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An Effective Inbeam Screening of Background by Choppers at a Pulsed Spallation Neutron Source

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Abstract

The energy spectrum of background neutrons at a spallation neutron source extends to rather high energies. Shielding against these fast neutrons is difficult . It is proposed to fill the beam holes with a series of choppers to reduce effectively the pulsed background of fast neutrons. The effective shielding length during the proton pulse may extend up to about 4 m in a time-of-flight-spectrometer.

The spectrum of fast neutrons at a spallation neutron source extends to higher energies than at a conventional fission reactor neutron source. Therefore a more effective shielding is needed at a spallation neutron source. The main biological shield of the source will be thicker compared to that of a reactor and may consist of higher density materials such as steel. The shielding of the experiments must be more effective and will be in most cases different from that used on conventional neutron scattering instruments at reactors. Care should be taken that the improvement of the shielding does not cause losses in intensity due to an increased moderator to sample distance.

At a pulsed source the background is time dependent and may be separated in time from the useful neutrons by the choice of an adequate length of the flight path. Using non-moderating or highly absorbing shielding at the instruments reduces the background to low counting rates. Due to the high intensity of fast neutrons during the spallation process there will be no access to such an instrument during operation.

A better solution for background screening will be an effective shielding inside the biological shield with choppers synchronized to the pulsed source. The best we can do is to close the beam tubes with as much as possible of an effective shielding material during the time the proton pulse hits the target and open them for the time the neutrons of interest should pass through.

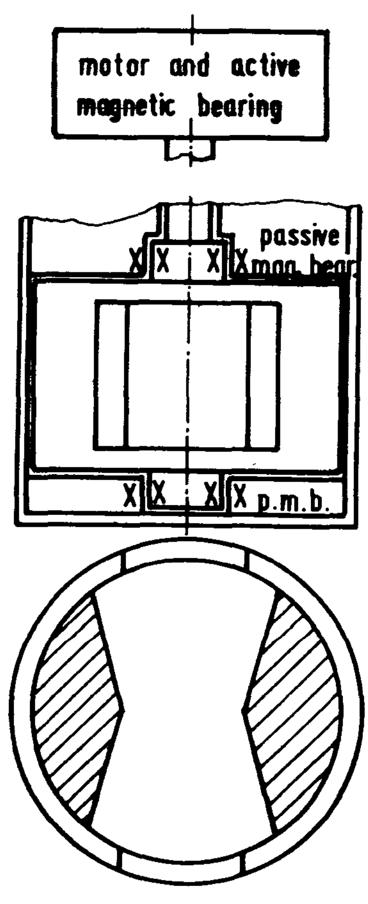

Fig. 1 Chopper for background shielding

If we could do it mechanically a big (of about the same size as the biological shield) rotating wheel beam shutter with a curved beam hole would be perfect to select one neutron energy. For several reasons the size of the chopper wheels inside the biological shield will be limited to somewhat between 20 cm and 40 cm in diameter. Therefore a series of choppers will be necessary for a good screening of fast neutron background.

The features of such a chopper is shown in fig.1. The chopper will be housed in a tube which fits into the shielding of the source. It will consist of a vertical cylindrical rotor centered by passive magnetic bearings and an active magnetic suspension at the far end outside the biological shield. The shape of the beam hole through the rotor allows a 100% transmission of neutrons within the energy band and the pulse length of interest. The speed of the choppers will be about 12000 rpm for the choppers nearest to the moderator and 3000 rpm at the end of the beam hole in front of the sample. The total shielding length obtainable is related to the diameter and speed of rotation of the choppers. With the size of the rotors the stored energy, which is proportional to the forth power of the rotor's diameter, raises rapidly. Limiting the stored energy to values below 50 Wh restricts the rotor diameter to about 20 cm for choppers spinning at 18000 rpm and about 40 cm at 3000 rpm.

The efficiency of this shielding may be demonstrated for three typical instruments: a time of flight (TOF) spectrometer, an inverse TOF instrument and a triple axis spectrometer when installed at a source as the German SNQ (Spallationsneutronenquelle) project. Contrary to most existing or planned sources the SNQ is planned to give 0,5 msec of pulse length at a rate of 100 pulses a second. This pulse structure makes these types of instruments rather attractive at the SNQ.

Time of flight spectrometer at the SNQ.

The optimum in flexibility may be achieved using two fermichoppers for the selection of energy and the energy and time resolution combined with a series of background choppers in between (fig. 2). The same considerations are valid for a spallation source with short pulses as the SNQ-option with compressor ring. Then of course no fermichopper close to the moderator is needed.

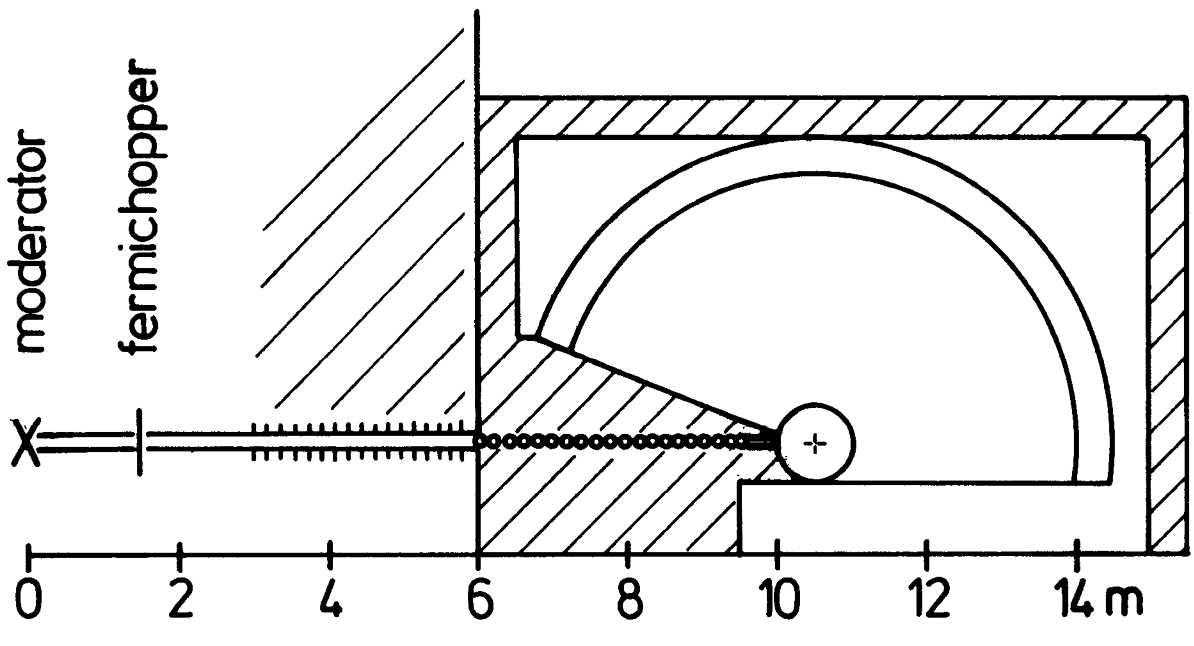

Fig. 2 Time of flight spectrometer with background choppers

This TOF-spectrometer may be compared to the IN4 at the HFR at Grenoble. The length of the total flight path in both spectrometers will be about the same. Admitting aproximately the same losses in intensity for the two fermichoppers compared to the losses in reflectivity of the two monochromator crystals at the IN4 the flux at the sample position will be higher by a factor of about 20 (which is the peak to avarage flux ratio of the SNQ) times the repetition times ratio of SNQ and IN4 (for same energy and resolution). If we admit a rather high repetition rate at the IN4 of 2.5 msec between pulses this factor will be about 5. To be able to use this gain factor and the higher flexibility of such an instrument, the background should be of the same order of magnitude or less compared to the IN4. This will be achieved by the phased chopper system combined with the pulse structure of the SNQ. The fast neutron background will be reduced by the total shielding length accomplished by the background choppers during the linac pulse.

An optimal shielding (fig. 2) will consist of a densely packed series of choppers with vertical axes starting at about 3 m from the moderator and ending at the outer edge of the biological shield. Outside the biological shield all the remaining space in front of the sample may be used for shielding by large choppers with horizontal axes. Since TOF-instruments with an analyser flight path of 3 m to 4 m to the detectors need large, flat flight boxes they should be arranged vertically (as IN4) to enable a maximum of instruments at the SNQ. Under the assumtion of a moderator surface of 10 cm x 10 cm and a sample sized 5 cm horizontal and 2.5 cm vertical the dimensions of choppers in the beamline and their speed of rotation, phases with respect to the proton pulse and shielding lengths were calculated for neutron energies of 20 meV and 100 meV (see table 1).

d (m)	Chopper dimensions (cm)				E_o = 20 meV			E_o = 100 meV		
	diam.	slit ↔	slit ↕	axis	speed sec^{-1}	phase degrees	l_s %	speed sec^{-1}	phase degrees	l_s %
1.5-3	13	9	9	│	fermi chopper					
3	20	8.6	7.9	│	150	83.2	48	200	48.6	36
4	20	8.1	7.1	│	100	73.8	49	200	64.8	48
5	20	7.6	6.4	│	100	92.5	54	200	82.8	54
6	23	7.1	5.7	-	100	110.5	66	150	74.0	67
7	23	6.7	5.0	-	50	64.3	69	150	81.5	71
8	30	6.2	4.3	-	50	73.8	79	100	65.9	78
9	30	5.7	3.6	-	50	82.8	82	100	74.2	82
9.5	5	5.5	3.2	-	fermi chopper					

Table 1 Dimensions and speed of supressor choppers in a TOF instrument (d = distance of chopper from moderator, phase = phase between end of proton pulse and open position of the chopper, l_s = shielding length of the chopper during the proton pulse relative to the length of the device)

A total shielding length of all the choppers during the proton pulse of about 4.2 cm can be obtained when the phases of the choppers are synchronized for thermal neutrons. At higher neutron velocities the time between the proton pulse and the time the neutrons should pass through the first background choppers becomes shorter and reduces the effective shielding length which can be obtained (to about 3,5 m at E_n = 200 meV).

While in a TOF spectrometer with two choppers for energy selection at the SNQ with rather long pulses only the distance between the fermi choppers is relevant, the maximum distance of the pulse generating fermi chopper from the moderator in an inverse TOF instrument is limited due to the energy selection by the finite length of the pulse from the moderator. A distance of 1,5 m from the moderator seems to be a good choice: on one hand good intensities within a wide range of neutron energies are available, on the other the distance is far enough to reduce the problems which may arise from the immediate vicinity of the target (nuclear heating, activation).

For higher flexibility we propose to use a fermi chopper (fig. 3) with a series of collimators on top of each other. The collimation and thereby the resolution may be changed by simply changing the level of the entire chopper.

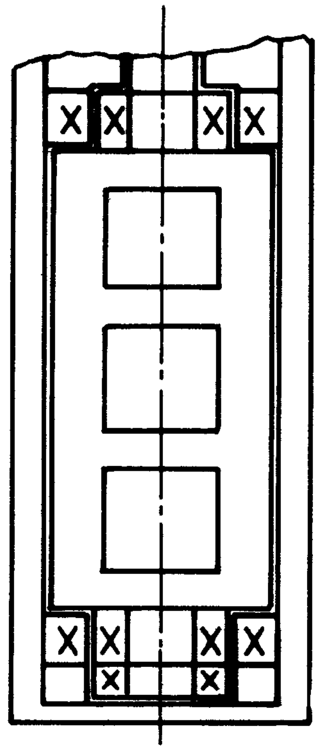

Fig. 3 Fermi chopper with three interchangeable collimators

Further adaption of time resolution can be achieved by spinning the chopper at multiples of 50/sec.

The background screening at an inverse time of flight spectrometer.

The best conditions for an inverse TOF spectrometer would be a narrow, symmetric neutron pulse emerging from the moderator. This may be achieved at a spallation neutron source with short proton pulses and with a poisoned and decoupled moderator. The option of the SNQ project with a storage ring certainly will give optimal conditions. While the gain in the peak flux by such a compressor ring will be enormous for epithermal neutrons it will be only a factor between two and three in the thermal region. Without storage ring a chopper is needed to provide short symmetric pulses. The pulse width and hence the intensity may be optimized to the problem of interest.

The proposed screening of an inverse TOF spectrometer by choppers is similar for both types of sources. As demonstrated in fig. 4 the transmission time of background choppers will rise with the distance from the fermi chopper (or moderator). The distance from the moderator of the time zero defining fermi chopper limits the energy band to be transmitted. A limitation at the low energy side is needed to avoid time overlap at the detectors. The energy band of interest and thereby the energy with optimal transmission may be adapted by the choice of the chopper's phases. The example in fig. 4 gives optimal transmission at 60 meV and is designed for an energy band ranging from 20 meV to 200 meV.

Choppers for a triple axis spectrometer.

The pulse structure of the German SNQ allows an application of choppers for background screening without losses in intensity for all types of instruments using a monochromatic neutron beam. The choppers will have the same shape as those of an inverse TOF spectrometer with an angle of transmission corresponding to the length of the neutron pulse. The phases of the choppers will be adapted to the energy of the neutrons of interest and thereby an energy band will be preselected. In combination with a crystal monochromator there will be no higher order contaminations. The inbeam screening with choppers at a triple axis spectrometer will reduce essentially the shielding problems at such an instrument. Access to the sample enviroment will be allowed which would be impossible without such a shielding. A facility of high flexibility may be installed at the quasi-continuous SNQ.

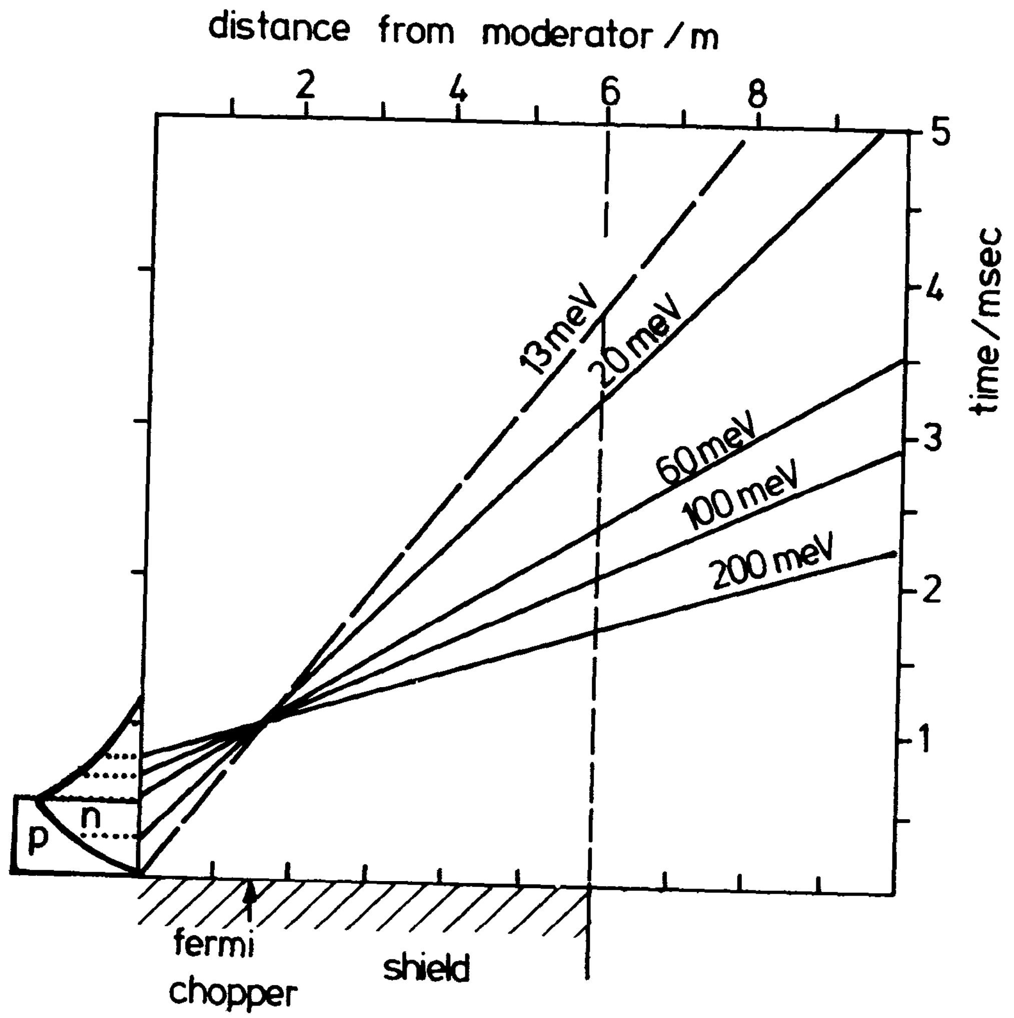

Fig. 4 The neutron time to flight path distribution at an inverse TOF-spectrometer