Tailoring Intensities and Pulse Shapes in Coupled Moderator-Reflector Systems

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Abstract

In this paper we introduce an idea for controlling the trading off of intensity and pulse width in coupled moderator-reflector systems by heterogeneously poisoning the reflector, with particular application for cold moderators. We describe measurements which illustrate the effect, performed at the Hokkaido Linac neutron source. The principle may be useful for varying on-line the performance of coupled moderator-reflector systems.

Introduction

Coupled moderator-reflector systems, in which neutrons pass freely back and forth between the hydrogenous principal moderator and the surrounding reflector provide higher time-average neutron beam intensities but have longer pulse widths than decoupled moderators in pulsed neutron sources. The concept has been recognized for some time (Bauer, et al1), Kiyanagi, et al2)) but has not yet been applied in an operating facility. In general, such systems would be useful for purposes that need cold neutrons but do not require precise time resolution, such as small angle scattering, or for instruments requiring "quasi-steady" beams. In these systems, the cold moderator may be of liquid Hydrogen, which is suitable for use in high intensity facilities. Neutrons from the reflector entering the moderator at long times are thermal neutrons equilibrated in the ambient-temperature reflector, rethermalize in the cold moderator and contribute to the neutron flux emerging from the viewed surface of the moderator. The lifetime of the thermal neutrons in the reflector is typically quite long, several hundreds of microseconds up to milliseconds, which is the reason for decoupling in the more conventional cases where it is desired to maintain short pulses. The central idea here is to vary the lifetime (and the spatial distribution) of the neutron distribution in the reflector, thus to vary the duration and consequently the time-integrated intensity of the neutron pulse emerging from the cold moderator.

Our study is by no means complete and has been constrained by practical requirements to contain certain features recognizably undesirable and unnecessary in potential practical applications, but successfully demonstrates the principle. Here, we describe our measurements and report the resulting time-average neutron spectra and the pulse widths and decay times of the beam from a liquid Hydrogen moderator. We conjecture how the principle might be applied to provide pulsed beams whose width and intensity could be varied from time to time without requiring disassembly and reassembly of the moderator-reflector system, and make some general observations.

Experimental Arrangements

The Hokkaido University electron linac provided a pulsed fast neutron source for the measurements, operating at approximately 50 Hz, with .3 μA time average current and 20 nsec pulse width for energy spectrum measurements and at 30 μA current and 3 μsec pulse width for pulse shape measurements. The target was a water-cooled lead block. Figure 1 shows the moderator-reflector assembly, which consisted of a graphite reflector approximately 1 × 1 × 1 m^3 in volume, a 2 × 12 × 12 cm^3 18 K liquid Hydrogen moderator with a 2 cm thick polyethylene premoderator (the setup remained from another series of measurements performed in the same interval, not a necessary feature of the principle under study here). Cadmium apertures defined the 10x10 cm^2 viewed area of the moderator. No absorbing liner was present in the beam path void. The electron beam struck the target in the direction perpendicular to the plane of the figure.

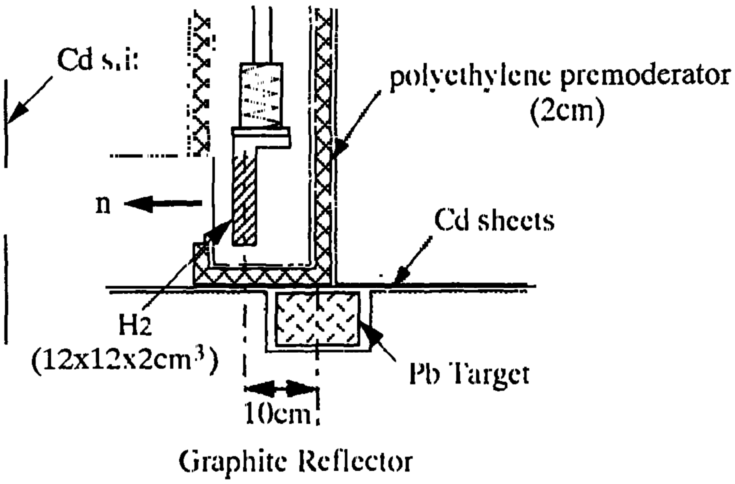

Figure 1 Coupled Liquid Hydrogen moderator with 2 cm ambient-temperature polyethylene premoderator. The present experiment was performed with and without the Cadmium sheets.

Figure 2 shows the flight path and detector systems. The flight path length between the moderator and the detector for spectrum measurements was 5.6 meters. The detector was a 1-inch diameter, 10 atmosphere ^{3}He counter with 6 inch active length. Cadmium apertures at the ends of the evacuated flight tube defined the neutron beam. Time channels were 40 μsec long.

For pulse shape measurements, the analyzer system consisted of a 5 mm thick mica crystal stack oriented at a Bragg angle of 85°. A Soller collimator of 30' divergence defined the beam incident on the crystal. A 1.6 mm wide aperture defined the opening in front of the detector, which was the same ^{3}He counter. The total flight path length for the pulse shape measurements was 6.6 meters. The time resolution of the analyzer system was approximately 0.1 %. Time channels were 5 μsec long for the pulse shape measurements.

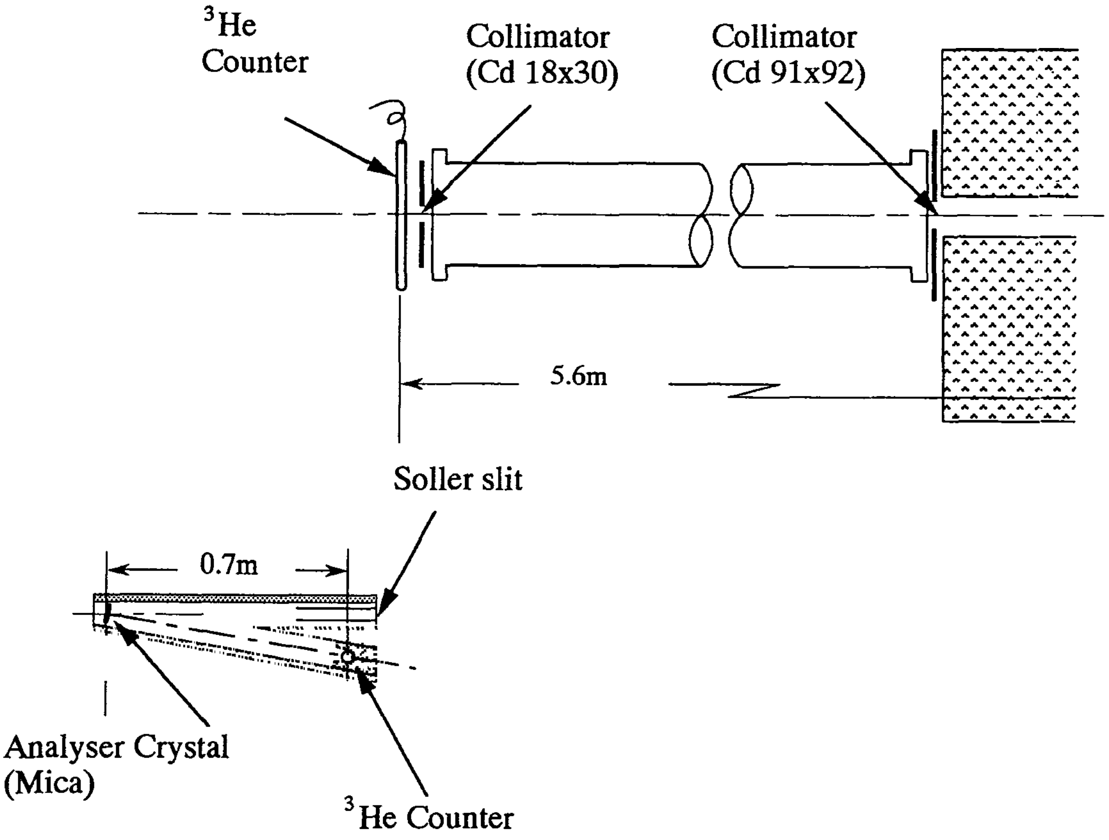

Figure 2. Detector arrangements for the spectrum measurements (upper figure) and for the pulse shape measurements (lower figure).

Spectra

Figure 3 shows the similarly-normalized time-of-flight counting rate distributions measured with and without Cadmium poisoning sheets in the reflector, and the ratio of the counting rate without to the rate with the Cadmium. Notable features are the epithermal components, which approach each other at short times, where their ratio is close to unity. The peaks at about 1.5 Å wavelength represent thermal neutrons from the ambient temperature premoderator. The peaks around 3 Å are due to the discontinuity in the H_2 scattering cross section. The hump at about 6 Å wavelength (difficult to discern) represents the rollover of the cold neutron spectrum from liquid Hydrogen, which is not a good Maxwellian as is well known. We conclude from these spectra as well as from the pulse shape measurements described below, that a significant number of neutrons from the premoderator behind the liquid Hydrogen, either penetrate the Hydrogen or are transmitted with only a few elastic scattering collisions, to emerge from the viewed surface. The ratio of intensities is about a factor of 1.4 for longer wavelength neutrons.

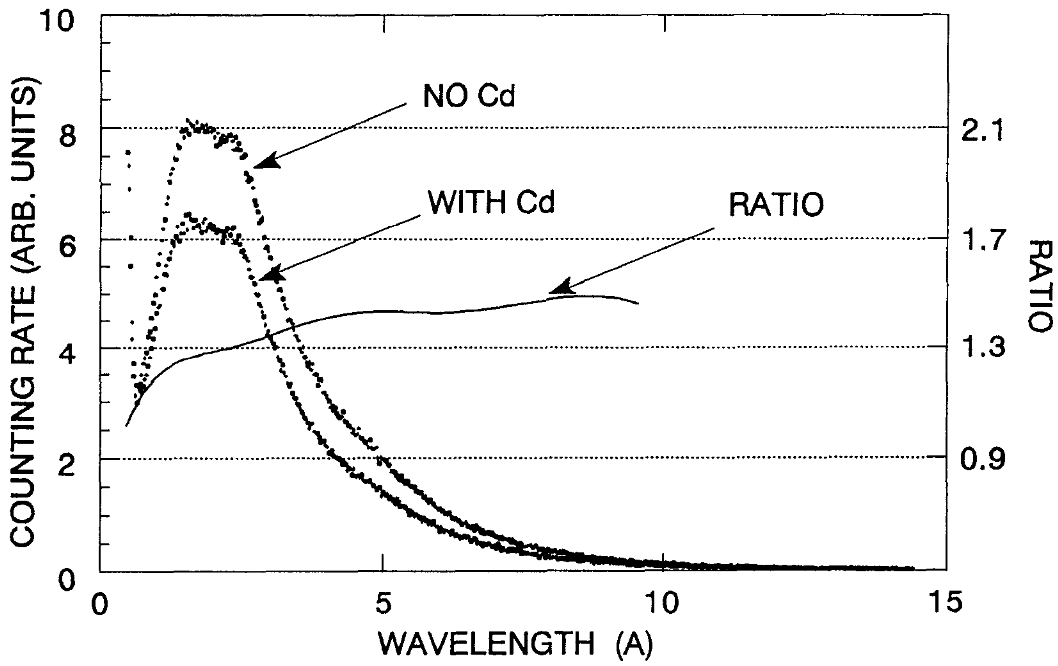

Figure 3. Counting rate per unit time-of-flight (arbitrary scale, same normalization) as a function of neutron wavelength for poisoned (lower curve) and unpoisoned (upper curve) reflector, and the ratio.

For the pulse shape measurements, the analyzer crystal reflects into the detector just those neutrons that satisfy the Bragg condition, $\lambda = 2d_{(00n)} \sin \vartheta_B$, which have separated in time as they have traveled the flight path. The time resolution of the analyzer system is sufficiently good that the shape of the emission time distribution is preserved when the neutrons arrive at the detector. We recorded the counting rate as a function of time over a interval which included the peaks due to neutrons reflected in all orders down to (004) of mica (d ~10.0 Å.) The highest order observed was (0038), above which the reflected intensity becomes small because of the rapidly-decreasing Debye-Waller factor. Vestiges of the (002) reflection can be seen in the data between the (004) and (006) peaks, where it overlaps from the previous frame.

First, we discuss the double peaks that we observed, although this is not the main point of our paper. Figure 4 shows the peaks (0018) to (0036) (λ = 1.11 ~ 2.22 Å) for the case without Cadmium in the reflector, and for reference, for another case with the same experimental arrangement, but decoupled and without premoderator, which provides short pulses from the Hydrogen only. Arrows (located by eye) indicate the peak locations.

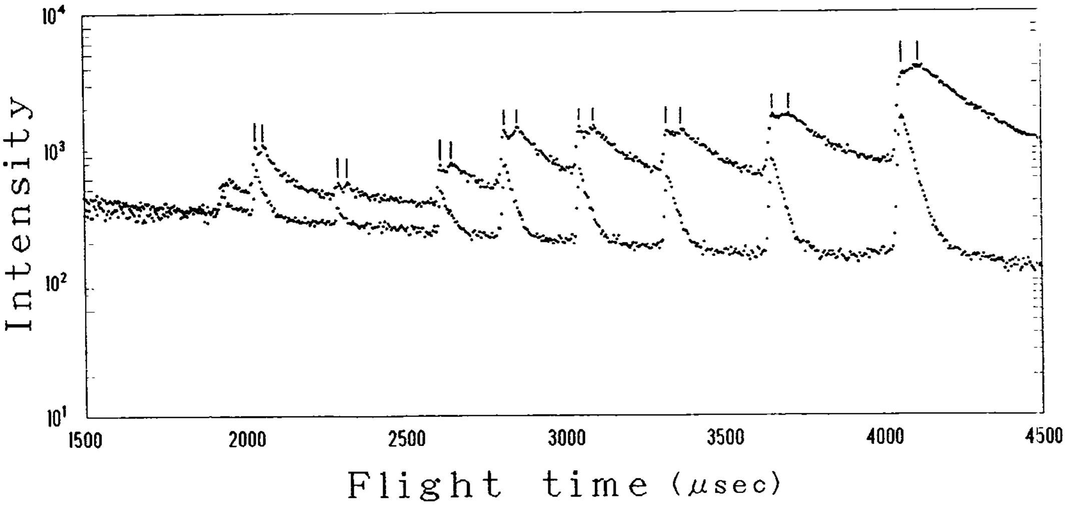

Figure 4. Observed double peaks for neutrons of wavelengths λ = 1.11 ~ 2.22 Å, for the case without Cadmium in the reflector (upper), and for the same moderator, decoupled and without premoderator (lower). Arrows indicate the locations of the peak doublets.

The double peaks arise from neutrons differently delayed by traveling different distances to the detector, but emerging simultaneously from their respective sources. Figure 5 shows the interval between the double peak pairs, for both cases with and without Cadmium in the reflector, plotted vs wavelength.

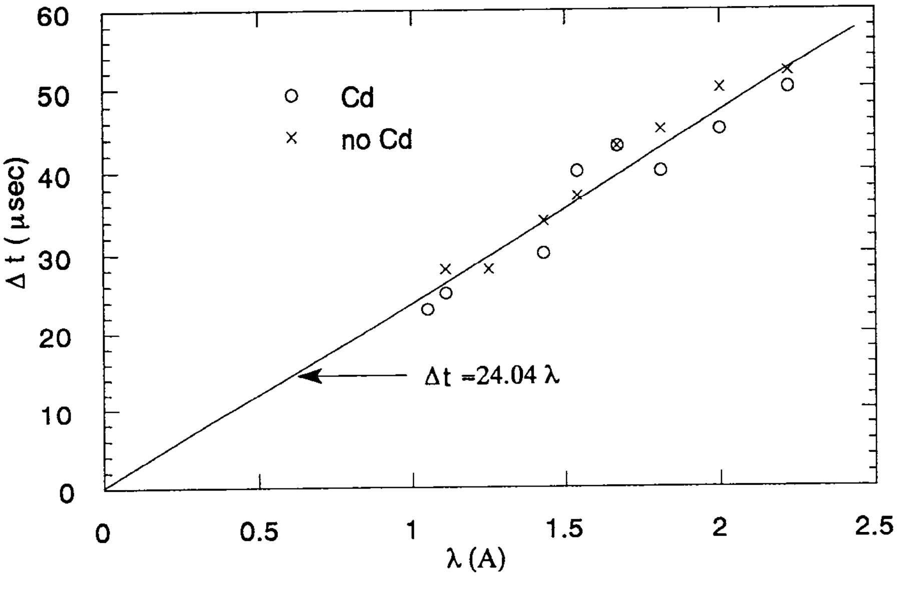

Figure 5. The interval between double peak pairs as a function of wavelength, for the cases with and without Cadmium in the reflector.

The fitted line represents the relationship Δt = ΔL/v = (m/h)ΔLλ; the slope of the line gives ΔL = 9.5 cm, which is almost identical to the actual distance between the viewed surface of the liquid Hydrogen moderator and the polyethylene premoderator behind it (ΔL = 9.6 cm.) The sharper pulses from the decoupled liquid Hydrogen moderator, shown for comparison in Figure 4, coincide exactly with the leading pulses of the double pulse pairs. These observations lend credence to the interpretation that the leading pulse is from the liquid Hydrogen and the following pulse is from the warm polyethylene premoderator, 9.6 cm farther away. Pulses of longer wavelengths than about 2.2 Å do not exhibit double peaks, as is reasonable because the intensity from the Hydrogen becomes dominant and the attenuation by the Hydrogen of the neutrons from behind diminishes their intensity.

Figures 6 a-d show the observed pulse shapes for wavelengths 3.94, 4.93, 6.57 and 9.86 Å respectively, after subtraction of a rationally-determined background, for the cases without and with Cadmium reflector poisoning, and normalized so that the areas correspond to the measured spectra. The time scales have been adjusted to correspond to the emission time, that is, the time that neutrons

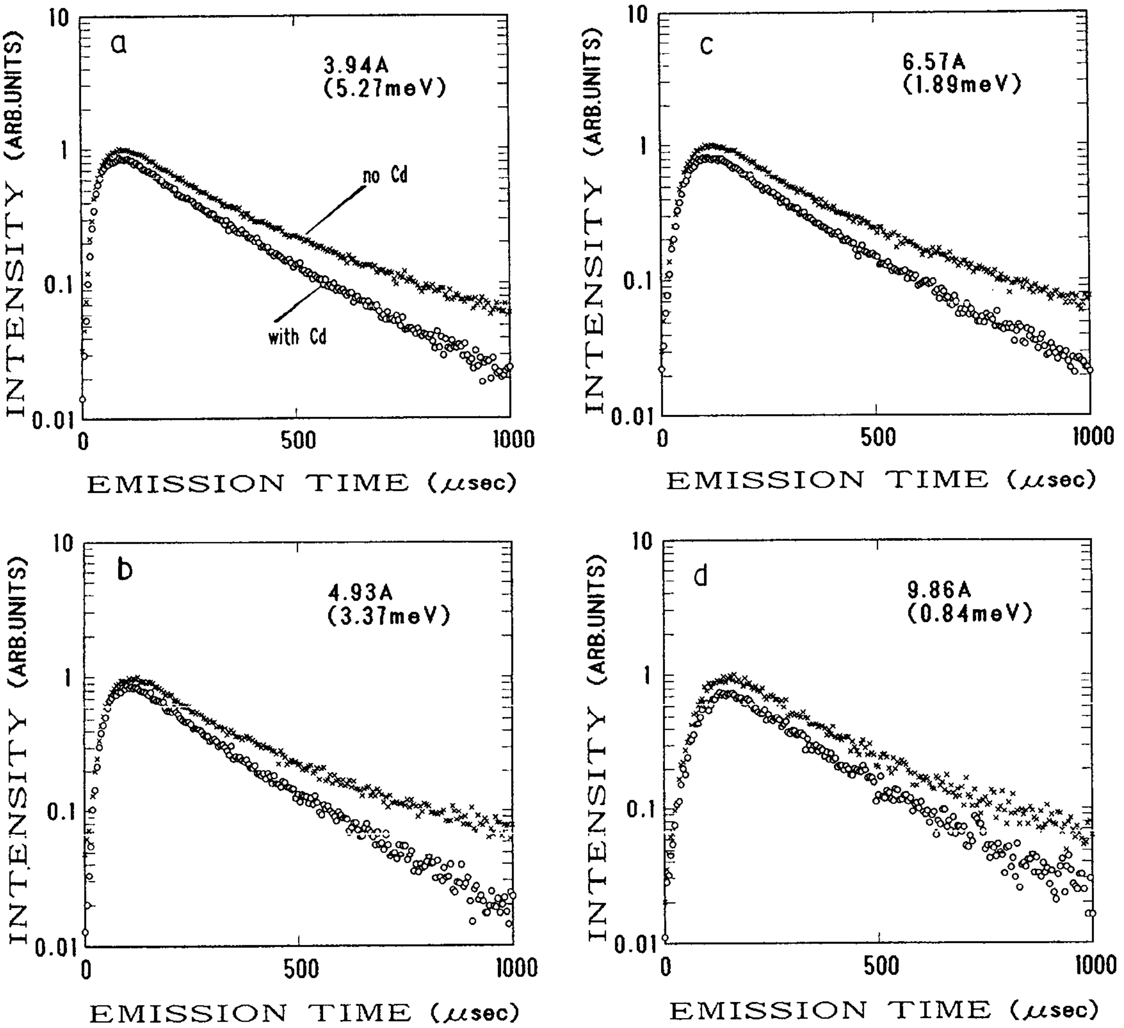

Figure 6. Intensity (log scale) as a function of emission time of neutrons from the liquid Hydrogen moderator in unpoisoned and poisoned reflectors. a. λ = 3.943Å; b. λ = 4.93Å; c. λ = 6.757Å, d. λ = 9.86Å.

crossed the viewed surface of the liquid Hydrogen. Notable features are that the shapes of the leading edges and the early decays are nearly indistinguishable, and that the trailing edges are shorter in the poisoned case than in the unpoisoned case. The peak values are about 20 % smaller in the poisoned case than in the unpoisoned case, and the remainder of the gain for the unpoisoned case over the poisoned case is due to the increased area in the longer tail.

Figure 7 shows the decay times determined as the slope of the logarithmic plot of intensity vs time on the trailing edges of the pulse shapes displayed in Figure 6. The decay in trailing edges exhibits two components. The decay time for the earlier decay was determined by fitting an exponential function to the decay after subtracting the longer-time exponential function determined from the long-time data. The decay times are independent of the wavelength in this range of wavelengths, as is to be expected if the decay is dominated by distinct eigenmodes of neutrons in the system. The long term decay time for the unpoisoned reflector is greater than that for the poisoned reflector, also as expected. The early decay time is independent of the reflector poisoning. The actual values are specific to the present geometry, not only of the reflector but also of the moderator and its immediate surroundings, since the total system represents a coupled entity.

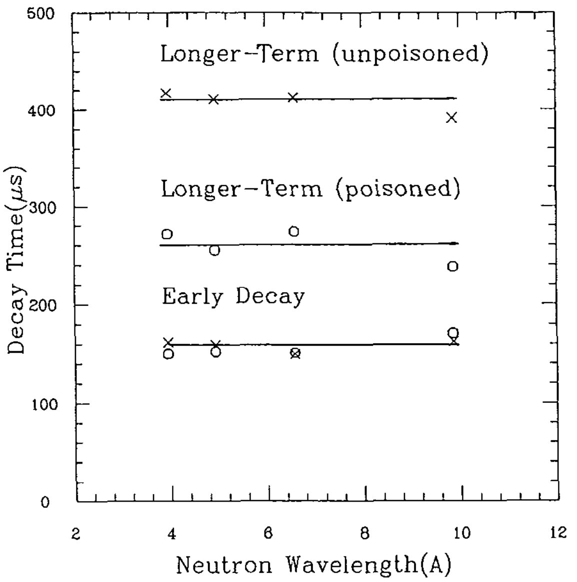

Figure 7. Decay times of the trailing edges of pulses from the liquid Hydrogen moderator in poisoned and unpoisoned reflectors.

The values of the decay times observed here are considerably shorter than would be expected in a uniform block of graphite the same size as the overall system. This is understandable, since the moderator and its surroundings themselves represent sinks for neutrons and are located in the center of the block, the position of greatest importance, analogous to the importance of control rods in a reactor.

Discussion and Conclusions

We have demonstrated that it is possible to control the decay times of coupled, reflected cold moderators, by introducing heterogeneous poisons in the reflector. This may make possible the trading off of intensity for resolution in a way that can be adjusted remotely without disassembling and reassembling a moderator-reflector system, say by moving absorber rods in the reflector or changing the density of neutron absorber in circulating channels in the reflector. The adjustments need not affect the performance of other, decoupled moderators within the same reflector. The fundamental design of such a system, however, would be greatly affected by the requirements imposed by the presence of other moderators, decouplers and void liners. Not only would attention need to be given to the desired range of pulse lengths, which could be adjusted in a large number of ways, but also to the requirement to provide the highest intensity, which implies tailoring the spatial distribution of neutrons in the reflector.

We are aware of the shortcomings of our analysis and discussion, that is, at least in the language we have used to describe the observations, we have implied the existence of discrete decay eigenvalues, which may not actually exist, particularly in systems with large voids, even though our exponential fitting seems to have provided a satisfactory result.

The double peaks that we saw prompts us to make a cautionary observation concerning cross talk and pulse broadening in coupled systems containing significant voids; the intuitive conclusion that the viewed moderator shields the viewed surface from what is behind is questionable. In any case, premoderators should be placed as close as possible to the viewed moderator, to avoid pulse distortion.

References

1. G.S.Bauer, et al., Proc. ICANS-IIIV(Didcot, July 8-12,1985) p.344.
2. Y.Kiyanagi, N.Watanabe and H.Iwasa, Nucl. Instrum. Methods, A312(1992)561.