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USE OF A COLD BERYLLIUM REFLECTOR-FILTER TO ENHANCE COLD SOURCE BRIGHTNESS AT LONG WAVELENGTHS

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ABSTRACT

Use of a cold beryllium reflector-filter to enhance cold source brightness at long wavelengths is a decades-old concept, yet it has never been implemented at any spallation source facility. Experimental investigations of its efficacy have met with limited success. Our calculations indicate that it provides a 47% boost in long-wavelength (>4 Å) brightness on a short-pulse source, while a gain factor of 1.57 is realized on a long-pulse source. Finally, calculations indicate that there is negligible benefit to its implementation on a steady-state source.

1 Introduction

The potential efficacy of a cold Be reflector-filter to enhance cold source brightness at long wavelengths has been recognized for decades. The concept takes advantage of the Bragg edge in the Be scattering cross section at 5 meV (see Figure 1). Above 5 meV, the cross section is 6.4 b. Just below 5 meV, the cross section depends on the Be temperature. At room temperature, it is 0.5 b. By cooling the Be to 77 K, the cross section drops by nearly two orders of magnitude to 8 mb, such that it is highly transparent to low-energy neutrons. At this temperature, the mean-free path of a 4-meV neutron is approximately 10 m, whereas a 7-meV neutron has a 9-mm mean-free path. Thus placement of a thick slab of 77-K Be at the emission surface of a cold moderator will reflect neutrons with energies greater than 5 meV back into the moderator while transmitting neutrons below this energy. The reflected neutrons then have another opportunity to downscatter to lower energy prior to escaping the moderator again. In this way the long-wavelength source brightness may be significantly enhanced.

Several experiments have been carried out to evaluate the effectiveness of a Be reflector-filter.[1,2] Carpenter, et al.,[1] measured the energy spectrum of a coupled, liquid hydrogen moderator with and without a warm (300 K), 3.8-cm-thick, Be reflector-filter in place. Unfortunately, their measurements of flux were not absolute and so no conclusion about long-wavelength gain as a result of using the reflector-filter can be drawn. However, the reflector-filter did add considerable structure to the spectrum, and shows the reflector-filter configuration to have a 2-meV-to-1-eV flux ratio that is perhaps 30% greater than that of the unfiltered configuration.

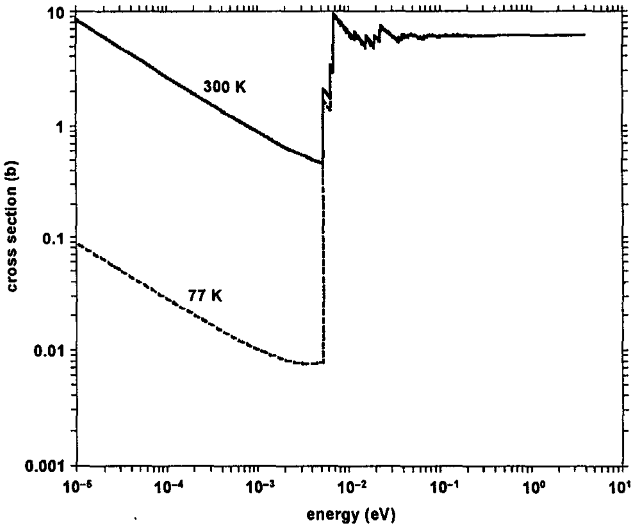


Figure 1. Total cross section of beryllium at 77 and 300 K.

Kiyanagi, et al.,[2] have measured experimentally the effect of a cold Be reflector-filter on a coupled liquid hydrogen moderator. Their experimental configuration utilized a 12×12×5-cm^3 moderator, a 2-cm-thick polyethylene premoderator, and a graphite reflector. The 1.5-cm-thick Be reflector-filter was attached directly to the hydrogen moderator so that its temperature was presumably 20 K. They measured no significant gain in the long-wavelength region due to the presence of the reflector-filter.

2 Analysis

A scattering kernel for 77-K beryllium was recently produced, allowing us to numerically analyze the performance of a cold Be reflector-filter on a variety of cold sources. Using the LAHET Code System,[3] we have investigated its efficacy on three types of sources: a short-pulse source, a long-pulse source, and a steady-state source.

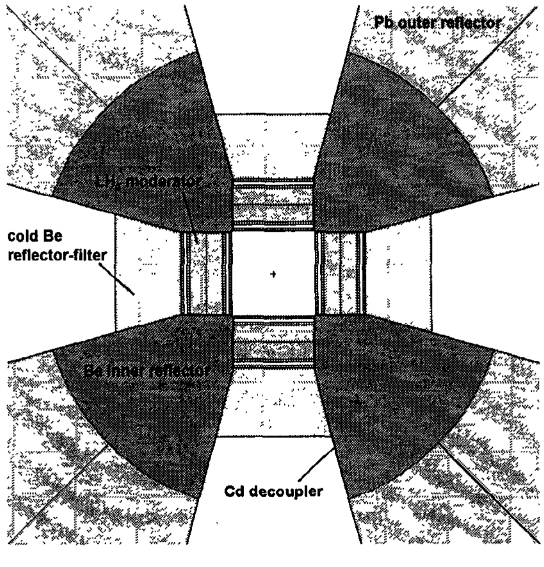


Figure 2. Short-pulse source configuration.

2.1 Short-Pulse Source Performance

We evaluated the performance of a cold Be reflector-filter installed on decoupled liquid hydrogen moderators arranged in flux-trap geometry. The decoupled moderator system chosen for this study is shown in Figure 2. The unpoisoned moderators are 12×12×5 cm^3 in size and decoupled by 0.081 cm of Cd. The flight paths have angular openings of 15° and are lined with 0.081-cm-thick Cd. The hydrogen composition is assumed to be 90% para-, 10% ortho-hydrogen. The inner reflector is room-temperature beryllium with a 70-cm diameter and height. The outer reflector is lead.

The reflector-filter thickness was varied and the source brightness, integrated below 5-meV energy, was calculated. Results are plotted in Figure 3. They show the long-wavelength brightness is 47% greater with a 10-cm reflector-filter than without one. Spectra for the unfiltered and 6-cm-thick reflector-filter configurations are plotted in Figure 4. Considerable structure is evident in the filtered case, due to reflection of neutrons with energies below 4 Å. Significant enhancement in the long-wavelength flux is also apparent. Plotted in Figure 5 is the wavelength-dependent ratio of the source brightness for these two cases. The magnitude of the dip in the ratio around 3 Å depends strongly on the reflector-filter thickness; some enhancement in the 2- to 3.5-Å range with a small penalty in long-wavelength gain may be realized by simply making the reflector-filter thinner. Because of the close proximity of the reflector-filter

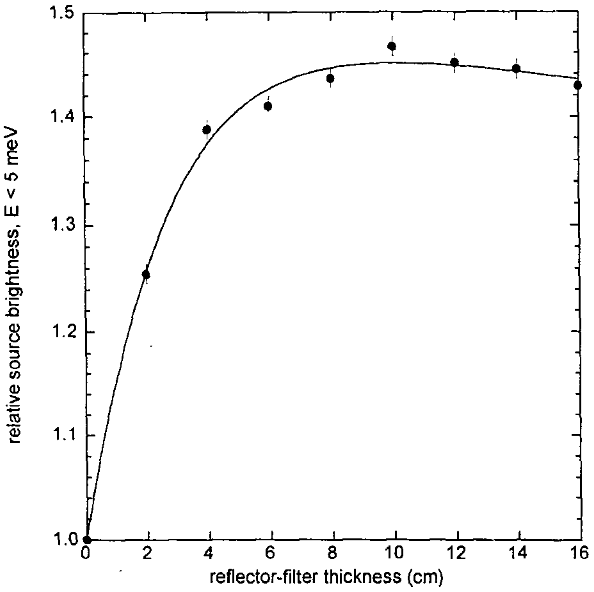


Figure 3. Relative source brightness (E < 5 meV) on a short-pulse source as a function of reflector-filter thickness.

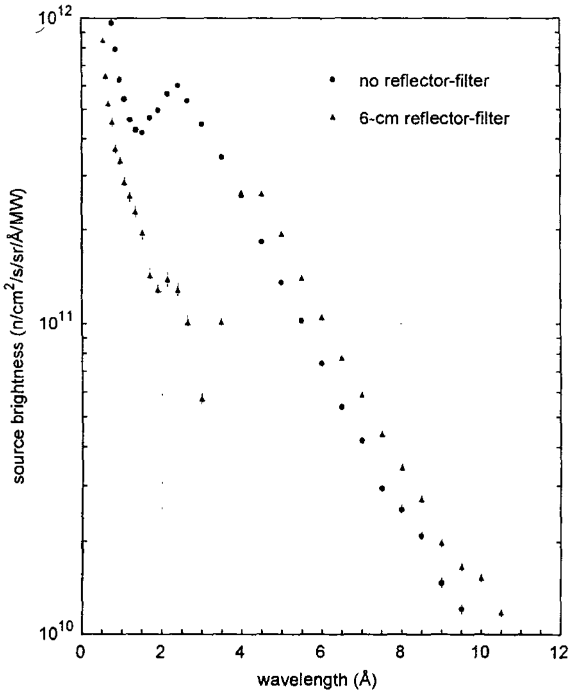


Figure 4. Wavelength-dependent source brightness of an unfiltered and filtered LH_2 moderator on a short-pulse source.

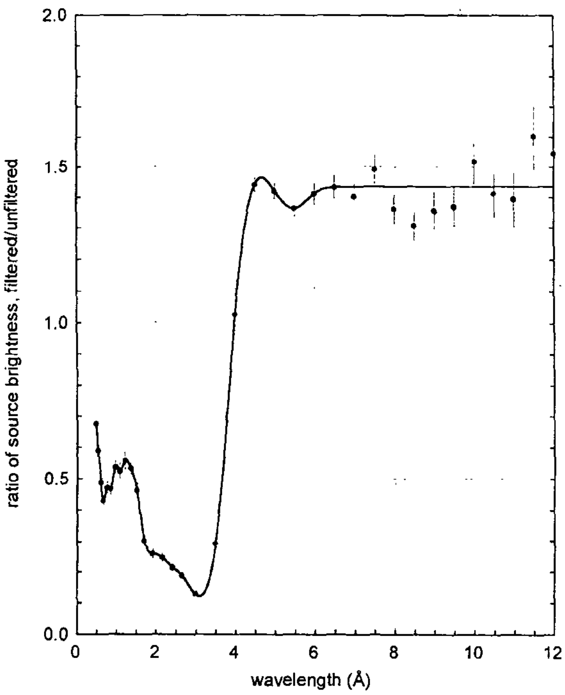
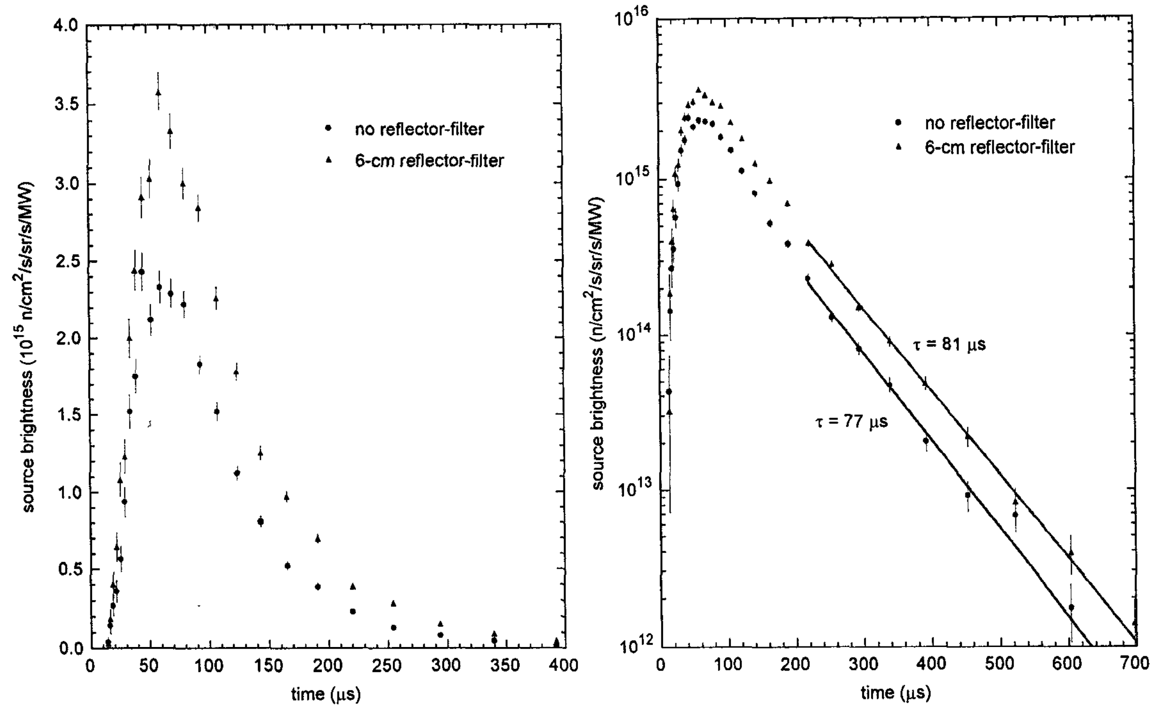


Figure 5. Ratio of source brightness for a decoupled LH_2 moderator with a 6-cm reflector-filter relative to an unfiltered one.



(a) (b)

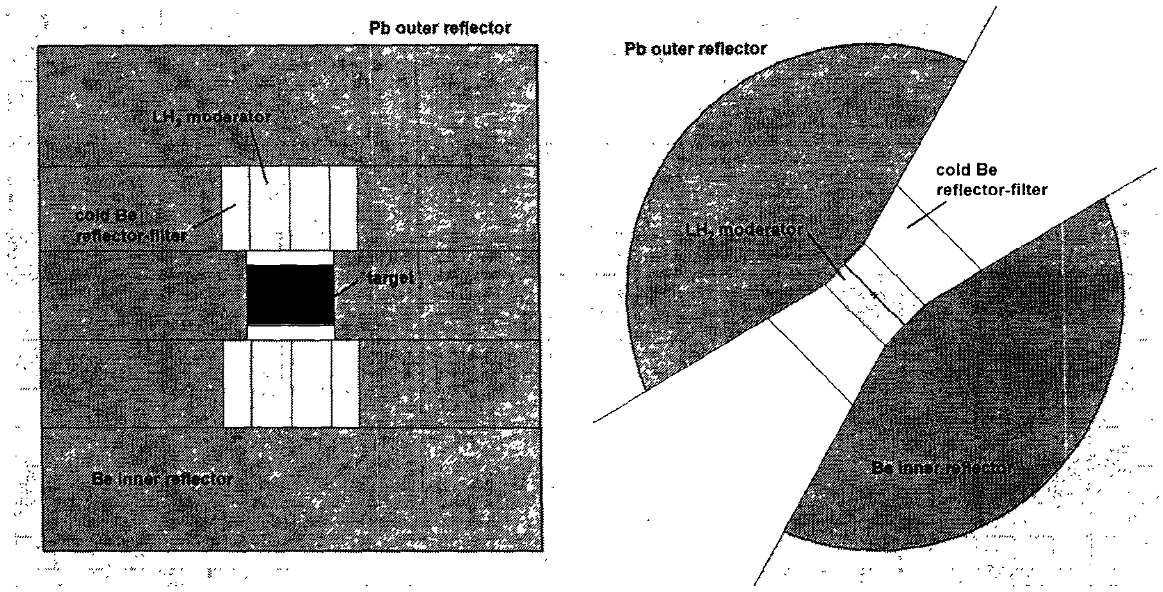
Figure 6. Time-dependent source brightness for filtered and unfiltered, decoupled LH_2 moderators, plotted on (a) linear, and (b) logarithmic time scales.

to the moderator, the enhancement in long-wavelength brightness occurs at early times in the neutron pulse, as shown in Figure 6. As seen in this figure, the decay time constants for the two cases are nearly the same.

2.2 Long-Pulse Source Performance

For evaluating the performance of a reflector-filter on a long-pulse source, we used the traditional wing moderator geometry, shown in Figure 7. The average source brightness was calculated from the four leakage surfaces of two wing moderators, one upper and one lower. The moderators are 12×12×8 cm^3 in size and composed of 90% para-, 10% ortho-hydrogen. They are coupled to a warm beryllium inner reflector with a 70-cm diameter and height, surrounded by a lead outer reflector. The inner and outer reflectors are decoupled by 0.081 cm of cadmium.

The same analysis was performed for this coupled moderator system as was performed for the decoupled moderator system. Relative integral source brightness ($E < 5$ meV) is plotted as a function of reflector-filter thickness in Figure 8. The long-wavelength brightness peaks at a reflector-filter thickness of 18 cm, where it is 57% brighter than the unfiltered case. Spectra for these two configurations are plotted in Figure 9, and the ratio of the spectra is shown in Figure 10. The epithermal flux in the filtered case is about half that of the unfiltered case. The high-energy portion of the Maxwellian peak of neutrons moderated in the 77-K Be can be seen between 1 and 2 Å. This feature is not observed in the flux trap geometry of the decoupled system, where the reflector filter is not strongly



(a) (b)

Figure 7. Long-pulse source geometry: (a) vertical slice through center of moderators; (b) horizontal slice through upper wing moderator.

coupled to the target. For the wing moderator geometry, however, the reflector-filter is fed directly by the target and this is the source of the peak at ~1.5 Å. Reflection of neutrons with energies just below 4 Å is clearly evident in the lower flux of the filtered case. Significant enhancement in the long-wavelength flux is also apparent. As in the decoupled moderator system, the gain in long-wavelength brightness occurs within the peak of the neutron pulse, and not in the tail, as can be seen in Figure 11, where the time-dependent source brightness is plotted for both cases.

2.3 *Steady-State Source Performance*

The geometry chosen to represent a steady-state source was a lead target immersed in a 2-m-diameter by 2-m-high tank of heavy water (see Figure 12). A liquid deuterium (90% para, 10% ortho) moderator, 30 cm in diameter and 35 cm long, has its center located 42.5 cm from the proton beam centerline. Off the cylindrical surface of the moderator and perpendicular to the proton beamline is an 8-cm-wide by 12-cm-high flight path. A cold Be reflector-filter is placed directly on the moderator's cylindrical surface.

The dependence of the long-wavelength (>4 Å) source brightness on reflector-filter

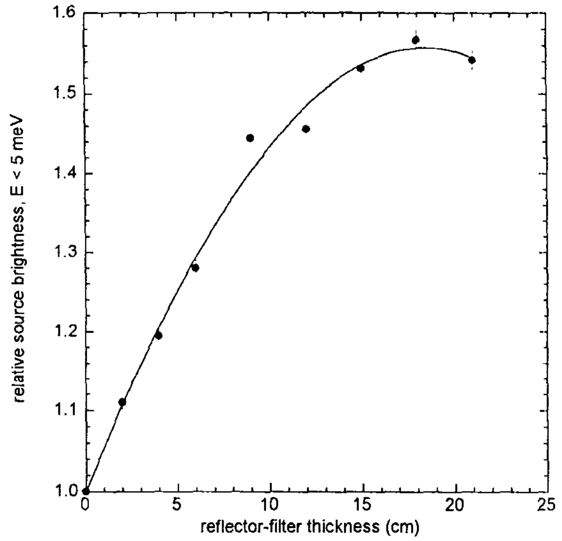


Figure 8. Relative source brightness ($E < 5$ meV) as a function of reflector-filter thickness for a coupled LH$_2$ moderator in wing geometry.

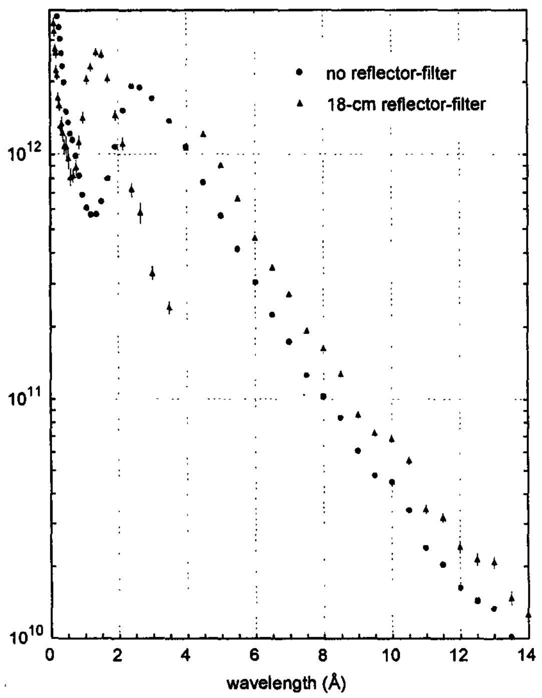


Figure 9. Source brightness as a function of wavelength for a coupled LH_2 moderator in wing geometry with and without an 18-cm reflector-filter.

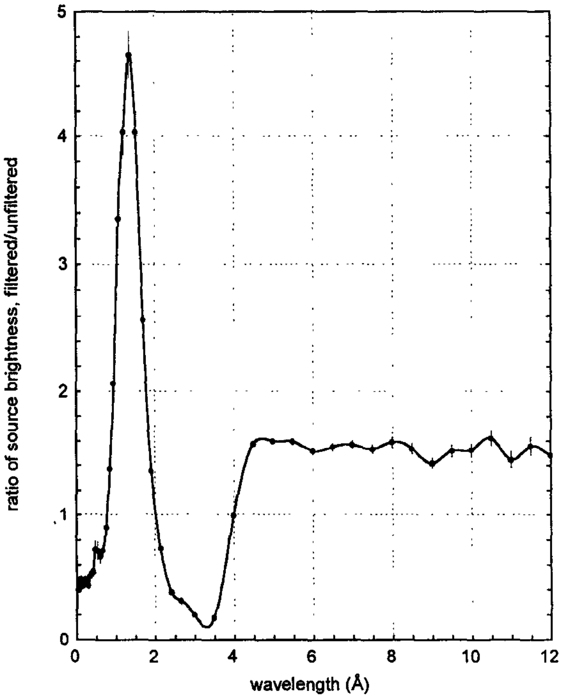
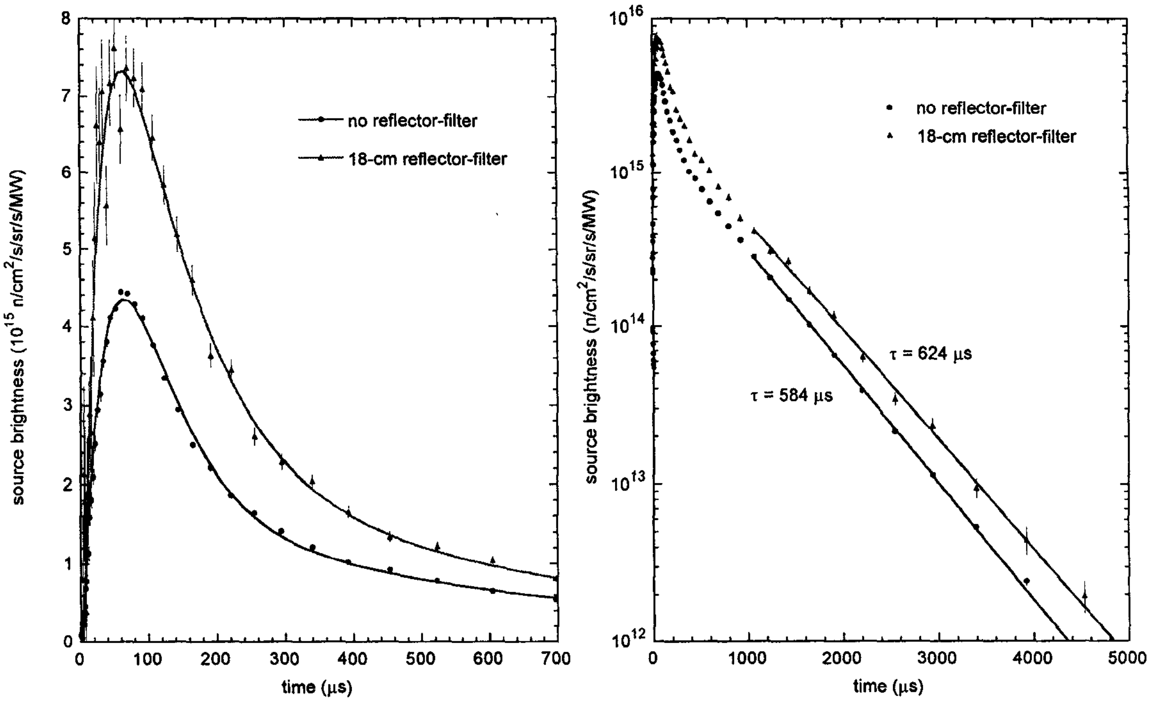
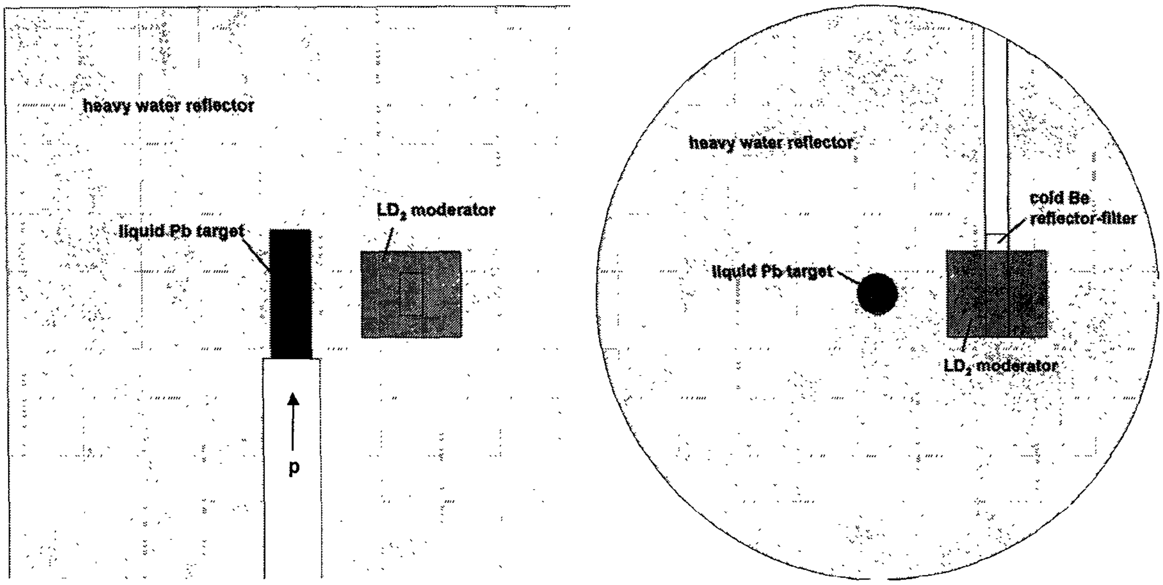


Figure 10. Source brightness as a function of wavelength for a coupled LH_2 moderator in wing geometry with an 18-cm reflector-filter relative to an unfiltered moderator.



(a) (b)

Figure 11. Time-dependent source brightness for a coupled LH_2 moderator in wing geometry with and without an 18-cm reflector-filter, plotted on (a) linear, and (b) logarithmic time scales.



(a) (b)

Figure 12. Steady-state source geometry: (a) vertical slice through proton beam centerline; (b) horizontal slice through the central axis of the moderator.

thickness is plotted in Figure 13. It shows that there is almost no gain to be derived by using a reflector-filter in this geometry. Figure 14 shows the wavelength-dependent source brightness with and without a 6-cm reflector-filter. Again, the lack of any enhancement in the long-wavelength region is evident. From these results, it is clear that the presence of the flight path does not significantly perturb the neutron flux at the moderator leakage surface; hence, there is no benefit in using a reflector-filter in this configuration.

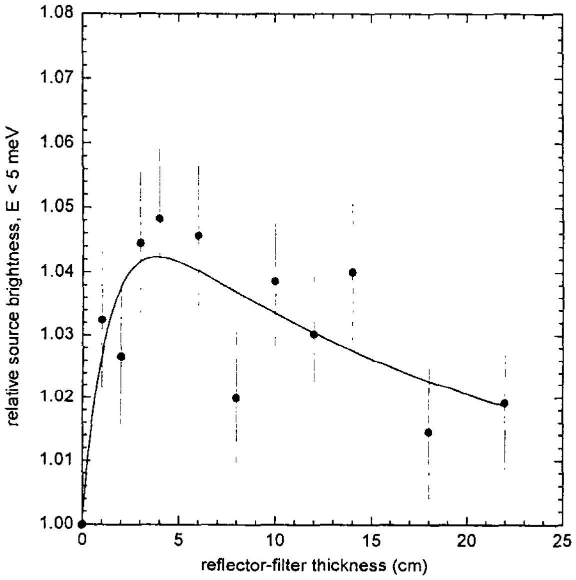


Figure 13. Low-energy (< 5 meV) relative source brightness as a function of reflector-filter thickness for a steady-state source.

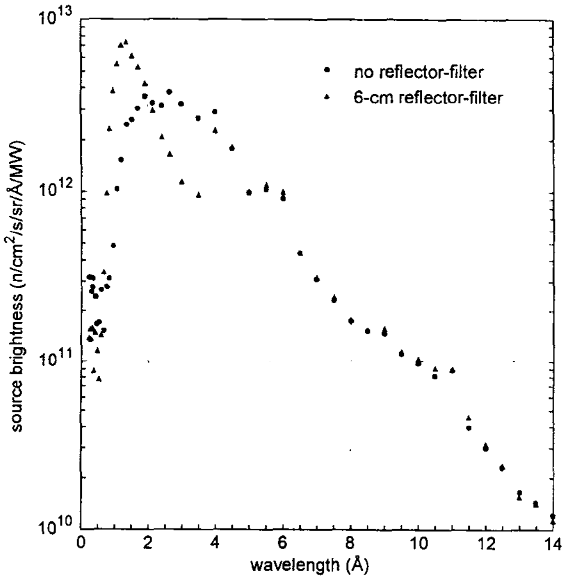


Figure 14. Spectra for a steady-state source with and without a 6-cm reflector-filter.

3 Conclusion

Simulations of various pulsed sources indicate that a cold Be reflector-filter can be effective in boosting the long-wavelength brightness of cold sources on both short- and long-pulsed sources by as much as 57%. Though not reported here, cursory calculations indicate that the magnitude of this gain may depend on the relative concentrations of ortho- and para-hydrogen, with higher ortho-hydrogen concentrations deriving a greater benefit from the use of a cold Be reflector-filter (all results reported here used a 10% ortho-hydrogen fraction). Calculations indicate that only marginal gains (~4%) in long-wavelength (>4 Å) source brightness may be realized by using a cold Be reflector-filter on a steady-state source.

4 References

[1] J. M. Carpenter, R. Kleb, T. A. Postol, R. H. Stefiuk, and D. F. R. Mildner, Nuc. Instr. Meth. **189** (1981) 405-501. Also see references 12 and 13 therein.

[1] Y. Kiyanagi, Y. Ogawa, N. Kosugi, H. Iwasa, M. Furusaka, and N. Watanabe, "Further Optimization of Coupled Liquid-Hydrogen Moderator for Intense Pulse Neutron Source," Proceedings of the 13th Meeting of the International Collaboration on Advanced Neutron Sources, September 11-14, 1995, Villigen, Switzerland.

[1] R. E. Prael and H. Lichtenstein, "User Guide to LCS: The LAHET Code System," LA-UR-89-3014, September, 1989.