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BEAM TUBE CONCEPT FOR SINQ

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1. INTRODUCTION

One of the design goals for SINQ is to achieve working conditions in the neutron experimental hall comparable with those found at reactors. Implicit in this aim is the requirement to have a very low fast and high-energy neutron flux at the sample, both from the point of view of radiological protection and experiment backgrounds.

Diagrams of proposed layouts for SINQ may be seen in Figs. 11 and 12 of ref. 1. Both beam-tubes and guides are included. Currently there is discussion within the project group, of the wavelength range which might be better (or as well) handled with guides and examination of the possibility of using them to replace some beam-tubes. In principle guides will not be subject to the background problems of beam-tubes.

The 'thermal' flux at the sample will be determined finally by the losses from meeting background conditions. The performance of the beam-tubes will depend on careful design. This work will mainly be carried out by the monochromator designers, with the 'neutron calculators' supplying necessary information on fluxes and attempting to calculate backgrounds; these calculations are difficult.

In view of these difficulties, as much freedom as possible has to be given to the designer: By decoupling the beam-tubes from the target station infrastructure: By avoiding having them on a critical path in the design and/or construction programme: By allowing sufficient flexibility that modifications may be carried out as operational experience is gained.

The above paragraphs present a 'mechanical' concept. The aim of the rest of this paper is to try and set out the problems from the high-energy neutrons and examine what needs to be calculated. That is, to consider the important question of a concept for the calculations. Because of its obvious advantages, some work has been done on trying to speed up the high-energy Monte-Carlo neutronics calculations; this work is incomplete, but presented in the hope it might provide useful ideas for other groups.

2. BEAM TUBES

2.1 General

The beam-tube is taken to include the whole region between the beam-tube tip in the moderator tank and the neutron port at the sample. It therefore includes collimators, tube liners, filters and monochromators. This is shown schematically in Fig. 1.

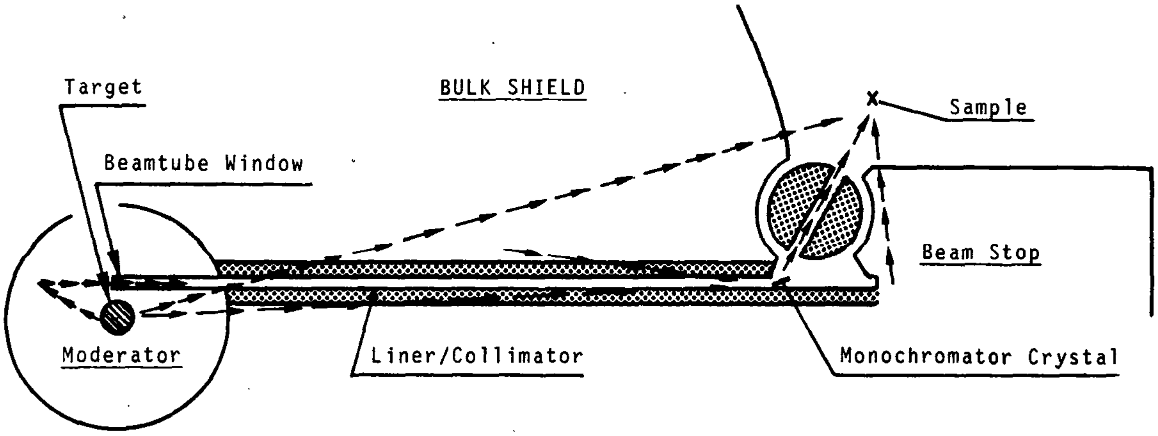


Fig. 1 Schematic layout for a beam-tube system. The arrowed lines→→→→ illustrate the principal sources of background caused by high energy neutrons.

The problem is to reduce the flux of unwanted neutrons to acceptable levels whilst also minimising the loss of wanted neutrons. At present it is not known what an 'acceptable level for background' means, but it is hoped to obtain some quantification by experiment at the "NE 1"neutron beam here at SIN.

The principle cause of neutron flux loss will be distance but other contributions might come from having to use beam-tip radii away from the thermal flux maximum in the moderator, double-monochromators and filters.

2.2 Backgrounds

Monochromator and instrument designers have come to terms with the fast neutrons present in reactors. SINQ will have these also, but the principle new problems stem from neutrons above 2 MeV and extending close to that of the primary proton energy (590 MeV).

The background at the sample from this 'new' problem area will mainly arise from:

1. The scattering of high-energy neutrons by the monochromator crystal.
2. Direct background through the shield and from the beam-stop.

The neutrons causing these may be considered to come from four sources:

(i) High-energy neutrons scattered by the D_2O into the beam-tube.

(ii) Secondaries from interactions in the beam-tube window.

(iii) Direct transmission through the shield and including reduced shield efficiency from voids created by the beam-tube and other equipment.

(iv) Leakage from the shield.

A schematic illustration of these background sources is included in Fig. 1.

2.3 High energy neutron scattering by a monochromator crystal

As the scattering of high-energy particles by the monochromator is probably going to be the main cause of background, a first estimate of the extent of the problem has been made using the deliberately pessimistic case of a 1 cm thick copper crystal.

Cierjacks et al.[2] have measured the high-energy neutron spectrum from a beam tube in a H_2O moderator. This measurement should include contributions from all four sources mentioned in subsection 2.2. In absolute flux terms, it is believed these results are pessimistic compared to the situation we will have in SINQ[3].

The calculation has used MECC (see section 3.2) to estimate inclusive differential cross-sections averaged over the measured spectrum and includes the effective thickness change as the crystal is tuned. The results are shown in Fig. 2.

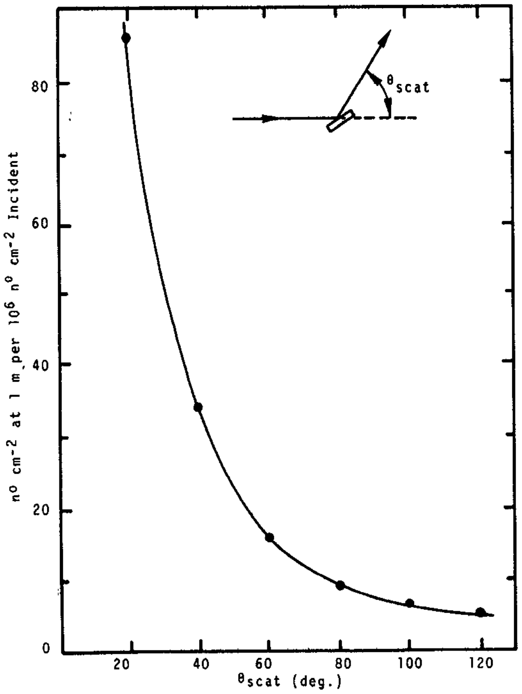


Fig. 2 Scattering by copper averaged over the HE neutron spectrum measured by Cierjacks et al.[2].

3. BEAM TUBE CALCULATIONS

3.1 General

The type of system to be calculated has been shown in Fig. 1 and the sources of background in section 2.2.

For radiation protection purposes there needs to be about 4 m of iron and 1 m of concrete between the moderator tank outer wall and the neutron hall. The calculations will need to quantify the spectra deep inside this shield, including asymmetries and inhomogeneities. The major problem in carrying out calculations is choice of method. No single method seems, at present, capable of doing this job.

The HETC package[4] is the major tool for detailed high-energy transport studies. It suffers from the major drawback of slow calculation speed, but can tackle the anisotropy and inhomogeneity of the problem; that is we can set the problem up but probably do not have enough time to actually complete the calculation. Similar remarks apply to Monte-Carlo neutronics codes, e.g. Morse[5], 05R[6] etc.

Deterministic methods are well developed for 2-D calculations and are being used for the SINQ bulk shield calculations[7]. Their use for beam-tube problems was reviewed by Armstrong et al.[8] at ICANS-VI. Extensions to 3-D are available, Takeuchi[9], and a test case based on the Cierjacks measurement (see section 2.3) is being sent to Dr. K. Takeuchi for comments and (hopefully) calculation.

Examination is being made of ways to speed up Monte-Carlo for the high-energy neutrons to enable some first estimates for their effect to be obtained. In the next few sub-sections these will be described and some results presented.

3.2 HET

The principle component of HET is a subroutine version of the Medium Energy Cascade code of Bertini[10]. This uses Monte-Carlo to compute the interaction of medium-energy particles with nuclei. In HET it operates at two levels; to calculate the interaction cross-section from the 'geometric' cross-section; to sample an outcome of an interaction. The Bertini code has been isolated from HET to allow direct calculation of interaction cross-sections. This will be referred to as MECC.

There is an 'outer loop' Monte-Carlo to follow the propagation of the particle cascade through the material which also takes account of other relevant physical processes. The remainder of HET contains geometry, bookkeeping and (user written) source description routines.

The 'slowness' of HET comes from the need to calculate each interaction.

3.3 Acceleration of the calculation

Calculations for beam-tubes will be made mainly to obtain particle fluxes. These depend on the geometry of the cascades, source particle distribution and calculated system. The geometry of the cascade only depends on the type and energy of the initiating particle and the material through which it is propagated.

A major increase of speed is obtained if calculations makes more use of the information in the cascades. This is most easily demonstrated with an example.

3.4 Calculation of a large iron sphere

The problem is to calculate the dose due to escape particles from various radii iron spheres with a 300 to 400 MeV neutron source at the middle. A full description of the calculation may be found in reference 11.

Escape particles are the result of the truncation of an infinite region particle cascade by the size of the system. The cascades will be initiated by the primary particles at various depths in the shield with the usual exponential probability.

HET was used to generate a set of 2000 infinite-extent-medium cascades. These were then subjected to a straightforward geometric transform to bring their starting point (the first interaction) to various depths in the shield (i.e. first collision biasing) and then analysed to enable the escapes (cascade track segments which cross the outer boundary) to be picked out. The total escapes are calculated by summation of the appropriately weighted contributions of all bias shells, but using the same set of cascades.

The calculation was made for radii up to 5 m. A plot of the calculated dose from escapes as a function of sphere radius is shown in Fig. 3 and the escape-neutron spectra for various thicknesses in Fig. 4.

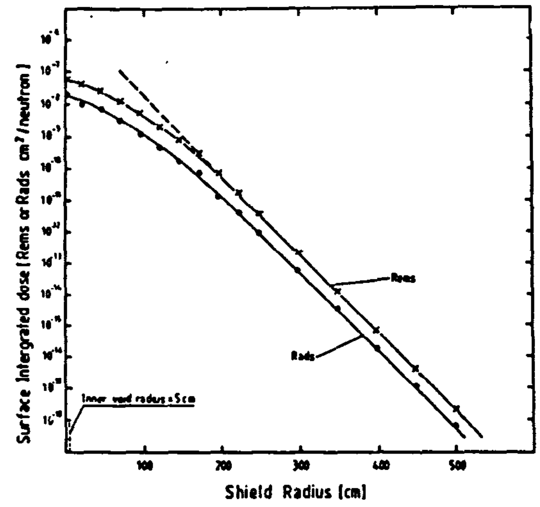


Fig. 3 Calculated surface integrated dose and dose-equivalent for various radii iron shields and source neutrons of energy 300 to 400 MeV.

In effect, the method makes the assumption that the 2000 cascades give a proper description of all that are possible. Further cases, for different neutron energies and also with concrete have been calculated. The shielding effect as represented by the large depth 'absorption' length were in reasonable agreement with typical values used in 'hand estimation' of shields.

3.5 Extension to beam-tube fluxes

The method of section 3.4 is at present limited to single media, mainly because no satisfactory storage system has yet been devised by us for the extra cascades for more than one medium.

A straightforward extension has been made to include the effect of voids. This is simply a matter of extending the length of cascade segments which cross a void. At present this has only been used for a test calculation of the effect of voids on surface escapes. It

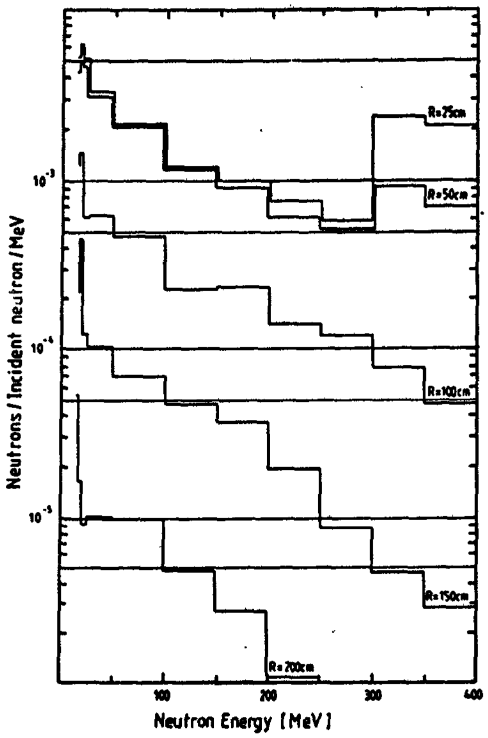


Fig. 4 Escape-neutron spectra for shields of thickness from 25 to 200 cm.

can also be used to allow estimates of the HE contribution from shield leakage into the beam-tube, but not in a straightforward manner for seeing the effect of different liner materials.

No suitable results are available for presentation.

3.6 High energy scattering by D_2O

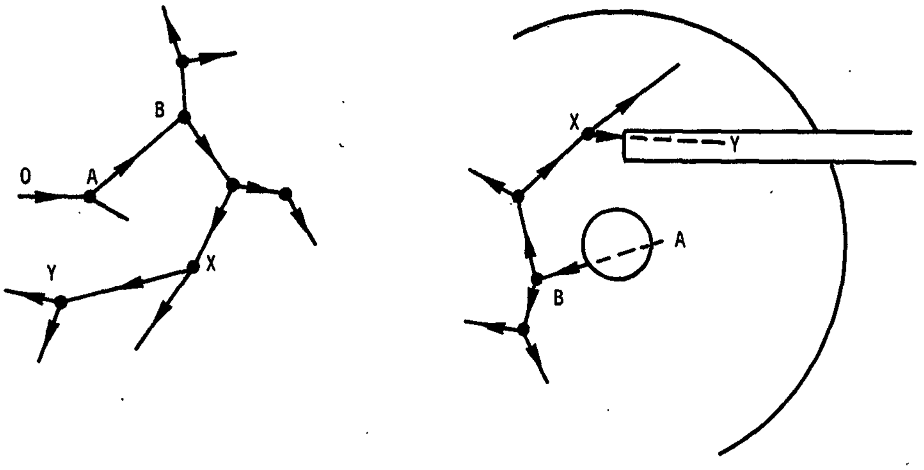
The methods used for the bulk shield estimate in section 3.4 have been taken a stage further to estimate the HE neutron flux scattered by the D_2O into the beam-tube (see Fig. 1).

The distribution (in position, angle and energy) of HE particle escapes from the target can be calculated directly with HET. The probability of scattering into the beam tube should be rather small. For design purposes a survey of how this component varies with beam tube tip radius is required.

The set of sample cascades (in D_2O this time) contains full information about the geometry of the cascade. A cascade segment can be used to compute the geometric transform which puts it along a beam-tube (a 2-D representation of this is shown in Fig. 5). The transform is then applied to the whole cascade, and if the transformed cascade-initiating particle's trajectory intersects the target at a point where it could have been produced (correct production angle and energy), the cascade then represents a contributing event.

As we 'know' the D_2O interaction cross-section (from the MECC code - modified to treat D collisions), both the initiating trajectory and the track-segment entering the beam-tube can be extended (or contracted) with a probability correction according to the usual exponential law. It should also be noted that the cascade transform is 'free' in the rotation about the cascade segment.

Full exploitation of the cascade information is made: The branches of the cascade following a track segment also represent a cascade but initiated by a particle of type and energy on this track segment.



(a) Sample cascade

(b) Transformed into moderator

Fig. 5 Two-dimensional representation of cascade selection for D_2O scattering calculation. (a) Cascade is initiated at A by particle starting from O. The track segment X-Y is used to construct the transform which puts this along the beam-tube (b). The segment A-B intersects the target.

First results are presented in Fig. 6 and show the relative HE neutron scattered flux in a beam-tube as a function of position. For reference the thermal flux variation is also shown. So far the calculation has not been absolutely normalised.

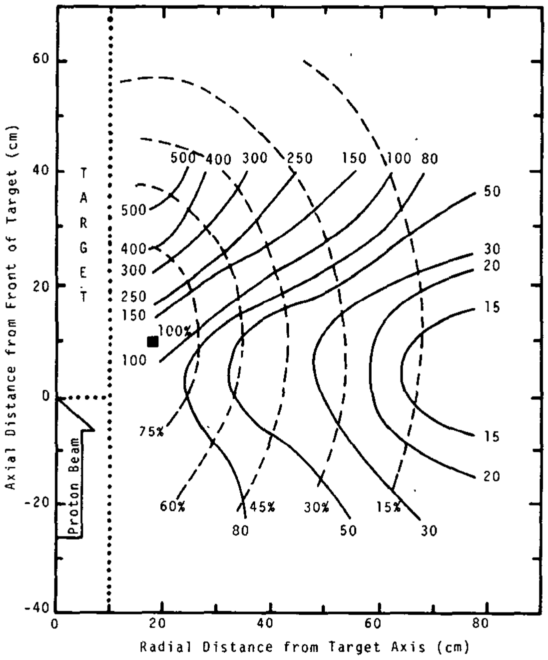


Fig. 6 Contours for the relative intensity for high-energy neutron scatters by D_2O into a tangential beam-tube. For comparison, the thermal flux distribution is also shown (- - -).

4. CONCLUSIONS AND DISCUSSION

There are many parameters available which are more or less effective in background reduction; beam-tube tip position in the moderator; size of the beam-tube; the material and dimensions of the beam-tube liner and collimators; layout geometry, materials etc. of the monochromator.

First estimates for the scattering of high energy neutrons by a monochromator crystal (section 2.3) show reduction factors of the order of 10^{-4} to 10^{-6} or better. Without knowing what incident flux or background level is tolerable it is not possible to judge if this is sufficient. Increased reduction may be obtained by choosing a thinner or possibly double monochromator. The incident HE flux will be minimised by correct choice of dimensions and material for the beam-tube liner and by variation of the beam-tube position in the moderator (section 3.6). Most of these measures will also entail loss of thermal flux.

The speeding up of Monte-Carlo calculations for high energy neutron fluxes has been successful for systems of one material whilst retaining the ability to handle complex geometries. It is also possible to treat voids. The calculation presented in section 3.4 required 1 hour to generate the cascades and an average of about 20 minutes for each of the radii. No one-step calculation has been attempted for comparison.

The application of Monte-Carlo effectively to the problems of the beam-tubes only looks feasible by reorganisation of the way the calculations are carried out. It does not seem possible to use HET as a 'complete package'. It still remains to be seen if some acceleration of the low-energy neutronics Monte-Carlo can also be made.

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