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AUTHOR(S): R. O. Nelson (P-23) and S. A. Wender (P-23)

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Los Alamos National Laboratory
Los Alamos, New Mexico 87545

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GAMMA-RAY PRODUCTION EXPERIMENTS AT THE WNR WHITE NEUTRON SOURCE

R.O. Nelson and S.A. Wender
P-23, M.S. H803, Los Alamos National Laboratory, Los Alamos, NM 87545, U.S.A.

ABSTRACT

Using the WNR white neutron source, photon production data have been acquired in the incident neutron energy range, $3 < E_n < 400$ MeV, for a number of target nuclei using BGO detectors and high-resolution Ge detectors. The gamma-ray energy range covered is $0.1 < E_\gamma < 10$ MeV for the Ge detectors and $1.0 < E_\gamma < 20$ MeV for the BGO detectors. The Ge detector measurements allow identification of reactions from the known energies of the gamma-ray transitions between low-lying states in the final nucleus. The lower resolution BGO data were also for discrete transitions. The data are useful both for testing nuclear reaction models at intermediate energies and for numerous applied purposes. We list the target nuclei studied to date and the status of the data.

1. Introduction

Gamma-ray production data have been acquired for a variety of targets at the WNR spallation neutron source at Los Alamos. Most of the recent measurements used Ge detectors, although earlier experiments were performed with BGO detectors. The data provide continuous coverage of the neutron energy range, typically, from 3 to 400 MeV. The γ-ray energy range measured is from approximately 100 keV to 3 MeV for heavier targets, and from a few hundred keV to 10 MeV for lighter mass targets. These energy ranges were chosen because relatively intense, higher energy gamma rays are expected from the lighter nuclei. This is due to the larger level spacings of the low lying states of light nuclei, as compared to heavier nuclei. The WNR facility is described by Lisowski et al.[1] A description of some of the Ge detector experiments is given in Ref. 2.

The data were acquired with two main goals in mind. First, the data provide information that can be used in evaluations and applications. Second, by extending the data to higher energies we can validate extensions and improvements in nuclear reaction model calculations.

Here we present an overview of the data that have been acquired to date. In many cases the data reduction task is still in progress. The data are acquired as both 2 parameter arrays (neutron time-of-flight versus gamma-ray pulse height) and as event data, which allows resorting of the data with maximal dispersion in the spectra as needed. The amounts of data to be handled are large and hence require automated data reduction procedures to expedite the process.

2. Data

Some common features of the measurements are listed here: The data were measured relative to the ^{235,238}U(n,f) cross sections using a fission ionization chamber.[3] Almost all of the Ge detector data were taken on a 41 m flight path. The BGO data were taken on an 18 m flight path.

Several experimental factors determine the energy range over which reliable cross section values can be extracted from our data. Because our flux decreases exponentially, and due to the fact that cross sections tend to be smaller at higher energies, the number of counts available limits the maximum energy at which we obtain useful data. One must also consider the production of γ rays by secondary particles produced in the sample. In order to correct for this contribution, we must make measurements with two or more different sample thicknesses. The magnitude of the correction depends upon the reaction threshold energy as well as the magnitude of the cross section at a given energy. Inelastic scattering to the first excited state of the target nucleus is an example of a reaction which, at high energies, can have a very large correction due to its small cross section, and the larger cross section for excitation of the same state by charged particles and lower-energy scattered neutrons. A reaction with a higher energy threshold, such as (n,3n), will require less of a correction because the same residual nucleus is unlikely to be created by secondary charged particles, and the mean free path of neutrons with sufficient energy to initiate the reaction is much larger than for lower energy neutrons.

Additionally one must consider the angular distribution of the γ rays. It is usually desired to obtain the angle integrated cross section for a reaction from the γ-ray data. For γ rays that are emitted isotropically a measurement at any one angle is sufficient. For dipole transitions a single measurement at 125° is sufficient. But for γ rays of higher multipolarity, it is necessary to make measurements at several angles to determine the angular distribution. The variation from isotropy is observed to be large in some cases, especially in the resonance region of light nuclei. White sources are well suited for making such measurements because the energy dependence of the cross section is obtained in one experiment. The ^{16}O(n,n'$_2\gamma$) reaction is an example of a reaction for which the octupole γ-decay exhibits striking anisotropy of the angular distribution. The resonance structure persists to energies near 20 MeV, with the angular distributions varying rapidly with incident neutron energy.

Our data can be divided into two categories. In the first category are data which have been acquired with relatively fewer counts and for only one target thickness. These data, listed in Table 1, can be used reliably for incident neutron energies less than approximately 20 MeV for reactions with low thresholds, and may be useful for reactions with high thresholds at higher energies if the cross sections are large. The second category, listed in Table 2, contains data that were taken with two or more sample thicknesses and with more counts. From these data, we expect that reliable cross sections may be extracted for many reactions even at higher energies. Data on C, N, and B were taken with lower resolution BGO detectors, but with an extended γ-ray energy range up to 20 MeV. These data are indicated in the column with the number of angles. The number of angles at which data were obtained, the status of the data reduction, and one or more applications are also listed in the tables.

Table 1. Samples for which limited data are available.

Sample	# of angles	Data Reduction Status	Application
B	2 +BGO	In progress	planetary exploration
Na	4	In progress	fusion, (n,2n) discrepancies
Si	2	In progress	planetary exploration
S	2	In progress	planetary exploration
Ca	2	In progress	planetary exploration
Ti	2	In progress	planetary exploration, structural material
Ni	2	In progress	structural material, planetary exploration
Mn	2	In progress	planetary exploration

Table 2. Samples for which more complete data are available.

Sample	# of angles	Data Reduction Status	Application
C	4 +BGO	Near completion preliminary results available	"standard", explosives detection, medical radiotherapy
N	4 +BGO	In progress, preliminary results	explosives detection, medical radiotherapy
O	7	In progress, preliminary results	medical radiotherapy, fusion experiment background, explosives detection
Al	2	Completed	model development
$^{nat,56}Fe$	4	In progress, preliminary results	compare with ORELA data, structural material, reaction model development
$^{207,208}Pb$	2	Completed	reaction model development, accelerator driven transmutation

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