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CONSIDERATIONS ON BACKGROUNDS AT SINQ

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1 INTRODUCTION.

The SINQ project [1] aims to build a neutron scattering facility for the wavelength range of about 1 to 10 Å based on a continuous spallation neutron source: The end result will be a set of scattering instruments with their associated facilities, operating with a neutron flux comparable to that at a medium flux research reactor. It is our hope that users will be unaware that the source is not a reactor.

Experimentalists have come to terms with background problems at reactors (fast neutrons and gammas) and these problems will also be present at SINQ but accompanied by possible new effects from, (i) a high-energy ($E > 10$ MeV) tail to the neutron spectrum, (ii) high energy charged particles and (iii) a high-energy tail to the gamma spectrum (from neutral pion decay). It is the aim of this paper to examine what we know of these new background precursors and to see their effect on the design. So far, studies have been restricted to examining the problem of the high energy neutrons.

The principal concern is background at the spectrometers. Unlike pulsed sources where the sample is in the direct beam from the moderator, the continuous type includes a monochromator and it is this which will scatter part of the high-energy neutron contamination of the thermal neutron beam toward the spectrometer. The major worries arise from: (i) Estimation of the high-energy component at the monochromator is very difficult (inaccurate!): (ii) The effect of high-energy neutron contamination on experiments is unknown: (iii) The reduction of background can only be made at the expense of thermal flux.

The sources of high energy neutron contamination are illustrated in Fig 1: It is assumed we know how to build a bulk-shield hence direct shield leakage, ground and sky shine are excluded from the discussion.

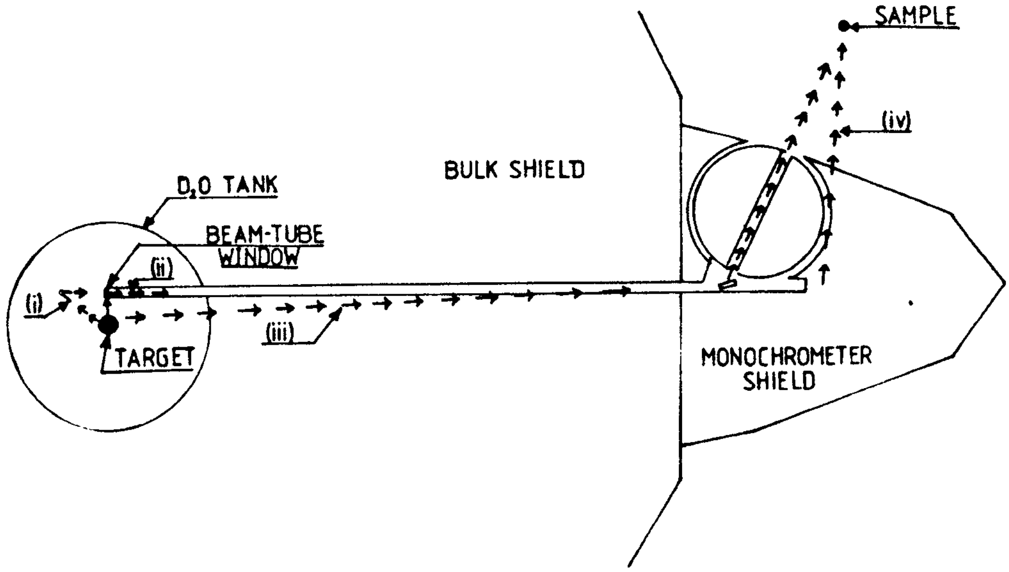

Fig 1: The principal sources of background caused by high-energy neutrons (direct shield leakage, sky and ground shine are neglected; see the text): (i) Scattering by heavy-water in the vicinity of the beam-tube window, (ii) scattering by the beam window, (iii) shield weakening due to the presence of the beam tube, (iv) leakage from the monochromator shielding.

2 THE EFFECT OF HIGH-ENERGY NEUTRONS.

The general consequence of background is to make the source less attractive to the user; reduced instrument resolution; increased experiment time due to more difficult background estimation; less convenient access to instruments. The possible effects may be collected together under three general headings:
(i) Measurement errors: (ii) Limitations on monochromator design: (iii) Radiation protection.

At present, little or nothing is known about the effects on the measurements being made, from having high-energy neutrons incident at the sample. This gives the major problem for design work that no guidance is available about levels of high-energy contamination which might be allowable in the beam from the monochromator. It is hoped that this may be quantified by experiment prior to construction of SINQ.

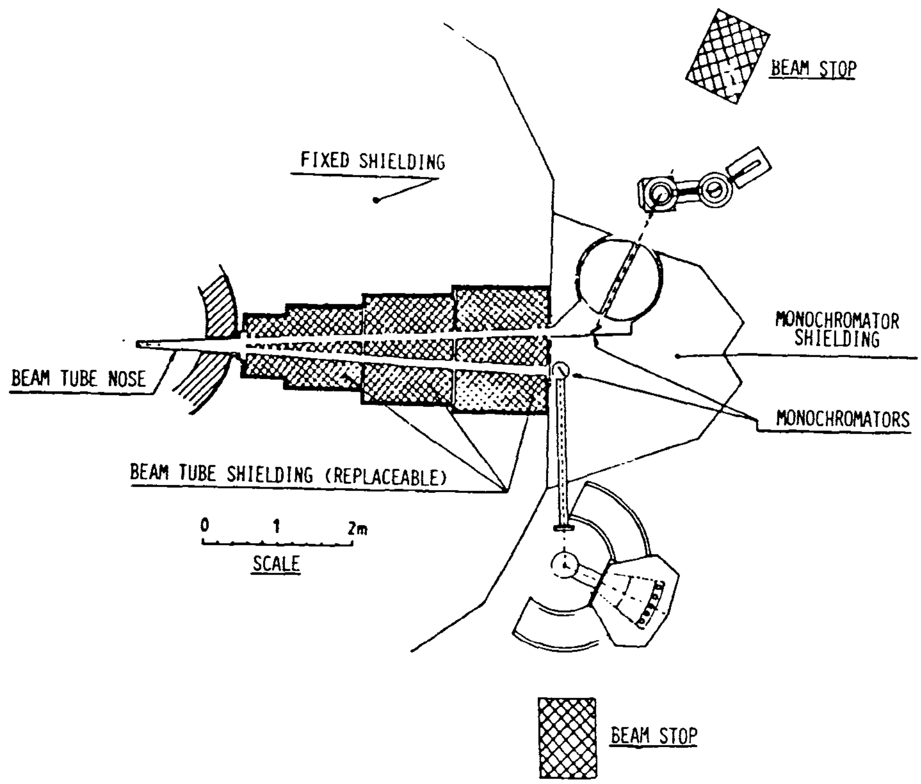

Fig 2: Schematic layout of a beam-tube pair with monochromators and instruments.

2.2 Limitations on monochromator design.

A sketch of a beam-tube pair with monochromators and instruments is shown in Fig 2. The presence of HE neutrons in the beam incident at the monochromator may be summarised as follows:

(a) The monochromator shielding external to the bulk shield will need to be large enough to effectively shield the HE neutrons; this restricts the space available for the instruments and is likely to be costly.

(b) The choice of monochromator crystal and configuration (transmission or reflection mode, single or double) will effect the fraction of HE neutrons scattered into the direction of the instrument. It would be unfortunate to have to restrict the design because of background.

(c) The smallest monochromator take-off angle will be set by the need to keep the monochromated beam out of the HE neutron flux directly passing through the crystal and its spreading out in the shield.

(d) The size of drums for adjustable monochromators will have to be sufficient to shield the HE scattered flux. They could become large hence cause thermal flux loss and be expensive.

(e) Increased activation problems in the monochromator system, hence difficulties with maintenance. HE neutrons tend to cause persistent activation whilst thermal neutrons generally cause short-lived.

2.3 Radiation protection considerations.

The expected thermal flux at the monochromator is of the order of $10^9/(cm^2.sec)$, with about 1% of this scattered toward the instrument by the monochromator. The (localised) equivalent dose of this beam is of the order of 40 rem/hour. A measurement by Cierjacks et al [2] showed a high energy flux of about $1.5 \times 10^7/(cm^2.sec)$ at 6 m along an 8 cm diameter beam tube for an 1mA proton beam incident at the target. The scattered HE neutron intensity into the monochromated beam direction has been estimated [3] to be 4 to 5 orders of magnitude lower than that incident; that is, $< 2 \times 10^3/(cm^2.sec)$ may be scattered toward the instrument and this corresponds to a (localised) equivalent dose of <0.4 rem/hour. This result is considered to be pessimistic compared to the situation expected with SINQ (see section 3.3).

The dose due to the high-energy neutrons should not add significantly to the radiation hazard from the thermal neutrons. The beam scattered by the sample should give doses at 1 m of less than 3 mrem/hour but attention will have to be paid to the provision of adequate shielding around the monochromator and efficient neutron catchers ("get-lost holes") behind the instruments.

3 ESTIMATION OF HIGH-ENERGY NEUTRON FLUXES IN BEAM TUBES.

The calculation of the HE neutron contamination in a beam tube is very difficult. These calculations need to estimate the neutron flux at the end of a narrow channel (50 to 100 cm^2 cross-sectional area) crossing about 5 m of shielding and having scatterers (beam window and D_2O) in the high intensity region close to the target; to allow design decisions, the calculations need to give information on how the contamination varies with pertinent parameters.

The HE flux escaping from the beam tube is considered to come from three principal sources, scattering by D_2O in the vicinity of the beam window, scattering by the window itself and shield weakening due to the beam tube. The Cierjacks et al [2] measurement was made with a geometric arrangement rather different from that being considered for SINQ; being the only experimental measurement available to us it is important to be able to compare it with our situation.

3.1 High-energy neutron scattering into the beam tube.

A first estimate for the variation with position in the moderator of the tangentially scattered HE neutron intensity into a beam-tube by D_2O was unnormalised [4]. A more direct estimate for this effect has been made by Monte-Carlo using the HETC [5] code. The calculation used in-core analysis to collect angular distributions at various positions in the moderator for HE neutrons, using as source a previously calculated target escape distribution. The angular distributions were extrapolated to give an estimate for the component tangential to the target. The calculation results are shown in Fig 3. The results show severe statistical fluctuation, but as a total of about 21 hours computer time was used, prospects of making any significant improvement look bleak.

The results have been used to normalise the previous calculation [4] of D_2O scattering and gives a factor of 5.9×10^{-12} to convert the numbers to units of $/(cm^2.sr.proton)$. The statistical fluctuations of the normalisation calculation give an RMS uncertainty of about 130%. The normalised results have been included into Fig 3 and show, within the uncertainties, reasonable consistency. The variation with position in the moderator of the contribution to HE neutron flux in the beam-tube of D_2O scattering, is shown in Fig 4.

The angular distributions in the moderator have been used to make a first estimate for the contribution of window scattering. The differential scattering cross-section averaged over the HE neutron spectrum from the target has been calculated for Aluminium using the MECCRL code [6]. This differential cross-section is folded with the angular distributions from the moderator calculation and the thickness variation of the window with angle. The estimated contribution as a function of position in the moderator is shown in Fig 5. The calculation also shows that there will be contributions from high-energy protons (about half the values for the HE neutrons), evaporation neutrons (roughly 60% of the HE neutrons) and evaporation protons.

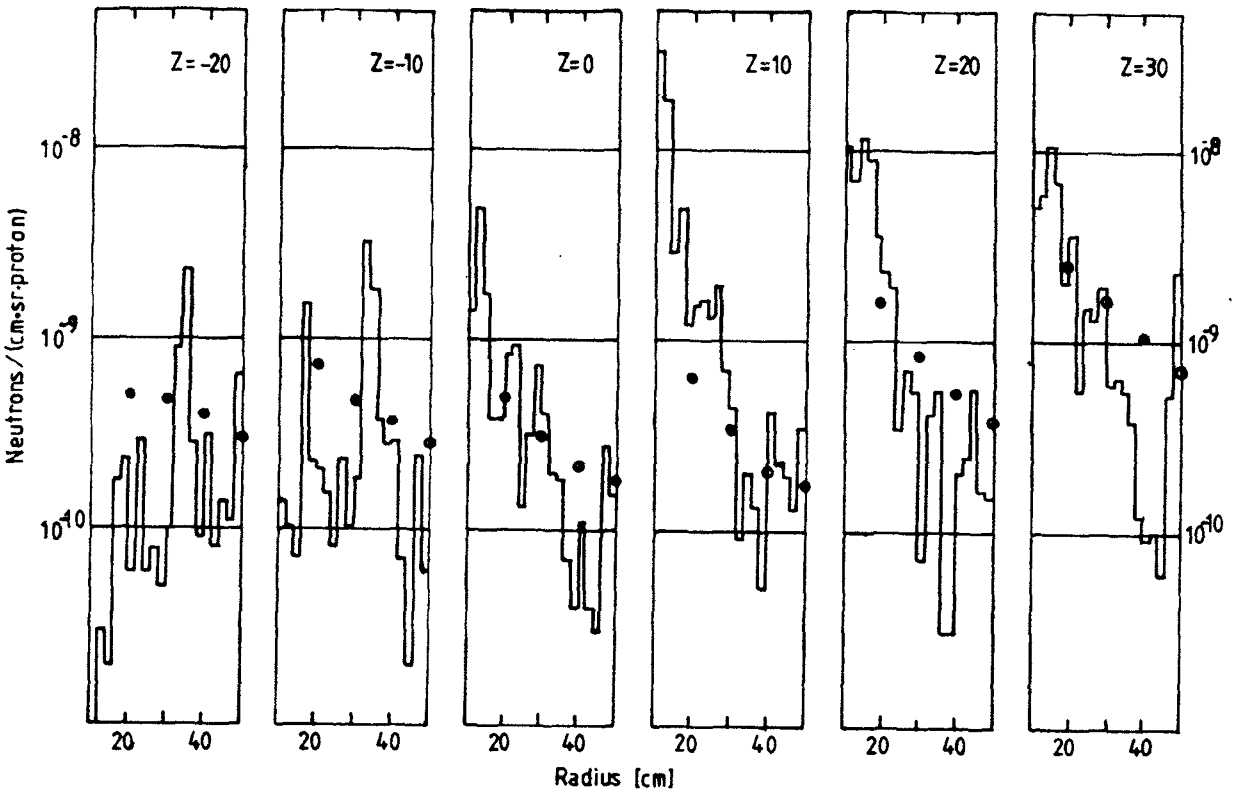

Fig 3: Radial variation of the tangentially scattered high energy neutrons by heavy-water for six positions (Z) relative to the front face of the target. 'o' are the normalised results from the calculation of reference 4.

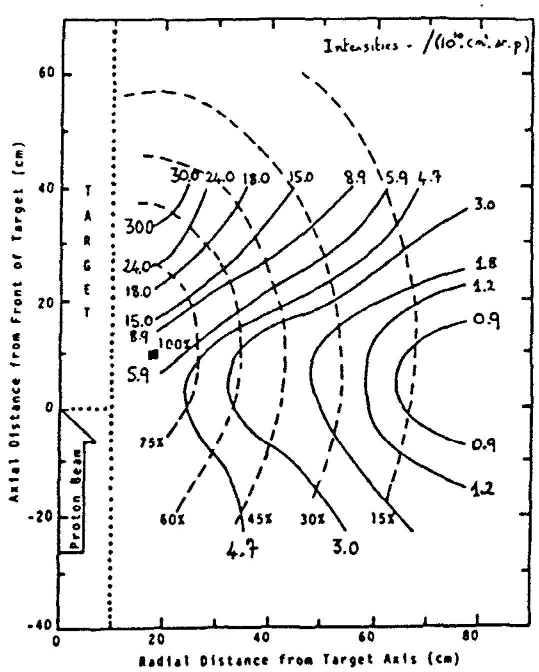

Fig 4:
Contours for the intensity of tangential HE neutron scatters by heavy-water as a function of position in the moderator. The thermal flux distribution is shown for comparison (dashed lines).

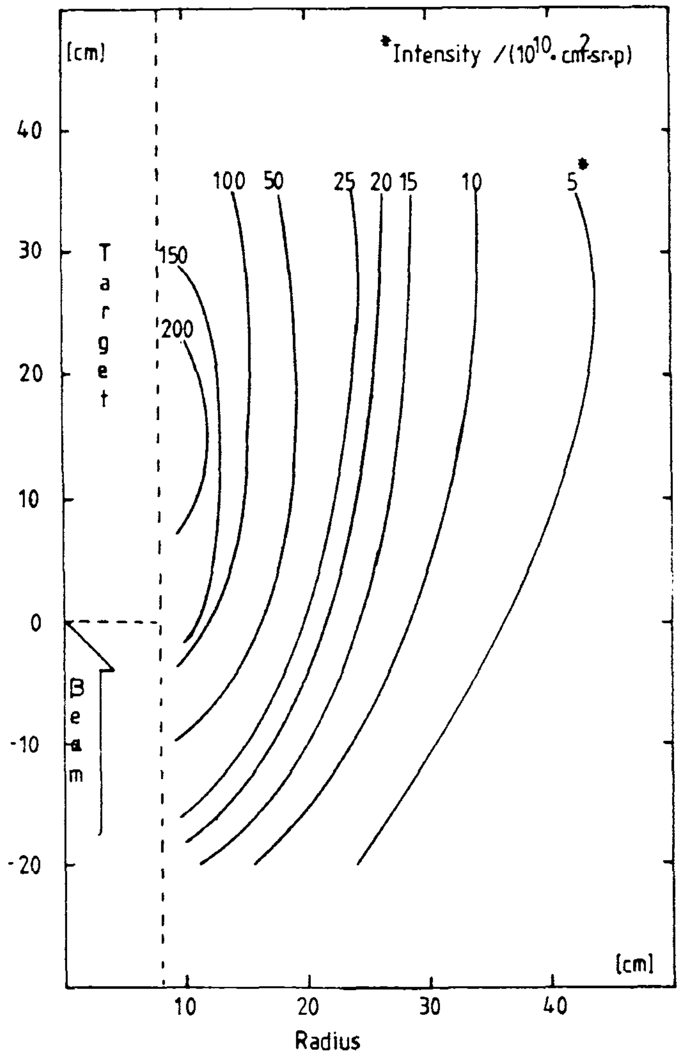

Fig 5: Contours for the intensity of the HE neutrons scattered by a 1 cm thick aluminium window, as a function of position in the moderator.
Note: The scales used for this figure are not the same as those for Fig 4.

3.2 Beam tube shield weakening.

A first estimate, based on the simple exponential shielding model, has been made of the effect of loss of path length in the shielding due to the presence of the beam tube. The calculation uses the simplified geometry illustrated in Fig 6. For SINQ, S = 5m, M = 1 m and the neutron fluxes at the monochromator for various size beam tubes and beam tube tip radii are shown in Fig 7.

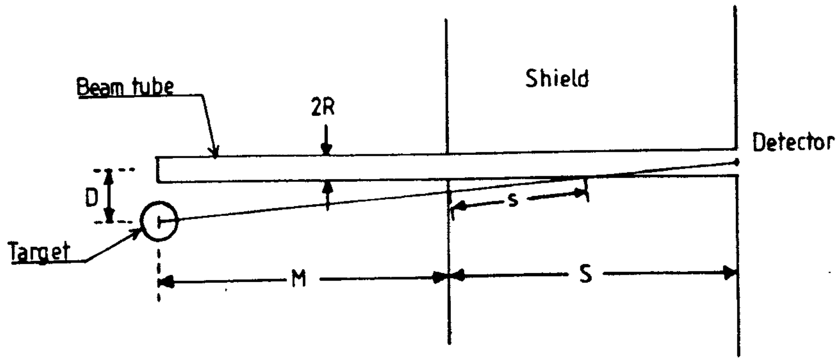

Fig 6: Simple exponential shielding model estimate for the effect of shield weakening due to the presence of a beam tube. The path length in shielding, s, is given by $s = S - (M + S) \times R/D$. Build-up is accounted for by reduction of the distance s by a length σ. For SINQ, the path is in Iron and a shielding length of 17.3cm and a value of σ of 75cm are used.

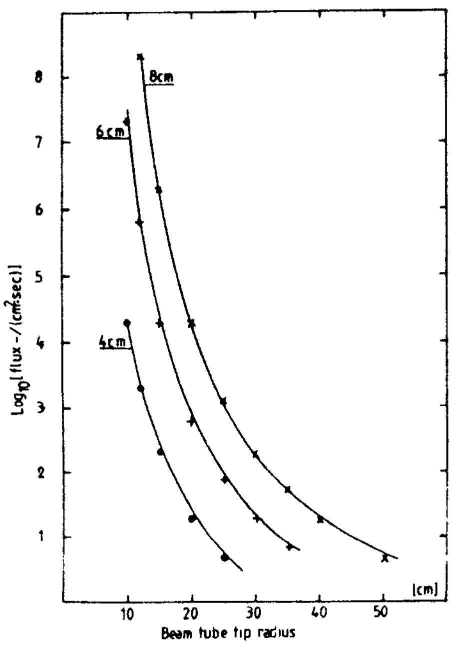

Fig 7:
High energy neutron intensity at the end of a 6m long beam tube due to shield-weakening, as a function of beam-tube tip radius and for SINQ at 1mA. Results for beam tubes of radii 4, 6 and 8cm are shown.

3.3 Comparison with the measurement of Cierjacks et al.

The results of Cierjacks et al [2] show a high energy (E>15 MeV) current at 6m down an 8cm diameter beam tube for 1mA proton current on the target of about 1.5 x 10^7 /(cm^2.sec). The moderator material used was light-water and the beam tube was at D = 13cm from a 15cm diameter target. The tube itself was at 30^o to the target axis.

The results of the calculations presented in sections 3.1 & 3.2 indicate the following contributions:

Scattering by H_2O (taken as = D_2O)	1.7 x 10^3/(cm^2.sec)
Scattering by Al window (3mm thick)	4.5 x 10^3/(cm^2.sec)
Beam hole shield weakening	0.9 to 10.0 x 10^7/(cm^2.sec)

The calculated value for the HE neutron contamination is in quite good agreement with the measurement and indicates that the shield weakening dominates; the order of magnitude range in the predicted value reflects the difficulty of choosing values for the parameters of the model used. This is also unfortunate, as in the case of SINQ it is the first two terms which dominate (see section 4.1) and these terms could be increased by factors of several hundred without giving a significant contribution in this case.

4. REDUCTION OF THE EFFECT OF HIGH ENERGY NEUTRON CONTAMINATION.

The pessimistic assumptions of the estimate presented in section 2.3 indicate that the expected HE contamination will not require special extra restrictions on instrument access. The principal problem will be background in the spectrometers from having HE neutrons incident at the sample. Having little guidance about allowable contamination (it ought to be as high as possible or thermal flux will be being wasted), the source parameters available for background reduction will be briefly discussed.

4.1 Beam tube tip radius.

The present design for SINQ requires that this be a fixed parameter for the source. The ideal chôice is for a radius in the viscinity of the thermal flux maximum in the moderator but has to be somewhat larger to reduce the fast neutron and gamma contamination and (where appropriate) the power load on cold sources. The current design uses radii of 25, 27 and 30 cm and has two layers of beam-tubes. The estimated HE neutron source strength at a monochromator 6m from the target and for a 1 mA proton current are now tabulated:-

Tip-radius [cm]	D_2O scattering [no/(cm^2.sec)]	Window scattering [no/(cm^2.sec)]	Shield weakening [no/(cm^2.sec)]
25 (lower level)	1500	1100	180
27 (upper level)	1500	3100	100
30 (lower level)	750	700	40
30 (upper level)	1200	3100	40

The present calculation indicates the contamination will be a factor of 3000 to 10000 lower than for the situation measured by Cierjacks et al [2]. This has obvious important consequences on the design for the monochromator shielding and the particularly strong variation of the shield-weakening contribution requires confirmation.

4.2 Beam tube length and aperture.

Reduction of the beam tube aperture will cause reduction of the HE neutron contamination as will increasing the beam tube length. They will also reduce the thermal flux. The design concept includes special equipment boxes in the bulk shield to allow the size and the materials in this region to be changed (see Fig 2). The monochromator and its shielding are added externally to the bulk-shield. In the case of take-off angles greater than 90^o, the monochromator will be moved radially to a position outside the limits of the bulk shield to allow space for the instrument.

4.3 Monochromator design.

The predicted 4 to 5 orders of magnitude reduction of the HE contamination scattered to the instrument would seem to give a very low contamination at the sample. The use of distance between monochromator sample and/or double monochromator systems will allow further reduction should the actual contamination be significantly higher than predicted or a very large depression be required for background supression. The loss of thermal flux due to added distance may be partly compensated by use of focusing monochromators.

5 CONCLUSIONS AND DISCUSSION.

The high-energy neutron contamination of the thermal beam at the monochomator will not be known with any great certainty when SINQ starts operation as long as we have to rely on calculation. In a similar way, the effect of high-energy neutrons at the sample on instrument background being extremely uncertain means there is no guidance as to what levels should be aimed for.

The magnitudes for the estimated HE neutrons incident at the sample, indicate that they do not significantly increase the radiation protection problem at the scattering instruments. Removal of the monochromator crystal and the provision of a rather modest shutter, should allow access to the instruments whilst the source is running.

The final decision on what beam tube tip radii should be used is important as it determines the basic high-energy neutron contamination at the monochromator. The predicted large reduction of the shield-weakening term will need confirmation by more exact methods; the inclusion of leakage out of the bulk-shield and into the beam tube may start to become significant at the low levels predicted. There would seem to be sufficient flexability with other variables in the system, to produce low high-energy neutron contamination at the sample; this mitigates the consequence of uncertainty in the estimates but, most likely, will be paid-for by having a final SINQ performance (ie thermal neutron flux) below its potential best.

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[4] F Atchison, Proc. 7th ICANS, Chalk River 1983. AECL-8488, 266 (1984)

[5] Radiation Shielding Information Centre code package CCC-178, HETC.

[6] MECCRL is the Intra-nuclear cascade/evaporation code extracted from HETC (see reference 4 for more details).