EUROPEAN
SPALLATION
SOURCE

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Standards for Shielding of Neutron Beamlines and Instruments

DRAFT

Executive Summary

This document summarises the standards and standard practices defined by the ESS Neutron Optics and Shielding Group (ESS-NOSG) pertaining to shielding of the neutron beams, instruments and associated hardware. Optics is handled in a separate document [1].

This document is written at a time when detailed calculations are just beginning. Many of the numbers in this document exceed the specifications of existing spallation sources for good reason, and will only be relaxed once the requirements are clarified on an instrument-by-instrument basis, and once the data from recent measurements at SNS and PSI are fully analysed. It will then become a continuously evolving document as more data is gathered from further measurements and modelling work.

Contents

1 Introduction

The ESS needs to improve on the background levels that were achieved at the SNS, in particular due to the fact that 70% of the TDR reference suite contains instruments that wish to measure across a frame boundary. This potentially exposes the instruments to a spiked background phenomenon, possibly with long decay tails, known by some as the “prompt pulse”, which is a high energy physics phenomenon. In some cases, the background could be subtracted, but in many cases this is not foreseen to be a solution. The guidelines in this report should minimise the high energy background problem on the ESS instrument suite.

2 Basic Principles

The materials and geometries in this document will appear to be different in many ways to standard practices at reactor sources. The behaviour of thermal and cold neutrons is not the primary issue. The ESS is a 5 MW, 2 GeV facility that can provide signficant background and radiological effects from the high energy particles that result from the proton physics in the accelerator and target. Many of the differences that are described here are a result of the high energy background studies that have been performed with our partners at PSI, SNS and ISIS. Compromising on any of these areas potentially increases the background and radiological hazards on not just the instrument in question, but the neighbouring beamlines also.

2.1 Materials

The primary capture element of neutrons in and around the instruments will be boron. Boron emits lower energy gamma radiation compared to other materials, and borated sheeting is available that does not cause significant outgassing problems compared to B4C.

In comparison, cadmium is toxic, and transparent to fast neutrons. Gadolinium in both metal and oxide form may be used for certain applications, e.g. very close to beams to form slits and apertures. Hydrogenous materials also containing boron are fine, provided that they are capped with a layer of materials that are very rich in boron directly facing the instrument detectors. Our experience is that sacrificing boron in order to use other materials can appear cheaper initially, but fixing background problems later is more costly in the long run.

In the beam delivery systems, the high energy hadron interactions will be intentionally induced in laminates based around copper, antimony-free lead, steel, nickel and aluminium. Voids will be created, and interactions within the voids will be induced in carbonated materials and aluminium.

Tungsten or lead will be used in key areas to induce hadronic showers where background suppression is required in a very small volume. The cost of a small amount of tungsten or lead can affect the total cost of large-volume shielding substantially. One area that this is likely to be requried is the lateral shielding between the beamlines. More detailed models are required on a case-by-case basis for this region, as it depends very strongly on the neighbouring instrument type and beam geometry. Starting numbers would be in the region of 20-40 cm thickness of material (approx. 1 neutron mean free path at 2 GeV, which is much more than 1 mean free path at MeV and keV energies).

2.2 Block Assembly

The general guideline for assembling shielding at high energy physics labs is to use the "$7\times$" rule. We provide additional margin for error by increasing this to a "$10\times$" rule, as shown in figure 1. The gap formed between shielding blocks caused by manufacturing tolerances, or indeed a tube cut into a shielding block to feed cables and hoses etc, must form a chicane that is $10\times$ larger than the gap to maintain opacity to high energy particles.

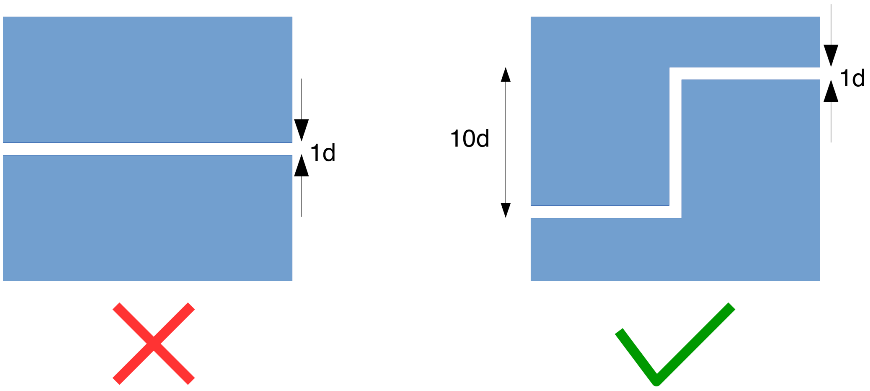

Figure 1: $10\times$ rule for chicanes and steps. Gaps between shielding blocks and conduit paths need to follow this rule to remain opaque to high energy particles.

2.3 Block Joins

The joints between blocks that are not planned to be disassembled regularly (permanent walls, interfaces with target building etc) will be filled with cement/grout at least 50% of the way through the blocks. This requires that the cement is injected into the spaces between the blocks, forming a smooth surface. There are many examples of this at ISIS-TS2, one is shown in figure 2 on page 6.

3 Neutron Guides

3.1 Collimator Blocks

Several collimator blocks will be used along the length of the guides to reduce the high energy background coming down the beams themselves. These are fabricated from 1 metre by 1 metre by 1 metre blocks, with the centre of the neutron beam axis running through the centre of the collimation block using metallic guides. The current specifications of the blocks is that they are made from copper, with an additional 50 mm layer of aluminium on the outside. These will be optimised later in 2014-2015, when the composition and geometry will be updated. Larger blocks are required for large dimensions of guide so that the minimum

Figure 2: Fully grouted shielding walls at ISIS, with no obvious gaps between the permanent structures. The gaps are sealed at the rear, then the cement is pushed into the gap and smoothed flat.

transverse thickness of copper between the supermirror and the edge of the copper block is 400 mm, so that it exceeds one tenth value for high energy neutrons in the transverse direction [2]. The copper block will be covered on all outer surfaces by aluminium plates that are 50 mm thick to provide a physical barrier of contact (Cu presents radiological hazards for around 1 week after exposure to neutrons).

Any bolts and screws used in the assembly of the copper blocks will be made from high quality brass. *No stainless steel will be used anywhere* to avoid activation.

If copper is prohibitively expensive at the time of procurement, or for geometrical reasons, antimony-free lead and/or tungsten can be used with a proportional adjustment in longitudinal thickness based on the difference in tenth values [2]. The transverse thickness from the neutron beam to the outer surface of the collimator block, perpendicular to the beam axis, should always be at least 400 mm to provide a geometrical line-of-sight barrier in any case.

3.2 Direct View of Source

Neutron guides with a direct view of the source will have three collimator blocks as described in section 3.1. The first collimator block will be located between 6-10 metres from the moderator centre. All of the first collimator blocks will be aligned as close as possible around a circumference to avoid the possibility of cross-talk between the beams, or arranged in such a way that cross talk through the gaps is avoided. If it is necessary to stagger the collimator blocks, then additional collimation material will probably be required to fill the diagonal gaps between the neighbouring beamline blocks.

The second collimator block is located at the mid-point of the curvature to lose first line of sight, or half way to the instrument, whichever is the nearest to the moderator. The third collimator block will be located at the point of losing line of sight once, or 75% of the way to the instrument, whichever is nearest to the moderator.

The shielding around the beam lines will be 1.5 metres of concrete or concrete mass equivalent.

The vacuum housing on the guides will be made from aluminium. Screws, nuts and bolts may be made from coated mild steel or brass.

3.3 Out of Line-of-Sight

The shielding around the beam lines will depend on the m-value of the guides in question, and a full radiological study is required. However, ballpark numbers for the last sections of guide can be obtained by looking at any thermal beamline at a similar instrument, at a reactor or spallation source, and adding 5 m of safety margin for the line of sight calculation before reducing the shielding thickness from that described in section 3.2. It should be noted that this is only a starting point pending the detailed design that must follow.

Vacuum systems may be made from either aluminium or nickel-plated mild steel. FATs using x-ray fluorescence on every piece of vacuum housing will exclude zinc plating on all vacuum systems from being installed. Screws, nuts and bolts may be made from coated mild steel or brass.

3.4 Shielding Internal Surfaces

The internal wall and ceiling surfaces facing the beamlines must not be smooth. It doesn't matter whether they are machined, as shown in figure 3 or moulded, as shown in figure 4.

3.5 Floor Steps

A minimum of three floor steps are required before emerging from the bunker. The floor steps are designed around the $10\times$ rule on page 5. The steps increase the floor height with increasing distance from the source, and reduce the possibility of ground-shine background at the instrument position. The ESS bunker needs to have these features, and the 150 m long guides will have two such steps between the guide halls. The 60 m instruments also need two steps between the bunker exit and the cave. An example from ISIS-TS2 is shown in figure 5 on page 9.

4 Beam Stops

4.1 Direct View Beamstops

Beamstops with a direct view of the source are made from laminations. The beamstop is located at least 2 metres behind the instrument via a "get-lost" tube, pending a detailed model of the instrument. The concept is based on the ChipIR beamstop at ISIS-TS2, scaled suitably for an ESS source view and the difference in incident hadron energy that this brings.

Figure 3: Concrete surfaces machined and providing increased roughness. The roughness should be greatest along the beam axis, unlike some of these decorative panel examples. Many thanks to DTI for this example.

Figure 4: Concrete surfaces moulded for increased roughness. The waviness should be greatest along the beam axis, unlike this example shown here which is a decorative motorway barrier. Many thanks to DTI for this example.

Figure 5: A step in the shielding support floor to reduce ground-shine. This example is partially covered by the wooden panel. The step is in the white concrete base, near to the orange blocks.

4.2 Beamstops Out of Line-of-Sight

These beamstops may be located 2 metres behind the instrument via a "get-lost" tube and are substantially smaller than the direct view beamstops described in section 4.1, since they only deal with thermal and cold neutrons in principle. Examples are prevalent at reactor sources. A sheet of boron 10 mm thick and 50 cm of concrete may be sufficient. Exact numbers will be developed in 2014. Back-illumination from the boron sheet to the detectors should be prevented by designing the get lost tube cone so that it matches the expected beam divergence and geometry, plus 10 mm.

5 Instrument Caves

5.1 Cave Walls – Out of Line-of-Sight

The instrument caves for beam enclosures outside line of sight are similar to the TS2 instrument caves. These are steel cans filled with borated wax, as shown in figure 6. The thickness of the wax is 400 mm minimum. This is designed to prevent cosmic neutron backgrounds, and to minimise the effect of high energy backgrounds that escape from all around the facility, by providing a large barrier to any neutrons thermalising in the surroundings. A more detailed illustration is shown in figure 7.

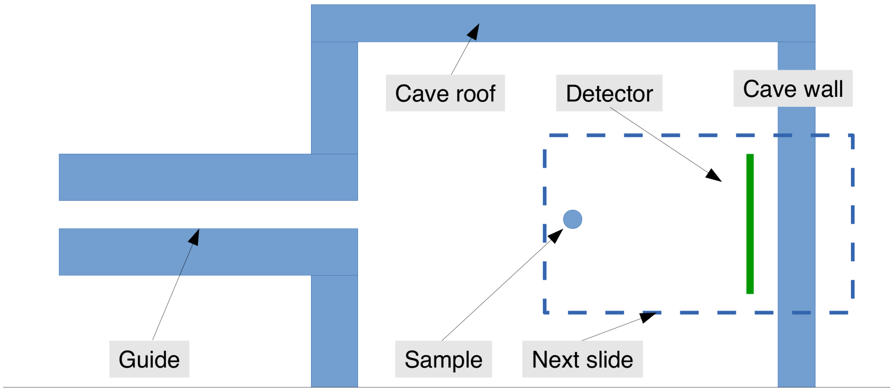

Figure 6: Instrument cave for instruments that are out of line-of-sight of the source. The broken line illustrates the boundary of the exploded view in figure 7.

5.2 Cave Walls – Direct View of Source

The instrument caves within line of sight of the source for the two guide halls nearest the target (less than 80 metre long instruments) have two components. The outer surface of the cave will be surrounded by 2 metre thick concrete enclosures, or mass equivalent to 2 metre thick concrete. If heavy concrete and steel are used, nonetheless the outer portion of the cave will still be made from regular concrete and be 1 metre thick. Within this outer cave, a second cave internal surface as described in section 5.1 is required for instruments that are

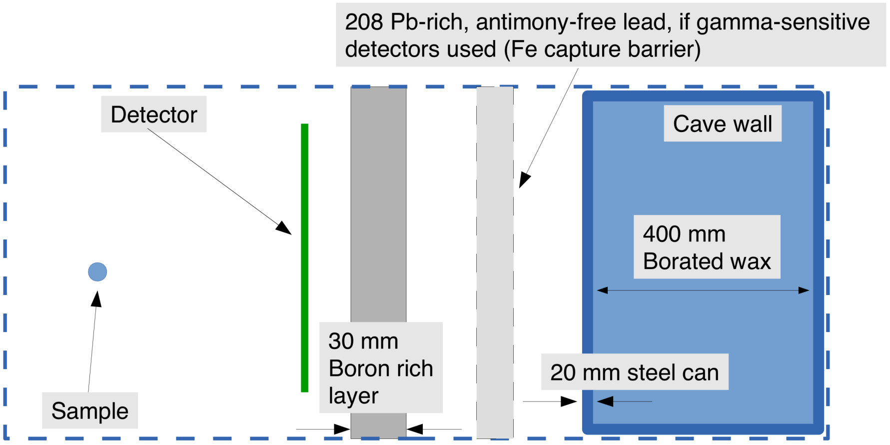

Figure 7: Detailed view of the cave wall for instruments that are out of line-of-sight of the source.

concerned about their own backgrounds, to reduce the back-scattering from thermalised neutrons in the concrete. The dimensions of the inner cave layers have yet to be determined for these line-of-sight instruments.

It is not yet clear whether long instruments (150 m) will have a direct view of the source, and if they do the nature of their cave is being defined. It is likely that the caves for the long instruments are the same as those described in section 5.1.

5.3 Internal Wall Surfaces

The innermost surface of all instrument caves, directly behind the detectors, will be coated entirely with >50% boron rich sheeting of 30 mm thickness as the first surface encountered. B4C is acceptable if cheaper, and the outgassing into a vacuum is not problematic. B4C will not be used in evacuated tanks due to outgassing. Behind the boron layer, borated polyethylene or steel structures may be used. Removal of these borated surfaces might be possible in certain areas, subject to approval by both NOSG and the Instrument Scientist.

5.4 Structural Materials

Any support structures that approach within 500 mm of the neutron beam centre axis require approval from NOSG for composition for radiological and background assessment reasons. Any support structures that can be illuminated by scattered neutrons from the sample position require approval from NOSG for composition for radiological and background assessment reasons with the shielding coordinator. No stainless steel will be used anywhere within 500 mm of a neutron beam.

Where support frame structures are used for steps, braces etc, and cable trays, these should be wooden structures. *Wood treated with boric-acid is the preferred structural material everywhere possible* where the load-bearing properties are sufficient. This also brings environmental and cost benefits. The next preferred material is aluminium. Steel use should be minimised as much as possible for these alternatives.

5.5 Cave Floors

The floor of the instrument caves, wherever possible, will be covered by boron carbide non-slip surfaces as used at ISIS-TS2. If the instrument has a "dance floor" then clearly the mechanical properties of the polished floor surface take priority over the neutronic properties of the ground.

6 Putting It All Together

This section shows how both the shielding and optics concepts should be merged into a single concept. This section appears in both the Shielding Standards document and the Optics Standards document.

In figure 8 on page 12 we show how the shielding and optical ideas come together into one common concept. Three collimator blocks are used within the bunker and line-of-sight (LOS) to minimise fast neutron escape down the axis of the beamline. The collimator blocks are coupled very closely to a copper substrate guide, with steps in the outer planes following the $10\times$ rule. Between the collimator blocks, expansion areas are used to allow the particle showers to expand before the next collimator block is encountered. This allows the system more closely to follow an inverse-square law. Multiple zigzag reflections of the fast particles in a confined space actually transports them very efficiently rather than attenuating them, so we need to allow them to expand.

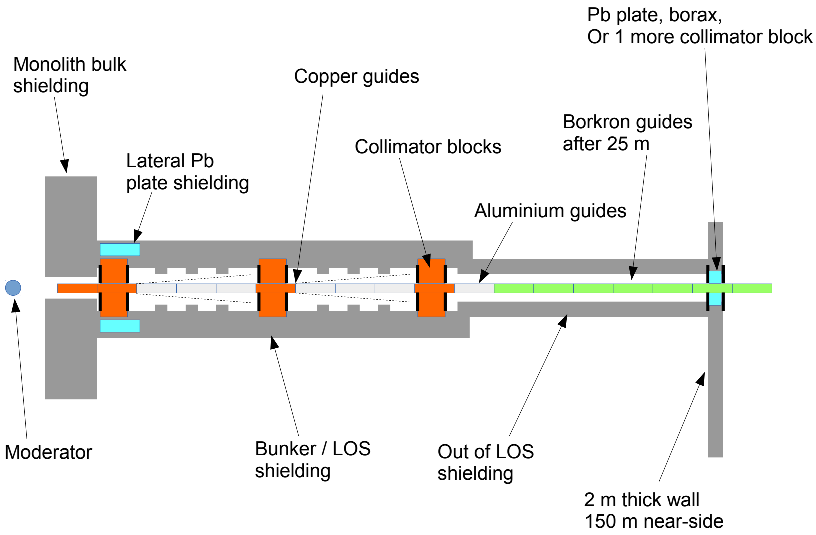

Figure 8: Top-down schematic of a beamline with ESS-compliant shielding surrounding it. The neutron source is on the left, the instrument is on the right. For completeness, we also show the 150 m wall traversal for the long instruments.

References

[1] P M Bentley. Neutron optics standards for the ess. Technical report, European Spallation Source ESS AB, 2014.

[2] A. H. Sullivan. *A guide to radiation and radioactivity levels near high energy particle accelerators*. Nuclear Technology Publishing ISBN 1 870965 18 3, 1992.