and in the data reduction procedures. More and better data have been obtained on a variety of targets. Here we briefly describe the experimental setup, discuss the data reduction procedure, and present some of the cross sections and angular distributions for carbon and nitrogen.

II. EXPERIMENT

The experiments were performed on the 15° right flight path of the WNR facility. The general features of the 15° right, five-crystal BGO spectrometer setup and of the beam pulse structure are described in Ref. 3. The samples consisted of a 2.5 cm diameter by 5.1 cm long graphite cylinder, a 5.7 cm diameter stainless steel sphere filled with 55.8 g of ammonia (NH_3) liquid (99.6% ^{14}N), and a similar sphere filled with 58.58 g of ammonia isotopically enriched in ^{15}N (99.8% ^{15}N). Although ^{15}N is generally of little importance in applications due to its low natural abundance, the availability of the sample and theoretical interest motivated its inclusion in our study. The samples were mounted at a distance of 17.30 m from the neutron production target, suspended by string in the case of C, and by a thin stainless steel filling tube for the ammonia filled spheres. Five 7.6 cm diameter by 7.6 cm long BGO detectors with Pb collimators were mounted at angles of 39°, 55°, 90°, 125°, and 144° with respect to the neutron beam.

The neutron flux was measured with a fission chamber[4] containing both ^{235}U and ^{238}U fission foils located a distance of 15.50 m from the production target. The neutron fluence for each neutron energy group was determined from the two-dimensional (neutron TOF versus fission pulse height) fissic chamber spectra. A typical neutron flux spectrum for $2 < E_n < 800$ MeV is shown in Ref. 3.

Two-dimensional spectra, neutron TOF (1024 channels) versus γ pulse-height (512 channels), were acquired for each of the BGO detectors. The time resolution, as determined from the γ-ray flash from the neutron-production target, varied from 2 to 5 ns FWHM, depending upon the properties and settings of the individual detectors and electronics. The γ-ray energy resolution of the full-energy peak was typically 500 keV FWHM at 2.3 MeV, but varied somewhat between detectors.

III. DATA REDUCTION

The data were binned into neutron energy groups based upon the experimental neutron energy resolution, the structure observed in the data, and the available statistics. For C the bin sizes vary from 100 keV at $E_n = 3$ MeV to 20 MeV at $E_n = 200$ MeV. For N the bins are somewhat coarser to improve the statistics within a given bin.

Background events that are random in time are subtracted from each spectrum first, using data from a portion of the TOF spectrum at "long" times after a beam burst. Next, sample-out spectra are normalized by the ratio of the fluences and subtracted from the sample-in spectra.

Because we cannot distinguish γ-ray events from neutron events in the BGO detectors it is necessary to perform a neutron background subtraction. We accomplish this subtraction by approximating the neutron background using measured neutron scattering spectra from Be, normalized by the ratio of the ENDF[5] cross sections for neutron elastic scattering from Be and the target materials. This technique works fairly well, but is only applicable in the neutron energy range below 20 MeV where the ENDF elastic scattering cross sections are available. At higher incident neutron energies we must rely on other background subtraction techniques to extract the γ-ray signal from the data.

The γ-ray spectra are unfolded using the FERD program[6] and response functions generated using the procedure described in Ref. 7. The response functions include the product of the detector efficiency and solid angle. The resulting normalized spectra can be converted to doubly-differential cross sections using the neutron fluence and sample thickness. Excitation functions for individual transitions are obtained by summing the peaks, and angular distributions are calculated from the data at each neutron energy. The angular distribution coefficients are defined by the equation:

$$\sigma(\theta) = A_0 (1 + a_2P_2 + a_4P_4 + ...)$$

Where P_n is the n^{th} order Legendre polynomial, and a_n are the normalized coefficients of the expansion.

Final corrections to the data for γ-rays produced by secondary particles and γ-ray attenuation in the sample are made last. These corrections have not been applied to the preliminary results presented here. Corrections for contributions due to secondary particles can be large, especially for low threshold reactions at high incident neutron energies[8].

IV. RESULTS AND DISCUSSION

The previous data[1] for the C(n,n'γ) $E_\gamma = 4.44$ MeV reaction at 90° and 125° agree within errors with our results below $E_n = 10$ MeV. Between 10 and 20 MeV we obtain cross sections that are approximately 20% higher. The ENDF[5] evaluation does not describe the data well because it is based on data at only two angles. As can been seen from the angular distribution coefficients in Fig. 1, the a4 term is not negligible.

In Fig. 2 we show the $^{14}N(n,x\gamma)$ spectrum for $E_n = 15$ MeV. The solid line is the result of a GNASH[9] model calculation.[10] For neutron energies below 40 MeV, the maximum energy at which the calculations were performed, the calculations reproduce the data fairly well. Agreement is worst near 20 MeV. There is no ENDF evaluation for discrete γ-ray production from N.

We expect to finalize the analysis of the carbon and nitrogen data, and to submit the results for publication in the next few months.

More recently we have used high resolution Ge detectors to investigate individual transitions for a variety of targets. Results on Pb and Al are presented elsewhere in this conference[11,12]. These measurement were performed at only two angles. Ge detector measurements have advantages over experiments using BGO detectors in that the backgrounds are generally easier to subtract, and unfolding is not necessary to resolve individual γ rays. This summer we plan to measure γ-ray production from oxygen using Ge detectors at 6 or more angles to further improve the γ-ray database for C, N, and O.

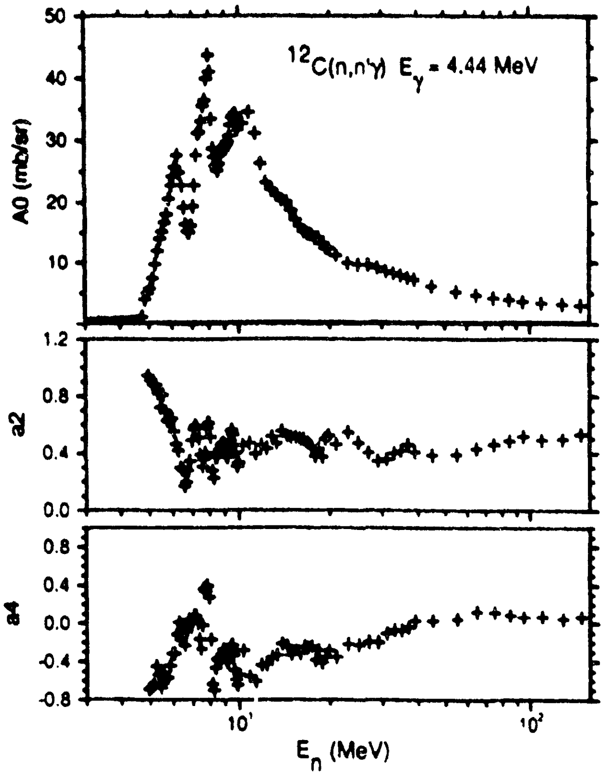

Fig. 1. Cross sections and angular distribution coefficients for the $^{12}C(n,n'\gamma)$ E_γ= 4.44 MeV transition for $4 < E_n < 150$ MeV.

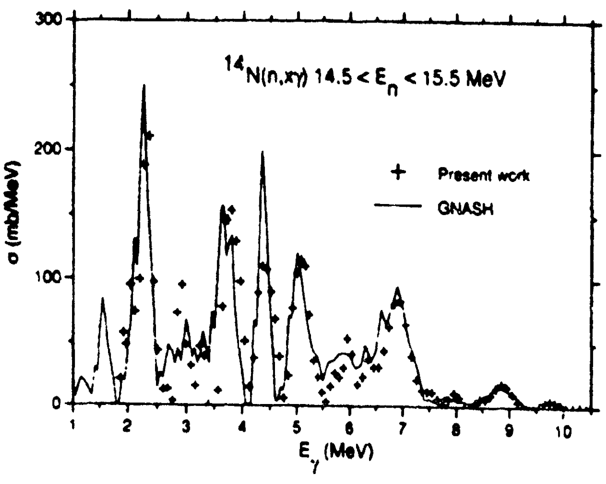

Fig. 2. Spectrum from $^{14}N(n,x\gamma)$ for E_n = 15 MeV. The solid line is a GNASH model calculation.

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