

# UPGRADE OF THE SPS TARGET EXTERNAL DUMP FOR HIGH INTENSITY OPERATION IN CERN'S NORTH AREA

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## Abstract

As part of the consolidation of CERN's North Experimental Area (NA-CONS project), a dump located in the TT20 transfer line has been redesigned to comply with the higher beam intensities required for the future BDF/SHiP facility, and to improve its operational reliability. The new dump must be capable of dissipating up to 45 kW of steady-state power generated by the slow extraction of 400 GeV/c protons from the SPS under various operational scenarios. In addition, it shall also be able to withstand short, high-intensity pulses during machine development phases. Building upon proven design concepts implemented in the previous generation of SPS dumps [1,2], the dump core consists of graphite blocks clamped by actively cooled CuCr1Zr plates, and is enclosed by two shielding layers, steel and marble, for radiological protection. The design has been validated by performing beam-matter and thermo-mechanical simulations. A dedicated testbench was used to estimate the thermal contact conductance between materials and provide realistic values for the simulations. This contribution presents the main stages of this upgrade, from definition of updated beam parameters to conceptual design and validation.

## INTRODUCTION

The Target External Dump (TED) is a movable dump/beam stopper located in the TT20 transfer line connecting the Super Proton Synchrotron (SPS) to the experimental areas of CERN's North Area. This device absorbs high-energy proton and ion beams during accesses, commissioning and machine development (MD) phases, when the slow extraction system is set up and optimized. The TED, mounted on rails transverse to the beam direction, is moved to the in-beam position during those phases, while remaining out of beam during normal beam operation. In view of the increased beam intensities foreseen for the Search for Hidden Particles (SHiP) experiment after Long Shutdown 3 (LS3), the existing TED approaches its thermo-mechanical limits [3]. While the commissioning scenarios are within the current TED's capabilities, the MD cases significantly exceed the allowed pulsed intensity. In addition to these thermomechanical limitations, the age of the existing device, installed in 1975, poses a challenge for its long-term reliability. A joint consolidation and upgrade was therefore required to maintain reliable absorption of

steady-state power and to withstand short, intense pulses, while maintaining structural integrity and adequate radiation shielding [4]. The redesigned TED is based on updated beam requirements [5] and validated through analyses and dedicated thermal contact conductance measurements.

## BEAM PARAMETERS

The beam parameters of the design-driving scenarios during post-LS3 operation are summarized in Table 1. Up to 45 kW of average power will be deposited on the TED during commissioning and MD phases. Higher intensity pulses are foreseen during MD, with intensities of up to  $7 \times 10^{13}$  protons per pulse for possible future operational modes. This increase in intensity will be compensated by increasing the duty cycle, thereby limiting the average power on the TED.

Table 1: Design Driving Beam Parameters [5]

Parameter	Commissioning [BDF/SHiP]	MD [Ultimate]
Energy per proton [GeV]	400	400
Pulse intensity [ $\times 10^{13}$ ]	0.5	7.0
Beam size sigma H [mm]	3.9	> 3.9
Beam size sigma V [mm]	1.5	> 1.5
Spill length [s]	1.0	1.0 – 9.6
Cycle length [s]	7.2	7.2
Repetition period [s]	7.2	~ 120
Average power [kW]	44	~ 40

## UPGRADED TED

The new TED consists of a core assembly which is made of graphite and CuCr1Zr, encapsulated by two layers of radiation shielding, made of steel and marble respectively (Fig. 1). The overall design aims to combine efficient beam absorption with efficient heat extraction and adequate shielding of secondary radiation, while respecting the dimensional and integration constraints of the existing TT20 installation. Particular attention was given to preserving the external envelope and support interfaces of the current device, to limit modifications to the surrounding infrastructure.

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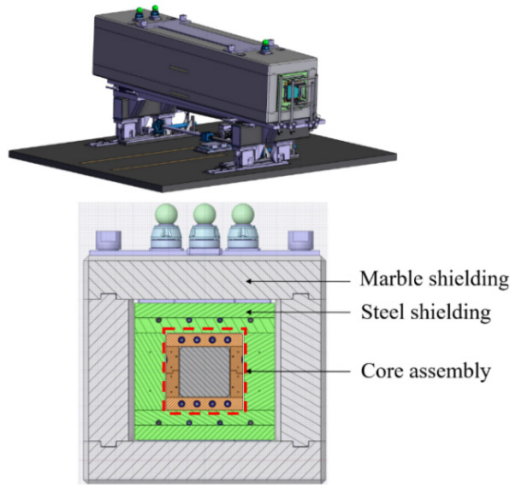


Figure 1: Isometric view of the new TT20 TED assembly (top) and transverse cross section depicting dump layout (bottom).

The core assembly of the TED (Fig. 2) includes 5 isostatic graphite blocks with a total length of 3.5 m, followed by 0.5 m of high-density CuCr1Zr blocks (UNS C18150). The low density of isostatic graphite allows for a gradual absorption of the intercepted beam energy over the dump's length. The final 0.5 m of CuCr1Zr ensures longitudinal containment of the particle shower within the device, minimizing downstream radiation leakage. These blocks are clamped by 2 CuCr1Zr plates which are cooled by 0.8 kg/s of water flowing through deep drilled channels, extracting the heat from the blocks through thermal contact. To complete the core assembly, 4 CuCr1Zr side plates fully encapsulate the core blocks and are bolted to the top and bottom cooling plates. These are not actively cooled, and they do not extract heat from the core blocks. Their main function is to intercept secondary particles and dissipate the produced heat towards the cooling plates. The clamping of the graphite blocks is done using 260 mm long M12 bolts that go through the side plates and connect the upper to the lower CuCr1Zr cooling plate. A gap between the side plates ensures that the cooling plates are always in contact with the graphite blocks.

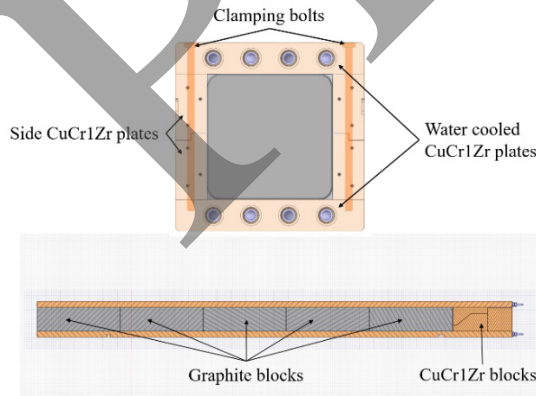


Figure 2: Transverse cross section (top) and longitudinal section (bottom) of the TED core assembly.

The core assembly is surrounded by 6 Steel S355 plates, which form the first layer of radiation shielding (Fig. 3). Since around 19.5 kW of power is deposited into the steel shielding, 4 of the plates are actively cooled by clamping stainless-steel tubes between them [1]. The remaining side plates are cooled through contact with the actively cooled plates. A chromium coating is applied on the steel plates to increase corrosion resistance. A final layer of radiation shielding consisting of 4 marble blocks completes the TED assembly (Fig. 3). The TED assembly is mounted on a motorized trolley which can move the dump transversally along guiding rails, allowing for accurate in-beam and out-of-beam positioning.

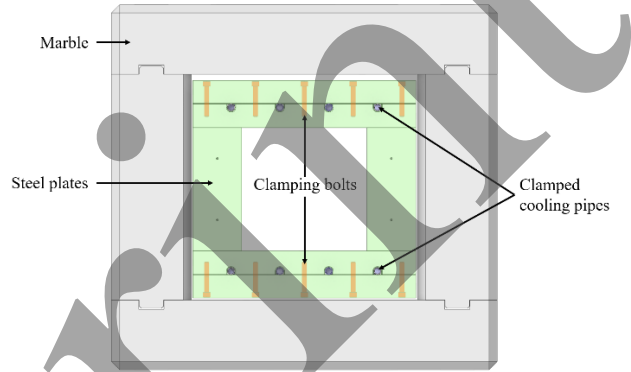


Figure 3: TED steel and marble shielding.

## BEAM MATTER INTERACTION AND THERMOMECHANICAL ANALYSIS

The FLUKA code [6,7] was used to model beam-matter interaction and obtain energy deposition maps in the TED assembly. Figure 4 depicts the peak energy density profile deposited in the graphite blocks during the Ultimate MD scenario.

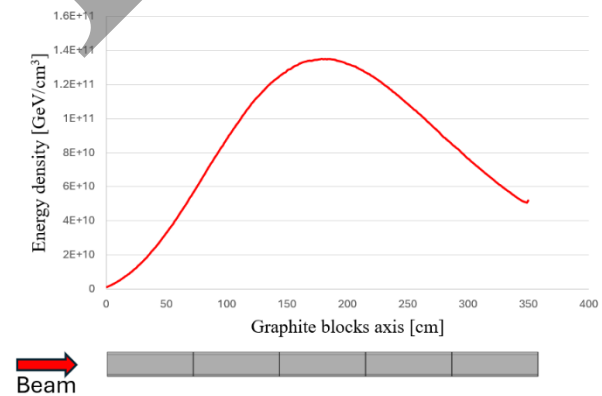


Figure 4: Peak energy density deposited along graphite blocks axis, Ultimate MD scenario, pulse intensity  $7 \times 10^{13}$  protons.

Using this energy deposition and specific pulse time and repetition periods, a heat map is generated which is then used as input for subsequent simulations. A thermomechanical assessment was conducted with ANSYS® Workbench™ [8] to monitor cooling performance and ensure

that stress remains within the material limits. The Ultimate MD scenario with an intensity of  $7 \times 10^{13}$  protons per pulse was used as the design driver. To incorporate a safety margin and allow for future operational flexibility, the assessment was performed assuming 90 kW of average power deposited in the dump, twice the amount specified in the worst operational scenarios. Cooling was modelled by applying a constant HTC of 3000 W/m<sup>2</sup>K (calculated with Dittus-Boelter correlation [9]) in the cooling channels. The steady state temperature condition was simulated, followed by 2 transient pulses to obtain the maximum temperature expected in the dump. The peak temperature in the graphite blocks is 265 °C, while the downstream CuCr1Zr blocks reach up to 290 °C (Figure 5, top). The obtained temperature fields are used as input for a structural assessment. For CuCr1Zr (Figure 5, middle) the maximum obtained equivalent stress of 225 MPa lies within the 230 MPa yield strength limit, for 300 °C. As graphite is a brittle material, the maximum principal stress (2 MPa tensile stress, Fig. 5, bottom) was compared against the material tensile strength (40 MPa). In the steel shielding, peak temperature and stress are well within the material limits.

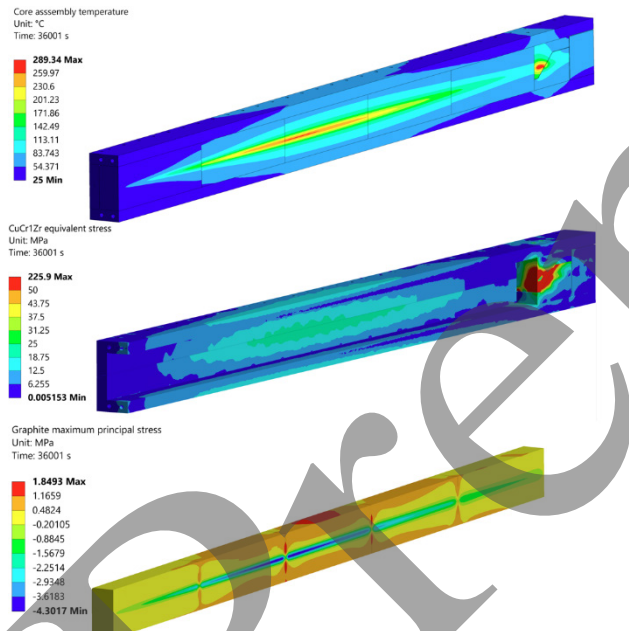


Figure 5: Core assembly temperature field (top), CuCr1Zr equivalent stress (middle) and graphite tensile stress (bottom).

## THERMAL CONTACT CONDUCTANCE (TCC) ASSESSMENT

As the graphite blocks in the core are indirectly cooled through contact with cooling plates, identifying a realistic TCC value is of utmost importance. As revealed by the operational feedback from the TIDVG#5 dump [2], TCC values are very dependent on parameters such as surface roughness, flatness of the surfaces in contact and thermal gradients. To reduce uncertainties, a test bench was set up to measure the TCC value for isostatic graphite in contact with CuCr1Zr [10]. The test bench allows for

measurements both under vacuum and in air. It consists of 2 CuCr1Zr columns separated by a disk of isostatic graphite. A heating element present in the lower column and a water-cooling circuit in the top column ensure steady state heat flow through the graphite disk. The temperature gradient along the column is measured with PT100 sensors, allowing to derive heat flux through measured temperature gradient. The test bench, along with the TCC results obtained during the testing campaign are depicted in Fig. 6.

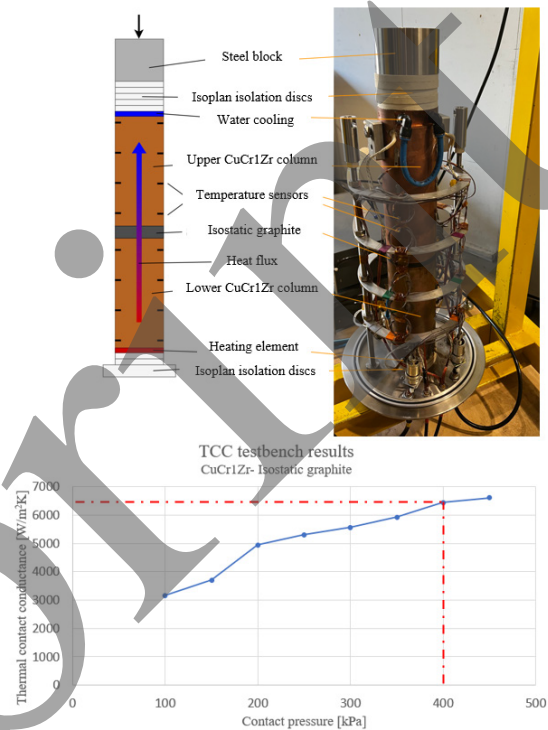


Figure 6: TCC measurement bench (top), obtained results and expected minimum values for TED (bottom).

## CONCLUSION

The Target External Dump in the TT20 transfer line has been redesigned to meet the increased beam intensity requirements foreseen for post-LS3 operation and the SHiP physics programme. The upgraded device needs to be capable of dissipating up to 45 kW of average power during commissioning and machine development, while also withstanding high-intensity MD pulses. Combined beam-matter and thermo-mechanical analyses demonstrate that temperatures and stresses in graphite, CuCr1Zr and steel shielding remain within acceptable material limits, even under conservative assumptions of 90 kW average deposited power. Dedicated thermal contact conductance measurements were performed to reduce uncertainties associated with passive cooling of the graphite core. The new TED is scheduled for installation during LS3 and will ensure reliable and safe set up of the SPS slow extraction system as the North Area enters a higher intensity regime.

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