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SECOND TARGET STATION (STS) PROJECT

Interface Sheet for Target Assembly and Proton Beam

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1. PURPOSE

This document defines the Proton Beam Parameters interface between Accelerator Systems (AS) and Target Systems (TS). The interface described in this document will provide inputs to the RTST Beam Line Optics design, Target design and Accelerator Interface Components design.

2. SCOPE

The scope of this document is the complete proton beam definition for the interface between Accelerator Systems, Target Systems' Accelerator Interface Components, and the Target as identified in the parent Interface Control Document S01020500-IC0002 between Accelerator Systems and Target Systems. This document also discusses expected variability in proton beam parameters that will be used to inform target fatigue analysis and potentially the Accelerator Operating Envelope (AOE) to be defined prior to commissioning.

The scope of this document does not include physical hardware connections such as the vacuum interface between Accelerator Systems and Target Systems, which will be defined and controlled by a separate Interface Sheet as indicated in the parent Interface Control Document.

2.1 INTERFACING PARTS OR COMPONENTS

No.	Components (Accelerator Physics)		Components (Target Systems Accelerator Interface Components)	
	Name	Functional reference Number	Name	Functional reference Number
1	Accelerator Physics	S02030000-DAC10000	Target Systems Assembly Drawing	S03000000-A001.asm

3. ACRONYMS

AIC	Accelerator Interface Components
AOE	Accelerator Operating Envelope
AS	Accelerator Systems
ASE	Accelerator Safety Envelope
BCM	Beam Current Monitor
FTS	First Target Station
MPS	Machine Protection System
MTBF	Mean Time Between Failures
PBW	Proton Beam Window
PPS	Personnel Protection System
PPU	Proton Power Upgrade
RLS	Repetition (rate) Limiting System
RTBT	Ring to (first) Target Beam Transport line
RTST	Ring to Second Target beam transport line
SSC	Structure, System or Component
SNS	Spallation Neutron Source
STS	Second Target Station
TBC	To Be Confirmed
TBD	To Be Determined
TS	Target Systems
WBS	Work Breakdown Structure

4. REFERENCES

4.1 DOCUMENTS APPLICABLE TO THE INTERFACING SSCS

Ref	Document Titles	Document Control System Location
[1]	S02030000-DRD10000 Second Target Station Project Beam Optics Preliminary Design Review Report	EDRM
[2]	S01020500-TDO10000 Estimated Maximum Charge per Pulse of the SNS Accelerator	EDRM
[3]	8000-CS-111-00-SK00A Second Target Station Enlarged STS Site Plan	EDRM

5. INTERFACE DEFINITION

5.1 INTERFACE OVERVIEW

Following completion of the Proton Power Upgrade (PPU) project, the Spallation Neutron Source (SNS) accelerator will be capable of creating proton beams with average kinetic energy up to 1.3 GeV and average power up to 2.8 MW with a repetition rate of 60 Hz. In the Second Target Station (STS) design, every fourth proton pulse is extracted from the existing Ring to target Beam Transport (RTBT) beamline and steered into the Ring To Second Target (RTST) beamline, which will transport the pulse to a rotating tungsten spallation target for the production of neutrons. The interface between the proton beam and the target consists of the proton beam properties that impact neutron production and target lifetime.

5.2 RESPONSIBILITIES

Proton beam extraction from the RTBT and transport to the second target is in Accelerator Systems (AS) scope. The target and Proton Beam Tube Assembly (PBTA) that provides the final section of the vacuum system from the RTST gamma blocker, through the target monolith wall, and terminates at the Proton Beam Window (PBW) are in Target Systems (TS) scope. Note that both AS and TS scopes include a harp for beam profile measurements.

Accelerator Physics within the AS group is responsible for developing a beam optics design capable of delivering the proton beam via the RTST to the Accelerator Interface Components (AIC) and ultimately the Target Assembly, with an available range of beam spot sizes sufficient to satisfy neutron production and target lifetime design goals. The beam optics design will be implemented using existing technology.

The TS design teams are responsible for the design of components that receive and utilize the pulsed proton beam.

The responsibilities of the interfacing WBSs are given in Table 1.

Table 1: Responsibilities of interfaces WBSs

Interface Property	Responsible WBS
Target face location	TS – Target Assemblies
PBW location	TS – AIC
Proton beam spot size range for normal operation	TS
Proton beam density distribution at target face	AS
Modelling of proton scattering by the PBW	TS – Neutronics
Beam centroid position monitoring at PBW	TS – AIC

5.3 INTERFACE DATA

5.3.1 STS BEAM PARAMETERS

Proton beam from accelerator

The STS accelerator systems will divert every fourth proton pulse from the first target RTBT beamline to the second target RTST beamline. The properties of the proton beam are determined by front end, linac, and ring injection control settings and are independent of the RTST design. Nominal proton beam parameters for normal operation to the second target station are given in Table 2.

Table 2: Nominal second target station proton beam characteristics for normal operation.

Average beam power per second	700 kW
Pulse frequency	15 Hz
Energy per pulse	46.7 kJ
Proton kinetic energy	1.3 GeV
Number of protons per pulse	2.24×10^{14}
Number of protons per second	3.37×10^{15}
Proton pulse length	661 ns
Power per pulse (nominal energy per pulse/ nominal pulse length)	~70600 MW (46.7 kJ/661 ns)

Target Systems Components Locations

AS particle tracking simulations track protons to the target face and generate proton density distributions at that face and at the PBW. The locations of the target face and PBW are given in Table 3.

Table 3: Nominal Target component locations

Assumed target surface position for optics model	101 mm upstream of STS coordinate system origin. See [3] for location in SNS global coordinates
Proton Beam Window position	Center of PBW thin section is 2.491 m upstream of STS coordinate system origin

Proton Beam at the Target

Table 4 gives the TS assumptions for the tolerance on beam spot centroid position variability and proton beam spot size. These are inputs for the beam optics design and inform magnet power supply specifications and final focusing magnet specifications, respectively.

Table 4: Proton beam parameter inputs to the beamline design.

Width of Beam on Target (95% of protons)	125 mm $\leq$ beam width $\leq$188 mm
Nominal height of beam spot on target (95% of protons)	48 mm
Nominal range of beam spot area on target (90% of protons)	60 cm^2 - 90 cm^2
Assumed beam centroid vertical position tolerance[1]	+/- 4 mm
Assumed beam centroid horizontal position tolerance[1]	+/- 6 mm

[1] *Based on FTS Accelerator Operating Envelope (AOE)*

Table 5 gives the peak proton densities determined by particle tracking simulations based on the spot size assumptions [1]. The beam width is defined by taking a cross section of the proton density as determined by particle tracking simulation along the horizontal axis of the proton distribution, through the spot centroid, and determining the horizontal extent on that line that contains 95% of the protons in the spot. These simulations do not take into account scattering at the PBW, which is in TS – Neutronics scope.

Beam spot height is defined similarly but using a cross-section along the vertical axis of the proton distribution.

A box centered on the beam spot centroid with height and width as defined above will contain 90% of the protons in the spot, according to the particle tracking model.

Table 5: Proton beam parameter inputs to the Target design, as determined by particle tracking simulations

Peak proton density at target for 60 cm^2 spot (neglecting PBW scattering)	5.2×10^{10} protons/pulse/mm^2
Peak proton density at target for 90 cm^2 spot (neglecting PBW scattering)	3.4×10^{10} protons/pulse/mm^2

5.3.2 Limits of Normal Operation

Prior to operation, limits on the values of relevant operating parameter values will be documented in the Accelerator Safety Envelope (ASE), which defines the safe operating limits for relevant STS systems, and Accelerator Operating Envelope (AOE), which ensures margin between actual operating conditions and the ASE. Definition of the AOE and ASE parameter limits is beyond the scope of this document. However, operating parameters expected to be relevant to the AOE for STS operation are given in Table 6.

Table 6: Expected parameter operating ranges

Parameter	Expected Normal Range	Expected AOE Limits
Beam power	700 kW ± 1 – 2 %	770 kW (TBC) Beam power is determined by BCM measurement of charge delivered, combined with pulse energy measurement in the ring. Not currently interlocked to MPS
Beam centroid position	± 0.1 mm vertical ± 3 mm horizontal	± 4 mm vertical ± 6 mm horizontal Enforced by PBW halo thermocouple measurements interlocked to MPS
Peak proton density	3.4×10^{10} protons/pulse/mm^2 (90 cm^2 nominal spot) up to 5.2×10^{10} protons/pulse/mm^2 (60 cm^2 nominal spot)	Operators alerted at 10% (TBC) over nominal and at specified maximum (TBD), as measured using the TS harp. Not interlocked to MPS

5.3.3 Maximum Beam Power

The design limit on the average output power of the linac for reliable operation is 2.8 MW at a repetition rate of 60 Hz. With the STS beam extraction operating at 15 Hz, the average power will therefore be 700 kW. It is expected that the 15 Hz repetition rate will be enforced by an independent circuit interlocked with the MPS and also by a Repetition Limiting System (RLS), which is a PPS credited engineering control.

It has been estimated that an average beam power of up to 900 kW at 15 Hz might be obtained in the future [2]. This is not in the scope of the STS project and SNS Operations have no plan currently to implement this. Any planned development in this direction in the future will need to consider the safety and reliability implications and include any necessary mitigations.

5.3.4 Mis-Steered Pulses

Particle tracking simulations have been used to study the impact of potential failures of ring extraction kicker and pulsed dipole power supplies [1]. The results are given in Table 7.

Table 7: Effect of pulsed magnet failures

Failure	Expected frequency	Expected #mis-steered pulses per failure event	Predicted effect on beam at target
Pulsed dipole power supply failure	Very rare. MTBF will be part of the vendor selection criteria	≤ 1. MPS aborts pulse before ring is loaded if pulsed dipole fails to reach field on time	PD#2, #3 or #4 failure: Pulse is lost, no protons reach target PD#1 failure: 30% of protons in pulse reach target. Horizontal deflection of the beam at second target ~ 17 cm
Single extraction kicker failure due to power supply failing to charge	Common. 3 events in 12 months	0. MPS aborts beam before ring is loaded.	Vertical deflection of the beam at second target of up to ~ 10 mm
Single extraction kicker failure due to power supply output current too low	Extremely rare, < 1 event per 20 years	1 – 60. If power supply voltage is good but output current is low, MPS will pause beam after a single pulse is sent but will reset after 2 pulse cycles. This may repeat up to a maximum of 60 faults. Operator intervention is then required. This type of failure has not been observed	Vertical deflection of the beam at second target of up to ~ 10 mm
Two extraction kicker power supplies fail simultaneously	Extremely rare, < 1 event per 20 years	0. MPS aborts beam before ring is loaded.	Vertical deflection of the beam at second target of ~ -15 to +5 mm
Extraction kicker power supply controller failure (results in multiple kicker magnets failing to ramp)	Extremely rare, < 1 event per 20 years	0. MPS aborts beam before ring is loaded.	Vertical deflection of the beam at second target of ~ +8 – +26 mm