Some Comments on Beam-tube Shielding

C. G. Windsor, AERE Harwell and Tohoku University, Sendai

Both for radiation protection and for spectrometer background reduction we must shield against both fast (> 1 ev) and slow neutrons. Figure 1 shows some of the causes of biological and spectrometer background in a typical beam-tube spectrometer.

To clarify the discussion let us define two types of surface. "Bright" surfaces are those which see the moderator directly. "Visible" surfaces are those which are seen by the counter, either directly or by scattering from the sample or crystal analyser.

1. Neutrons transmitted by the bulk shield are relatively easy to calculate. $\emptyset = \emptyset_o e^{-\lambda t} / L^2$ gives a fair answer. They are usually not a problem. For example our spectrometer background gives us a fair monitor of the local fast neutron intensity. As the measurements on page 607 indicate, this usually drops to negligible levels on closing off the beam.

2. How much should we shield an external beam tube? A simple model as in figure 2 gives an estimate for a conical beam tube with "reflecting" surface. The difference in the neutron flux at distance r and r + δr must equal the flux to be shielded over the length δr. The loss of flux per unit area is

$$\frac{\delta\emptyset}{\delta A} = \frac{\emptyset_o}{32}\left(\frac{W_m}{r}\right)^3$$

For a moderator of width 15 cm the tube brightness at 5 m works out at $\sim 10^{-6}$ of the source brightness. Thus the shielding required is certainly not negligible compared with the main shield attenuation.

3. How can we minimise "bright" surfaces? Figure 1 illustrated the converging/diverging lines which define the ideal spectrometer whose "bright" surfaces are never "visible". Figure 3 shows the typical arrangement of stepped irisis which attempts to approximate to this ideal arrangement. The thin irisis should be a few scattering lengths thick. Much discussion at ICANS IV centred over what energy range the various parts of this collimator will function. There is no problem for < 1 eV neutrons, but for the fast neutrons there will be some penetration of the irises - one on its own is insufficient to attenuate the beam to negligible values. Thus there will be a penumbra of fast neutrons present outside the geometric penumbra of the beam tube irisis.

4. Where should the final collimator go?

It is obvious that the final beam umbra should match the sample size. Should the final collimator be near the sample where penumbra effects are reduced? Alternatively should it be reasonably remote from the sample where it can be well shielded? How thick should it be? What energy range of neutrons are we trying to stop with the final collimator? Probably the best solution is to divide all these functions - first a rough fast neutron final collimator placed well back in the beam tube shield, then a thick main collimator in a position well away from the sample, finally near the sample, a final "thin" collimator to clean up the penumbra.

5. How do we reduce visible surfaces.

It is clear that we must never let visible surfaces be anywhere near bright ones! All visible surfaces should be cadmium or borated. They should never be extensive in area. For example a simple "nose" or collimator in front of a counter reduces its visible surface by a large factor. We usually remember "first order" visible surfaces seen by the counter but forget "second order" ones seen by say a crystal analyser or by the sample. All these surfaces should be cadmium or borated. Every iron, concrete, wax or even paint surface is a nice neutron moderator and reflector.

6. How big should the centre hole of a spectrometer be?

Obviously it should be a little larger than the geometric penumbra of our beam, but by how much? Experiment and calculation are needed here. We need to know the extent of the fast neutron penumbra to the beam. We must expect it to be there and ensure that these penumbra fast neutrons are moderated and absorbed before they can get near a visible surface.

7. What material should we put where the beam hits inside the beam stop?

For spectrometer background reasons we should try to absorb rather than scatter all the neutrons we can in the beam stop. This means fast neturon absorbers like boron carbide powder are best. More moderating materials like borated resin reflect a percentage of the faster neutrons, and so are not so good. An iron or concrete surface here gives a fast neutron source with comparable intensity to that of the beam itself!

8. What shape should the beam stop be?

A "bottle" shape as in figure 4 ensures that reflected neutrons are mostly absorbed before they can reach the spectrometer environment. From solid angle considerations the bottle should be as long as possible. Thus the beam stop should be as far away from the spectrometer as possible.

Really fast MeV neutrons will penetrate the boron carbide area. They must be moderated and stopped in hydrogenous borated material which should therefore surround the actual beam stop.

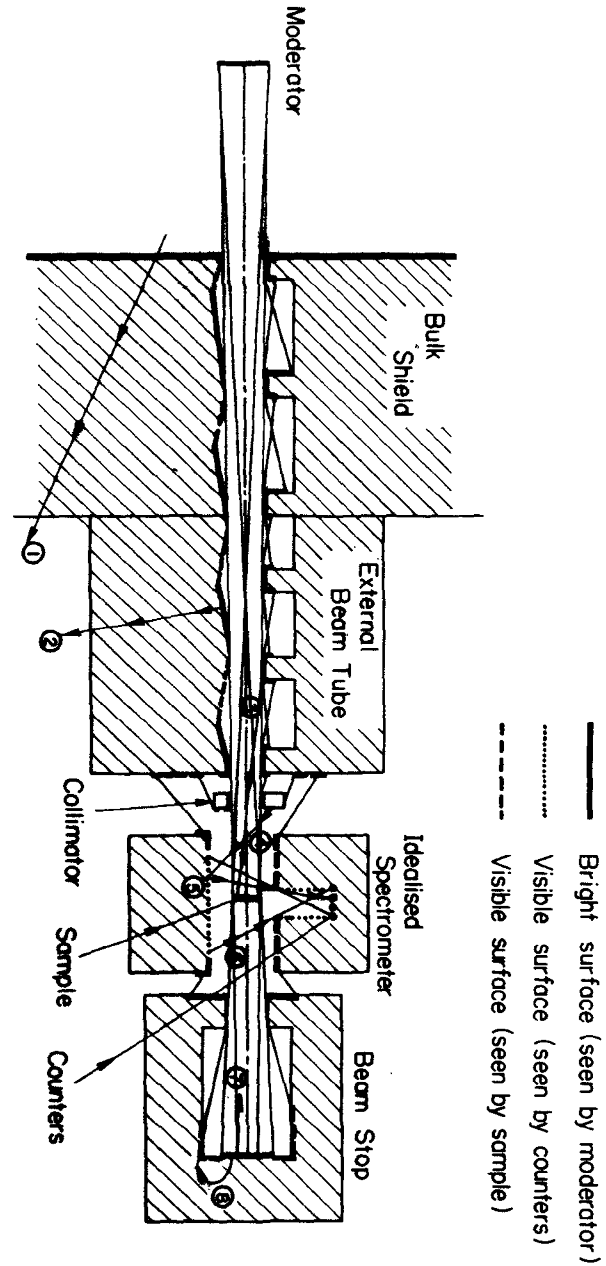

Fig. 1. Some sources of background in an idealised pulsed neutron spectrometer.

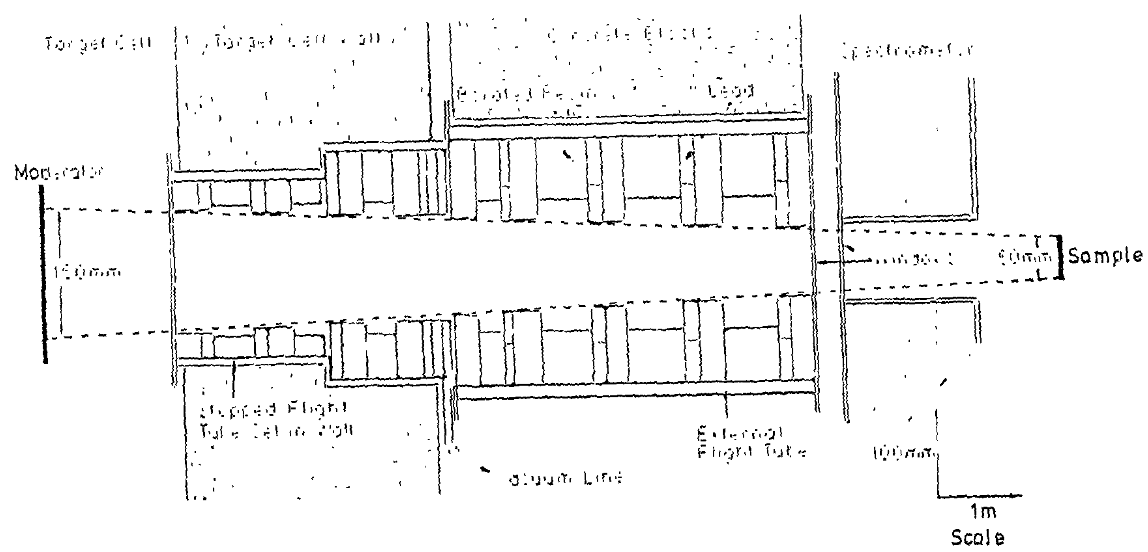

Figure 3 . An expanded view of a typical beam tube on the Harwell linac. The absorber sections converge from a 150 mm diameter moderator area to a 50 mm diameter sample.

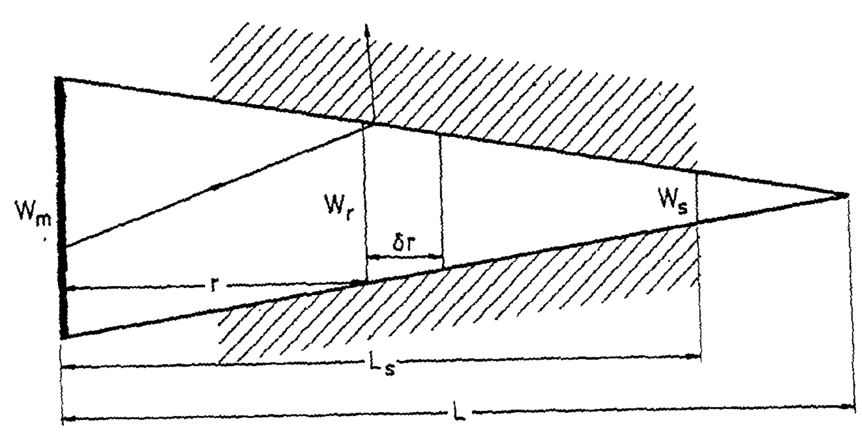

Figure 2 Neutrons incident on a beam tube wall are generally scattered outwards and must be shielded. A uniform conical tube is assumed. The effective source brightness of the conical segment δr, is equal to loss of flux between r and $r+\delta r$ divided by its area $\pi W_r \delta r$.