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THE HIGH-ENERGY NEUTRON BACKGROUND AT SINQ

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1. Introduction

The sources of high-energy (E_n > 15 Mev) neutron background at SINQ were reviewed by F. Atchison [1]. We now report the results of a study, using HET Monte-Carlo [2] and point-kernel methods, which was undertaken as a re-examination of these five sources of background, namely :

(1) The weakening of the iron bulk shield due to the beam tubes.

(2) The scattering of neutrons in the D_2O.

(3) The back-scattering of neutrons from the iron bulk shield.

(4) The scattering of neutrons in the windows at the beam tube tips.

(5) The penetration of the background neutrons into the monochromator shield, approximated by a large homogeneous block of iron.

Processes (1) to (4) contribute to the background at the monochromator, process (5) is relevant for the background further downstream. The geometry used in the study is a simplified SINQ arragement (see fig. 1).

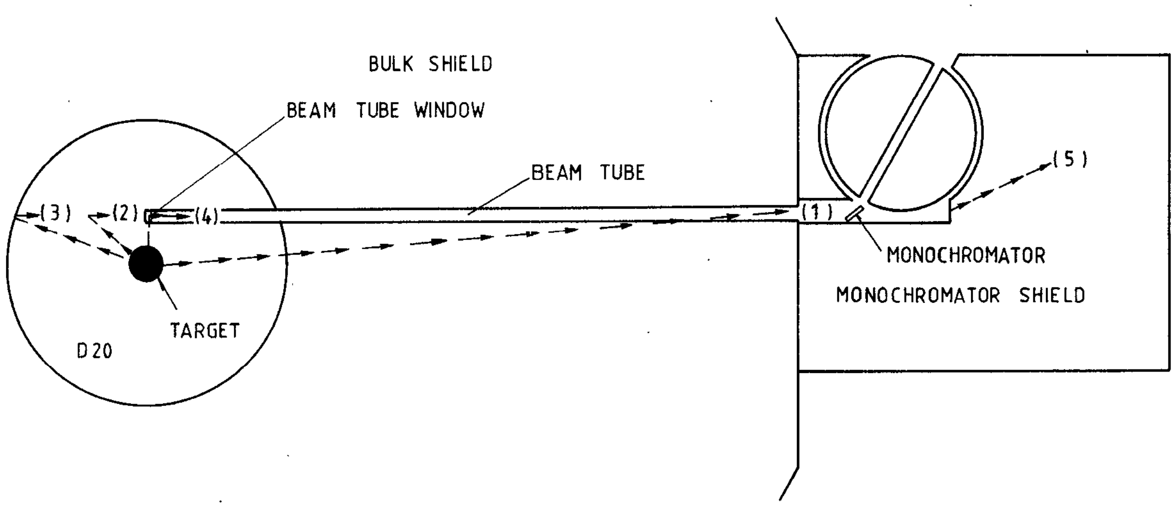


Fig. 1 Simplified geometry of the SINQ target and shielding, showing the investigated sources of high-energy neutron background.

The background was estimated as function of the radial distance of the beam tube tip from the centre of the target, and at two different values $z_D = -1.5$ cm and $z_D = 21.5$ cm for the level of the horizontal beam tubes with respect to the entrance face of the vertical target. The monochromator at D is taken on the beam tube axis. The beam tubes are 8 x 15 cm^2 in cross-section, 530 cm long, and are set in the tangential direction; their tips are covered by Al windows 5 mm thick.

2. Organisation of the study

The problem was treated in four main steps.

i) Lead-bismuth target and shield weakening. The cascades of 100 000 protons from the incoming beam were tracked through the target. The ca. 87 000 nucleons leaving the target were histogrammed and used as source term for a point-kernel calculation of the background due to the weakening of the bulk shield by the beam tubes.

ii) Scattering in the D_2O tank and bulk shield. A Monte-Carlo run was done for the continued propagation of the 87 000 escape particles through the D_2O tank and bulk shield, temporarily neglecting the beam tubes and their windows. The tangential neutron flux at the position foreseen for the beam tube window determines, by drift through vacuum, the contribution of scattering on D_2O and iron to the background at the monochromator. The component due to the iron was then deduced by examining the reflectivity of the bulk shield.

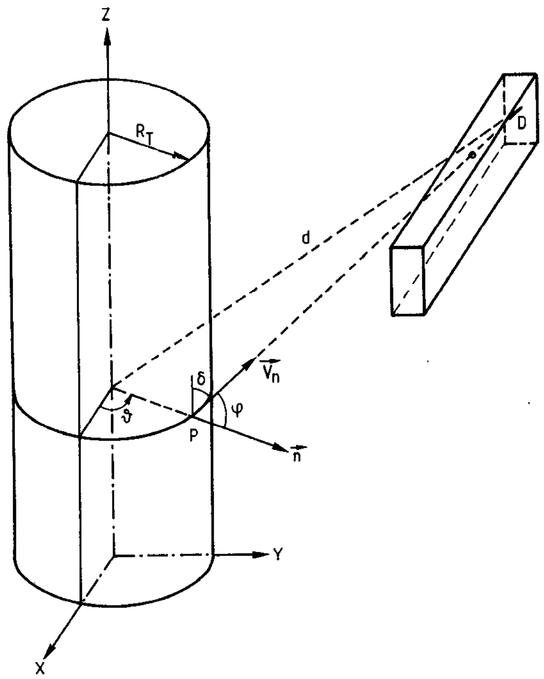
iii) Scattering in the beam tube windows. The flux observed in the D_2O at the position of the beam tube tips was used as source term for HET investigations of the Al window.

iv) Monochromator shield. The penetration of the high-energy background flux of neutrons into a massive, structureless monochromator shield of iron was studied by a joint Monte-Carlo and point-kernel method.

The following 3 sections of chapter 2 give more details about steps i) to iii). Chapter 3 presents the results for the high-energy background flux incident on the monochromator, and chapter 4 reports on the penetration of the flux into the monochromator shielding.

2.1 Shield Weakening

The particles escaping from the lead-bismuth target were histogrammed in the four variables energy, z, $u = \cos(\phi)$, and $w = \cos(\delta)$. The binning in the angular variables u and w comprises 25 bins and is illustrated in figs. 2a) and 2b). The choice of angular cooordinates relative to the normal to the target surface at the escape point P exploits the cylindrical symmetry of the situation.



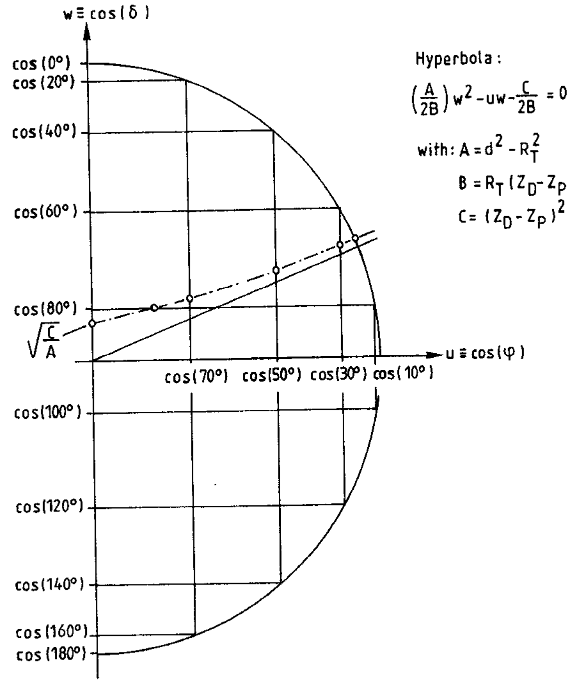


Fig. 2a Definition of the parameters used for the angular binning of the high-energy neutron escapes. v_n is the velocity vector of the neutron.

Fig. 2b Limits of the angular bins in (u,w) space, and the hyperbola engendered by the horizontal scan of the escape point P.

In the point-kernel calculation, the bins with $\phi > 70°$ (neutrons emitted nearly tangentially to the target surface) are affected with large errors (statistics of a few events), and enter the results with a large weight (near-parallelism to the beam tube). It is therefore necessary to calculate separately the contribution of each bin of the source histogram, in order to know which fraction of the resulting background is due to these potentially dangerous bins.

The contribution of each individual bin to the background at the monochromator position (point D) was obtained by numerical integration over those portions of the target surface which "see" the point D in the direction appropriate for the bin in consideration. The target surface was scanned at constant z and with varying azimuthal angle Θ for the escape point P. In this scan the straight segment from P to D determines a hyperbola in (u,w) space, whose intersections with the bin limits u=const, w=const, or $u^2+w^2=1$ were found (fig. 2b). These intersection points were then mapped back to give lower and upper limits for Θ. A constant worst-case attenuation length of 17.3 cm was taken for neutrons in iron, and a constant worst-case length of 75 cm was subtracted from the path to account for build-up. The D_2O was treated as vacuum.

The contribution of the bins with $\phi > 70°$ to the shield weakening depends strongly on the radial position of the beam tube tip. For radii at or beyond the position of the maximum thermal flux, the contributions of these bins no longer dominate, although they are still appreciable (up to 30%) in some cases.

2.2 D_2O Tank and Bulk Shield

The Monte Carlo runs which followed the cascades through D_2O tank and bulk shield were analysed as follows : for each combination of z and r values for the beam tube tip, the set of all possible azimuthal angles for the tip defines a ring-shaped volume of rectangular cross-section. Any portion of nucleon track within this "ring" is divided into elements of 1 cm length or less. Each track element makes a contribution of weight $\alpha/2\pi$ to the histogram of nucleons potentially entering a beam tube, where α is the angle defined by the start and end points of the track element, as seen from the target centre.

The high-energy background flux at the monochromator is essentially given by the number of neutrons entering the beam tube at a small angle relative to its axis. The results quoted in chapter 3 were obtained by assuming isotropic distribution over the solid angle, by taking drift in vacuum, and by normalization to an incoming proton current of 1 mA.

The number of high-energy nucleons back-scattered from the bulk shield in the range -9 cm $< z <$ 29 cm and in the approximate direction of the beam tube tips is 0.00025 nucleons per cm^2 per sterad and per 100 000 protons (very poor statistics). In vacuum, this would correspond to a few percent of the D_2O contribution. As the back-scatters still have a path of 100 cm through D_2O to cover before they enter the beam tube, and as most of them are of relatively low energy (15 to 30 MeV), the back-scattering from iron can safely be neglected.

2.3 Beam Tube Windows

The results of the HET run in D_2O were used to build maps of the neutron flux incident on the faces and edges of the Al windows. These maps gave the source terms for HET investigations of a system consisting only of the window itself.

For the neutrons incident on the faces of the Al windows, the histogram of the flux in D_2O is already available from section 2.2. There is an excess of typically 3 % between the number of high-energy neutrons escaping the windows within a 20° cone centered on the normal to the window, and the number of neutrons started within the same cone on the opposite face of the window. The results must be considered as upper values, as no corrections were made for the lost contributions of those volumes of D_2O which were replaced by aluminium.

For the neutrons incident on the window edges, the source term is determined by the neutrons penetrating into the "ring" defined by the window position. Each neutron entering this volume contributes with a weight of $\beta/2\pi$, where β is the angle subtended by 0.5 cm (i.e. the thickness of the window) at the radius of the entry point.

3. Results : Flux incident on Monochromator

The results for the processes mainly responsible for the high-energy background at the monochromator are shown in fig. 3. For comparison, the thermal fluxes calculated by F. Atchison [3] are also presented. The maximum thermal flux is reached at a radius of about 20 cm. The background due to the shield weakening is only given at one z-value, as the coarseness of the angular binning of the source term only very poorly resolves a height difference of 23 cm at 530 cm.

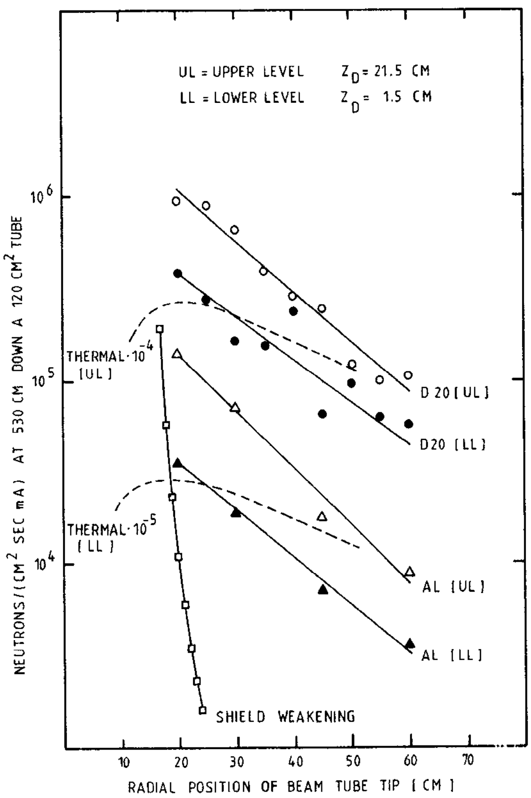


Fig. 3 Thermal neutron flux of ref. [3] and high-energy neutron background at the monochromator for scattering on D_2O and on the Al windows, at two beam tube levels. The shield weakening contribution is also shown.

Fig. 3 indicates that, for beam tube tip positions between 20 and 40 cm, the high-energy background flux is of the order of several 100 000 neutrons per second, cm² and mA. The D_2O scattering gives the greatest contribution to the background. The background flux is significantly higher for the upper level beam tubes and, as the thermal flux varies little with the beam tube level, the lower level tubes enjoy somewhat better signal to noise ratios.

Fig. 3 also shows that, as the beam tube tip moves outwards, the thermal flux decreases less rapidly than the background. A more favourable signal to noise ratio could therefore be achieved by placing the beam tubes at larger radii, however at the cost of a loss of thermal flux. The choice of the final value for the beam tube radii is therefore dependent on the answer to the question : "what is the highest tolerable high-energy background ?"

The decrease of the neutron flux through the shield is exponential, and the background due to shield weakening is very sensitive to variations of the beam tube geometry. For example, placing the monochromator at the worst edge of the tube, instead of on the tube axis, can increase this component of the high-energy background by a factor of several hundred. On the other hand the replacement of worst case attenuation coefficients and buildup factors by energy dependent ones [4],[5] decreases the background by an even greater factor. In any case, due to its very steep decrease with beam tip radius, the shield weakening becomes negligible at beam tip radii beyond the maximum of the thermal flux.

4. Monochromator Shield

The shape of the high-energy tail of the background neutrons incident on the monochromator is shown in fig. 4 for a typical beam tube position.

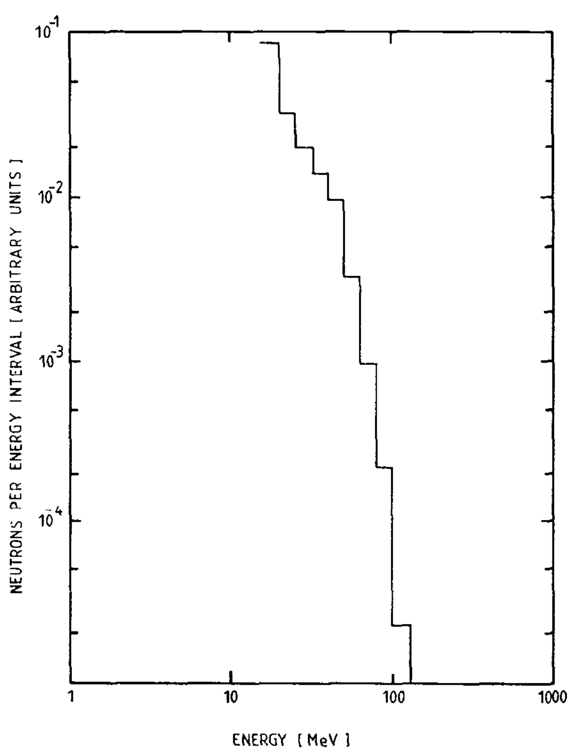


Fig. 4 Shape (in arbitrary units) of the energy spectrum of the combined Al and D_2O contributions to the high-energy background at the monochromator, and for a typical beam tube position.

The neutrons coming down the beam tube are highly directional, and for simplicity can be assumed along the central axis of the monochromator shield. Using the MECCRL code [6] for the intranuclear part of the HET cascades, the interaction cross-section σ_i and the differential cross -section $d^2\sigma/dEd\Omega$ for the production of nucleon secondaries by primary neutrons incident on iron were obtained at different energies. This information was then used to calculate the source of second-generation particles along the axis of the monochromator shield. The flux of high-energy nucleons in the monochromator shielding was then estimated by a point-kernel approximation.

The resulting flux map is shown in fig. 5 for the case of an 8 x 15 cm^2 beam tube with 300 000 high-energy neutrons/sec cm^2 coming down the tube (conditions prevalent at the lower level with a radial position of 25 cm for the beam tube tip). As must be the case, there is very good correlation with the energy deposition map obtained from HET/ENDEN5. This method, however, smooths out the large fluctuations observed with HET at the greater radii.

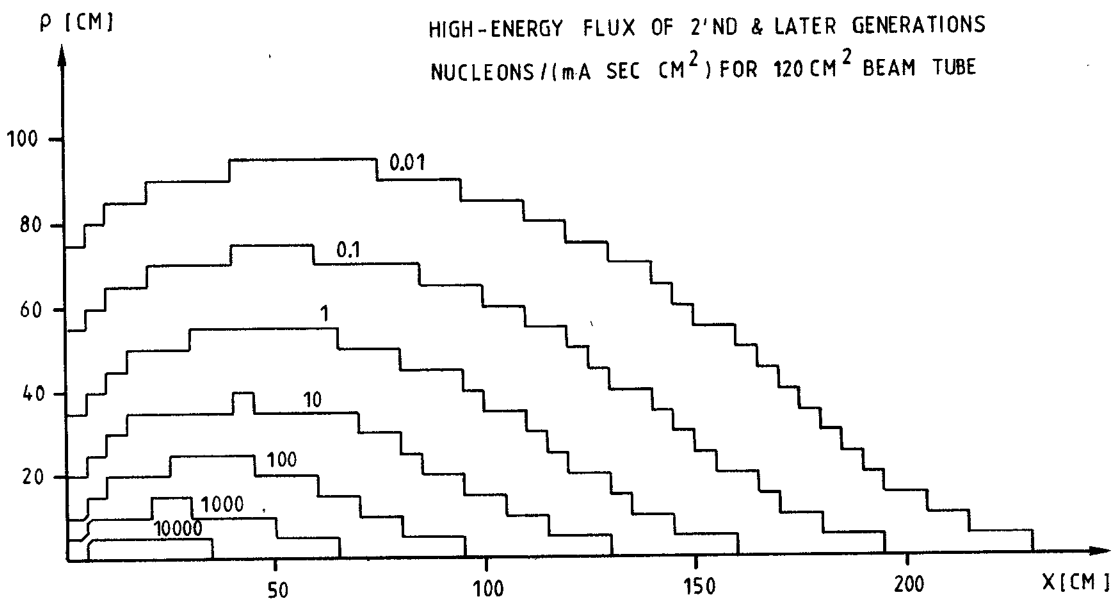


Fig. 5 Flux map of the high-energy background neutrons of the second and later generations in the monochromator shield. The cylindrical coordinates (x, ρ) give the prolongation of the beam tube axis into the monochromator shield and the distance normal thereto.

Aknowledgements

Francis Atchison emphasized the need and suggested the method for treating the point-kernel integration on a bin by angular bin basis, and communicated the build-up factors for neutrons in iron, which he had determined in an earlier study. The adaptations of the HET and MECCRL programmes to the SIN VAX system and the HET modifications which are necessary for treating deuterium are also due to him.

References

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[6] H.W. Bertini, M.P. Guthrie, and O.W. Hermann, ORNL-4564, (1971).