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MEASUREMENTS OF THE $^{10}B(n,\alpha)$ CROSS SECTIONS FOR NEUTRON ENERGIES FROM 1 TO 1000 keV *

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ABSTRACT

The $^{10}B(n,\alpha)$ and $^{10}B(n,\alpha_1\gamma)$ cross sections have been measured relative to the H(n, n) cross section from ~1-1000 keV. These measurements were made with a Linac pulsed neutron source and time-of-flight techniques using a 230-meter flight path. The $^{10}B(n,\alpha)$ data were obtained with BF_3 gas proportional counters and also with a large ion chamber constructed with thin ^{10}B-loaded self-supporting films. The $^{10}B(n,\alpha_1\gamma)$ data were obtained with a Ge(Li) detector. The incident neutron flux spectrum was measured with a hydrogen gas proportional counter from ~1-50 keV and with a methane gas proportional counter from 13-1000 keV. Presently, the measurements have been analyzed for neutron energies from 4 to 100 keV for the $^{10}B(n,\alpha)$ reaction and from 4 to 1000 keV for the $^{10}B(n,\alpha_1\gamma)$ reaction. Analysis is continuing, and it is expected that final results for both of these cross sections will be obtained from ~1 to 1000 keV with an overall uncertainty varying from ~1% at 1 keV to ~ 3% at 1000 keV.

1. INTRODUCTION

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The large magnitude and relatively smooth energy dependence of the $^{10}B(n,\alpha)$ and $^{10}B(n,\alpha_1\gamma)$ cross sections, combined with the ease of their implementation in neutron detectors, has led to their frequent use as standard cross sections for neutron flux determinations. In spite of their importance in the keV to MeV region, however, relatively few measurements of these cross sections have been made. Many of the direct measurements made previously may contain systematic errors from long-counter flux

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determinations and are subject to a variety of uncertainties associated with background determinations. The indirect results (e.g. the $^{10}B(n,\alpha)$ cross sections deduced from the total and scattering cross sections) may contain substantial systematic errors inherent in such determinations. The present measurements were undertaken in order to remove or reduce these uncertainties by making high-accuracy, direct measurements relative to the H(n, n) standard cross section.

2. NEUTRON SOURCE

Time-of-flight measurements were made with short bursts of photoneutrons produced by bombarding a tungsten alloy target with 80-MeV electrons from the Gulf Radiation Technology linear accelerator. The electron target was surrounded by a cylinder of uranium which moderates the neutrons by inelastic scattering and also reduces the intense bremsstrahlung burst. The neutrons were also moderated by a 2.5-cm-thick polyethylene slab, and a ^{10}B filter was employed to prevent overlap of low-energy neutrons produced from previous linac pulses.

The neutrons traversed an evacuated, collimated flight path terminating at a station located 230 m from the tungsten target. During the various measurements, the incident neutron flux was monitored by ^{3}He gas proportional counters located ahead of the final collimators and such that they were not viewed by the detectors used in the measurements.

3. FLUX MEASUREMENTS

The neutron flux throughout the energy region ~ 1-1000 keV was measured with hydrogen and methane gas proportional counters. The hydrogen counter measurements extend from below 1 keV to 50 keV, and the

methane measurements cover the interval from 13 to 1000 keV. A four-parameter computer-based data-acquisition system was used to measure the neutron flight time, a "low-gain" pulse height, a "high-gain" pulse height and the pulse rise time. The linear pulse for each event was routed to two separate amplifiers having gains which differed by a factor of about 16. These low-gain and high-gain pulse-height parameters allowed the digitization of the pulse amplitude over a very wide dynamic range, thus allowing a large energy overlap between the hydrogen and methane data. Gamma-ray discrimination was accomplished with the rise-time parameter. The time-of-flight distribution was formed by sorting these data with pulse-height bounds which were a constant fraction of the maximum proton-recoil energy, so that heavy-ion recoils could be biased out. Collimators were used to prevent neutrons and gamma rays from the tungsten target from striking the walls of the counters, which significantly reduced the wall-scattering effects and also reduced the gamma-ray background. Corrections were made to the data for backgrounds, self-shielding, multiple scattering, end-window transmission and small neutron-scattering effects.

The detection efficiency of the counters was determined from calculations made to extrapolate the pulse-height distributions to zero pulse height. Lack of information on the energy dependence of the ion-pair defect for hydrogen and methane can introduce an uncertainty in these calculations. From the present measurements of the leading edge of the pulse-height distribution as a function of incident neutron energy, new information was obtained about the ion-pair defect. However, this technique cannot be applied reliably at very low neutron energies. Further information on the ion-pair defect would allow this present uncertainty in the detection efficiency, which is significant only at the lowest neutron energies, to be removed.

4. ION-CHAMBER MEASUREMENTS

The $^{10}B(n,\alpha)$ cross section was determined from measurements made with a large, gridded ionization chamber containing thin self-supporting films. The films used in the chanber were 25 cm x 25 cm in size and were prepared using a new technique which allows the dispersal of a ^{10}B colloid in a thin plastic substrate. A second chamber, used for background determinations, was identical to the first chamber except that the ^{10}B was replaced by carbon. The four-parameter data-acquisition system was used to record the neutron flight time, the pulse height from each side of the films and the sum pulse height. Also, "bit tagging" was employed to indicate when a coincidence occured between the different sides of the films. These data were corrected for backgrounds and a small energy dependence of the detection efficiency.

5. BF_3 MEASUREMENTS

Data on the $^{10}B(n,\alpha)$ cross section were also obtained with BF_3 counters. A small admixture of methane was used in these counters so that an absolute measurement could be obtained by directly comparing the proton-recoil and alpha-particle pulse-height distributions. The BF_3 data were obtained with the same computer acquisition system employed for the flux measurements. The data were corrected for backgrounds, self-shielding, multiple scattering, wall scattering, end-window transmission, neutron-scattering effects and a small energy variation of the detector efficiency.

6. Ge(Li) MEASUREMENTS

The $^{10}B(n,\alpha_1\gamma)$ cross section was determined by detecting, as a function of neutron energy, the 478-keV gamma ray from the decay of the

first excited state of ^{7}Li. An 80-cm^3 Ge(Li) gamma-ray spectrometer was positioned in the center of the neutron beam and was shadow-shielded from source neutrons and gamma rays. The Ge(Li) detector viewed a ring-shaped sample of ^{10}B. The data were obtained in both one- and two-parameter data-acquisition modes, i.e. neutron flight time only and this parameter combined with the pulse height. Background under the 478-keV peak was determined by accumulating time-of-flight data for a pulse-height window set just above the 478-keV gamma-ray peak. Also, measurements were made with a carbon sample to determine the small background (less than 2%) from neutrons scattered from the sample and interacting in the Ge(Li) detector and surrounding materials. Corrections were made to the Ge(Li) data for multiple scattering and self-shielding of the neutrons in the sample.

7. RESULTS AND CONCLUSIONS

The incident neutron flux measurements obtained in the present work are of much higher accuracy than those used in earlier determinations of the $^{10}B(n,\alpha)$ cross sections. The total systematic uncertainty is $\sim 1\%$ from 10 keV to 1 MeV. Further improvements in the data below 10 keV are expected from future ion-pair defect studies and additional flux measurements in this region.

The present ionization chamber, BF_3 and Ge(Li) data have been divided by the neutron flux and normalized in the interval from 10-20 keV to the $^{10}B(n,\alpha)$ and $^{10}B(n,\alpha_1\gamma)$ cross sections obtained from ENDF/B Version III and the branching ratio of Irving.[1] With further improvements in the quality of the flux data below 10 keV, these normalizations can be performed at lower energies where the cross section is even closer to 1/v.

The $^{10}B(n,\alpha_1\gamma)$ measurements obtained with the Ge(Li) spectrometer yield a significant improvement in the precision of this cross section. This is largely a result of the excellent signal-to-background ratio provided

by the high-resolution Ge(Li) detector combined with the high-efficiency ring-geometry configuration. These advantages also minimized the statistical uncertainties. Although they are small, the backgrounds, such as those due to scattered neutrons, have been carefully assessed.

The present $^{10}B(n,\alpha_1\gamma)$ measurements are shown in Fig. 1 together with previous data. The error bars shown on the present measurements are a result of a detailed error analysis combining both systematic and statistical uncertainties. The present results introduce direct measuements below 100 keV and high-accuracy data in the 100- to 1000-keV energy range. The present data are seen to disagree significantly with the earlier measurements shown in Fig. 1; however, they are in very good agreement with preliminary measurements of Coates[5] which extend up to ~ 250-keV neutron energy.

The present measurements provide $^{10}B(n,\alpha)$ cross sections below 100 keV from BF_3 measurements and below 750 keV from the ionization-chamber measurements. Data which are presently considered final are those shown in Fig. 2 from 4 to 80 keV. These data are from the BF_3 measurements (which agree excellently with the data from the ion-chamber measurements and have superior counting statistics in this energy region). The error bars shown on the present measurements are, as in Fig. 1, the total uncertainties. Also shown in Fig. 2 are earlier measurements and the ENDF/B-III data. In general there is good agreement between the present results and the earlier measurements, and the present data provide an improvement in the uncertainties in this energy region.

While the ionization-chamber results are not yet final, a preliminary indication from these measurements is that the $^{10}B(n,\alpha)$ cross section is significantly higher than the ENDF/B-III data above ~100 keV. Our preliminary data are in best agreement with the data of Bogart and Nichols.[10] Also, structure in the cross section near 450 keV, which is not well resolved in previous measurements, is clearly defined in the ion-chamber data. This structure is qualitatively similar to that predicted in

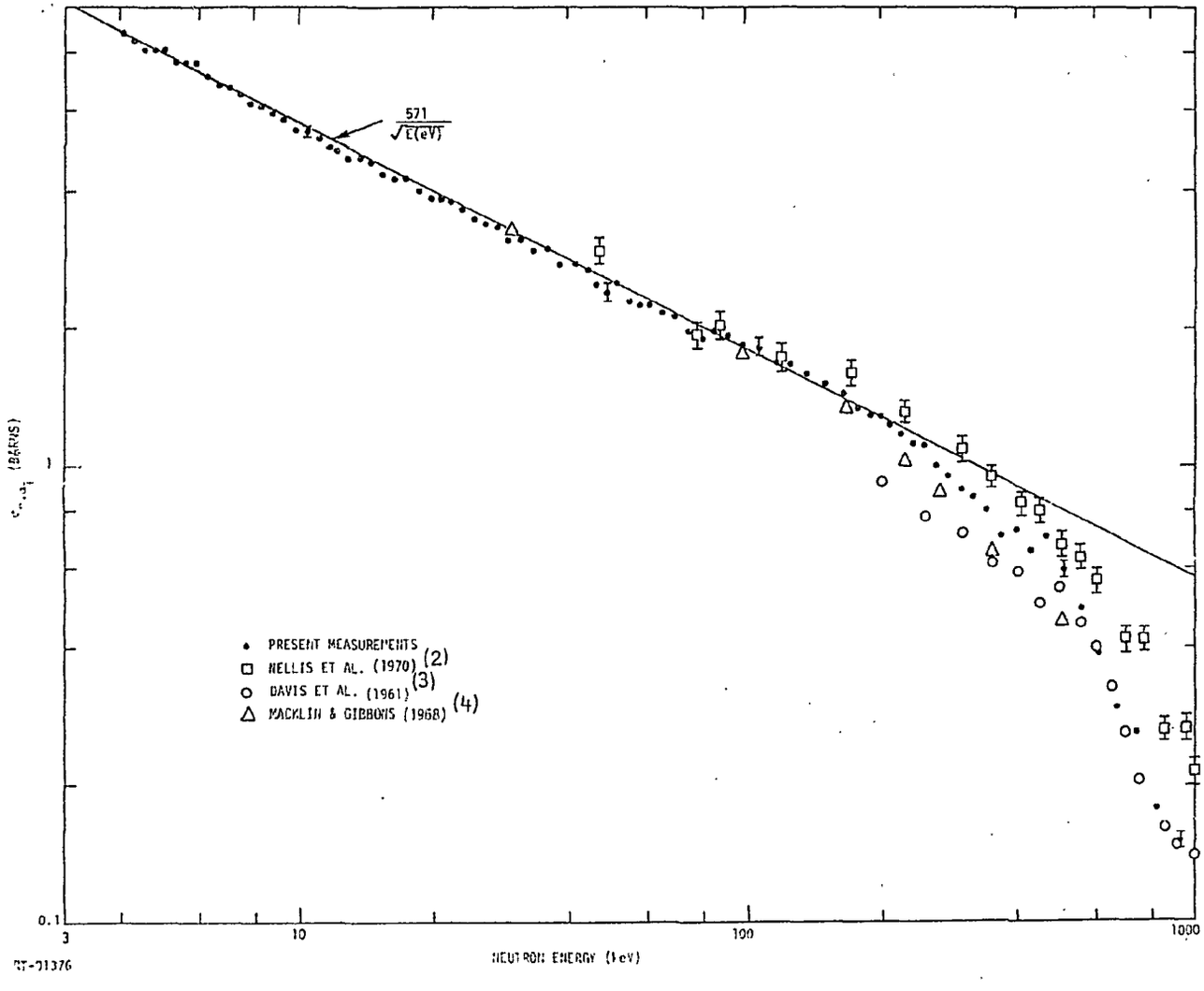

Fig. 1. Measurements of the $^{10}B(n,\alpha_1\gamma)$ cross section

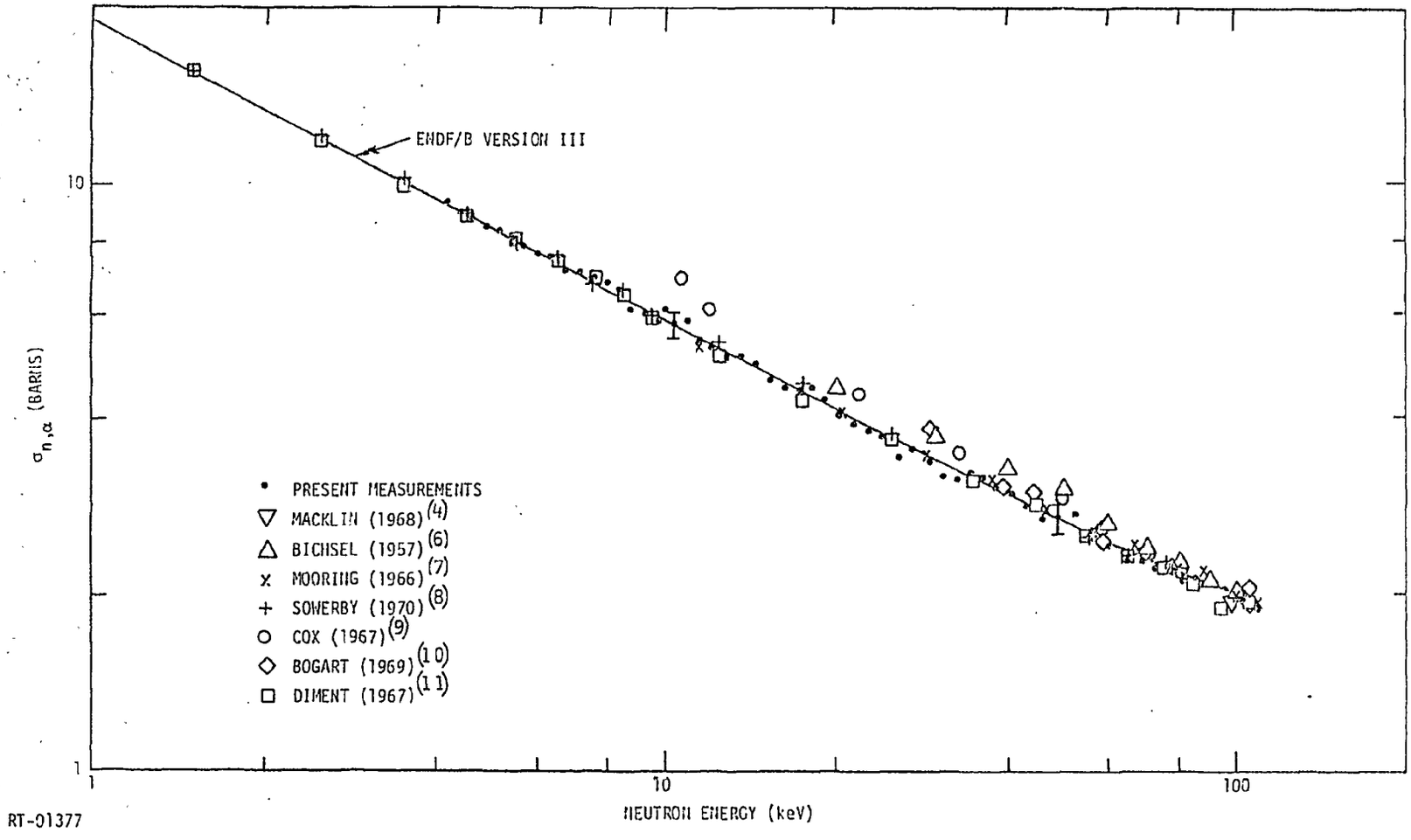

Fig. 2. Measurements of the $^{10}B(n,\alpha)$ cross section. The data of Mooring[7] have been averaged to facilitate a comparison with the other measurements.

the (n,α_0) channel by Lane et al.[12] from an R-matrix analysis of elastic scattering, polarization and other reactions proceeding through the compound nucleus ^{11}B. Additional analysis and experimental verifications are in progress. It is anticipated that the $^{10}B(n,\alpha)$ cross section, with an overall uncertainty $\sim 3\%$, will be obtained from these measurements up to 750-keV neutron energy.

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