ICANS XIV
14th Meeting of the International Collaboration
on Advanced Neutron Sources
June 14–19, 1998
Starved Rock Lodge, Utica, IL, USA

A RING MODERATOR CONCEPT FOR A LONG-PULSE SOURCE

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ABSTRACT

We propose a novel target-moderator configuration for use at a long-pulse spallation source in which a ring-shaped moderator is placed above a slab target. This single moderator could serve all flight paths of a long-pulse source, greatly simplifying the engineering of the target system over traditional four-moderator systems. It offers great flexibility in the number and layout of flight paths, with a total angular opening of 240°. Source brightness is nearly equivalent to that of a traditional wing moderator.

1 Introduction

We propose a novel target-moderator configuration for use at a long-pulse spallation source. The configuration consists of a single slab target with a single ring moderator in wing geometry, as depicted in Figure 1. This single moderator serves all flight paths. The curved neutron emission surface, which could potentially lead to broadening of the leading edge of the neutron pulse at a short-pulse source, is not a concern in long-pulse source applications, where the proton beam pulse width dominates the neutron pulse rise time.

This configuration provides several mechanical design and operation advantages. First, there is only one moderator serving all flight paths, which greatly simplifies the routing of supply lines as compared to conventional configurations with four or more moderators. In addition to mechanical simplification, this reduction in supply lines means a reduction in the displacement of reflector material, which should enhance neutronic performance. Second, this configuration is well adapted to the servicing concept of horizontal target extraction and vertical moderator extraction, as proposed for the LPSS target station (reference).[1] The target insert or the moderator insert may be extracted independently of one another, unlike configurations that have moderators placed below the target in which the target insert must be extracted prior to extraction of the moderator insert. Third, an ultra-cold neutron source may be easily accommodated underneath the target or upstream of the moderator, both of which are high-flux regions. Finally, there is great flexibility in the number and placement of flight paths served by the moderator. Angular spacing between flight paths can be easily adjusted on an instrument-by-instrument basis, thereby optimizing instrument floor space and maximizing the number of flight paths.

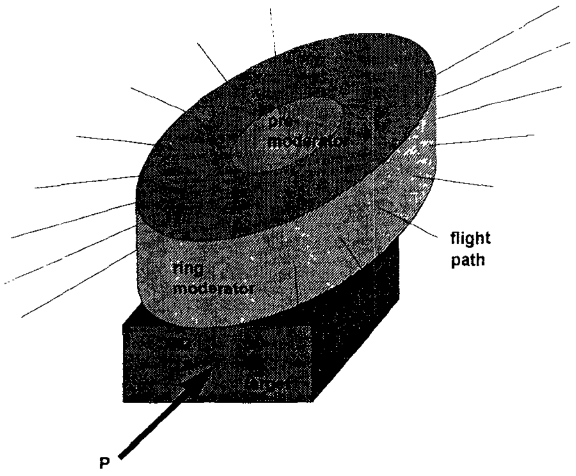


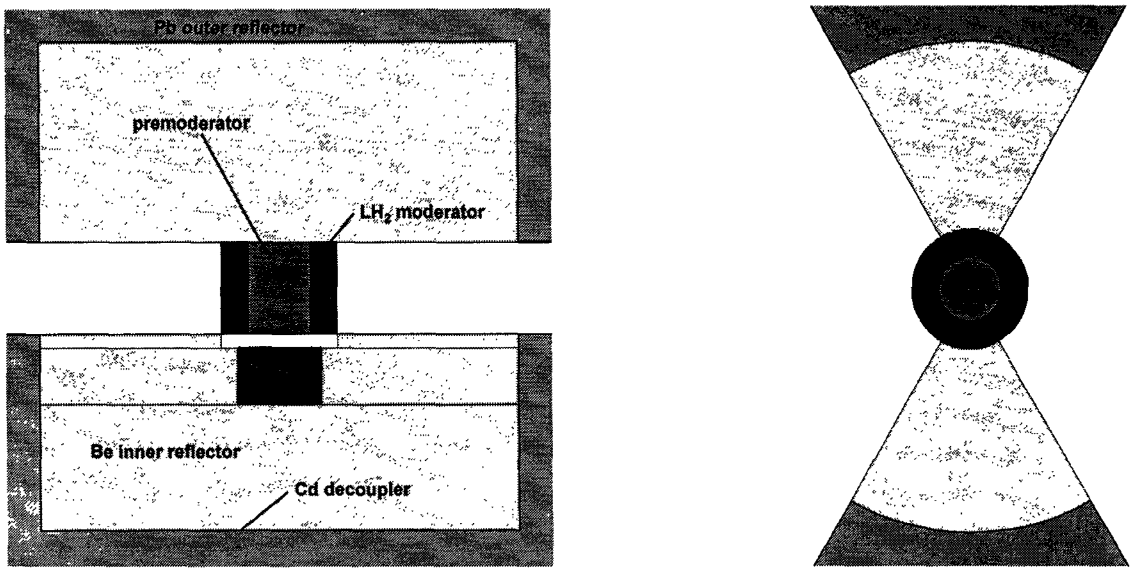
Figure 1. Slab target with a ring moderator in wing geometry.

The neutronic performance of such a ring moderator has been evaluated using the LAHET Code System.[2] Numerous material and geometrical optimizations were performed, and a reasonably well optimized geometry determined. The neutronic performance of the ring moderator has been found to compare favorably with that of a traditional wing moderator.

2 Material and Geometric Optimizations

Optimization studies performed included target aspect ratio, moderator position above the target, premoderator diameter, moderator thickness, inner reflector size, and reflector-filter thickness. Each of these is described below. Generally, our figure of merit is the time-averaged source brightness over the energy interval 0 to 5 meV, calculated using 12 point detectors, each viewing a 10x10 cm^2 area of the moderator surface and separated by 15° from one another. These 12 point detectors represent the central 12 of 16 presumed flight paths, shown in Figure 1, that could view the moderator through the two 120° angular openings in the reflector.

The starting point for the optimization studies is shown in Figure 2 in the form of vertical and horizontal cross-sectional slices through the MCNP geometry. Specifications of the "baseline" geometry are given here, although these varied depending on the particular optimization study. We used a partially coupled composite reflector. The inner reflector material is beryllium, the outer reflector material is lead, and there is a 0.081-cm-thick sheet of cadmium between them. The inner Be reflector diameter and height are both 70 cm; the total reflector diameter is 1.5 m and its height is 1.7 m. The slab target is 8.16 cm high by 12.25 cm wide for an aspect ratio of 1.5. The premoderator is beryllium cooled by 15 v% light water. Based on recent comparisons of calculated results to experiment,[3] we assumed a 90% para-, 10% ortho-hydrogen composition of liquid hydrogen for the ring moderator material. Each side of the moderator has a flight path angular opening of 120°. The moderator is 12 cm high.



(a) (b)

Figure 2. LCS model of the ring moderator target station: (a) vertical, and (b) horizontal slices through the center of the ring moderator.

2.1 Target Aspect Ratio

The target aspect ratio is defined as the target width divided by the target height. A target with an aspect ratio greater than unity, that is, one that is wider than it is tall, is termed a "slab" target. Intuitively, a slab target should couple well with a ring moderator by positioning the neutron source closer to the moderator. We varied the target aspect ratio from 0.25 to 4. For each geometry, the beam aspect ratio was the same as the target aspect ratio, with the beam spot area fixed at 38.5 cm^2. The spatial profile was parabolic, and the peak current density was held constant for all aspect ratios such that the peak power density in the target did not vary with target aspect ratio. Thus we are justified in using the same coolant volume fraction in the target for all aspect ratios. The results of this study are plotted in Figure 3. It shows the source brightness to have a broad peak centered near an aspect ratio of 1.4. For an aspect ratio between 1 and 2, the source brightness varies by less than 2%, suggesting that factors other than neutronic performance, such as thermal-hydraulic performance or fabricability would probably guide the selection of target aspect ratio within the range 1 to 2.

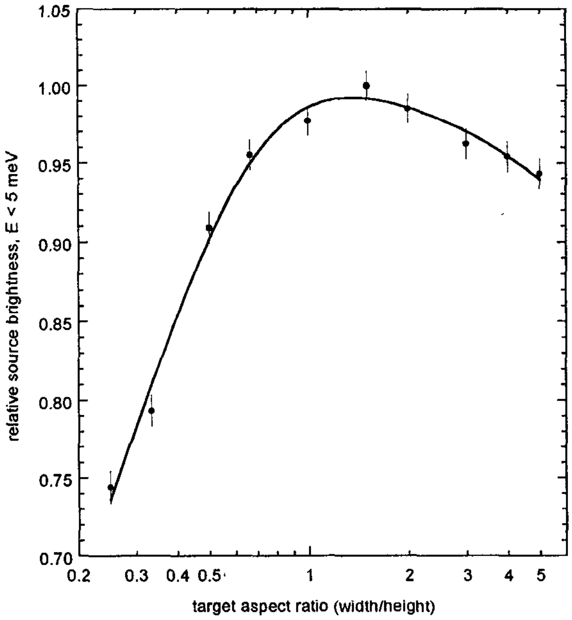


Figure 3. Dependence of source brightness on target aspect ratio.

2.2 Moderator Position

The distance *d* of the moderator central axis relative to the front face of the target (see Figure 4) can be adjusted to achieve various performance objectives. For example, flight paths viewing the upstream end of the ring moderator can be made brighter (at the sacrifice of brightness of flight paths viewing the downstream portion of the ring moderator) by simply moving the moderator downstream from its "optimal" position. Here, the optimal target position is defined as that which provides the highest brightness averaged over the central 12 of 16 flight paths. The variation of the average source brightness as a function of *d* is shown in Figure 4. It shows the optimal moderator position is that in which the central axis of the moderator is 5 cm upstream of the front face of the target. This position also provides the most uniform source brightness for all sixteen flight paths.

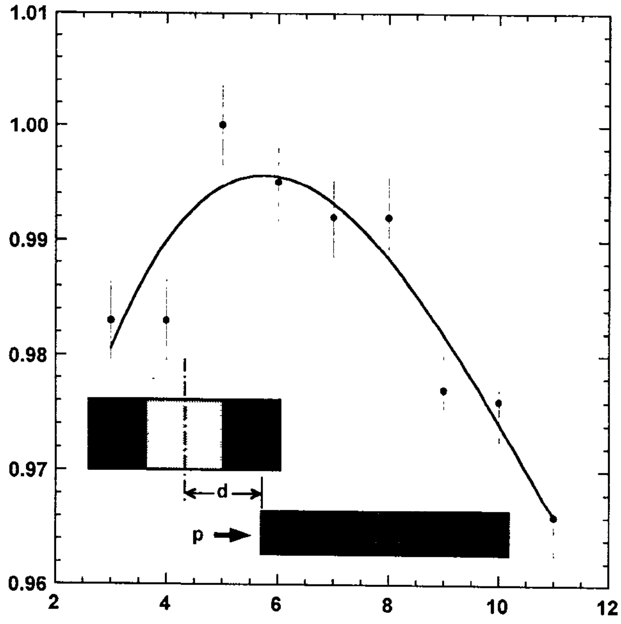


Figure 4. Dependence of source brightness on moderator position relative to the front face of the target.

2.3 Premoderator Diameter and Moderator Thickness

Source brightness has a moderate dependence on the premoderator diameter and moderator thickness. We performed a parametric study in which the Be premoderator diameter was varied from 0 to 7 cm and the hydrogen moderator thickness was varied from 6 to 10 cm. The results, plotted in Figure 5, show that, as the moderator becomes progressively thicker, the optimum premoderator diameter decreases until, at a moderator thickness of 9 cm, there is no longer any need for a premoderator. For a 90% para-hydrogen fraction, the moderator is somewhat transparent to low-energy neutrons and requires a relatively thick

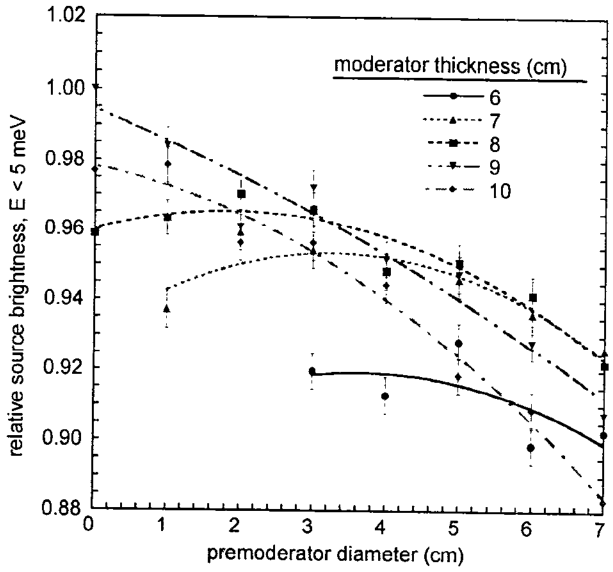


Figure 5. Source brightness dependence on ring moderator thickness and outside diameter.

moderator of 9 cm to achieve optimal source brightness. Beyond 9 cm thickness, the source brightness begins to decrease regardless of premoderator size.

2.4 Inner Reflector Size

As shown in previous studies of coupled moderator systems,[4] if the inner reflector is composed of a moderating medium such as beryllium or graphite, its size has a strong influence on time-averaged source brightness by changing the decay time constant of the neutron pulse. This phenomenon holds true for this target-moderator system as well, as shown in Figure 6, where the time-averaged source brightness and standard deviation of the neutron pulse are plotted as a function of the inner Be reflector size (both diameter and height). We see that both increase monotonically with inner reflector size. The pulse width is linearly proportional to the inner reflector size, while the time-averaged source brightness is slowly approaching a saturated value. For an inner reflector diameter and height equal to 140 cm, the time-averaged source brightness has increased by 45% over that of a 60-cm reflector size, whereas the standard deviation of the neutron pulse increases four-fold. As all flight paths share the same temporal characteristics, the instrument requiring the shortest decay constant will set the inner reflector size. This would be true for any target-moderator system in which all moderators are fully coupled to the reflector since, for coupled moderators, the reflector determines the decay constant of the neutron pulse.

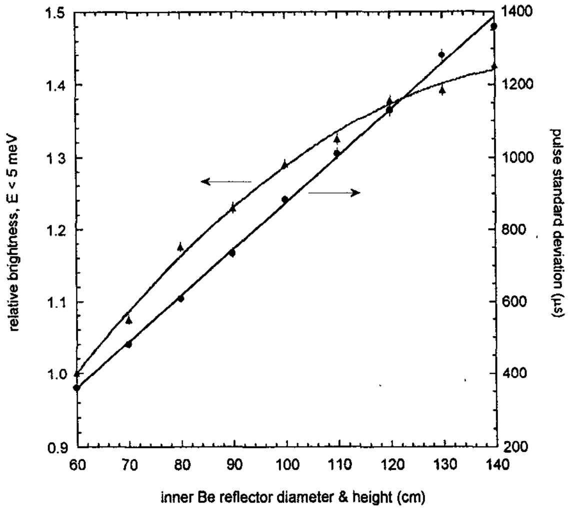


Figure 6. Variation of source brightness and pulse width standard deviation with inner Be reflector size.

3 Ring Moderator Performance Relative to that of a Traditional Wing Moderator

We have compared the performance of the optimized ring moderator-slab target geometry to that of a traditional wing moderator. The materials and geometries were matched as closely as possible between the two systems in order to obtain a meaningful comparison. The wing moderator is 12 cm wide by 12 cm high by 8 cm thick, while the ring moderator is 12 cm high by 16 cm diameter with no premoderator. Spectra for the two systems are plotted in Figure 7. The ratio of these two spectra (ring moderator source brightness to wing moderator source brightness) is plotted in Figure 8, which shows the ring moderator brightness varies from 75 to 91% of the brightness of a traditional wing moderator over the wavelength range 2 – 12 Å. For the integral brightness below 5 meV, the ring moderator has 90% of the brightness of a traditional wing moderator. The reason the ring moderator does not perform quite as well as a wing moderator is presumably due to the displacement of reflector resulting from the large angular openings that service the flight paths.

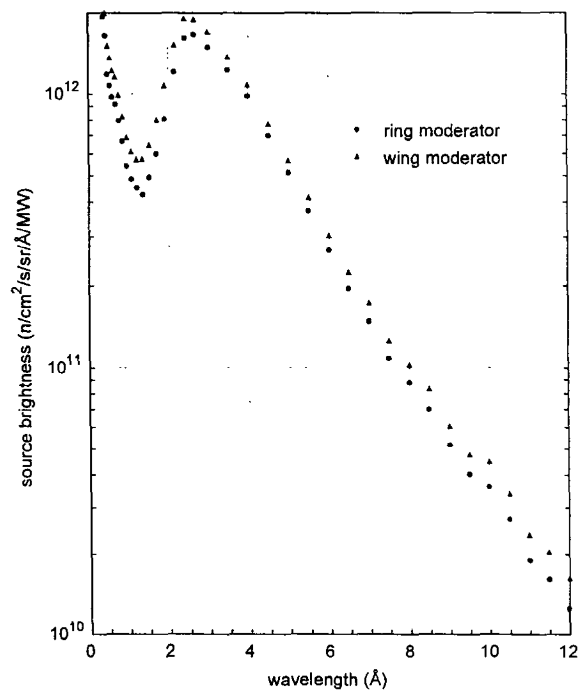


Figure 7. Wavelength-dependent source brightness for a ring moderator and a traditional coupled wing moderator.

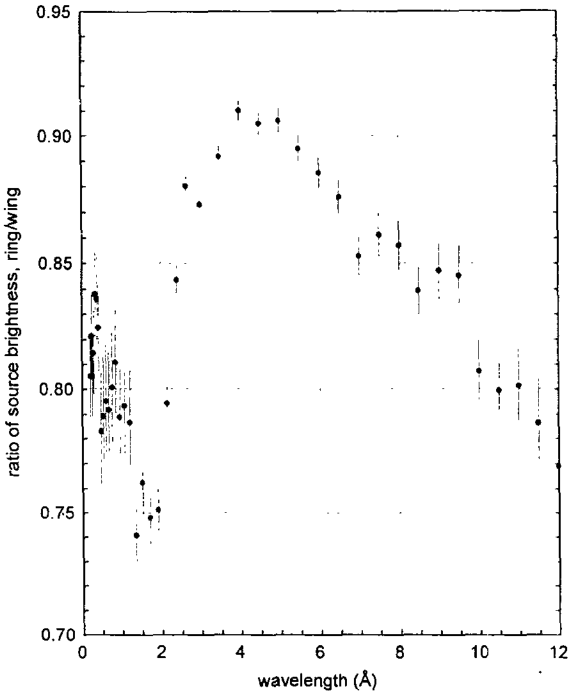


Figure 8. Wavelength-dependent source brightness of a ring moderator relative to that of a wing moderator.

4 Use of a Cold Be Reflector-Filter to Enhance Source Brightness

The large angular opening of 120° serving multiple flight paths on each side of the moderator causes a significant displacement of critical reflector material. As a solution to this problem, we considered using a cold (77 K) Be reflector-filter to reflect superthermal neutrons leaking from the moderator emission surface back into the moderator. These neutrons are then given a second chance to downscatter into the thermal region and leak from the moderator as cold neutrons. Cold neutrons, on the other hand, are not reflected back into the moderator due to the precipitous drop in the Be cross section below 5 meV. We have investigated the use of a cold Be reflector-filter on the ring moderator system and found it to significantly enhance the brightness of neutrons with wavelengths greater than 4 Å. Shown in Figure 9 are the spectra for a standard ring moderator and one with a 13-cm-thick cold Be reflector-filter butted up against the moderator emission surface. Figure 10 shows the ratio (filtered to unfiltered) of the spectra. Beyond 4 Å, source brightness is enhanced by a factor of 1.6. This gain comes with virtually no increase in the pulse width, as shown in Figure 11. With the use of a cold Be reflector-filter, the time-averaged source brightness below 5 meV of a ring moderator-slab target system driven by a 1-MW, 800-MeV proton beam is 35% of the calculated source brightness of the CS-2 cold source at the Institut Laue-Langevin.[5] The efficacy of a cold Be reflector-filter on a long-pulse source, as well as other sources, is discussed in more detail elsewhere.[6]

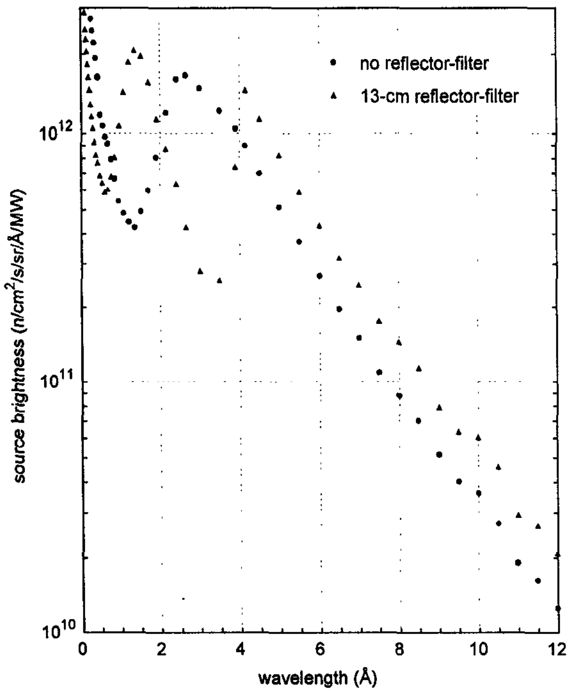


Figure 9. Wavelength-dependent source brightness for a ring moderator with and without a cold Be reflector-filter.

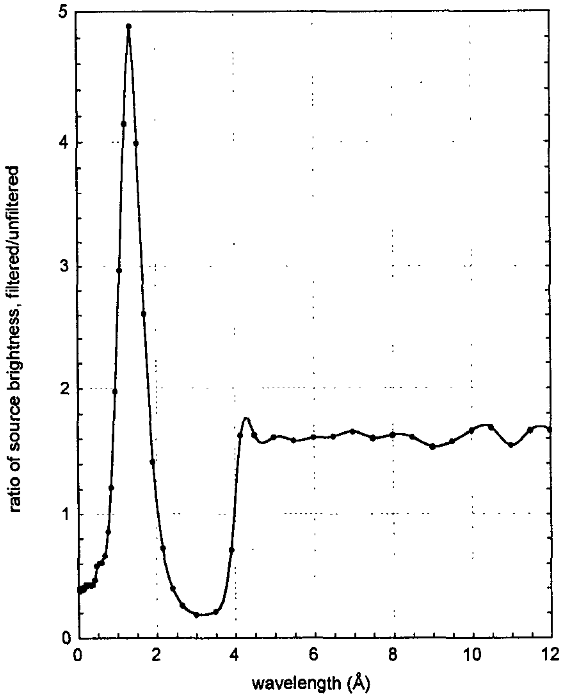
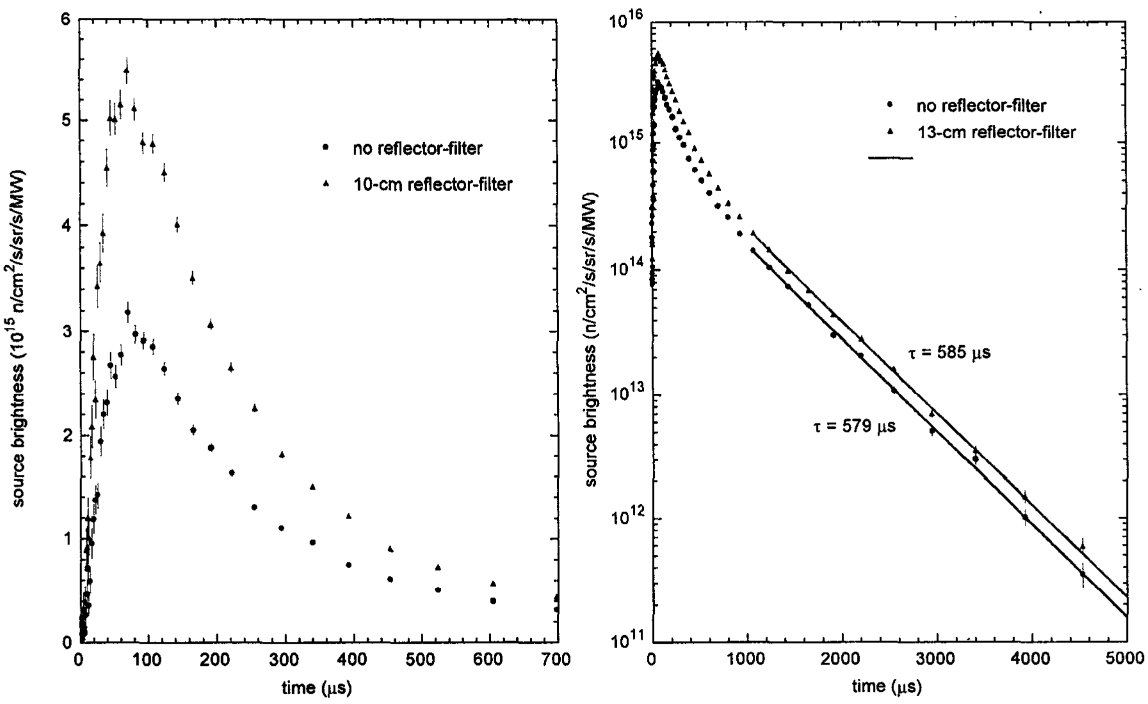


Figure 10. Wavelength-dependent source brightness of a filtered ring moderator relative to that of an unfiltered one.



(a) (b)

Figure 11. Time dependent source brightness (E < 5 meV) for an unreflected ring moderator and a ring moderator with a 10-cm-thick cold Be reflector-filter plotted on (a) linear, and (b) logarithmic scales.

5 Conclusion

We have proposed a novel target-moderator configuration in which a ring-shaped moderator is placed above a slab target. This single moderator could service all flight paths of a long-pulse source, greatly simplifying the engineering of the target system over traditional four-moderator systems. It offers great flexibility in the number and layout of flight paths, with a total angular opening of 240°. Its performance is nearly equivalent to that of a traditional wing moderator. With the use of a cold Be reflector-filter, a 1-MW long-pulse source utilizing a slab target-ring moderator geometry delivers a time-averaged cold source brightness ($E < 5$ meV) equivalent to 1/3 that of the world's most intense cold source.

6 References

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5. P. Ageron, Nucl. Instr. Meth. **A284** (1989), 179-199. From Figure 2 of this paper, the integral brightness below 5 meV of the CS-2 cold source is calculated to be 7.25×10^{12} n/cm^2/s/sr.
6. E. J. Pitcher, G. J. Russell, and P. D. Ferguson, "Use of a Cold Be Reflector-Filter to Enhance Cold Source Brightness at Long Wavelengths," these proceedings.