SHIELDING CALCULATIONS FOR THE EIGER MONOCHROMATOR

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Preliminary shielding calculations for the new monochromator EIGER, to be installed at one of the thermal neutron beam tubes of SINQ, were performed with the Monte Carlo particle transport code MCNPX. Various shielding versions were calculated and compared. The results are used as a basis for the final design evaluation.

INTRODUCTION AND BOUNDARY CONDITIONS

A new monochromator will be installed at the SINQ thermal neutron beam tube S_8, called EIGER (Enhanced Intensitiy and Greater Energy Range). This report describes preliminary calculations that were performed with the Monte Carlo particle transport code MCNPX [1] to optimize the design of the shielding for this monochromator, and their results. A more detailed account is given in [2].

Table 1 lists the initially available parameters.

The shielding will be cylindrical with a uniform thickness, since it needs to be rotated for different angular settings. If possible, the shielding thickness should not exceed 1 m; the inner radius is assumed to be 17.5 cm. Iron should not be used because of the presence of magnetic fields.

The total dose rate due to neutrons and photons outside of the fenced-in experimental area, that is, at a distance of about 4 m from the monochromator position, should be below 1 μSv/h.

Thermal neutron flux	Monochromator		
	material	effective area	thickness
10^9 n/cm^2 s	graphite, (Cu)	3 x 17 cm^2	3-5 mm

Table 1: Some relevant parameters for the shielding calculations.

THE INCOMING NEUTRON SPECTRUM

For the shielding calculations, the spectrum of neutrons impinging on the monochromator needs to be known. The non-thermal components are particularly important since they determine the design of the shielding. The spectrum was constructed from available information as described below.

The shape of the thermal neutron spectrum was taken to be the same as measured at the NEUTRA (Neutron Transmission Radiography) thermal beam port [3].

The higher-energy neutron components were taken from earlier calculations of neutron intensities at SINQ with the code package HETC [4]; Table 2 lists the neutron currents at 530 cm down the beam tube S_8. For further use, they were normalized to the thermal neutron peak of [3].

Since the dose rate conversion factors vary strongly between 0.01 MeV and 20 MeV neutron energies, the spectrum shape in this energy region was defined in more detail using results from calculations for the NEUTRA station with MCNPX [5].

The final neutron spectrum used as input for the shielding calculations is shown in Fig. 1.

neutron energy	< 0.625 eV	0.625–10^4 eV	0.01–20 MeV	20–100 MeV	> 100 MeV
neutron current	$7.7 \cdot 10^8$	$4.4 \cdot 10^7$	$2.6 \cdot 10^7$	$3.2 \cdot 10^4$	$3.8 \cdot 10^3$

Table 2: Neutron currents [s^{-1}] at 530 cm down the beam tube S_8, taken from ref. [4].

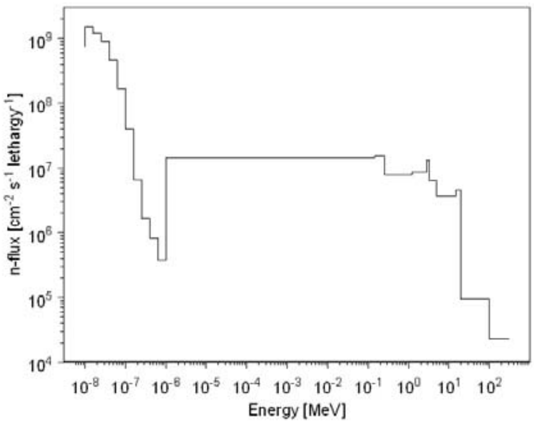

Fig. 1: Neutron flux per unit lethargy on the monochromator used as input for the calculations.

THE CALCULATION MODEL

The shielding calculations were performed with MCNPX, version 2.5.d, using cross section tables from ENDFB-VI. For simplicity, a spherical geometry was used, with concentric shells of different shielding materials; the inner radius was 20 cm. The geometry was divided up into smaller, conical-shaped regions which were assigned different weights for the purpose of variance reduction. The monochromator is positioned at the center of the sphere and irradiated with a parallel beam of neutrons having an energy spectrum as shown in Fig. 1. Neutron and photon fluxes are tallied within 30 cm outside of the shielding sphere in angular bins of 10° width with respect to the incoming neutron beam. F4 track length tallies are used. An example of the geometry is shown in Fig. 2.

The particle fluxes are converted to dose rates using the appropriate energy-dependent flux-to-dose conversion factors. Since the results from MCNPX are per starting neutron, the normalization factor $5.1 \cdot 10^{10}$ n/s is used to obtain the final results.

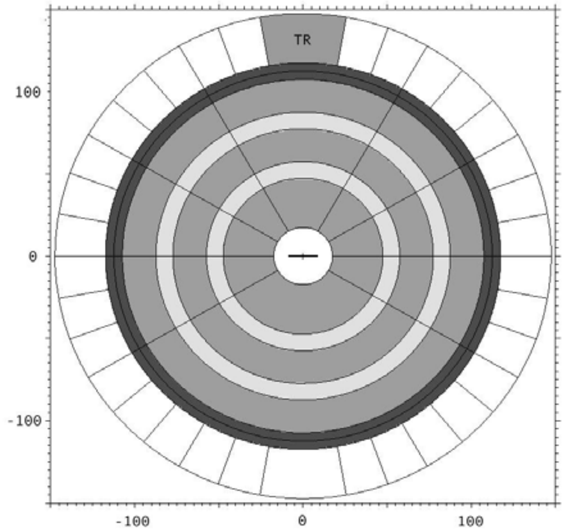

Fig. 2: Geometry layout for the shielding calculations; it corresponds to versions V6 and V7 in Table 3. Dimensions are in centimeters. The source neutrons hit the monochromator at the center of the shielding sphere from below. The shaded tally region (TR) outside of the sphere is used to obtain the neutron and photon fluxes in the forward direction at ±10°.

RESULTS

Table 3 lists for five of the eight considered shielding versions the material thicknesses, from the inside out, and the corresponding calculated dose rates. The neutron dose rates are always dominated by neutrons of about 1 MeV and above.

Version	V2	V3	V4	V6	V7
Layer 1 [cm]	Pb 38	B_4C 3	Pb 30	Pb 30	W 30
Layer 2 [cm]	PE 10	Conc 50	Conc 50	PE 10	PE 10
Layer 3 [cm]	Pb 17	B-Conc 50	Pb 10	Pb 20	W 20
Layer 4 [cm]	PE/B_4C 10		PE/B_4C 10	PE 10	PE 10
Layer 5 [cm]				Pb 20	W 20
Layer 6 [cm]				PE/B_4C 10	PE/B_4C 10
n dose rate [μSv/h]	130	180	44	21	1
γ dose rate [μSv/h]	< 1	5	8	< 1	< 0.1
n+γ [μSv/h]	130	185	52	21	1

Table 3: Summary of various shielding layouts (the order of materials is from the inside out) and the corresponding calculated dose rates within 30 cm outside of the shielding in the forward direction at ±10°.

Used materials are:

Boroncarbide (B_4C): ρ=1.5 g/cm^3 (60% filling vol.)
Lead (Pb): ρ=11.4 g/cm^3
Tungsten (W): ρ=19.3 g/cm^3
Polyethylene (PE): ρ=0.95 g/cm^3
Borated PE (PE/B_4C): ρ=1.03 g/cm^3 ; 5 wt.% B_4C
Normal concrete (Conc): ρ=2.4 g/cm^3
Borated concrete (B-Conc): ρ=2.4 g/cm^3; 1 wt.% B

Lead and tungsten have been used as pure elements in MCNPX, PE is $(CH_2)_n$. The composition for normal concrete is shown in Table 4.

Replacing the graphite monochromator with a copper monochromator in the calculation model does not significantly change the results (< 10 %).

The dose rates decrease rapidly towards more backward angles, as illustrated in Table 5.

At a distance of 4 m from the monochromator position (that is, outside of the proposed experimental area), the dose rates are reduced by a factor of about 16. Therefore, version V6 would probably need additional shielding in the forward direction, whereas in version V7, the amount of tungsten can be reduced. The results are being used as a basis for the final design evaluation.

H	C	O	Mg	Al	Si	Ca	Fe
0.62	17.44	40.80	3.25	1.16	3.43	32.54	0.76

Table 4: Chemical composition of normal concrete in units of wt.%, used in MCNPX.

angular range [°]	0-10	10-20	20-30	30-40	40-50
n dose rate [μSv/h]	21	8.4	4.2	1.8	0.8

Table 5: Neutron dose rates just outside of the shielding for version V6 as a function of angle with respect to the incoming neutron beam.

REFERENCES

[1] L.S. Waters, *MCNPX User's Manual Version 2.3.0*, Los Alamos National Laboratory report LA-UR-02-2607, Los Alamos, New Mexico, April 2002.

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[3] E. Lehmann, PSI, private communication, October 2003.

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