LA-UR-05-3168

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Intended for: ICANS-XVII
17th Meeting of the International Collaboration on Advanced Neutron Sources
April 25-29, 2005
Santa Fe, New Mexico

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Implementation of the beryllium reflector filter concept in the LANSCE 1L target Mark-III upgrade

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Abstract

We have investigated the possibility of implementing the idea of a beryllium reflector filter in the LANSCE 1L target Mark-III upgrade. We will present different concepts of beryllium reflector filters (megaphone, chevron and swiss-cheese concept) and their effect on the integrated cold flux and the time distribution of the lower tier hydrogen flux-trap moderator as a function of the three instruments, (SPEAR, LQD and Asterix) which are served by this moderator.

1. Introduction

As part of the LANSCE 1L target upgrade study it is the declared goal to increase the cold flux (E<5meV) of the lower tier partially coupled liquid hydrogen moderator by a factor of two. This goal is proposed to be achieved by adding a pre-moderator system to the moderator and by implementing the cold beryllium reflector concept. The cold beryllium reflector filter concept was tested in an experiment at the weapons neutron research (WNR) facility at LANSCE in January 2003 by Pitcher et al [1]. Based on the success of this experiment it was then decided to implement this concept into the 1L target Mark-III upgrade. In this context a series of Monte Carlo transport calculations [2] was performed to optimize the cold neutron flux.

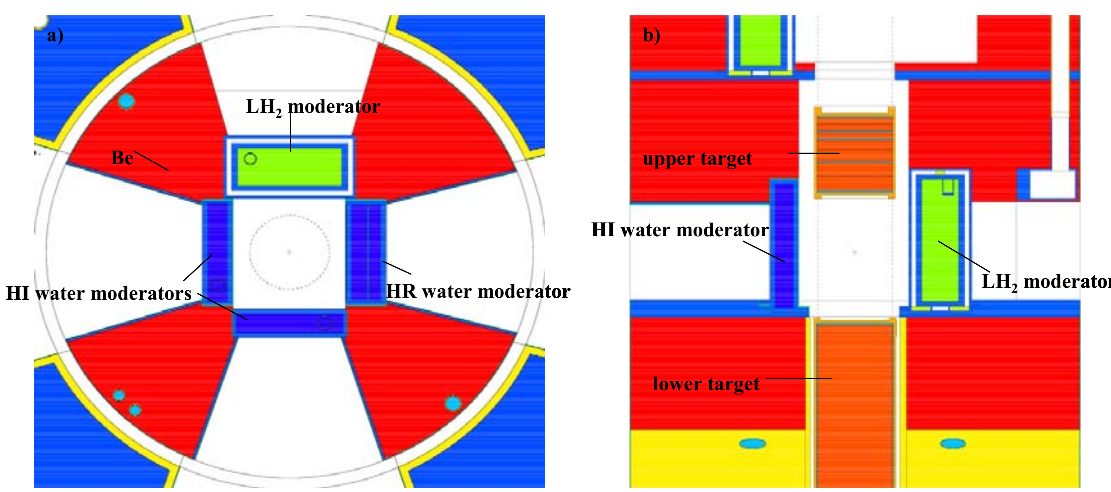

Figure 1: Cross-section of the current 1L target (Mark-II) in horizontal (a) and vertical (b) direction.

2. Pre-moderator

As part of the effort to enhance the flux of the lower tier liquid hydrogen moderator we investigated the effectiveness of a light water flux-trap pre-moderator on the performance of the moderator. Figure 1a,b shows the current design of the flux-trap moderators of the 1L target that includes not only the liquid hydrogen moderator but also two high intensity and one high resolution decoupled water moderators. As a first step we introduced a light water pre-moderator on the flux-trap side of the liquid hydrogen moderator. This concept can be seen in figure 2a,b. In order to optimize the performance we varied the thickness of the pre-moderator. The results are shown in figure 3. One can observe from this figure that the maximum gain from the flux-trap pre-moderator concept is about 19%. However, one also notices that the gain due to the pre-moderator varies only slightly over the range from 0.5 to 2.5 cm. It is therefore possible, if design constraints require it to vary the thickness of the pre-moderator without influencing the performance on a noticeable level.

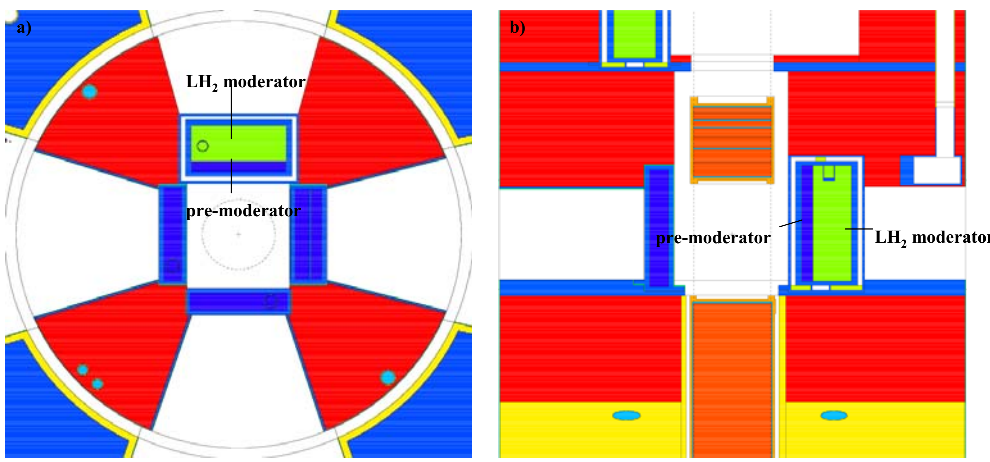

Figure 2: Cross-section through the lower tier hydrogen moderator with a light water pre-moderator in horizontal (a) and vertical (b) direction.

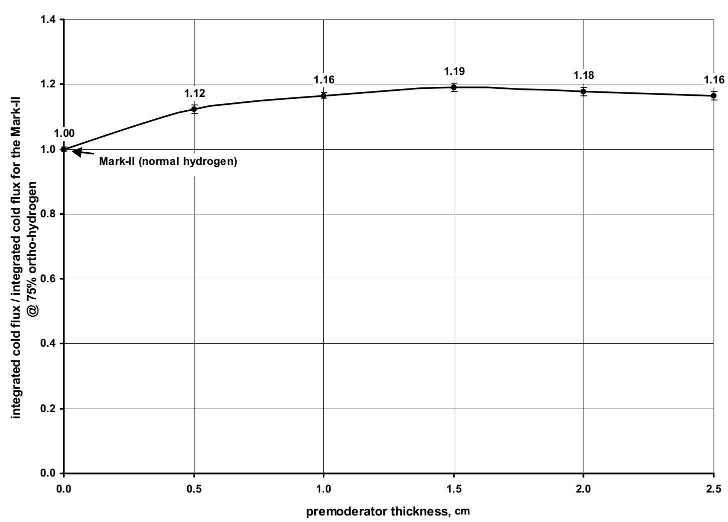

Figure 3: Variation of the flux-trap liquid hydrogen moderator's integrated cold flux (E<5meV, λ=4Å) as a function of the thickness of the light water flux-trap pre-moderator.

3. Solid beryllium reflector filter

In a second step we added a solid cold beryllium reflector filter at various thicknesses to the design. A cross-section of this model can be seen in figure 4a,b. The results of these calculations (figure 5) show that the effectiveness of the beryllium reflector filter concept increases with increasing thickness of the filter. However the effectiveness converges to a maximum of about 1.87 for a thickness larger than 11cm. In order to maximize the effect of the beryllium filter concept while still staying within the boundaries of the inner reflector module of the 1L target, we decided to set the thickness of the beryllium filter and the pre-moderator to 12 cm an 1.5 cm respectively. Based on these dimensions we calculated the effectiveness of this concept as a function of wavelength (figure 6). It can be observed in this figure that the effectiveness of the beryllium reflector filter does not vary greatly for neutrons with a wavelength of more than 4 Å (E<5 meV).

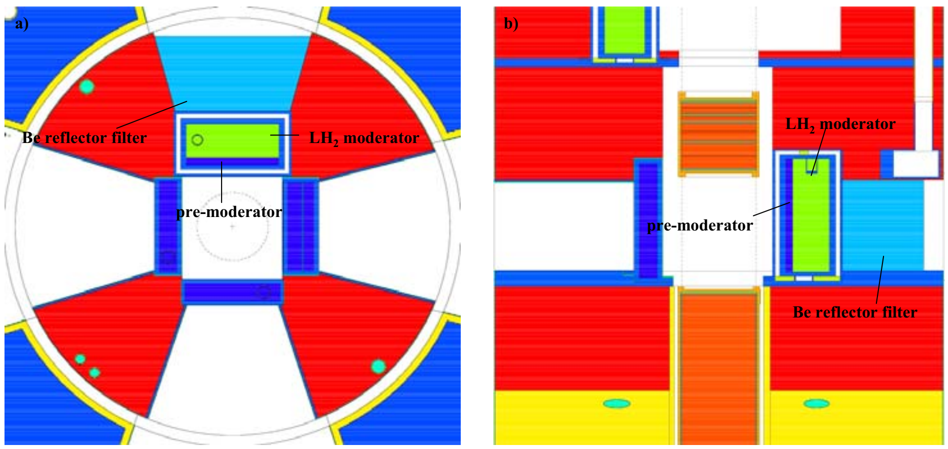

Figure 4: Cross-section through the lower tier hydrogen moderator with a light water pre-moderator and a solid cold beryllium reflector filter in horizontal (a) and vertical (b) direction.

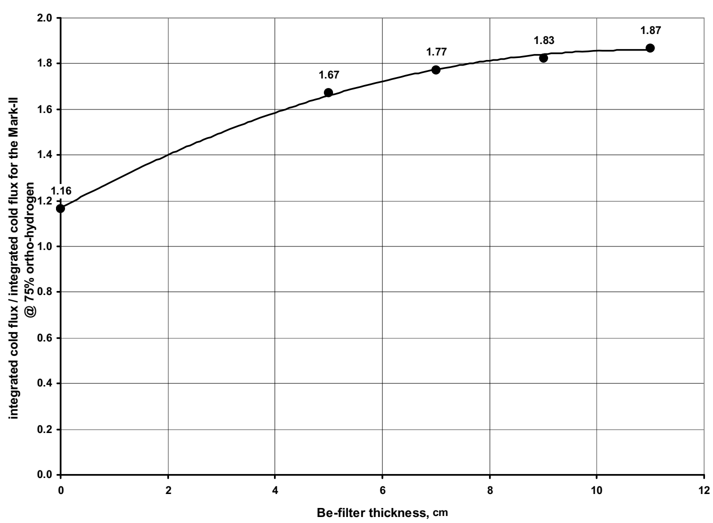

Figure 5: Variation of the flux-trap liquid hydrogen moderator's integrated cold flux (E<5 meV, λ=4 Å) as a function of the thickness of the cold beryllium reflector filter (1 cm thick pre-moderator).

However the gain in flux above 4 Å causes a loss of neutrons below 4 Å. This is due to the fact that the beryllium cross-section below 4 Å is dominated by coherent elastic scattering, which causes the neutrons of these wavelengths to reflect back into the moderator where they have a second chance to be scattered down into the energy regime below 5 meV. In addition to this it can be observed that the effectiveness of the beryllium reflector filter has a local maximum at about 1.5 Å. This wavelength also marks the transition between the areas where elastic coherent scattering (1.5 – 4 Å) is dominating and where most of the scattering is due to inelastic incoherent reactions (<1.5Å). This local maximum is due to high-energy neutrons that are thermalized in the beryllium filter itself, but not scattered far enough down so that they can be reflected back into the moderator by coherent elastic scattering.

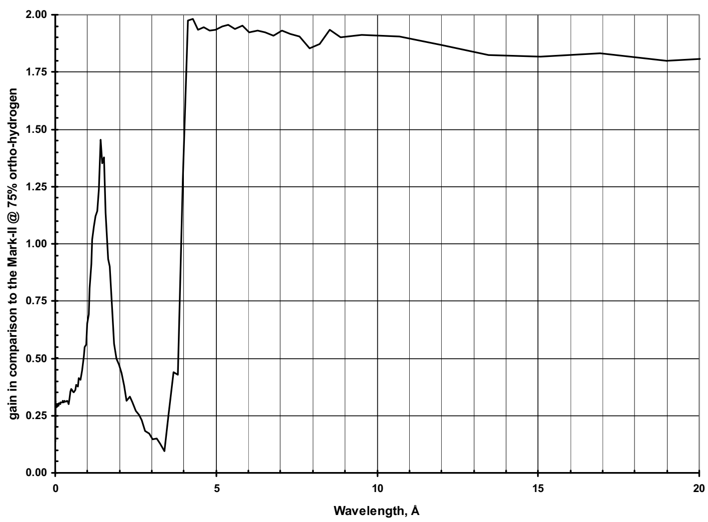

Figure 6: Effectiveness of the cold solid beryllium reflector filter (12 cm thick, 1.5 cm pre-moderator) as a function of the wavelength

Even tough this concept almost fulfills the outlined goal of increasing the cold flux by a factor of two, one of the three instrument scientist who's instrument is served by this moderator raised the concern that the loss of neutrons between 1 and 4 Å does not compensate for the gain of neutrons above 4 Å. We were therefore challenged with the task to preserve the short wavelength neutrons for this flight path while still meeting our goal of increasing the flux of the long wavelength neutrons by a factor of two.

4. Alternative concepts

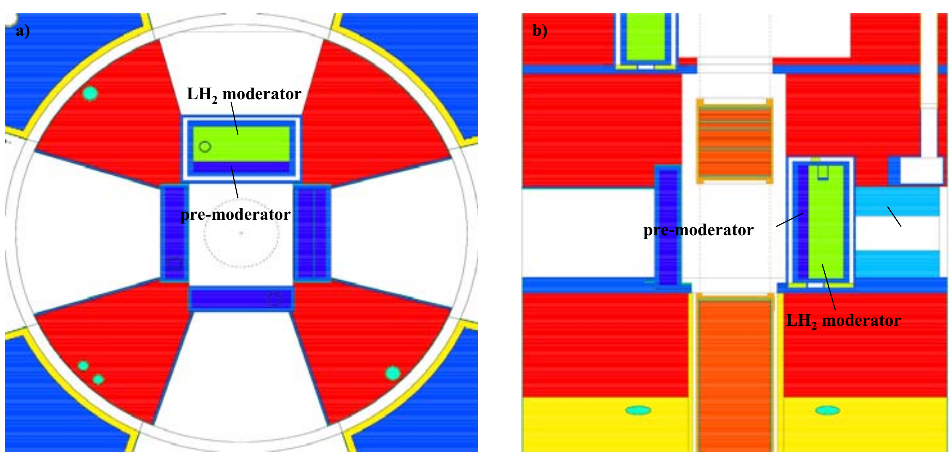

Figure 7: Cross-section through the lower tier hydrogen moderator with a light water pre-moderator and a megaphone type cold beryllium reflector filter in horizontal (a) and vertical (b) direction.

As mentioned in the last chapter we were challenged to come up with a design that not only increases the long wavelength flux by a factor of two but also preserves the short wavelength neutrons for at least one of the instruments (SPEAR). The first concept we investigated was the megaphone design as shown in figure 7a,b. In this approach we cut out a 5 cm high portion of the beryllium reflector, which is equivalent to the field of view of the SPEAR instrument. As it can be seen in figure 8 this concept not only preserves the low wavelength flux but increases it for the instruments SPEAR and LQD (very small pinhole collimation system). However the gain for the long wavelength neutrons decrease to a factor of 1.6.

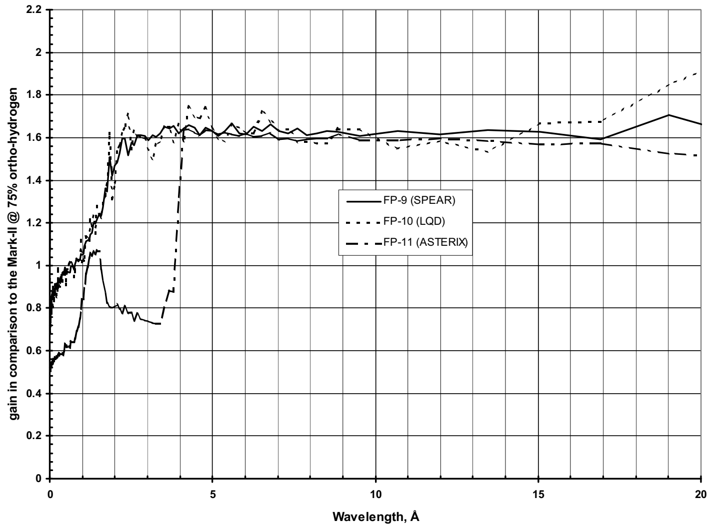

Figure 8: Effectiveness of the cold megaphone beryllium reflector filter (12cm thick, 1.5cm pre-moderator, opening 5cm) as a function of the wavelength

In a next step we investigated the so-called chevron design as shown in figure 9a,b. In this concept we cut 5 mm thick vertical grooves into the beryllium reflector filter that covers the field of view of the SPEAR instrument. These grooves are orientated towards the SPEAR instrument. Figure 10 shows the effectiveness of this concept. This concept preserves the short wavelength neutrons for the SPEAR instrument while it also provides a gain for the long wavelength neutrons of a factor of about 1.9. However, this concept raises concerns in regard to the homogeneity of the spectrum observed at the sample location as a function of the position on the sample.

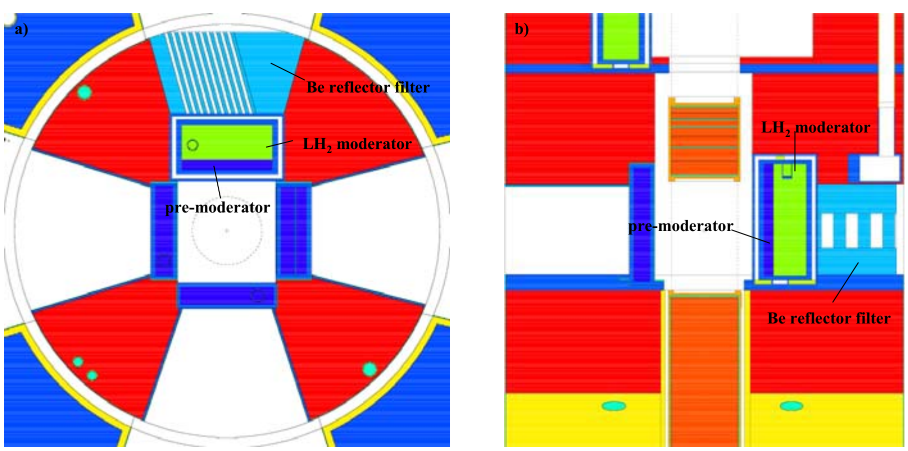

Figure 9: Cross-section through the lower tier hydrogen moderator with a light water pre-moderator and a chevron type cold beryllium reflector filter in horizontal (a) and vertical (b) direction.

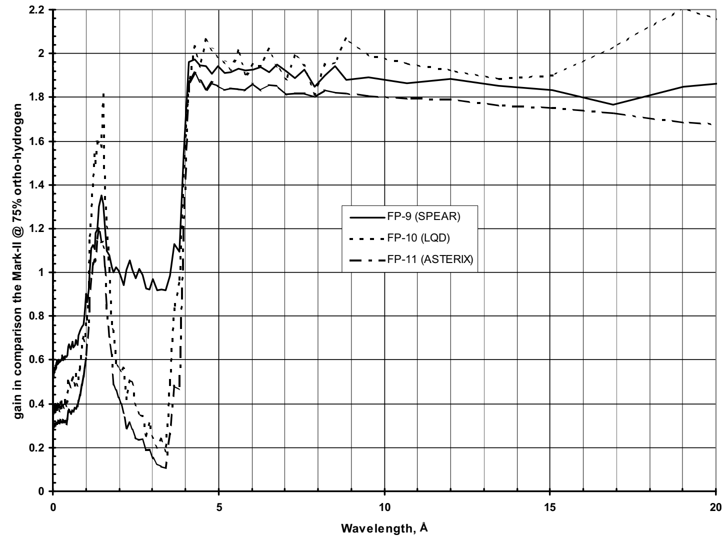

Figure 10: Effectiveness of the cold chevron beryllium reflector filter (12 cm thick, 1.5 cm pre-moderator, opening 5cm) as a function of the wavelength

In order to address this problem we investigated the so-called swiss-cheese concept. This design includes about one hundred 5 mm thick holes drilled into the beryllium over the area that is viewed by the SPEAR instrument (figure 11a,b). As it can be seen in figure 12 this concept gives basically the same gain as the chevron design however it does not raise the same homogeneity concern as the chevron design.

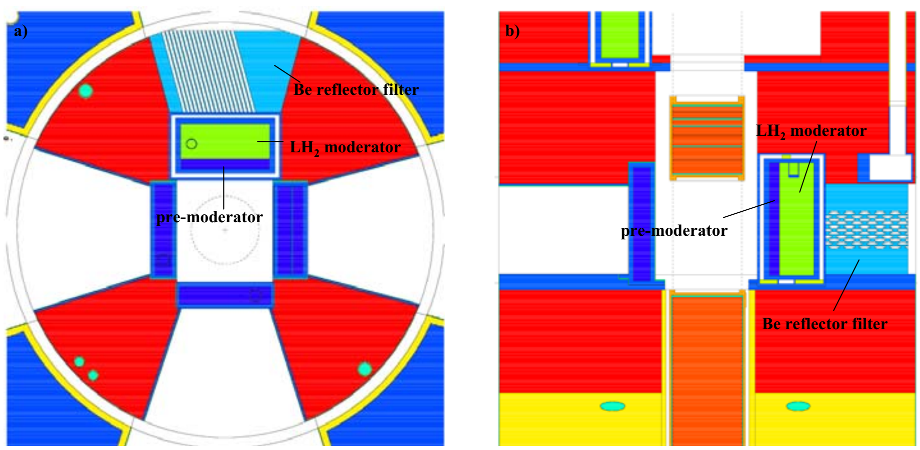

Figure 11: Cross-section through the lower tier hydrogen moderator with a light water pre-moderator and a swiss-cheese type cold beryllium reflector filter in horizontal (a) and vertical (b) direction.

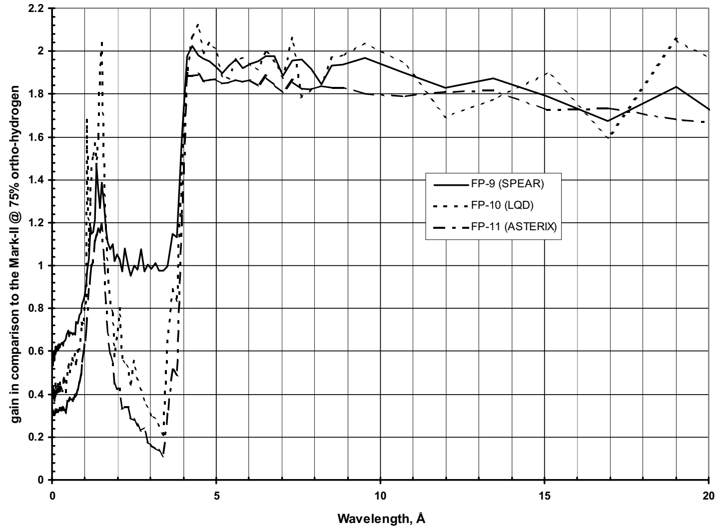

Figure 12: Effectiveness of the cold swiss-cheese beryllium reflector filter (12cm thick, 1.5cm pre-moderator, opening 5cm) as a function of the wavelength

5. Time Distribution and Time Integrated Flux

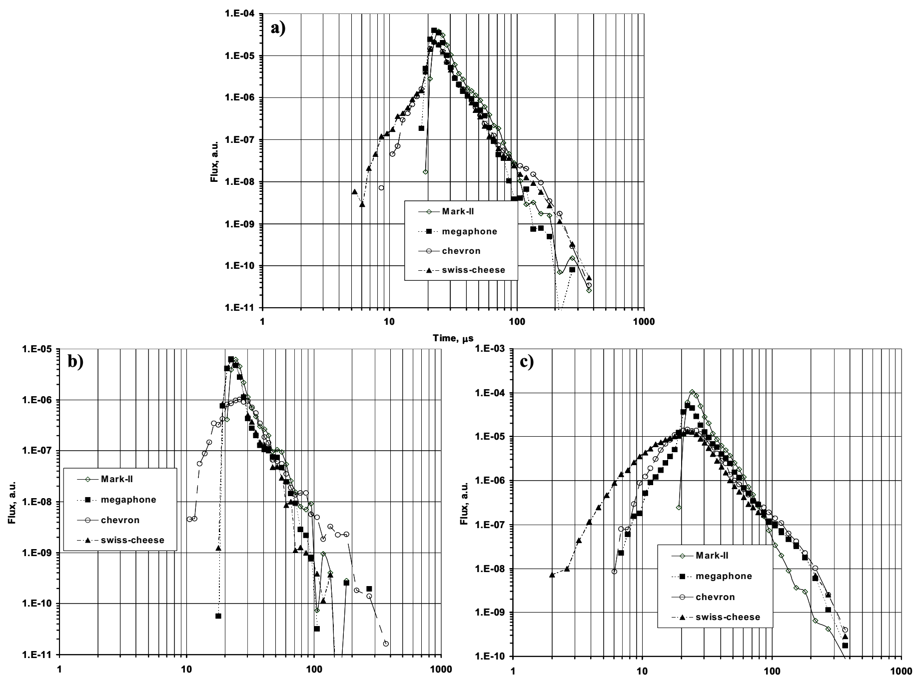

Figure 13: Pulse shape as a function of the cold beryllium reflector filter concept and the flight path for 0.5Å neutrons. (SPEAR (a), LQD (b) and Asterix (c))

So far we have presented only integrated fluxes. However for time of flight instruments time distribution and time integrated flux are also important. We have therefore investigated the influence of the various concepts shown in the last chapter on the time distribution and on the time integrated flux as a function of wavelength. In order to cover the main area we calculated the time distribution and the time integrated flux for all three instruments (SPEAR, LQD and Asterix) for 0.5 Å, 3 Å and 5 Å neutrons (figure 13-18). These wavelengths were chosen because they represent all three main areas of the beryllium cross-section. In the region of 0.5 Å the cold beryllium cross-section is mainly driven by inelastic incoherent scattering, whereas in the 3 Å range coherent elastic scattering is dominating. The 5 Å neutrons represent the regime above 4 Å where the cold beryllium reflector filter is almost transparent to these neutrons.

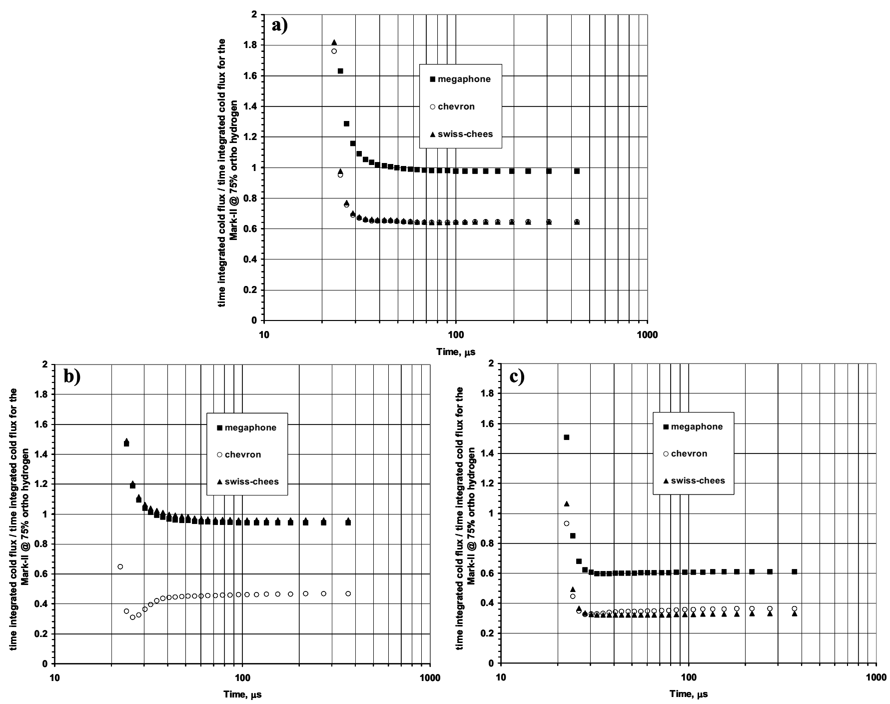

Figure 14: Time integrated flux as a function of the cold beryllium reflector filter concept and the flight path for 0.5 Å neutrons. (SPEAR (a), LQD (b) and Asterix (c))

In figure 13a,b,c one can see the time distribution for the three instruments for 0.5 Å neutrons. In the case of the SPEAR instrument (figure 13a) it can be seen that the time distribution is almost independent of the concept. Only the first part of the distribution changes slightly as a function of the design. The same thing can be seen in figure 14a, which shows the reflector filter effectiveness for this instrument at 0.5 Å. It can be seen that after about 30 µs the effectiveness does not change.

In the case of the LQD instrument a similar conclusion can be drawn for figure 13b and 14b with the exception that in the case of the chevron concept the peak flux would decrease significantly. However since the swiss-cheese concept is the preferred one, this does not raise any concerns.

In the case of the Asterix instrument (figure 13c and 14c) both the chevron and the swiss-cheese concept lead to a broadening of the pulse and to a decreased peak flux. However since neutrons of this wavelength are not used by this instrument anyway, this does not matter.

Figure 15a-c and figure 16a-c show the time distributions and the time integrated fluxes for these instruments at 3 Å. From the time distributions shown in figure 15a-c one can come to the same conclusion as for the 0.5 Å neutrons. However figure 14a-c show that for all instruments a slight broadening of the pulse occurs for all concepts. Nevertheless this broadening is on such a small order that it can be neglected. In the case of Asterix the same argument holds as it was used for the 0.5 Å neutrons, since this instrument only uses neutrons with a wavelength longer than 4 Å.

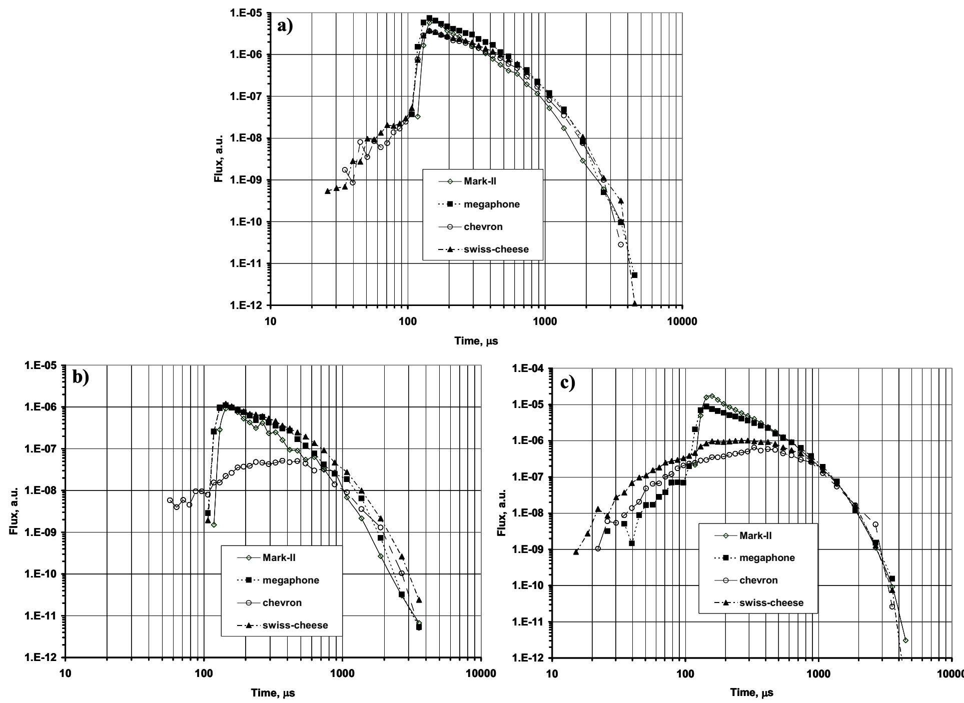

Figure 15: Pulse shape as a function of the cold beryllium reflector filter concept and the flight path for 3.0Å neutrons. (SPEAR (a), LQD (b) and Asterix (c))

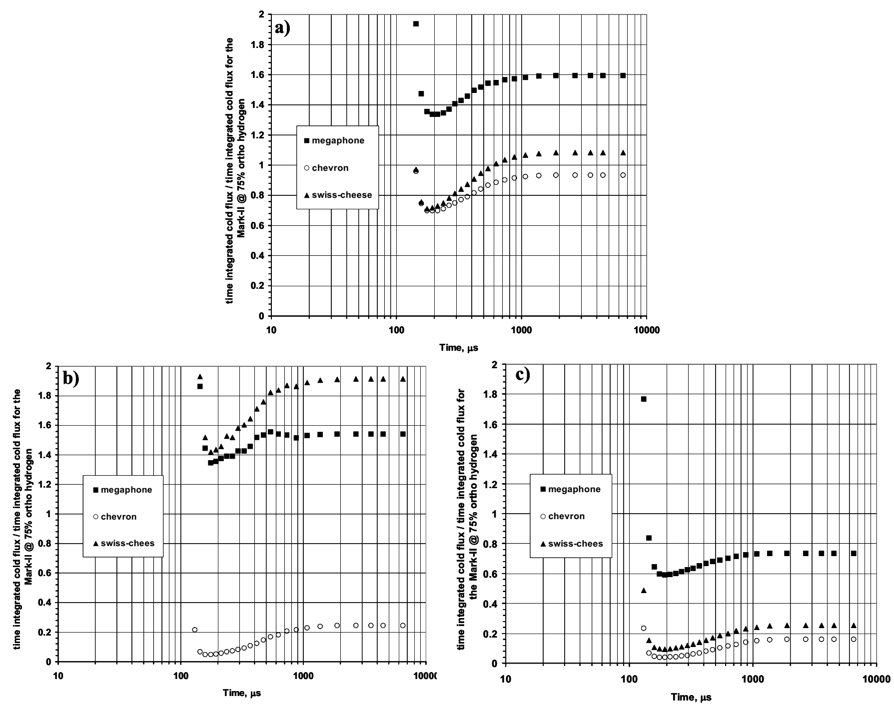

Figure 16: Time integrated flux as a function of the cold beryllium reflector filter concept and the flight path for 3.0 Å neutrons. (SPEAR (a), LQD (b) and Asterix (c))

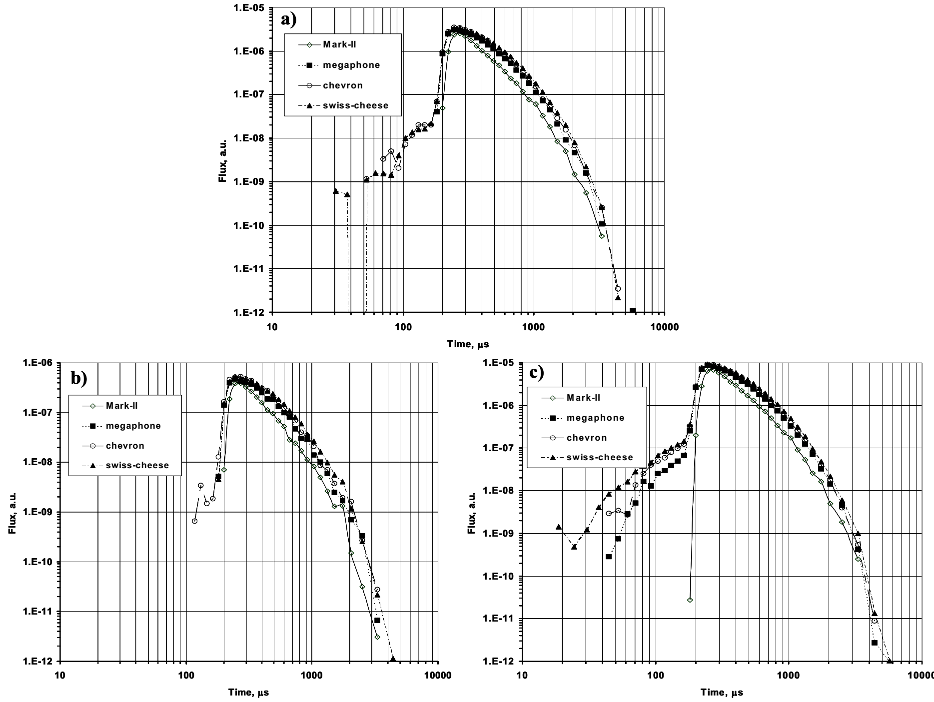

Figure 17: Pulse shape as a function of the cold beryllium reflector filter concept and the flight path for 5.0Å neutrons. (SPEAR (a), LQD (b) and Asterix (c))

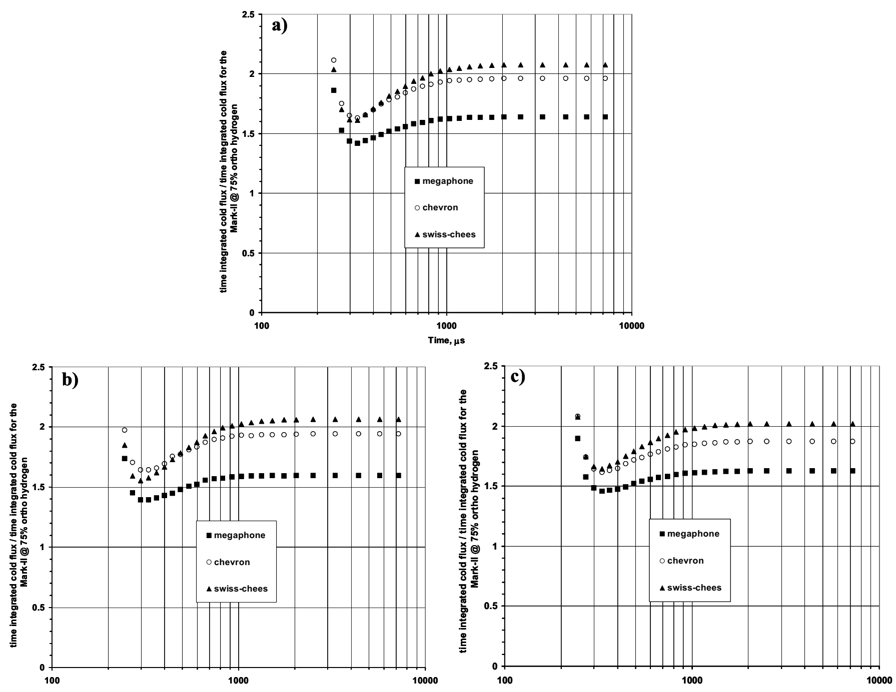

Figure 18: Time integrated flux as a function of the cold beryllium reflector filter concept and the flight path for 5.0 Å neutrons. (SPEAR (a), LQD (b) and Asterix (c))

Thirdly we looked at neutrons with a wavelength of 5Å for which the results of the time distributions are shown in figure 17a-c. It can be seen in this figures that neither of the discussed concepts changes the pulse shape significantly. However in figure 18a-c one can see from the time integrated fluxes that for the chevron and the swiss-cheese concept the pulse broadens slightly but stays within acceptable boundaries for the instruments.

6. Conclusion

We have shown in this paper that it is possible to increase the long wavelength neutron flux for the lower tier partially coupled hydrogen moderator by roughly a factor of two while still being able to preserve the short wavelength flux desired for the SPEAR instrument. This goal can be achieved by introducing the so-called swiss-cheese concept. This design not only enhances the integrated cold flux by the desired amount but it also keeps that shape of the pulse almost unchanged.

References

[1] E.J Pitcher; G.J. Russell; G. Muhrer; J.J. Jarmer; R.K. Corzine; *in Proceedings of the ICANS-XVI meeting, Neuss, Germany, 2003,* edited by G. Mank and H. Conrad p. 849.

[2] L. Waters et al., Los Alamos National Laboratory Report LA-CP-02-408, August 2002.