LA-UR-03-5514

Approved for public release; distribution is unlimited. 07/29/03

Title: EXPERIMENTAL INVESTIGATION OF A COLD BERYLLIUM REFLECTOR-FILTER

1/3

Author(s): Eric Pitcher, Rhonda Corzine, George Morgan, Raymond Klann, Michael James, Michael Paciotti

Submitted to: Sixth International Meeting on Nuclear Applications of Accelerator Technology,
San Diego, California
June 1-5, 2003

LOS ALAMOS NATIONAL LABORATORY
3 9338 01045 4592

Los Alamos
NATIONAL LABORATORY

Los Alamos National Laboratory, an affirmative action/equal opportunity employer, is operated by the University of California for the U.S. Department of Energy under contract W-7405-ENG-36. By acceptance of this article, the publisher recognizes that the U.S. Government retains a nonexclusive, royalty-free license to publish or reproduce the published form of this contribution, or to allow others to do so, for U.S. Government purposes. Los Alamos National Laboratory requests that the publisher identify this article as work performed under the auspices of the U.S. Department of Energy. Los Alamos National Laboratory strongly supports academic freedom and a researcher's right to publish; as an institution, however, the Laboratory does not endorse the viewpoint of a publication or guarantee its technical correctness.

Form 836 (8/00)

Time-of-Flight Measurement of Neutron Leakage from a Lead-Bismuth Target

Eric Pitcher[1], Karen Corzine[1], George Morgan[1], Raymond Klann[2], Michael James[1], and Michael Paciotti[1]
[1]*Los Alamos National Laboratory, Los Alamos, New Mexico, U.S.A. 87545, pitcher@lanl.gov*
[2]*Argonne National Laboratory, Argonne, Illinois, U.S.A. 60439*

Abstract – *An experiment was conducted at the Weapons Neutron Research facility at Los Alamos National Laboratory in which neutrons leaking from a thick lead-bismuth target bombarded by 800-MeV protons were measured. Results are presented for a 50-cm-long, 20-cm-diameter PbBi target. The leakage was measured two ways: by activation foils placed on the cylindrical surface of the target, and by neutron detectors placed on collimated flight paths at several angles (7.5°, 30°, 60°, and 150°) relative to the incident proton beam direction. The time-of-flight measurements are presented in this paper. In this method, neutron energies were resolved by time-of-flight from the target to the detectors. Neutron transport through the collimated flight paths to the detectors was simulated using the radiation transport code MCNPX. Except for the 60° flight path, good agreement with experimental data is observed for neutron energies corresponding to the evaporation phase of the spallation process. For higher energy neutrons, calculations and measurements are in good agreement at forward angles, while calculations exceed measurements in the backward direction.*

I. INTRODUCTION

Spallation neutron sources create high-energy neutrons whose energies extend up to the incident proton energy. These high-energy neutrons impact the operation of accelerator-driven systems in three ways. First, they dominate the production of H and He atoms in structural materials near the target but outside of the proton beam footprint, leading to a reduction in ductility and limiting the lifetime of the structural material. Second, they produce low-energy source neutrons in the material surrounding the target, which may impact, for example, reactivity in an accelerator-driven sub-critical assembly. Finally, the high-energy neutrons dominate the radiation dose in the vicinity of a spallation source and drive the design of spallation source shielding. For these reasons, it is important to be able to properly characterize the energy and angular distribution of neutrons leaking from a spallation target with simulation codes. The purpose of the experiment reported here is to provide measured data that may be used to benchmark radiation transport codes. The present series of experiments extends the existing database of energy- and angle-dependent thin- and thick-target neutron yields produced by previous experiments [1-10].

II. EXPERIMENTAL METHOD

The experiment was carried out in the Target 2 area at the Weapons Neutron Research (WNR) facility at LANSCE. Target 2 is a shielded room approximately 12 meters in diameter with a series of flight paths radiating from the center of the room, as shown in Figure 1. Proton beams up to 100 nA can be accommodated. Neutrons leaking from the target could be observed through four flight paths at angles of 7.5°, 30°, 60° and 150° with respect to the incident proton beam.

A schematic diagram of the experimental configuration is shown in Figure 2. The LANSCE accelerator provided the proton beam, which exited the beamline vacuum through a thin stainless steel window, traveled about 2 meters through air, and then was incident on the target. A primary requirement for the measurement of proton interactions is the determination of the parameters of the incident beam. These parameters include the total integrated beam striking the target assembly in each measurement, the position of the beam on the target, and the beam intensity profile Prior to the measurements, radiochromic film was used to determine the alignment of the axis of the target with the proton beam. This alignment procedure is described in detail in below.

The dimensions for the cylindrical target for this experiment were 20 cm diameter and 50 cm length. Lead-bismuth eutectic is an alloy with 44.5% lead and 55.5%

A primary requirement for the measurement of proton interactions is the determination of the parameters of the incident beam. These parameters include the total integrated beam striking the target assembly in each irradiation, the position of the beam on the target, and the beam intensity profile. The beam monitor system is shown schematically in Figure 2.

A system was implemented to image the proton beam spot on the front face of the target. As shown in Figure 2 and consisted of a Cr-doped aluminum oxide phosphor indexed and accurately mounted on the target. A thin aluminized Mylar pellicle reflected the light from this phosphor into a lens system that relayed the image to a mirror and then into a shielded camera system consisting of a gated image intensifier and a CCD video camera. This system permitted both real-time observation of the beam size and position and also recording of the beam intensity profiles during the course of the irradiation. The image was relayed to the LANSCE accelerator control room, which permitted the operators to quickly correct any diffuse or dislocated beam spots. A VCR was part of the imaging system and recorded the beam spot over the course of the irradiation.

The incident beam current was monitored in the LANSCE Central Control Room using a standard LANSCE current monitor [11] located in the proton beamline about three meters upstream from the target. A digital reading from this monitor was recorded at 10-second intervals over the course of each irradiation, and the file of current values so generated was used to document the time-dependence of the current and, from its integral, to determine the total number of protons incident on the sample for a given irradiation. The systematic uncertainty in the calibration of this beam monitor is estimated to be about 3%. The monitor reads out with a precision of 1 nA. The nominal current used in this work was about 30 nA, so this adds a second uncertainty of about 3% for an overall uncertainty of about 4.5%.

As indicated in Figure 2, a second device was also used to monitor the proton beam current. This was a Bergoz Model ICT-122-070-20:1 integrating current transformer (ICT). The transformer was mounted between the beamline vacuum exit window and the pellicle used in the beam imaging system. The signal was processed by a charge sensitive preamplifier, linear main amplifier, and analog-to-digital converter (ADC). This device measured the charge in each micropulse of the beam and was used for real-time monitoring of the proton beam at the control station for the TOF experiments. Additionally the ADC outputs were stored in a histogram for each irradiation. The centroid of this histogram provided a measure of the average charge per beam pulse. Multiplication by the total number of beam pulses gave the integrated beam charge. This system was calibrated by recording the ADC output for the injection of a known charge into a wire loop through the ICT. Overall uncertainty of this technique was estimated to be 2%, determined mainly by the uncertainty of the injected calibration charge.

A third method employing an aluminum activation foil (see Figure 2) was used to determine the integrated proton fluence on the target assembly for several irradiations as a check on the data provided by the other techniques. The method employed a stack of three aluminum foils, each nominally 0.32 mm in thickness. The exact thickness of each foil was determined by weighing the foil and carefully measuring its dimensions (nominally 10 cm × 10 cm). Thickness measurements with a micrometer were also used to test the uniformity. Variations over the foil were found to be negligible. The proton beam fluence was then determined by counting the ^{24}Na activation products using a Germanium gamma-ray detector. Only the middle foil in each stack was counted, the presence of the upstream and downstream foils was to ensure that the center foil was in equilibrium with any recoiling reaction products. The cross section for production of ^{24}Na by 800-MeV protons has been studied previously and has an uncertainty of less than 2% [12]. The half-life for ^{24}Na is 14.9590 hours and the 1.368-MeV gamma ray is produced in 99.9936% of the decays. A calibrated ^{60}Co source was counted simultaneously with the aluminum foil. In this way the activity of the ^{24}Na could be determined by direct comparison of the counting rate with the ^{60}Co source, requiring only a small correction for the difference in energies between the 1.332-Mev gamma ray from 60Co and the 1.368-Mev gamma ray from ^{24}Na. The ^{60}Co source was NIST-traceable with quoted uncertainties of 2% (at the 99% confidence level). The measured activity was corrected for decay after irradiation. A small additional correction for decay of the ^{24}Na during the irradiation (2 to 4 hours) has been applied. Overall uncertainty in the proton beam determination by this method is less than 2%.

Two data acquisition sequences were performed at each of the three target positions. These target positions were nominally with the face of the target at 0 cm, 20 cm (upstream), and 40 cm with respect to the intersection of the proton beam axis and flight path axes. However, the target was actually shifted 1 cm downstream so the target positions were −1, 19 and 39 cm. The first data acquisition sequence used the plastic detectors to obtain data in the high-neutron-energy region (~0.5 to 800 MeV). This required about 1.5 hours of beam (~20 nA) on target at each target position and used 20-μs spacing for the beam pulses. The second sequence used the Li-loaded glass detectors to obtain data in the lower-energy region (<0.1 to 1 MeV). About 8 hours of beam time (~25 nA) were required for each target position with a beam pulse spacing of 40 μs.

The data from the plastic detectors were acquired in two time-of-flight spectra, corresponding to two different

utilize the powerful next-event estimator variance reduction technique to significantly reduce the run time as compared to analog Monte Carlo transport. However, as will be shown and as discussed in the MCNPX manual [14], point detectors give incorrect results in this particular application.

The second technique used to calculate the neutron flux at the detector positions was the surface flux (type 2) tally. With tally surface areas of 79 cm^2 located 30 to 60 m from the target and full analog transport, these calculations were very time consuming. Typical runs used over 10^7 minutes of cpu time on 1.7-GHz Pentium IV processors. As a means of reducing the run time, the collimation systems were replicated multiple times in azimuth. This scheme is depicted graphically in Figure 5 for the 7.5° and 30° flight paths, where the collimation is replicated five and ten times, respectively.

The two tally techniques are compared in Figure 6, where the transition energy from the point detector tally to the surface current tally is changed from 150 MeV to 1 MeV. In the tabular range where the point detector tally may be used, its result is considerably less than the surface current tally over most of the energy range, with the largest discrepancy, a factor of 4.2, occurring at the highest energy (150 MeV). This discrepancy becomes smaller at lower energies, decreasing to a factor of 1.3 at 1 MeV. This discrepancy is due to the fact that neutrons created by nuclear interactions whose incident particles are not in the tabular region (in this case, neutrons created by all protons and pions, and by neutrons with energies greater than 150 MeV) do not contribute to the point detector tally. Even for this thick target configuration, such neutrons comprise a significant fraction of those that are transported to the detector positions. So the point detector tally underpredicts the detector flux, and is invalid in this application. All

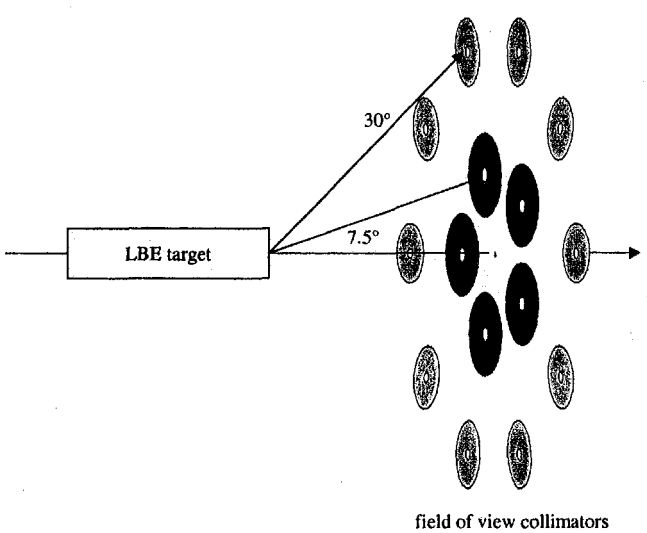

Figure 5. Azimuthal replication of the collimators.

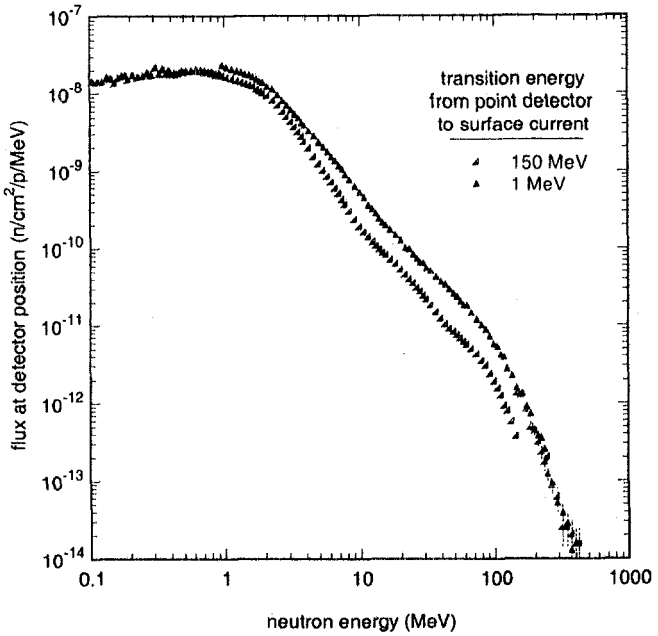

Figure 6. Comparison of the two tally methods: flux at 150°.

calculated results presented here use the surface current tally above 1 MeV and the point detector tally below 1 MeV.

The calculated source brightness is shown in Figure 7. Qualitatively, the calculated results show the same trends as the measured data displayed in Figure 3, with the exception that the leakage flux of lower-energy (~1 MeV) neutrons is higher for the 60° flight path than for the 30° flight path.

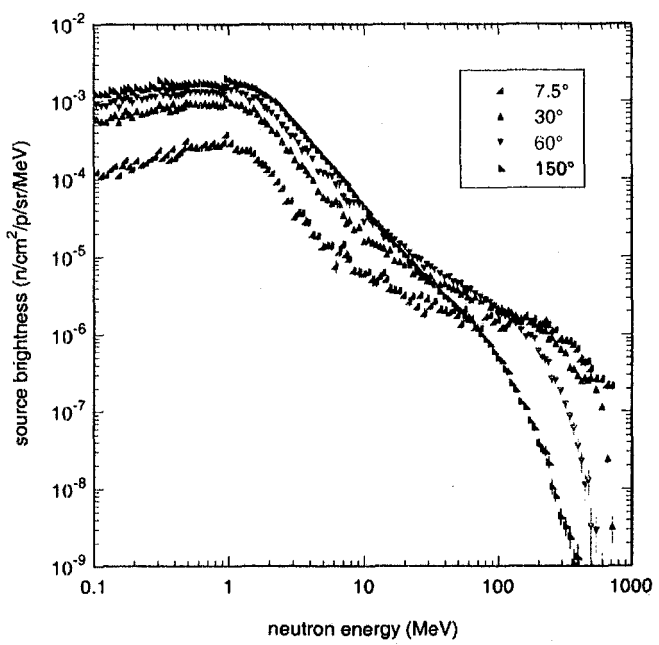

Figure 7. Calculated energy-dependent source brightness.

MCNPX, and calculated results have been compared to the measurements. Agreement is excellent at 7.5° and 30°. The measured low-energy neutron yield at 60° appear to be anomalously low, and are therefore not considered to be reliable. Agreement between experiment and calculation at 150° is excellent below ~80 MeV neutron energy. Above this energy, calculated results overpredict the measured values by a significant amount.

VII. ACKNOWLEDGEMENTS

The authors wish to thank Keith Woloshun and Valentina Tcharnotskaia for fabricating the target, and Gregg Chaparro for his assistance in setting up the experiment. This work was supported by the U.S. Department of Energy under contract No. W-7405-Eng-36 with the University of California.

REFERENCES

1. M.M. Meier, D.B. Holtkamp, G.L. Morgan, H. Robinson, G.J. Russell, E.R. Whitaker, W.B. Amian, and N. Paul, "318 and 800 MeV (*p,xn*) Cross Sections," *Radiation Effects* **96**, 73 (1986).
2. M.M. Meier, C.A. Goulding, G.L. Morgan, and J.L. Ullmann, "Neutron Yields from Stopping- and Near-Stopping-Length Targets for 256-MeV Protons," *Nucl. Sci. Eng.* **104**, 339 (1990).
3. M.M. Meier, D.A. Clark, C.A. Goulding, J.B. McClelland, G.L. Morgan, C.E. Moss, and W.B. Amian, "Differential Neutron Production Cross-Sections and Neutron Yields from Stopping-Length Targets for 113-MeV Protons," *Nucl. Sci. Eng.* **102**, 310 (1989).
4. M.M. Meier, W.B. Amian, C.A. Goulding, G.L. Morgan, and C.E. Moss, "Neutron Yields from Stopping-Length Targets for 256-MeV Protons," *Nucl. Sci. Eng.* **110**, 299 (1992).
5. M.M. Meier, W.B. Amian, C.A. Goulding, G.L. Morgan, and C.E. Moss, "Differential Neutron Production Cross Sections for 256-MeV Protons," *Nucl. Sci. Eng.* **110**, 289 (1992).
6. W.B. Amian, R.C. Byrd, C.A. Goulding, M.M. Meier, G.L. Morgan, C.E. Moss, and D.A. Clark, "Differential Neutron Production Cross Sections for 800-MeV Protons," *Nucl. Sci. Eng.* **112**, 78 (1992).
7. W.B. Amian, M.M. Meier, R.C. Byrd, C.A. Goulding, G.L. Morgan, and C.E. Moss, "Efficiency Calibration of a Cylindrical BC418 Neutron Detector at Neutron Energies Between 135 and 800 MeV," *Nucl. Instrum. Methods* **A313**, 452 (1992).
8. W.B. Amian, R.C. Byrd, D.A. Clark, C.A. Goulding, M.M. Meier, G.L. Morgan, and C.E. Moss, "Differential Neutron Production Cross Sections for 597-MeV Protons," *Nucl. Sci. Eng.* **115**, 1 (1993).
9. S. Leray, A Boudard, R. Legrain, Y. Terrien, W. Wlazlo, F. Borne, F. Boué, S. Crespin, D. Drake, J. Fréhaut, X. Ledoux, E. Martinez, Y. Patin, P. Pras, E. Petibon, J.L. Boyard, F. Brochard, J.C. Duchazeaubeneix, J.M. Durand, L. Kowalski, S.I. Meigo, G. Milleret, F. Plouin, J. Thun, D.M. Whittal, D. Durand, C. Lebrun, J.F. Lecolley, F.R. Lecolley, F. Lefebvres, M. Louvel, C. Varignon, S. Ménard, J.P. Shapira, F. Hanappe, L. Stuttge, "Spallation Neutron Studies at SATURNE, CEA/Saclay report DAPNIA/SPhN-98-45 (1998).
10. X. Ledoux, F. Borne, A Boudard, F. Brochard, S. Crespin, D. Drake, J.C. Duchazeaubeneix, D. Durand, J.M. Durand, J. Fréhaut, F. Hanappe, L. Kowalski, F.R. Lecolley, J.F. Lecolley, F. Lefebvres, R. Legrain, S. Leray, M. Louvel, E. Martinez, S.I. Meigo, S. Ménard, G. Milleret, Y. Patin, E. Petibon, P. Pras, L. Stuttge, Y. Terrien, J. Thun, M Uematsu, C. Varignon, D.M. Whittal, and W. Wlazło, "Spallation Neutron Production by 0.8, 1.2, and 1.6 GeV Protons on Pb Targets," *Phys. Rev. Letters* **82**, 4412 (1999).
11. F.R. Gallegos, *Development of a Low Intensity Current Monitor System*, Los Alamos National Laboratory report LA-UR-91-3400 (1991).
12. G. Morgan, G. Butler, M. Cappiello, S. Carius, L. Daemen, B. DeVolder, J. Freshut, C. Goulding, R. Grace, R. Green, P. Lisowski, P. Littleton, J. King, N. King, R. Prail, T. Stratton, S. Turner, J. Ullmann, F. Venneri, and M. Yates, "LANL Sunnyside Experiment: Study of Neutron Production in Accelerator-Driven Targets", International Conference on Accelerator-Driven Transmutation Technologies and Applications, *AIP Conference Proceedings* **346**, 682 (1994).
13. M.B. Chadwick, P.G. Young, R.E. MacFarlane, P. Moller, G.M. Hale, R.C. Little, A.J. Koning, S. Chiba, "LA150 Documentation of Cross Sections, Heating, and Damage: Part A (Incident Neutrons) and Part B (Incident Protons), Los Alamos National Laboratory report LA-UR-96-1222 (1996).
14. L. Waters, ed., MCNPX User's Manual Version 2.4.0, Los Alamos National Laboratory report LA-CP-02-408, (2002).
15. R.E. Prael and M. Bosion, "Adaptation of the Multistage Preequilibrium Model for the Monte Carlo Method (I)," Los Alamos National Laboratory report LA-UR-88-3238 (1988).