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# TIME-STRUCTURE OF THERMAL NEUTRON LEAKAGE FROM FAST AND SLOW MODERATORS FOR SPALLATION NEUTRON SOURCES

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## ABSTRACT

The dwell-times of neutrons slowed down either in small polyethylene moderators or a large $D_2O$ volume have been measured. The fast neutrons have been produced by bombarding lead, lead-bismuth, depleted uranium and tungsten targets of slab or cylindrical shape with short pulses of 590 MeV protons. Lead and beryllium reflectors have been employed for the rectangular shaped grooved polyethylene moderators. The geometry-adapted (jagged) polyethylene moderators used with the cylindrical target have been measured only in "$D_2O$-reflected" configuration. The essential result of the numerical analysis of about 40 target-moderator-reflector configurations tested is that for the "fast" (light hydrogen) moderators the most intense flux component decays in 100 μs or less.

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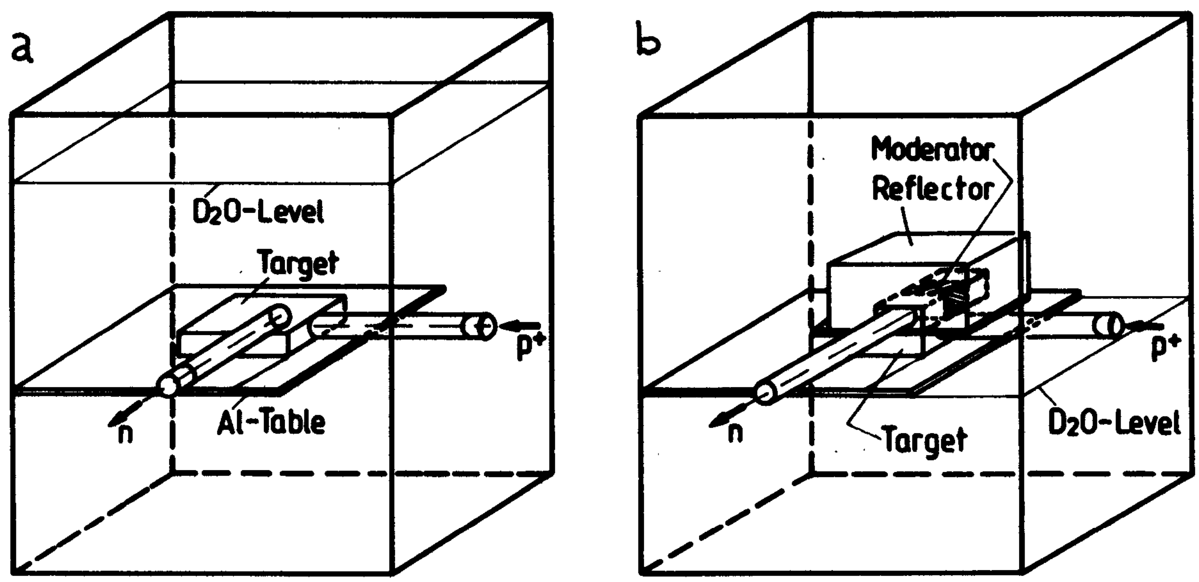
## 1. INTRODUCTION

The main advantage of the latest type of high intensity neutron source is the nearly unrestricted time structure which can be imposed on the primary fast neutron flux. The width of the thermal neutron peak flux is, however, governed both by the proton pulse width and the dwell time of the thermalized neutrons in the moderator. In other words, even an infinitely short proton pulse would result in a thermal neutron peak decaying with a finite half-width determined by geometry and material of the moderator. Besides short neutron pulses necessary for time-of-flight spectroscopy the designer of a spallation source is interested in obtaining as high peak and average fluxes as possible. In order to optimize pulse width, peak flux and average flux the precise dwell times of thermalized neutrons in different moderators have to be measured. The experimental analysis of moderator characteristics is quite difficult, if the proton pulse on the target is inadequately broad. Therefore we repeated and extended our previous investigations /Bauer et al. 1981a/ at the Swiss proton cyclotron (SIN) with a considerably improved proton chopper.

## 2. EXPERIMENTAL

This improved proton chopper of the Fermi type was machined from a solid cylinder of aluminum (instead of a hollow cylinder as the one used in the previous experiment). The resulting proton pulse shape was a single triangle of 200 μs FWHM. The measurements have been performed at the Swiss Institute for Nuclear Research (SIN) with its 590 MeV proton beam from the isochronous cyclotron pulsed at 200 Hz using the chopper just mentionned. The target-moderator-reflector set-up was the same as described in a previous report /Bauer 1981a/ and is outlined in figure 1.



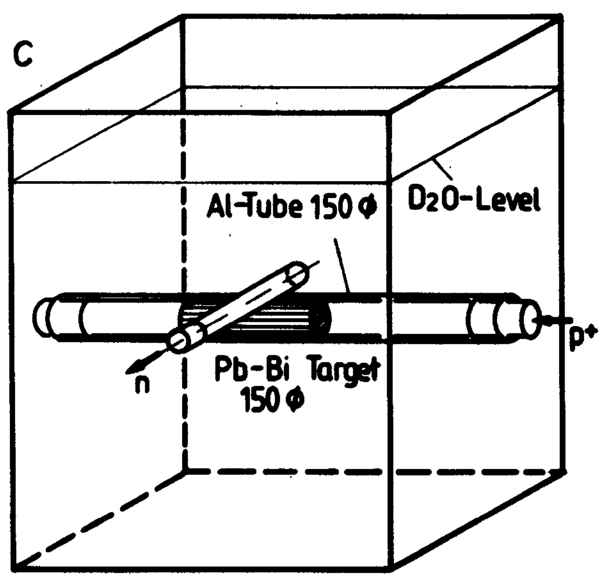




Fig. 1

Schematic representation of target-moderator-reflector arrangement

a) Slab target in $D_2O$-tank
b) Slab target with hybrid moderator configuration
c) Cylindrical target in $D_2O$-tank

Two types of arrangements have been investigated: the slab target geometry representing the lay-out of the proposed German spallation source SNQ and a cylindrical target configuration simulating the liquid metal target proposed for the Swiss project.

In the case of the cylindrical target jagged polyethylene moderators of sixfold rotational symmetry, both with and without grooves, have been employed. This new moderator is shown in figure 2.

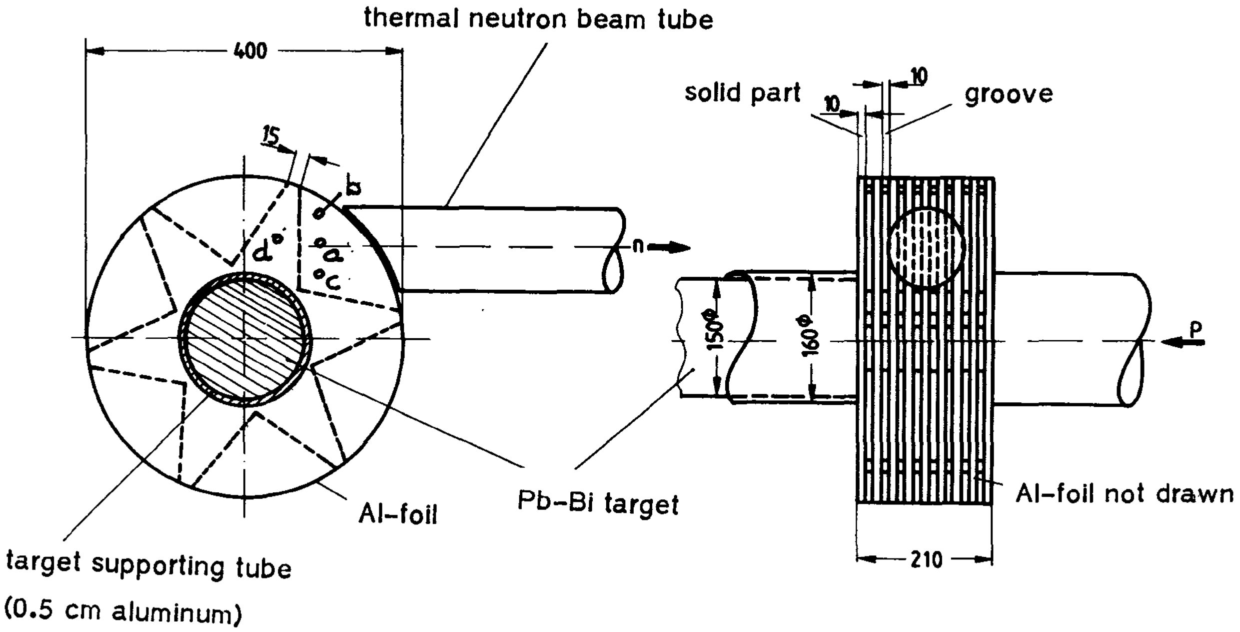



Fig. 2
The jagged moderator for cylindrical targets

In order to more realistically simulate the flux depression by beam holes, additional aluminum tubes not shown in figure 1 viewing the moderators have been mounted.

The time structure of the thermal neutron field in the polyethylene moderator and in the $D_2O$ tank have been measured inserting a small, low-efficiency $BF_3$ counter (0.6 cm diameter, 3 cm long) into holes in the polyethylene moderators. The neutron intensities measured as a function of time as well as the primary proton distribution were stored in a small computer with time-of-flight interface. The time channel width was 25 µs. The primary proton time distribution (triangle!) was measured with a scintillator telescope viewing a carbon scatterer in the direct beam.

## 3. DATA EVALUATION AND RESULTS

In order to extract the neutron dwell times from the measured intensity distributions we assumed a mathematical expression for the neutron field decay of the form

$$f(t) = f_1 \cdot \exp(-t/\tau_1) + f_2 \cdot \exp(-t/\tau_2),$$

since we found that two time constants $\tau_1$ and $\tau_2$ were sufficient for a proper description of our data. This above expression was convoluted numerically with the measured triangular-shaped primary proton distribution and the resulting convolution fitted to the experimental data varying the four parameters $f_1$, $f_2$, $\tau_1$ and $\tau_2$. In a series of cases (mainly with the fast moderator and lead reflector) it was found that only two parameters ($f_1$ and $\tau_1$) were necessary for a perfect fit. In figure 3 is given an example of the experimental data and the resulting fitted curve.

### 3.1 Results for slab targets

Three different target materials have been used in slab geometry simulating the target wheel of the German spallation project: a lead target of 10x75x60 $cm^3$ (height x depth x width), a tungsten target of 10x30x21 $cm^3$ and a target of depleted uranium of 10x50x45 $cm^3$. The grooved polyethylene moderator was placed at the maximum of the fast neutron flux emerging from the targets. Table 1 shows selected results from the numerical fitting calculations mentioned above. Besides the proper fitting parameters derived quantities like the integrated intensity and the standard deviation of the distribution are listed.

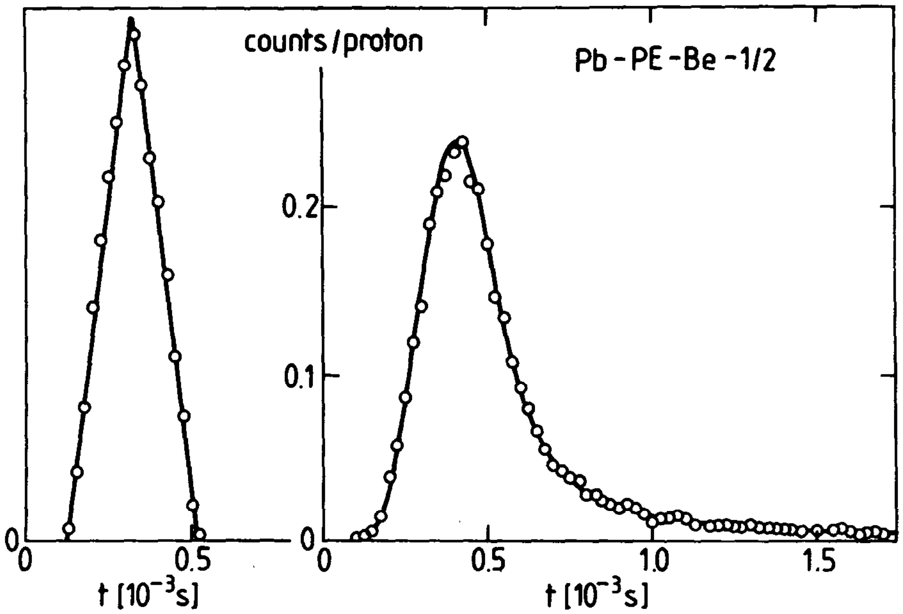



Fig. 3
Shape of the proton signal (left), example of a measured intensity distribution in the polyethylene moderator and the theoretical curve fitting the experimental data.

From the data listed in Table 1 it can be seen that the time structure of the thermal neutron peaks emerging from the grooved polyethylene moderator may be characterized by a single decay time if a lead reflector is used. This was already found in energy-selective measurements previously performed /Bauer et al. 1981b/. In the cases, where two time constants were necessary for data fitting, the dominating, i.e. high intensity component also decayed in times comparable with that of the single component neutron fields. These times range from 80 µs to 128 µs being thus significantly shorter than the 200 µs found before /Bauer et al. 1981a/.

| configuration T - M - R - $D_2O$ | $\tau_1$ $10^{-6}$s | $f_1$ $\times 10^5$ | $\tau_2$ $10^{-6}$s | $f_2$ $\times 10^5$ | integr. intensity I | standard deviations $10^{-6}$s |
|---|---|---|---|---|---|---|
| Pb-PE-Pb-1/2 | 124 | 4.4 | - | - | 54.7 | 175 |
| Pb-PE-Pb- 1 | 117 | 7.1 | 1680 | 0.79 | 215.5 | 1866 |
| Pb-PE-Pb- 1 decoupled | 93 | 6.0 | - | - | 56.9 | 132 |
| Pb-PE-Be-1/2 | 80 | 4.9 | 289 | 1.30 | 95.2 | 370 |
| Pb-PE-Be- 1 | 137 | 6.7 | 996 | 0.70 | 162.2 | 935 |
| Pb-PE-Be- 1 decoupled | 85 | 7.2 | 389 | 0.20 | 67.2 | 203 |
| Pb-PE-Be-1/2 decoupled | 92 | 5.4 | - | - | 49.6 | 130 |
| Pb-PE-Be- 0 decoupled | 100 | 4.7 | - | - | 47.4 | 141 |
| Pb-PE-Be-1/2 * | 104 | 5.3 | 588 | 0.40 | 80.9 | 485 |
| W -PE-Pb-1/2 | 115 | 4.6 | - | - | 53.1 | 163 |
| U -PE-Pb-1/2 | 128 | 7.9 | - | - | 100.5 | 181 |

Table 1

Dwell times $\tau$, scale factors f, integrated intensities and standard deviations for selected slab target-moderator-reflector configurations.
Symbols and definitions: T = target; M = moderator; R = reflector; $D_2O$ = level of tank filling; i.e.: 0 = empty, 1/2 = up to the target, 1 = full; PE = polyethylene; $I = \int f(t)dt = f_1\tau_1+f_2\tau_2$
$S = \sqrt{\sigma^2}$, where $\sigma^2$ is given by: $\sigma^2 = 2(f_1\tau_1^3 + f_2\tau_2^3)/(f_1\tau_1 + f_2\tau_2)$
* 4 cm of Be between PE moderator surface and beam tube

### 3.2 Results for cylindrical target with jagged polyethylene moderator

An eutectic lead-bismuth target of 15 cm in diameter and 60 cm length was inserted in the through tube of the $D_2O$ tank (compare figure 1). The jagged polyethylene moderator was placed at the maximum of the fast neutron flux. The arrangement can be seen in figure 2. Two moderators have been tested, one with grooves in the gap between the jags and another one with empty gaps. In both cases the moderator was cased with an aluminum foil to prevent $D_2O$ to enter the space between the jags. The time structure of the thermal neutron pulses has been measured inserting the $BF_3$ counter into different bore holes in both the jags and the gaps. In all but one cases the tank was completely filled with $D_2O$. Both decoupled (Cd casing of the moderator) and coupled moderators have been investigated. A compilation of the results from the fitting computations is given in table 2.

| configuration<br>Pb/Bi - PE ✳$_i$ - $D_2O$<br>grooved | | $\tau_1$<br>$10^{-6}$s | $f_1$<br>$\times 10^5$ | $\tau_2$<br>$10^{-6}$s | $f_2$<br>$\times 10^5$ | integr. intensity<br>I | standard deviation<br>S [ $10^{-6}$s ] |
|---|---|---|---|---|---|---|---|
| i = a | 0 | 143 | 3.7 | - | - | 53.0 | 202 |
| no PE | 1 | 125 | 0.9 | 3170 | 0.9 | 306.2 | 4406 |
| i = a | 1 | 131 | 5.5 | 2330 | 0.4 | 172.6 | 2520 |
| i = b | 1 | 170 | 2.3 | 2370 | 0.3 | 100.2 | 2604 |
| i = c | 1 | 150 | 6.5 | 2250 | 0.2 | 141.2 | 1795 |
| i = d | 1 | 110 | 11.2 | 2360 | 0.3 | 190.1 | 1983 |
| i = a decoupled | 1 | 126 | 5.5 | 1760 | 0.2 | 96.0 | 1318 |
| i = b decoupled | 1 | 148 | 2.9 | - | - | 42.5 | 209 |
| i = d decoupled | 1 | 102 | 12.2 | 1480 | 0.2 | 157.2 | 961 |
| i = a (no grooves) | 1 | 263 | 2.0 | 2240 | 0.5 | 167.4 | 2635 |
| i = d (no grooves) | 1 | 86 | 11.3 | 1550 | 0.5 | 167.6 | 1420 |

Table 2

Dwell times $\tau$, scale factors f, integrated intensities and standard deviations of the cylindrical target-moderator-reflector arrangement. The configuration was the same in all but the first case listed, where the $D_2O$ tank was empty. The index i at the symbol ✳ denotes the position, where the neutron counter has been inserted (see figure 2). The remaining symbols have been defined in the caption of table 1.

## 4. CONCLUSIONS

In the case of the grooved fast moderator for slab targets the neutron peaks were found to be shorter than deduced from previous measurements. A dwell time of 80...120 μs is considerably shorter than the proton pulses of 500 μs of the SNQ linac. Thus the maximum possible peak flux will not be reached. As compared to previous estimates based on decay times of 200 μs the peak flux would only increase by 8 % due to the reduction of the dwell time to 100 μs. Shortening, for instance, the proton pulse to 250 μs would yield a gain of 100 % with a dwell time of 100 μs, whereas a gain of 55 % only would result, if the dwell time was 200 μs. Thus there is a big incentive to try to increase the pulse proton current to 200 mA and shorten the pulse to 250 μs.

For the cylindrical target (in liquid state), which shall be employed for the Swiss spallation source, the above considerations may be of no importance, as it was proposed to operate that source continuously. Besides that, the $D_2O$ moderator would dominate the time structure. Thereby the proton pulse length is no important parameter.

## REFERENCES

G.S. Bauer, W.E. Fischer, F. Gompf, M. Küchle, W. Reichardt, and H. Spitzer (1981 a)
"Thermal Neutron Leakage and Time Structure Measured for Various Target-Moderator-Reflector Configurations for a Spallation Neutron Source"
paper D2-4 in "ICANS V" pp. 445-474, G.S. Bauer and D. Filges, eds., report Jül-Conf-45, Kernforschungsanlage Jülich

G.S. Bauer, H.M. Conrad, H. Spitzer, K. Friedrich, and G. Milleret (1981 b)
"Measurement of Time Structure and Thermal Neutron Spectra for Various Target-Moderator-Reflector Configurations of an Intensity-Modulated Spallation Neutron Source"
paper D2-5 in "ICANS V" pp. 475-488, G.S. Bauer and D. Filges, eds., report Jül-Conf-45, Kernforschungsanlage Jülich