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NEUTRON FLUX ENHANCEMENT AT LASREF

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ABSTRACT

The accelerator at the Los Alamos Meson Physics Facility produces a 1-mA beam of protons at an energy of 800 MeV. Since 1985, the Los Alamos Spallation Radiation Effects Facility (LASREF) has made use of the neutron flux that is generated as the incident protons interact with the nuclei in targets and a copper beam stop. A variety of basic and applied experiments in radiation damage and radiation effects have been completed.

Recent studies indicate that the flux at LASREF can be increased by at least a factor of ten from the present level of about $5 \times 10^{17} \text{ m}^{-2}\text{s}^{-1}$. This requires changing the beam-stop material from Cu to W and optimizing the geometry of the beam-target interaction region. These studies are motivated by the need for a large volume, high energy, and high intensity neutron source in the development of materials for advanced energy concepts such as fusion reactors.

Introduction

The Los Alamos Spallation Radiation Effects Facility (LASREF) at Los Alamos Meson Physics Facility (LAMPF) provides a neutron flux generated by 800-MeV protons as they interact through spallation reactions with metal targets at the beam stop. Over the past seven years[1], a number of radiation-damage and radiation-effects experiments studying basic mechanisms as well as applications to accelerators have been completed at LASREF.

The initial neutron flux and spectrum characterization of the facility was done by calculation[2] using the Nucleon Meson Transport Code (NMTC)[3] and the High Energy Transport Code (HETC)[4]. Activation foil measurements[5] confirmed the calculations and determined the dependence of flux and spectrum on position within the facility as well as on the beam-stop target geometry. Subsequently each experiment has included a set of activation foils that are analyzed, through use of the STAY'SL code[6], to determine achieved fluence and the attendant spectrum.

Early computations of radiation damage parameters due to high-energy particles[7] considered 800-MeV protons incident on copper. These computations used a modified NMTC code, VEGAS Nucleon Meson Transport Code (VNMTC). VNMTC was later adapted to compute radiation damage parameters on copper as a result of exposure to the LASREF neutron flux and spectrum[8].

Calculations[2,8] determined the maximum available neutron flux at $5.5 \text{ E}+17 \text{ m}^{-2}\text{s}^{-1}$ ($E > 1 \text{ keV}$). Measurements[5] later showed that the maximum achievable flux was $4.6 \text{ E}+17 \text{ m}^{-2}\text{s}^{-1}$ ($E > 1 \text{ keV}$). This flux level is sufficient for many studies of basic mechanisms of radiation damage and for accelerator material development. This level was also determined to be adequate[9] for development of radiation-hardened materials needed for fusion-reactor plasma and magnetic-field diagnostic systems. However, a higher flux is needed for study of radiation effects on fusion-reactor first-wall materials. A higher flux is also needed for development of materials for the target-blanket system at the Accelerator Transmutation of Waste (ATW) project where neutron flux levels may approach $10^{20} \text{ m}^{-2}\text{s}^{-1}$.

The purpose of this report is to describe a study that determined a new geometry for LASREF resulting in an increased flux. The work described here has lead to a hypothesis that suggests that the addition of a higher atomic number element such as uranium or lead on the outer radius of the tungsten target would moderate the high-energy ($E > 50$ MeV) neutrons through (n,xn) reactions.

LASREF geometry

Figure 1 is a schematic diagram showing the neutron-producing targets and eight of the twelve neutron-irradiation areas (inserts) at LASREF. Measurements[5] showed that the effect of a distributed source as produced by the Isotope Production (IP) targets was a factor of 1.6 decrease in maximum achievable flux, relative to measurements made for only a copper beam stop. For the calculations described below, the IP targets have been removed. The resulting geometry is shown in Figure 2.

For the present calculations, the geometry was modeled as a right circular cylinder of target material. Neutron flux was determined at the surface of the target.

The present LAMPF beam stop is made of copper with the diameter set at 210 mm to accommodate a Gaussian-like radial intensity profile beam with $2\sigma = 50$ mm (σ is one standard deviation). Recently, the beam size at LASREF was reduced to $2\sigma = 35$ mm, allowing consideration of a smaller-diameter beam stop. In addition, experience with a machineable tungsten alloy (90%W, 3.5%Ni, 1.5%Cu) showed that this material can be used as a high-energy-proton beam stop. Based on the above and the hypothesis that neutron flux would be increased both by a reduction in beam-stop diameter (closer to the source of neutron production) as well as by an increase in the atomic number of the beam stop material, the following parameters were chosen for this study; beam-stop diameter of both 210 mm and 105 mm for both copper and a tungsten alloy.

Calculations

The Los Alamos High Energy Transport code (LAHET)[11], an extension of HETC, was used for these calculations. This code provides an option of intranuclear cascade models; either the Bertini-Serber[12] or ISABEL[13,14] model may be used. Benchmark calculations[15] of neutron yields from stopping-length targets bombarded by 113-MeV and

256-MeV protons showed that the two models give similar results; the Bertini-Serber model was used for this study. This code also uses the Fermi breakup model for excited light nuclei (instead of an evaporation model) and a multistage preequilibrium model operating between the intranuclear cascade and the Fermi breakup model.

The beam was modeled as Gaussian with $2\sigma = 35$ mm. It was necessary to use 1.6×10^5 800 MeV protons for the LAHET calculation and 8×10^4 800 MeV protons for the MCNP calculation in order to obtain acceptable, statistically significant results. The number of neutrons and protons leaving the surface of the beam stop were tallied as a function of distance along the beam stop; total length of the beam stop was set at 0.71 m. The calculations used the Los Alamos National Laboratory, CRAY X-MP/416 computers; about 7 hours of Central Processing Unit time was necessary for each case.

Results

The results of the calculations are shown in Figure 3 as a plot of neutron flux in energy bins as a function of neutron energy for both a copper and tungsten beam stop, each at radii of 52.5 mm and 105 mm. The flux is determined at the surface of the beam stop and at a level based on a total proton beam current of 1 mA. The same results are given in Figure 4 as a plot of integral flux, total flux above energy E as a function of neutron energy. As the radius of the beam stop decreases and the measure of neutron flux is made nearer the source of neutron production, the neutron flux increases. This increase is a factor of about 2.2 increase for a decrease in radius (r) of a factor of 2. For a given beam-stop radius, the increase in neutron flux from tungsten relative to copper is a factor of 2.3.

It is interesting to compare the calculated and measured flux at LASREF to that at an operating neutron source, Fast Flux Test Facility (FFTF)[16], as well as to a fusion reactor design, DEMO[17], and the International Thermonuclear Experimental Reactor (ITER)[18]. Figure 5 shows this comparison on an integral flux plot. The total flux at LASREF calculated for a small diameter tungsten target is seen to be comparable in total flux to that expected at ITER. Figure 6 compares the different spectra at FFTF, DEMO, and that calculated for a small-diameter tungsten target at LASREF by plotting

neutron flux in energy bins as a function of energy. The objective of the present study is to determine a geometry of suitable materials at LASREF that will moderate the high-energy ($E > 50$ MeV) neutrons to energies in the range $5 < E < 20$ MeV. When such a geometry is found, LASREF will be a more suitable test bed for metal-alloy studies for fusion-reactor systems[9].

In Table 1, a summary is given of neutron flux at the present LASREF, what can be expected as the LASREF beam stop is modified, as well as the flux available at FFTF and expected at DEMO and ITER.

TABLE 1. Comparison of neutron flux at LASREF (1 mA), FFTF, DEMO and ITER.

Reference	Beamstop radius mm	Neutron flux($\times 10^{17} \text{ m}^{-2} \text{ s}^{-1}$) ($E > 1$ keV)
Wechsler, et al.[8]	105	5.5
Davidson, et al.[5]	105 (flux at 120 mm)	2.8 (with IP targets) 4.6 (copper beam stop)
Present (copper)	105	8.1
Present (copper)	52.5	18.1
Present (tungsten)	105	19.0
Present (tungsten)	52.5	41.9
ITER[18]	—	40
DEMO[17]	—	134
FFTF[16]	—	452

For LASREF, the variation of neutron flux along the length of the beam stop is also of interest. Figure 7 shows the dependence of total neutron flux ($E > 1$ keV) on position along the beam stop for the small diameter configuration for both copper and tungsten. The variation can be as low as 10% over a distance of 100 mm. This will allow large-volume experiments to achieve a uniform flux.

Measurements[5] as well as calculations[2,8] have shown an approximate $1/r$ (r is radius) dependence of neutron flux on radius. At LASREF it is possible to place exper-

iments essentially on the surface of the beam stop and out to a radius as large as 0.5 m. Design of experiment capsules must recognize this flux gradient.

Protons as well as neutrons are generated at the LASREF beam stop. The majority of the protons are stopped in the beam stop itself. Table 2 gives the ratio of protons to neutrons as determined by this study.

TABLE 2. The ratio of the number of protons ($E > 1$ MeV) to the number of neutrons ($E > 1$ keV) for the beamstop configurations used in this study.

Beam Stop Radius	Copper Beam Stop	Tungsten Beam Stop
52.5 mm	2.8 E-02	7.8 E-03
105.0 mm	4.1 E-03	1.7 E-04

Conclusions

It is possible to increase the neutron flux at LASREF by a factor of about 10 by removing the IP targets, changing the beam-stop material from copper to tungsten, and decreasing the beam-stop diameter. Further, it has been hypothesized at a recent review of LASREF[9] that the addition of a higher-atomic-number element such as uranium or lead at the outer diameter of the beam stop would decrease the neutron flux in the high-energy ($E > 50$ MeV) region and increase the overall flux, through (n,xn) reactions. The resulting spectrum would then more closely resemble that expected at fusion reactor devices.

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Figure Captions

Figure 1. Schematic diagram of the neutron-irradiation area at LASREF showing 8 insert locations and the Isotope-Production targets and copper beam stop.

Figure 2: Schematic diagram of the neutron irradiation area as LASREF including 8 inserts and the copper beam stop.

Figure 3a: Calculated neutron flux for copper beam stops of radius 52.5 mm and 105 mm at LAMPF operating at a current of 1 mA. The plot shows neutron flux in energy bins as a function of energy.

Figure 3b: Calculated neutron flux for tungsten beam stops of radius 52.5 mm and 105 mm at LAMPF operating at 1 mA. The plot shows neutron flux in energy bins as a function of energy.

Figure 4: Calculated integral neutron flux as a function of energy comparing copper and tungsten beam stops of radius 52.5 mm and 105 mm at LAMPF operating at 1 mA.

Figure 5: Comparison of the integral neutron flux as a function of energy among FFTF, DEMO, ITER, and LASREF with 52.5-mm-radius tungsten beam stop. Also included is the flux level available at LASREF, at present.

Figure 6: Comparison of neutron flux in energy bins as a function of energy among FFTF, DEMO, and LASREF with a 52.5-mm-radius tungsten beam stop.

Figure 7: Calculated variation in total neutron flux as a function of distance along the beam stop for copper and tungsten at a radius of 52.5 mm.

LAMPF TARGET STATION A-6
NEUTRON IRRADIATION AREA

**LAMPF TARGET STATION A-6
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