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Requirements on Accelerator, Target, CF and Instrument Engineering from Neutron Optics and Shielding NON-REVIEWED DRAFT

Executive Summary

This document summarises the requirements for the Target monolith, Accelerator, Conventional Facilities, and Instrument Engineering, from the team working in the Science Directorate in the Neutron Optics and Shielding group.

This is a working document that will evolve as new information is gathered. Some iteration is to be expected between the stakeholders, the technical groups, and those in advisory roles, and this interaction will refine the data presented here.

Contents

1 Introduction

These requirements are a result of design goals, which were drawn up in consultation with stakeholders and advisory panel experts that are considered reasonable and achievable. The design goal, subject to adjustment in the future, is to reduce the integrated neutron flux in the region of 10 MeV – 3 GeV (which covers day one proton beam energy and a foreseen upgrade) by a factor of 100 compared to SNS, JPARC, SINQ and ISIS. This will enable any of the TDR reference instruments to function as designed, with an excellent signal-to-noise ratio, even whilst measuring across frame boundaries when subsequent proton pulses hit the target.

Due to the nature of the long pulse source, failure to meet the requirements in this document is understood to expose 70% of the TDR reference instruments to a risk of performance degradation, by making otherwise interesting and important regions of parameter space unusable. We assume that failure to address this problem and knowingly build so many instruments with peformance risks of this kind is unacceptable.

The numbers feeding this design goal have been gathered by an international collaboration on high energy backgrounds at spallation neutron sources. The collaboration is coordinated by the Neutron Optics and Shielding group at ESS, and involves SNS, PSI, Lund University and MAX IV. The figures presented in this document have been validated against an appropriate high energy physics shielding manual recommended by the ESS CCB [1], and verified with measurements at PSI, Switzerland, during May 2013 [2]. These efforts are summarised in separate documents in preparation.

More measurements are planned in the near future, both at PSI and at the SNS in September 2013. Furthermore, there are considerable modelling activities anticipated thereafter. As such, this document should be considered an evolving work subject to revisions as new information is gathered.

The Neutron Optics and Shielding group is very happy to assist where required in the design process, to help develop solutions with our colleagues in the Accelerator, Target and Conventional Facility teams that can meet these requirements. Some of the numbers sound ambitious to unfamiliar eyes, but they are not. A factor of 100 attentuation for a 2.5 GeV beam, once in equilibrium in the existing shielding, can be achieved with less than a metre of extra material in the right place with the correct composition, or by replacing parts of steel shielding for other metals in a few key areas. It is expected that the effort to meet these requirements strategically will reduce the total cost of the ESS, in contrast to meeting the objectives purely within the budget and scope of NSS and Operations, and the impact scientific output whilst such issues are addressed after operations begin. The emphasis is on doing things 100 times better, not 100 times more expensive, and this requires a strategic view.

Other angles on this problem such as eliminating design flaws in current practices of neutron beam extraction and delivery, beamline shielding and instrument shielding they are in addition to the efforts described in this document. The background issues at existing facilities appear to involve several physics mechanisms, which traverse scope interfaces across all of the ESS divisions involving science and construction.

2 Assumptions

The Target, Accelerator, and neutron beamlines will meet the radiological safety requirements of the ESS. This requirements document supplements the radiological safety requirements of the facility regarding living organisms. “Safe” in the present context is a supervised area, coded as a green area, < 3 μSv per hour [3].

3 Bunker Engineering

All piping conduits, service channels, and cuts of any kind through the shielding, outside of the basic design of the shielding blocks, must be kinked. Two kinks are required for each channel. The kink size must be 10$\times$ the width of the channel that is cut. The two kinks must be separated by at least 500 mm of steel or copper, 300 mm of tungsten, or 1000 mm of concrete. No channels shall be cut through any of the high energy collimation blocks.

4 Environment Inside The Monolith

The optical components embedded within the monolith shall be cooled and maintain a temperature below 110°C at all times. The heat loading calculations should assume that the assembly will contain steel, copper, glass, silicon, aluminium, tungsten and zerodur glass-ceramic.

The cooling gas needs to be better than N4 grade in terms of water and oxygen impurity.

5 Protection of Guide Systems

In the event of a vacuum failure, the interaction of ionising radiation and oxygen and nitrogen must be prevented, to avoid the creation of nitric acid and the acid-etching of the supermirrors that results. There are two scenarios.

5.1 A Heavy Shutter is Deployed in the Monolith

It is expected that a heavy shutter which reduces the radiation dose on the downstream side to levels that allow hands-on activity on the beam axis is a sufficient attenuation of the ionising radiation to protect the guides from nitric acid etching. As such, if a vacuum system fails then the other instruments can continue to operate. If the shutter fails to close, the guides will require a dry, inert gas flushing system that displaces moisture, oxygen and nitrogen in the guides (the mechanics of which fall within the scope of NSS) whilst repairs are arranged. If the flushing system and vacuum system both fail during operations then the proton beam must be switched off without delay.

5.2 No Heavy Shutter is Deployed in the Monolith

The guides will require a dry, inert gas flushing system that displaces oxygen and nitrogen in the guides. If the flushing system and vacuum system both fail during operations then the proton beam must be switched off without delay.

6 Alignment of Optical Systems

6.1 Beam Extraction Area

The aligment of optical systems is crucial for the performance of the neutron instrumentation. Typically, the baseline installation alignment is ±50 μm of a guide section. This must be maintained for both foreseen scenarios.

6.1.1 A Heavy Shutter is Deployed in the Monolith

In this scenario, a floating optic will be used like at the SNS short pulse source, which necessitates the provision of a system of kinematic sockets in the monolith structure and kinematic projections from the optical support structure in the shutter cassette, which aligns the optical element each time the shutter is opened. An accurate, full scale, exact duplicate model of one of the beam ports will be required from the Target to pre-align the cassettes before they are installed.

6.1.2 No Heavy Shutter is Deployed in the Monolith

An accurate, full scale, exact duplicate model of one of the beam ports will be required from the Target to pre-align the optical cassettes before they are installed.

6.2 General

The foundations for beam delivery shall be piled along the length of the instrument, and allow freedom in the lateral direction to curve the beam with a total displacement of 1 metre (example solution: run a pair of piles along the length of the guide central axis, which can be bridged by the guide support).

The foundations must be allowed to cure fully before optical systems are laid out. Advice from other facilities places a typical 2 year curing time before the concrete is sufficiently stable. This number requires some development with CF.

7 Diagnosis of Problems on Instruments

A method of modulating the neutron beam intensity on an instrument independently of neighbouring beamlines is required so that problems can be diagnosed in the beam extraction and beam delivery systems. A working figure that appears reasonable at present is a modulation of the high energy hadrons — including the vicinity of 2.5 GeV — provided by three mean free paths of material after the equilibrium point (i.e. $\sim$4 mean free paths beyond the theoretical shower maximum for a 2.5 GeV neutron). Note that this also places requirements on the appropriate filling of the windows in the Fe cross section, if the shutter is using ferrous materials. There are energy ranges where the Fe cross section is extremely small.

8 Background radiation

The requirements in this section are based on a reduction of the high energy background on neutron instrumentation, otherwise known as the prompt pulse. This phenomenon exists at all pulsed spallation neutron sources to varying degrees. Long pulse instrument optimisation exposes 70% of the instrument suite to the risk of having an unworkable background for some experiments. The design goal is to reduce the background seen on HYSPEC at the SNS and on AMATERAS at JPARC by 2 orders of magnitude. This reduction would eliminate the problem statistically for the majority of experiments, and the ESS could then measure across the frame boundary on any instrument.

The challenge here is to meet the background requirements on two types of instrument principally. On the one hand, SANS and reflectometry require $\sim 10^8$ signal to noise across the frame boundary. On the other hand, chopper spectrometry "only" requires $\sim 10^6$ signal to noise but presents the largest active volume of detectors. The latter seems at present to be the most challenging.

8.1 General Rule of Thumb and Open Questions

Existing facilities are largely exhibiting safe working conditions, and yet suffer from a background that is approximately 2 orders of magnitude too large. Therefore, radiologically safe shielding plus two tenth values for 2.5 GeV neutrons would appear to be a reasonable starting point for all background sources.

Detailed models on the exact process by which a fast neutron (> 10 MeV) creates a spike on the instrument detectors is on going. Higher energy (GeV) neutrons are more penetrating but these generate showers of neutrons. At the time of writing, very basic, preliminary calculations suggest that one fast neutron produces one detection event if it strikes the instrument close to the detectors, and this number is likely to be refined in the future.

8.2 Radiation Down Beamlines

Target station 2 at ISIS (ISIS-TS2) has observed a decrease of many orders of magnitude of the high energy background, emerging from the target down the neutron beamlines. This is attributed mainly to the avoidance of ferrous materials in the immediate vicinity of the target centre [4], and is aligned with the expectations from our collaborators at Lund University and MAX-IV [5] on the problem. The reason for this success is due to the conversion of photons in the 10-40 MeV range to photo-neutrons in Fe, which is transparent in the keV-MeV range. Therefore, the target may not use ferrous materials within 1 metre of the intersection of the target wheel surface and the centre of the proton beam, including all bolts, washers and screws. Acceptable materials are either high-z or low-z: tungsten, aluminium, tantalum, titanium, and lead. Plating materials can be platinum or zinc.

It should be noted that this requirement contains significant political weight, since ISIS will be asked to review the baseline target design before the UK commits to the ESS project, and best current practice is exhibited in this regard by ISIS-TS2.

8.3 Radiation emission from surface of monolith structure

Radiation leakage from the monolith for the short instruments manifests itself as both a direct-irradiation problem and scattered particles from interaction with the surroundings. For the long instruments, skyshine from high energy particles [6] becomes a more significant issue as it peaks at 100 m distance. The skyshine contribution is $\sim$0.4 times the direct-irradiation value, approximately, using data from other facilities (see also [1] and references therein), so for order of magnitude estimates we can use the same numbers for both ESS instrument halls.

8.3.1 Below 10 MeV

The contribution to this energy range from the Target is not considered to be relevant, if the requirements in sections 8.2 and 8.3.2 are met, and the safety requirements of the ESS are met.

8.3.2 Above 10 MeV up to Proton Beam Energy

Extrapolation of the HYSPEC background [2] to the monolith surface 40 metres away gives a source of $\sim$ 28 hadrons per square metre per second. The target monolith surface may therefore emit an integrated flux of up to 0.1 hadrons per square metre per second, of which the vast majority are expected to be neutrons. It is anticipated that photon flux in this energy regime is inconsequential for the neutron instruments if the shielding meets the hadron flux requirement.

8.4 Radiation Emission from Surface of Accelerator Mound

This is understood to be primarily a skyshine issue, except for the A2T region which could expose the neutron guide hall to bombardment by secondary particles that result from proton beam losses after the proton beam emerges above ground. This particular problem is being addressed, and is likely to be comparable to that in section 8.3.

8.4.1 Below 10 MeV

The Accelerator earth shielding surface may emit 1.0×10^6 neutrons per second, however it is expected that this will not be possible to produce whilst remaining within the radiological limits and meeting the requirements for the high energy particles in section 8.4.2.

8.4.2 Above 10 MeV up to Proton Beam Energy

The Accelerator earth shielding surface may emit 1×10^4 hadrons per second, of which the vast majority are expected to be neutrons. It is anticipated that photon flux in this energy regime is inconsequential for the neutron instruments if the shielding meets the hadron flux requirement.

8.5 Radiation Emission from Accelerator Stubs

This requirement is work in progress. We anticipate that the numbers will be no more than one order of magnitude higher than those in sections 8.4.1 and 8.4.2.

References

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