Experimental determination of neutron beam fluxes at LANSCE from gold foil activation

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Introduction

The purpose of this work was threefold: (1) to measure fluxes at the experimental locations for more efficient design and use of the instruments; (2) to compare measured fluxes with those predicted by state-of-the-art Monte Carlo computer code calculations incorporating a detailed mockup of the LANSCE target-moderator-reflector-shield geometry; and (3) to compare the fluxes from the unique flux-trap design with more conventional target-moderator systems of ISIS and ZING-P'.

In measurements taken at Rutherford-Appleton Laboratory, T. G. Perring, A. D. Taylor, and D. R. Perry[1] emphasized the thermal neutrons by suppressing the epithermal neutron activation through self-shielding in very thick gold foils. The experimenters then matched the activations with those calculated from independent, experimentally determined neutron-spectral shapes to calculate the 1 eV neutron fluxes.

T. G. Worlton and J. M. Carpenter[2] at Argonne measured the 1-eV fluxes directly by using cadmium-shielded 22.56-mg/cm^2 thick gold foils. They determined the necessary self-shielding corrections by irradiating a stack of three foils. Preliminary corrections were applied to the specific activities of the foils using the following approximation for the self-shielding correction g:

$$g(\tau) = e^{-\tau/2}\,[I_0(\tau/2) + I_1(\tau/2)],$$

where τ is the thickness $n\sigma x$, σ is the Doppler-broadened peak capture cross section (27, 370 b), and I_0 and I_1 are modified Bessel functions of the first kind.

Their final values for the corrected specific activities were then determined by extrapolating the proximate results as a function of foil thickness to zero thickness.

Our measurements at LANSCE parallel these latter experiments for the 1-eV flux. We have, however, irradiated bare Au foils for additional data on the subcadmium flux. In the future we plan to use a modified cadmium-difference method, taking into account the undermoderated spectrum from a pulsed-spallation source, which is rich in epithermal neutrons.

Measurement location

The measurements were made of flight paths (FP) 1, 3, 7 and 8 at LANSCE. The moderator configuration has been described previously by Russell, et al[3]. All of these flight paths view water moderators poisoned heterogeneously with gadolinium. FP 1 views a "high-resolution" moderator, with a boron decoupler/liner. FP 3 views a "high-intensity" moderator, which is decoupled with cadmium. FP 7 and 8 both view a second "high-intensity" moderator.

Proton beam monitor and normalization

The LANSCE experiments consisted of three successive irradiations in which we determined the relative number of protons from a current monitor that recorded the output of the Proton Storage Ring (input minus loss). In the last experiment we also determined the absolute number of protons from the number of reactions that occurred in an aluminum-monitor foil packet irradiated in a harp box ~3 m in front of the bending magnet for vertical insertion into the target. After irradiation the packet, which consisted of 0.025-mm-thick Al foil sandwiched between two 0.025-mm Al recoil compensating foils, remained in the box but out of the beam for an additional 12 days to avoid opening the beam line during the run cycle. Of the three reaction products we measured, the yields of ^{22}Na and ^{24}Na were clearly augmented by secondary low-energy neutron reactions, and only the ^{27}Al(p,x)^{7}Be reaction, where the product is removed from the target nucleus in Z and A, gave a valid result. The number of protons may still be an upper limit because the beam is defocused before it enters the tungsten target.

Two Au samples separated vertically by 1.27 cm were irradiated at the experimental location in each of the flight paths we studied. The upper foil was always a bare 0.0127-mm-thick foil for use as a monitor. In the first irradiation the lower sample consisted of a stack of three 0.0127-mm-thick Au foils in a 0.76-mm-thick cadmium cover. In the second run, and in FP 8 in the third run, both the upper and lower samples were bare gold.

The Au monitor foils indicated that while the relative neutron production per proton viewed by FP 8 was constant in all three runs, production for FP 1 and 3 were lower by 12% and 9%, respectively, in Run 1 than in Run 2, presumably because of poorer beam quality, which improved with changes in steering and focusing. The final number of protons based on the Al monitor foil and relative integrated beam current from the current monitor were, therefore, also normalized for beam quality through the Au monitors.

Calculation of epithermal flux

The neutron flux at 1 eV at the experimental location, normalized to the number of protons is given by the following:

$$I(E)_{1\,eV} = \frac{^{198}N}{^{197}N\, a_{Cd}\, g\, N_p RI\, (1 + 0.029/g)},$$

where $^{198}N/^{197}N$ = the number of ^{198}Au atoms produced per atom of Au in the foil

a_{Cd} = attenuation correction for the cadmium cover for 4.906-eV neutrons

g = gold self-shielding correction

N_p = number of protons for the irradiation

RI = 1.71×10^{-21} cm^2, resonance integral for Au in a neutron spectrum, which we assumed had the form $I(E) = I(E^*)\,[E/E^*]^{-0.92}$.

Our value for the self-shielding correction for Au from stacked foil data differed from the measurement of Worlton and Carpenter by less than 1% for the same foil thickness. The quantity 0.029/g is the contribution of the 1/v part of the Au capture cross section to the total activations.

Results and conclusions

The results are given in Table 1. Columns 1 and 2 delineate the flight path number and moderator type. Columns 3 and 4 give the flight-path lengths (from moderator to foil) and moderator field-of-view (i.e., the effective area of moderator viewed by the foil). This area, A, is obtained simply by projecting the limiting upstream thermal-neutron aperture (i.e., the aperture closest to the moderator) from a point in the foil plane on to the moderator surface. As the foils in each beam line were identical, the intensities measured should be proportional to a $\cos\theta/L^2$, where θ is the angle between the flight path and the moderator normal.

Table 1. Measured epithermal neutron-beam fluxes at LANSCE.

Flight Path	Moderator Type	Foil Position L (cm)	Moderator Field-of-view A (cm^2)	Cadmium Ratio	1 eV Flux, I(E) at L (10^{-9}/eV cm^2 p)	1 eV Flux, I(E) at moderator* (10^{10}/eV sr µA s)
1	High Resolution H_2O	3175	141.2	1.09	0.44	2.82
3	High Intensity H_2O A	900	131.5	1.29	5.26	3.01
7	High Intensity H_2O B	1300	139.8	1.13	2.61	2.84
8	High Intensity H_2O B	660	50.8	1.37	3.40	2.71

*For a 12 x 12 cm field of view.

Column 5 gives the cadmium ratios for each flight path. These were obtained with thick Au foils (22.6 mg/cm^2); the values for thin foils would be closer to unity. There appear to be significant differences between flight paths, even for FP 7 and 8, which view the same moderator. For these two beam lines, we have also examined the spectra measured by low-efficiency BF_3 monitors. The spectra were fitted to the standard spectral function previously used by Carpenter, et al.[4] The result of this analysis is that the epithermal-to-Maxwellian ratios for FP 7 and 8 agree to within 1%. It is, therefore, very unclear whether the differences in cadmium ratio are significant.

In columns 6 and 7, we list the epithermal fluxes at the foil position and moderator surface, respectively. In the latter case, we have corrected for the solid angle of the measurement. One would expect the epithermal fluxes to be similar for all four flight paths and, indeed, the agreement is very good. For comparison with calculations, see reference 5.

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