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FAST FORWARD NEUTRON PRODUCTION IN THE ^{7}Li(p,n)^{7}Be REACTION FOR 41- AND 64-MeV PROTONS

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OAK RIDGE NATIONAL LABORATORY
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ABSTRACT

Measurements have been made by the time-of-flight technique of the neutron energy spectra observed at zero degrees from the $^{7}Li(p,n)\,^{7}Be$ reaction using 41- and 64-MeV incident protons. The neutron production cross sections for the fast forward peak (corresponding to excitation of the ground and first excited states of Be) has been found to be 33 ± 6 mb/sr at a mean energy of 39 MeV and 36 ± 4 mb/sr at 60 MeV. These results are compared with thcse reported elsewhere and the suitability of such ^{7}Li targets as a source of monoenergetic neutrons is discussed.

FAST FORWARD NEUTRON PRODUCTION IN THE $^{7}Li(p,n)^{7}Be$ REACTION FOR 41-MeV AND 64-MeV PROTONS

There has been considerable interest in the development of a practical target for the production of a monoenergetic, medium-energy neutron beam using protons in the energy range 40-60 MeV. Whitehead[1]) pointed out the suitability of lithium targets, since more than half of the neutrons emitted in the forward direction fall in a narrow energy band. Studies of the $^{7}Li(p,n)^{7}Be$ cross sections at 30- and 50-MeV by Batty, et al.[2,3]) and at 94 MeV by Langsford[4]) show that this "fast" peak corresponds to transitions to the ground state (Q=-1.68 MeV) and to the first excited state (0.43 MeV of excitation) in ^{7}Be. Jungerman, et al.[5]) have measured the cross section corresponding to this peak at E =29.2 MeV and 39.2 MeV and Anderson et al.[6]) at 10-20 MeV. In this paper we report measurements made by the time-of-flight technique of the fast forward neutron production in 1.4- to 2-MeV thick lithium targets by 41- and 64-MeV protons.

Bursts of protons, about 1 ns in width, were produced by the Oak Ridge Isochronous Cyclotron. Using radio-frequency deflection, one of every 7 proton bursts was permitted to pass through the entrance slit of a 153-degree analyzing magnet, so that the burst separation at the target was greater than 300 ns.[7]) The beam was focussed on a lithium target placed at the entrance of a 17-degree bending magnet which cleared the primary beam into a carbon-lined Faraday cup[8]). Neutrons emitted from the target in the direction of the incident protons traversed a 4-m path to the detector.

The incident proton energy was established by the magnetic field of the 153-degree magnet, and the beam intensity was measured by a proton monitor placed across the beam immediately upstream of the target. For the 41-MeV measurement, an ion chamber[8]) having a total thickness of 101 mg/cm^2 aluminum-equivalent served as the beam monitor. An improved monitor[9]) was used for the 64-MeV experiment which measured charged particles scattered from the proton beam in a 2 mg/cm^2 Mylar plastic film placed across the beam and at a 45-degree angle to the beam direction. Before each measurement, the beam monitor was calibrated using the Faraday cup.

Targets were prepared from metallic lithium isotopically enriched to 99.3 weight per cent ^{7}Li by pressing under oil to a nominal thickness of 0.3 cm. The lithium disc was mounted in an aluminum frame having a 1.6-cm aperture. The beam spot diameter at the target was less than 1 cm. The proton energy loss in the targets was 2.0 MeV for the 41-MeV measurement and 1.4 MeV for the 64 MeV experiment.

The neutron detector consisted of a 7.62-cm by 7.62-cm diameter NE-213 liquid scintillator viewed by an RCA-4522 photomultiplier tube positioned so that neutrons entered along the axis of the detector. Pulse shape discrimination using cross-over timing was used to reduce gamma-ray background. A 3-mm NE-102 plastic detector mounted in front of the neutron detector and operating in anti-coincidence with it served to veto pulses from charged particles.

The efficiency of the NE-213 neutron detector was calculated with the 05S Monte Carlo program developed by Textor and Verbinski[10]) using modified values of the input cross sections due to Cohen, et al.[11]) As described elsewhere[12]), the proton light curve was revised at higher energies to achieve consistency with this and other experiments. This revision corresponded to extrapolation of the Textor and Verbinski curve from 10 MeV using Birks'[13]) relation

$$L = 4.55 + A\int_{10}^{E_p} \left(1 + B\,|dE/dx| \right)^{-1} dE$$

where L is the total light in the Textor and Verbinski units, emitted by a proton of energy E_p, and dE/dx is the rate of energy deposition along the proton path length. Values for dE/dx as a function of E for the NE-213 scintillator were those of Peelle[14]). The integral is performed from 10 MeV, where the Textor and Verbinski curve yields L = 4.55 pulse height units. The derived constants were A = 0.69 and B = 0.0025 cm^2/g. The 10-MeV cutoff was chosen because the slope of the dE/dx curve inferred from the Textor and Verbinski light curve begins to change rapidly at about 10 MeV. When the calculated pulse height distribution for each neutron energy was compared with the corresponding observed distribution, the shapes were found to agree near the upper end of the spectra. In analyzing the data, only those neutron events were accepted for which the pulse height fell within this region of overlap, corresponding to pulse heights above 3 MeV. The uncertainty in the estimate of the absolute efficiency is believed to be less than 10 per cent.

For the 64-MeV measurement, a 1.43-cm aluminum plate was placed 12.7 cm in front of the neutron detector to prevent protons elastically scattered by the target from reaching the two detectors and increasing the count rates. The effect on the measurement of (p,n) reactions in the plate due to these protons was found to be negligible. However, all neutrons elastically scattered by the plate were assumed detected together with neutrons from non-elastic events emitted into the solid angle subtended by the detector at the axial center of the plate. The differential cross section for such non-elastic events was calculated from that found by a Bertini intranuclear-cascade calculation[15]) of the secondary neutron energy spectra for 50-MeV neutrons on aluminum[16]), normalized by the ratio of the total cross sections at the two energies. In calculating this fraction account must be taken of the enhanced efficiency of the detector in detecting the lower energy neutrons resulting from the interactions in the aluminum. This was done by weighting the Bertini neutron energy spectrum by the detector efficiency. The aluminum plate was thus found to cause a 3.2% decrease in the overall detector efficiency compared with a 4.0% decrease if the effect of the non-elastic events in the aluminum plate is neglected.

The flight time of the neutrons over the 4-m path from target to detector was measured with a conventional time-to-amplitude converter using a start pulse taken from the anode of the photomultiplier tube and a stop pulse derived from the cyclotron rf. The timing resolution was about 2 ns, and, for the 64-MeV measurement, was monitored using the protons elastically scattered from the beam monitor film.[9]) Corrections were made for neutrons produced in the beam monitor film, the ion chamber, and the target frame by making background measurements with the target removed.

The neutron energy spectra are shown in figure 1. The error strikes include the experimental statistical errors

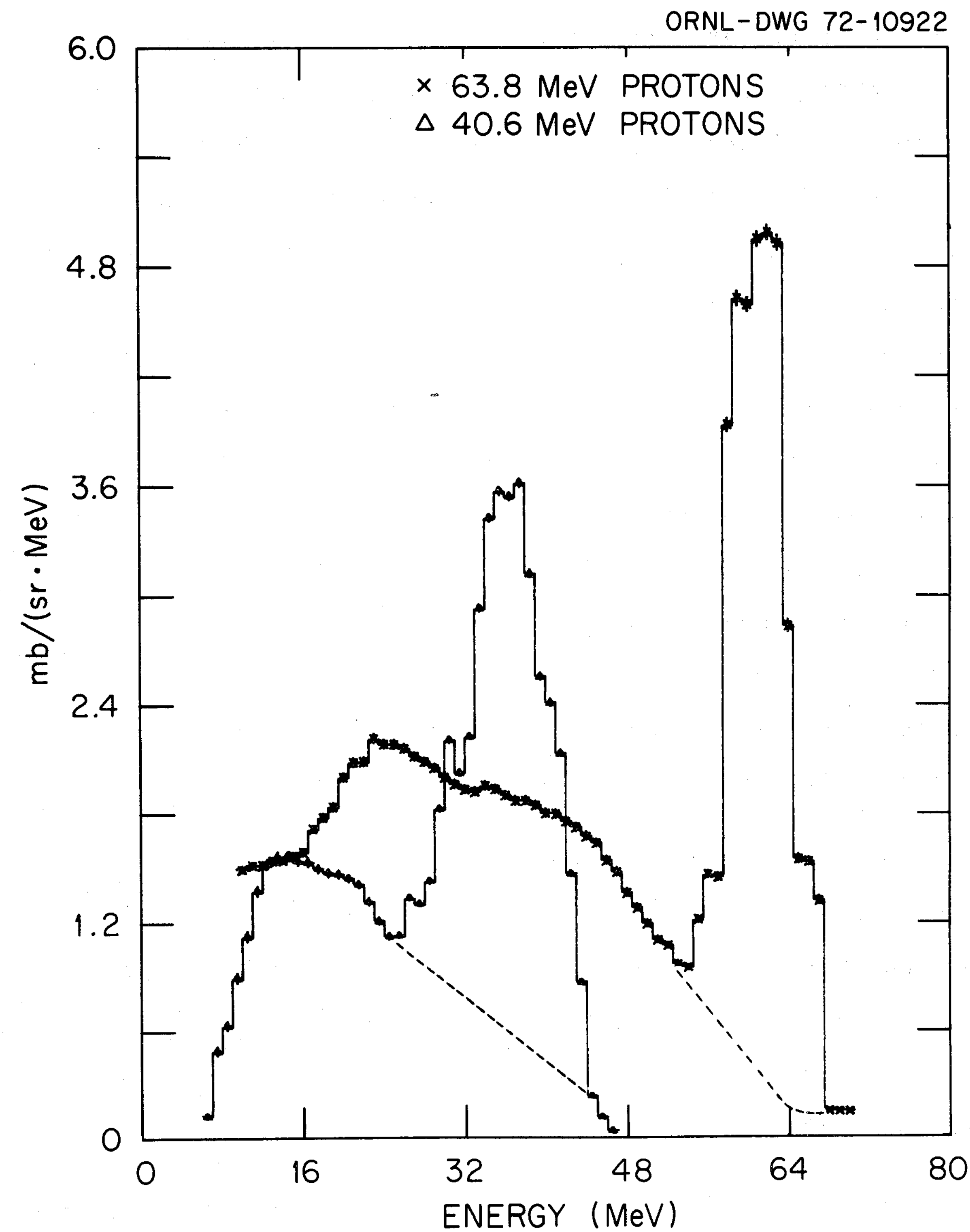

Figure 1. Secondary neutron energy spectra from the reaction $^{7}Li(p,n)^{7}Be$ viewed at zero degrees for incident proton energies of 41 MeV and 64 meV. The error strikes define the experimental statistical uncertainties. Dotted curves indicate the assumed background in determining the area under the peaks.

for the foreground and target-out background measurements. The dotted part of each curve shows the portion considered to be part of the continuous spectrum. This background is not included in the peak cross section determination. A spline fit was used for the high-energy peak background, and was believed good to within ±8%. A straight-line background was used for the 41-MeV peak background and was assigned an uncertainty of 15%. Other uncertainties in the efficiency, the total bombardment charge, and the target thickness were estimated to contribute about 10% uncertainty to each cross section. The cross sections found by integrating under the resultant peaks are 33 ± 6 mb/sr at a mean energy of 39 MeV and 36 ± 4 mb/sr at a mean energy of 60 MeV. The cross section at 39 MeV agrees within experimental error with the value of 36.5 ± 3.0 mb/sr found by Jungerman, *et al.*[5])

Figure 2 is a plot of the reported values for the $^{7}Li(p,n)^{7}Be$ high-energy peak cross section for incident protons having energies ranging from 10 to 100 MeV. The line has been drawn by hand to guide the eye among the data points. Our data appear to fit well into the trend as established by the other investigators.

These experiments indicate that ^{7}Li is a suitable source of monoenergetic neutrons over this energy range. The fact that most of the neutrons appear in the high-energy peak offsets the practical difficulties of working with

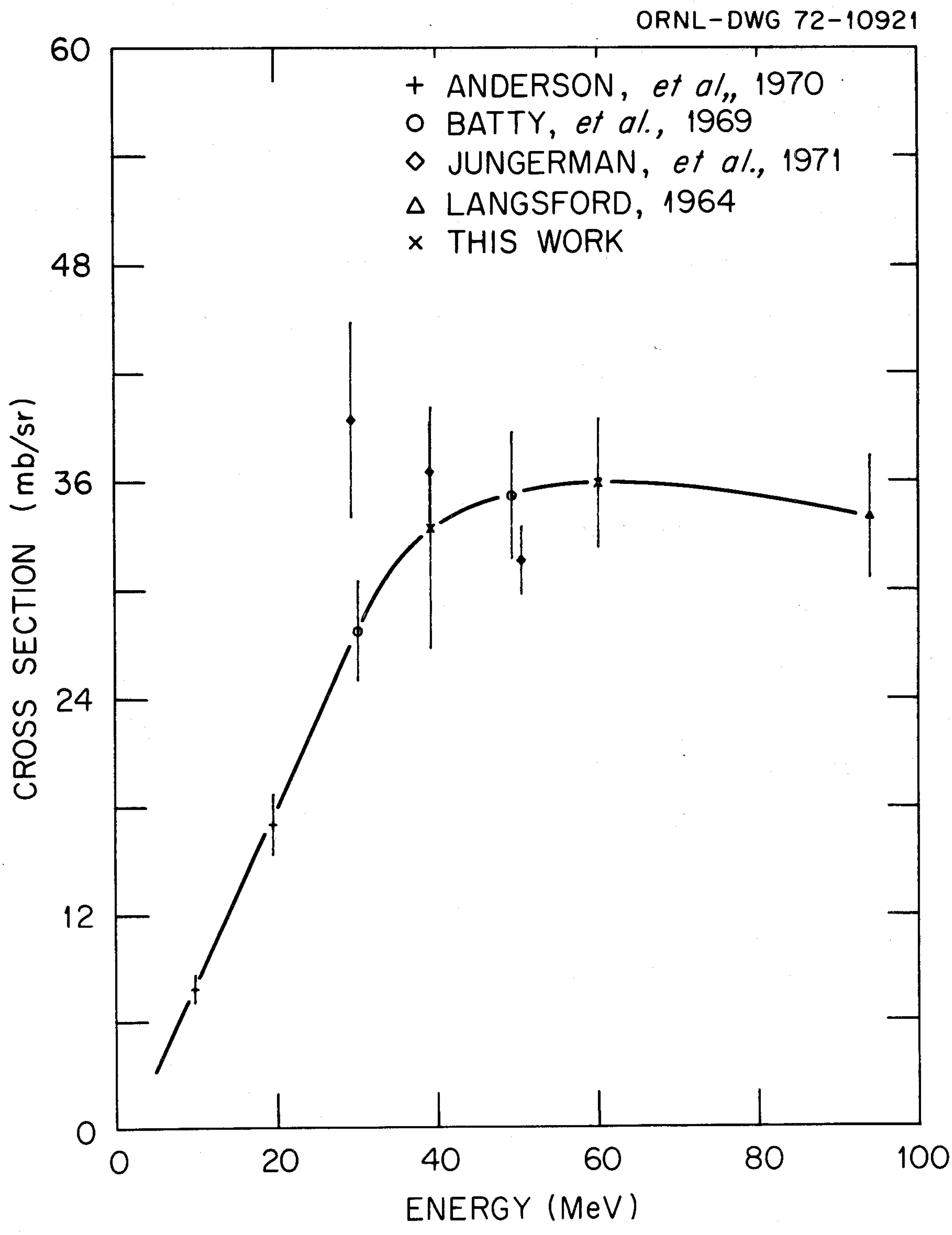

Figure 2. Neutron production cross sections from the $^{7}Li(p,n)\,^{7}Be$ reaction at zero degrees. The cross sections were found by integrating under the high-energy peak of the energy spectrum. The line has been drawn by hand to guide the eye among the data points.

elemental lithium: Although not pyrophoric, metallic lithium combines actively with the constituents of air and must be handled under oil. In a high vacuum system, a lithium target acts as a getter material in trapping the residual gases of the vacuum system and forming various compounds which increase the target thickness. Because of the small Q value of the $^{7}Li(p,n)^{7}Be$ reaction, most of the (p,n) reactions with the contaminants contribute neutrons to the tail, rather than the peak, of the energy spectrum. Selection of neutrons from the high-energy peak by time-of-flight techniques is a feasible approach.

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