TARGET COMPLEX DESIGN FOR A HIGH INTENSITY BEAM DUMP FACILITY IN THE NORTH EXPERIMENTAL AREA AT CERN

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Abstract

The Search for Hidden Particles (SHiP) is a new high-intensity fixed-target experiment to be located within the Experimental Cavern North 3 (ECN3) at CERN's North Area, utilising a 400 GeV proton beam from the SPS. The construction of a Beam Dump Facility (BDF) Target Complex is required for the successful operation of SHiP. It comprises an underground Target Station within the Tunnel Target Cave 8 (TCC8) cavern, upstream of ECN3, which will house a 1.5 m-long, 0.25 m-diameter HE-cooled tungsten target, and an above-ground service building that includes the target cooling systems, associated services, and waste package infrastructure. The required infrastructure to investigate target failures, including the cutting of spent targets and other CERN legacy waste in view of their packaging for disposal, has been studied. This contribution presents the current design status of the Target Complex, including radiation protection, remote handling, utilities and cooling/ventilation systems, installation and operation procedures, maintenance and decommissioning plans, and sustainability aspects.

INTRODUCTION

High-Intensity Experimental Cavern North 3 (HI-ECN3) is a project required for the operation of the new Search for Hidden Particles (SHiP) experiment looking for particles within the hidden sector [1]. The construction of the Beam Dump Facility (BDF) Target Complex is required as part of the HI-ECN3 project [2]. The new facility and experiment will be located in CERN's North Area and will receive a 400 GeV/c proton beam from the Super Proton Synchrotron (SPS) [3]. The beam will be fully absorbed by the BDF Target which has a 1.5 m-long, 0.25 m-diameter HE-cooled tungsten core [4]. A major part of the facility is the Target Complex, the development of this is detailed in this paper. An overview of the facility can be seen in Fig. 1, with the red labels indicating what makes up the Target Complex.

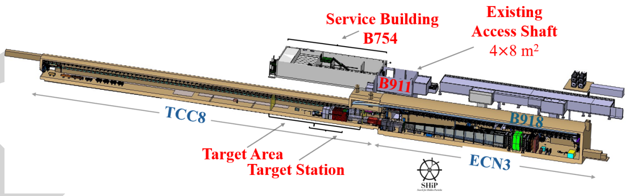

Figure 1: Overview of BDF/ SHiP Facility.

TARGET COMPLEX

The Target Complex consists of the underground Target Station and Target Area, the access shaft, and Building 911 (B911). Additionally, a new surface-level service building will be constructed to support the operation of the Target Station. TCC8, ECN3, B911 and the access shaft are all existing infrastructure and will be used to bring all components for BDF and SHiP underground for installation. A more detailed view of the Target Complex can be seen in Fig. 2.

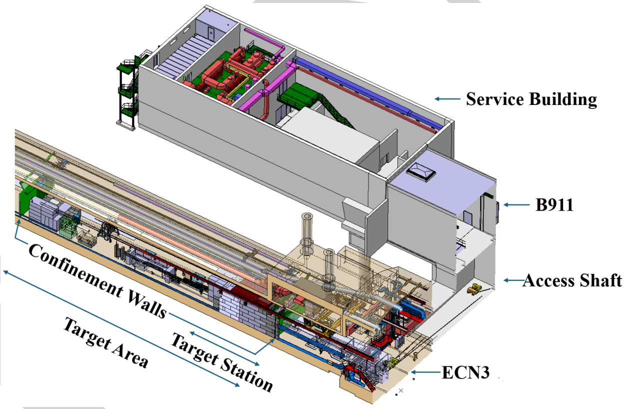

Figure 2: BDF Target Complex.

Target Area

Within the Target Complex is the Target Area, located 10 m underground in TCC8. The Target Area is defined by the surface between two ventilation confinement walls (Fig 2) and contains the Target Station, equipment for the first helium-cooling heat exchanger, the filter for the target helium-cooling, water-cooling cartridges of the proximity shielding, and the vacuum system for the vacuum vessel. Additionally, there is a space of around 400 m^2 upstream of the target, which will be used for the immediate storage of faulty components or during maintenance operations and target exchanges to place components of the Target Station to gain access within the system.

Target Station

The Target Station (Fig. 3) is located within the Target Area. It contains the BDF target alongside all relevant cooling, instrumentation, shielding, the magnetised hadron stopper (MHS) and a vacuum vessel. The MHS is the first element of the SHiP Muon Shield, composed of magnetised iron blocks positioned immediately downstream of the BDF

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target. The MHS absorbs residual secondary particles produced during the interactions of the high-energy proton beam with the target, and sweeps muons away from the main beam axis to reduce background for the SHiP experiment [5]. The Target Station includes around 470 m^3 of shielding, comprised of a mixture of copper, stainless steel, cast iron, and concrete and is around L 9 m x W 9 m x H 5 m. For sustainability reasons, shielding has been recovered from an unused facility at CERN and will be reused for the Target Station.

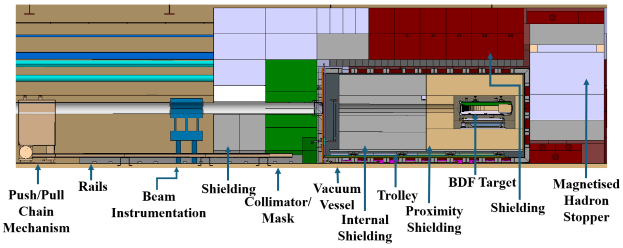

Figure 3: BDF Target Station.

Service Building

The service building will be a new construction of around 1000 m^2. It's primary function is to provide the services to the Target Station underground. There will be dedicated rooms for the power supply, networks, control, safety systems, normal and radiation protection (RP) changing rooms, and possibly a service cell. All cooling and ventilation equipment for the operation of the Target Station will be located here and it will host the helium and water cooling stations for the BDF Target and proximity shielding, respectively. The service building will directly connect to the existing access shaft building, which will ensure that material and equipment installed in the underground will remain within a controlled environment at all times before being dismantled, packaged and sent for disposal.

Service Cell The possibility to include a service cell has been studied as part of the Technical Design Review (TDR). The service cell is is designed according to the requirements of a Type A working area as defined in the Swiss Radiation Protection Ordinance [6]. The cell would be fully remotely operable with a 30-tonne overhead crane, wire diamond saw, power manipulator, master slave manipulators, and additional robotics to support operations. The functionality of the service cell would allow for Post Irradiation Examination (PIE) of the BDF targets which would identify any failure modes or weak-points in the target design to guarantee reliable physics operation. Additionally, the service cell would be used for the preparation and waste packaging of the BDF targets, and the cutting and waste packaging of other BDF waste and CERN legacy waste.

CONTAINMENTS

To prevent the spread of air activation and act as a barrier in case of fire, the confinement walls defining the Target Area will be fire-rated. The area will be underpressurised relative to adjacent spaces to control the pressure cascade in line with ISO 17873 and to limit corrosion of highly activated components near the target. The downstream confinement wall will be steel, lined with 5 cm of 30% borated polyethylene. The walls will allow for the passage of the overhead crane while remaining re-sealable to regain confinement. Additional measures to reduce air activation in TCC8 include extensive shielding and a vacuum vessel.

Vacuum Vessel

A large (L 6 m x W 3 m x H 2 m) vacuum vessel at 10^{-3} mbar will enclose the BDF target, internal shielding, and proximity shielding [7]. It's function is to reduce air activation in TCC8, and to reduce the corrosion of internal target components. Additionally, certain shielding within the Target Station requires active water cooling therefore, the vacuum vessel will have a secondary function of containing and draining the water in case of a leak in the cooling pipes. The target, internal shielding and proximity shielding are located on a trolley system within the vacuum vessel (Fig 3). When a target exchange occurs or maintenance of systems within the vacuum vessel are required, the vacuum vessel is opened, a push/pull chain mechanism is attached to the trolley and the systems are extracted.

The opening of the vacuum vessel is adapted for both human and robotic manipulation to optimise dose rates whilst ensuring redundancy. When the door is closed and the contents of the vacuum vessel remain inside, the area outside is accessible for human intervention. However, once the contents of the vessel have been extracted using the push/pull chain mechanism, it is no longer possible to be within the Target Area.

A shielded lifting tool is required to assist in the opening of the vacuum vessel door. It will have dual functionality of opening and removing the door, as well as serving as additional shielding whilst the worker opens the door. It is deemed that 5 cm of steel is sufficient for this quick operation and additional lead blankets could be placed if necessary in certain situations. Figure 4 displays the systems for the vacuum vessel.

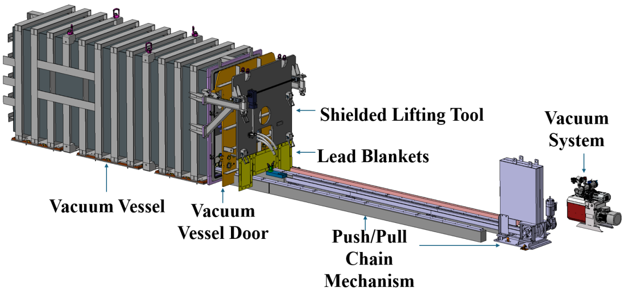

Figure 4: Vacuum Vessel System.

Proximity Shielding

The BDF target will be surrounded by a copper-based proximity shielding. A 25 kW heat load will be deposited into the proximity shielding due to beam interaction on the target which created the need for active water cooling [8]. Cooling pipes are embedded within each copper block and remove enough heat to maintain a temperature of around 45°C throughout the shielding. To access the target, the top block of the proximity shielding must be removed. To optimise this process, no fixed connections between the top and middle blocks will be implemented. Thermomechanical simulations are ongoing to optimise the pipe routing through the shielding blocks whilst maintaining a manufacturable and reliable design. Figure 5 displays the shielding blocks along with the cooling loop configurations.

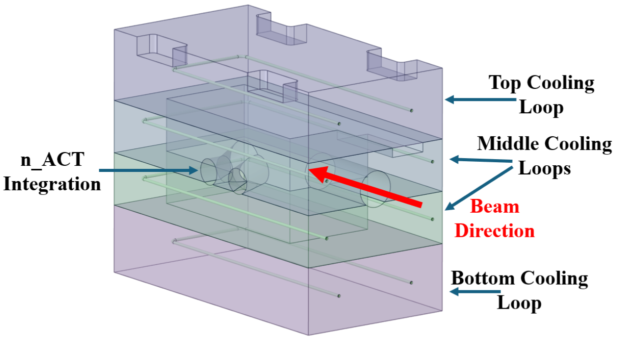

Figure 5: Proximity Shielding.

FAILURE MODES AND EFFECTS ANALYSIS

The Failure Modes and Effects Analysis (FMEA) for the HI-ECN3 BDF Target Complex provides a structured approach to identifying and assessing potential failure modes that could affect safety, performance, and availability of the system. The analysis covers the target core, cooling and mechanical support systems, instrumentation and diagnostics, as well as integration and operational aspects. Each failure mode is evaluated in terms of severity, likelihood of occurrence, and detectability, allowing risks to be prioritised and appropriate mitigation measures to be defined. The FMEA supports design optimisation and risk reduction and is maintained as a living document, updated throughout the design and implementation phases or following significant changes [9].

Multiple types of FMEA are being carried out throughout the project with Failure Modes for the main Functions of the system (FFMEA) being the starting point before moving onto Failure Modes of the Design (DFMEA) and the Failure Modes of the Processes (PFMEA).The analysis is carried out in alignment with the ALARA (As Low As Reasonably Achievable) principle, ensuring that any potential exposures, hazards, or risks are minimised through optimised design choices, procedural controls, and operational safeguards [10].

ADDITIONAL SCOPE

During BDF's operation, high neutron fluences are produced over a wide energy range enabling the opportunity for neutron activation experiments [11]. A collaboration with CERN's neutron Time of Flight facility (n_TOF) has been established, and the neutron activation station (n_ACT) proposal [11] has been submitted to implement activation stations in close proximity to the BDF target. These stations will allow samples to be activated close to the target and subsequently examined and tested.

A pneumatic transport system ("rabbit") is proposed, leading from the Target Station to a receiving station located in a Type A working area [6] within the service building, enabling retrieval independently of SHiP operation. Three activation stations have been proposed: BDF Internal Activation Station (BIAS) next to the vacuum vessel, BDF External activation Station (BEAS) at the end of a collimator outside of the Target Station shielding, and the BDF Rabbit Internal Station (BRIS) located next to the vacuum vessel and operated via the rabbit system (see Fig. 6).

Simulations indicate strong performance: the internal stations, BIAS and BRIS, can achieve $\geq 2 \times 10^{12}$ $\mathrm{n\,cm^{-2}}$ per proton pulse, a factor of 1000 higher than what is achieved at the n_TOF NEAR station. The external station, BEAS, achieves $\sim 10^{9}$ $\mathrm{n\,cm^{-2}}$ per proton pulse, giving an overall average neutron yield at BDF to be $\sim 10^{16}$ $\mathrm{n\,s^{-1}}$. These results make n_ACT@BDF comparable or superior in the neutron yield and fluences to the Compact Accelerator-based Neutron Sources (CANS) [11].

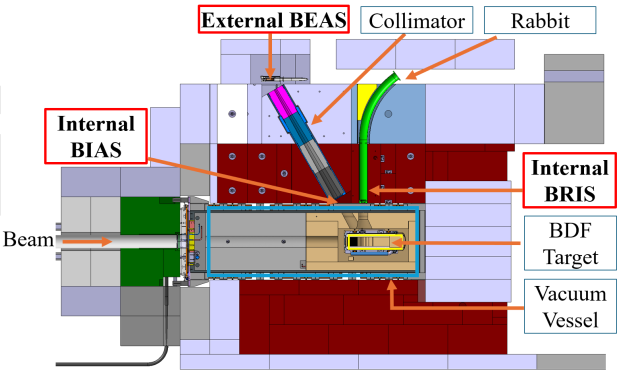

Figure 6: n_ACT Activation Stations.

CONCLUSION

The HI-ECN3 Target Complex design covers the full lifecycle of the facility from the construction to disposal and has been driven by the ALARA principle and heavily influenced by remote handling compatibility requirements as well as the results from FFMEA, DFMEA and PFMEA. The Target Complex hosts a state-of-the-art high powered Target Station optimised for the production of particles for the SHiP experiment. The Target Area has been designed to optimise safety, and the collective dose to workers and the environment through multiple containment layers.

REFERENCES

[1] A. Golutvin, R. Jacobsson, M. Fraser *et al.*, "BDF/SHiP at the ECN3 high-intensity beam facility", CERN, Geneva, Switzerland, Tech. Rep. CERN-SPSC-2022-032, Nov. 2022.

[2] M. A. Fraser, C. Ahdida, *et al.*, "The High Intensity ECN3 Project and the SPS Beam Dump Facility at CERN", presented at IPAC'26, Deauville, France, May 2026, paper THP4061, this conference.

[3] C. C. Ahdida *et al.*, "SPS Beam Dump Facility - Comprehensive Design Study", CERN, Geneva, Switzerland, Rep. CERN-2020-002, Mar. 2020. doi:10.23731/CYRM-2020-002

[4] M. Parkin *et al.*, "A helium-cooled target design for the SPS Beam Dump Facility (BDF) at CERN", in *Proc. IPAC'25*, Taipei, Taiwan, Jun. 2025, pp. 2634–2637. doi:10.18429/JACoW-IPAC2025-THPB059

[5] V. Bayliss and J. Boehm, "Development of a Magnet System for the CERN BDF/SHiP Facility", Rutherford Appleton Laboratory, STFC, Oxford, United Kingdom, Rep. CERN-SHiP-NOTE-2019-004, Dec. 2019.

[6] "814.501 Radiological Protection Ordinance of 26 April 2017 (RPO)", https://www.fedlex.admin.ch/eli/cc/2017/502/en

[7] G. Humphreys and J-L. Grenard, "Target Systems Vacuum Vessel and Feedthrough Design", Presented at the 2nd BDF Targ. Syst. Advisory Committee, Geneva, Switzerland, Mar. 2026, unpublished.

[8] G. Humphreys, J-L. Grenard, and P. Menachilis, "Review of Target Proximity Shielding Design", Presented at the 2nd BDF Targ. Syst. Advisory Committee, Geneva, Switzerland, Mar. 2026, unpublished.

[9] M. Parkin *et al.*, "Status of the FMEA Analyses for Target Systems", Presented at the 2nd BDF Targ. Syst. Advisory Committee, Geneva, Switzerland, Mar. 2026, unpublished.

[10] C. Ahdida *et al.*, "Radiation Protection Studies for CERN's HI-ECN3 Facility", CERN, Geneva, Switzerland, Rep. CERN-HI-ECN3-SLIDES-2024-001, Sep. 2024.

[11] C. Lederer-Woods, A. Mengoni, *et al.* "n_ACT@BDF: A Neutron Activation Station at the SPS Beam Dump Facility (BDF)", CERN, Geneva, Switzerland, Rep. CERN-SPSC-2025-038 ; SPSC-P-375, Nov. 2025. https://cds.cern.ch/record/2948460