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PROGRESSES AND DESIGN DEVELOPMENT FOR THE CERN ISOLDE BEAM DUMPS EXCHANGE

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Abstract

The CERN ISOLDE facility is currently equipped with two uncooled iron blocks acting as beam dumps. In order to guarantee the reliability and safety of the installation for the years to come, a study has been launched to evaluate the possibility to exchange the ISOLDE beam dumps during CERN's Long Shutdown 3. The consolidation would also allow compatibility with the PS Booster 2.0 GeV/c and intensity upgrade currently being discussed. The contribution will detail the challenges of the project and the path being proposed to tackle them.

INTRODUCTION

The ISOLDE facility produces radioactive ion beams (RIBs) via the isotope separation on-line (ISOL) technique [1]. Targets made of different materials are bombarded by a pulsed proton-beam with an energy of 1.4 GeV/c from the PS Booster and an average intensity up to 2 µA. The facility has two mass separators; the general purpose separator (GPS) and the high resolution separator (HRS). Downstream of the GPS and HRS targets, two dumps are installed in order to safely absorb the remaining beam (up to 62 % of the total beam energy if a light target is installed). These two dumps are made by a stack of iron blocks, surrounded by concrete blocks, and buried under 6 m of soil. The dumps were installed in 1991 and there is no active cooling on the blocks.

In the context of an ISOLDE-wide upgrade in order to safely operate at 2.0 GeV/c and higher intensities up to 6 µA, this contribution studies the dump-related aspects: evaluation of present operation (including thermocouple installation), dump exchange challenges, and future dump design.

Table 1: Current and Future Operating Parameters

Scenario	Beam energy	Beam intensity	Beam power
Current	1.4 GeV	2 µA	2.8 kW
Future	2.0 GeV	6 µA	12 kW

CURRENT DUMPS OPERATION

When originally installed in 1991, both the shielding and beam dump designs were based on the availability of 3.2×10^{13} protons/pulse at 1 GeV every 2.4 s, corresponding to an intensity of 2.1 µA and a beam power of 2.1 kW [2]. As shown in Table 1, the current beam parameters are already higher than that; in addition, the accessible dump faces show signs of corrosion and condensation is visible on the area. For these reasons, a re-evaluation of the thermo-mechanical performance of the dumps has been performed. Both dumps are made out of blocks in a range of sizes, as can be seen in Fig. 1. The dump blocks were not manufactured specifically for the purpose, but rather recycled from past CERN projects. The block material is steel, however the specific grade is not known. The surface roughness of the blocks is unknown. The dump blocks are surrounded by concrete blocks, which are covered with a waterproofing membrane. The assembly is covered by roughly 6 m of soil. The upstream face of the dumps where the beam hits is visible, but the rest of the blocks are not accessible. Up to 2023, there has been no active or passive instrumentation monitoring the dumps.

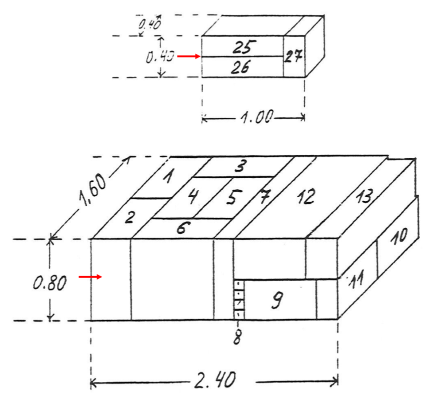

Figure 1: HRS dump blocks on the top, GPS dump blocks on the bottom. The concrete blocks are not shown. The dimensions shown are in meters. The red arrow shows the direction of the beam.

Finite Element Modelling

The energy deposition on the dump blocks was calculated with FLUKA Monte Carlo simulations [3], and imported into ANSYS® Mechanical™[4] for thermo-mechanical finite element analyses (FEA). Two scenarios were considered:

- No ISOLDE target present. This scenarios only happens for briefly during commissioning or dedicated tests.
- Light ISOLDE target. The beam first hits the ISOLDE target, which absorbs part of the energy. The lightest possible ISOLDE target was chosen as the most conservative scenario. Steady-state was studied for this

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scenario, as ISOLDE can operate in this configuration for several consecutive days.

In HRS, the entire dump blocks were simulated, along with the concrete blocks below and above. In GPS, the first block (numbered 2 in Fig. 1) was simulated, along with the metal blocks directly on top, and the concrete blocks below. The temperatures at the top and the bottom were fixed at 13 °C, as the soil around the dumps at a 6 m depth will remain at a constant temperature equal to the mean temperature in the area [5, 6]. The thermal contact conductance (TCC) values were calculated based on semi-empirical formulations [7], based on assumed values of surface roughness and material properties. Both the solid spot thermal conductance and the gap conductance at the interface were taken into account. Convection and radiation cooling were applied on all external surfaces. The emissivity value for the dump blocks was fixed at 0.8. The material properties were chosen inside realistic ranges for both steel and cast iron. Due to the mentioned uncertainties around the dump block geometry, material properties, and surface roughness, the cooling parameters (heat transfer coefficient, HTC) and material properties (specific heat and conductivity) were initially estimated and then later corrected with data from the thermocouple measurements (see next section).

Thermocouple Installation and Model Comparison

Two type-K thermocouples were installed in the visible face of each of the dumps in March 2023, in order to control the operation of the dump and compare the results with the simulations. The thermocouples are fixed to the dump surface using rad-hard SmCo magnets. The relative position of the thermocouples with respect to the beam position could not be precisely measured due to the high radioactive dose in the area. Two dedicated tests were performed: the beam was sent directly to the dumps with no ISOLDE target installed for 12-14 hours, and then allowed to cool back down to room temperature. For HRS, it was found that a generic steel with a relatively high value of specific heat (620 J/kgK), and an HTC of 25 W/m^{2}K (reference temperature of 22 °C, which is the temperature of the Target Area) agreed with the measured data within 20 %. For GPS, the same parameters were used, except a modified HTC value of 16 W/(m^{2}K) was used. The results of the model agreed with the measured data within 20 %. Figure 2 shows the comparison between the thermocouple measurements and the expected evolution of the temperature according to the model in the GPS dump. The thermocouples will continue to capture data in the rest of the 2023 ISOLDE physics run, hence the model and the assumptions will be further amended as more data becomes available.

DUMP EXCHANGE CHALLENGES

A study to exchange the dumps core with an updated design compliant with beam parameters has been performed. The main challenge is that the dismantling or removal of the dumps was not considered during the design and installation. Accessing the dumps from the ISOLDE target area has been studied; however it has been deemed unfeasible due to the lack of access, lack of handling infrastructure in the target area, and high radioactive dose rate in the area. Thus, the only way to access and dismantle the dumps is by excavating all the earth that surrounds them.

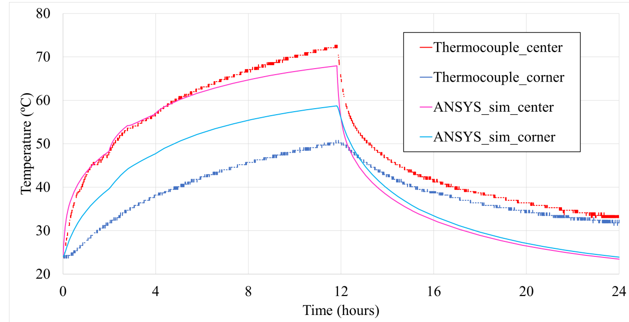

Figure 2: Graph showing the temperature evolution measured by the thermocouples vs the temperature simulated by the finite element model in the GPS dump.

The challenges to be tackled in this approach include:

- The space surrounding the ISOLDE target area is very limited due to existing installation. Consequently, the size of the worksite needs to be carefully planned.
- There are 7700 m^3 of soil to be excavated, of which up to 1500 m^3 are potentially radioactive. The latter requires personnel with specific training, decontamination procedures for any machinery, and measures to contain any possible contamination. All the procedures implying dose to personnel should follow the ALARA (As Low As Reasonably Achievable) principle.
- The radioactive earth should be re-used on-site, to avoid activation of more soil than necessary.
- The handling interface of the concrete and dump blocks (some weighting up to 8 t) is unknown; in addition, some of them might be deteriorated due to radiation or exposure to humidity and contact with ground soil.

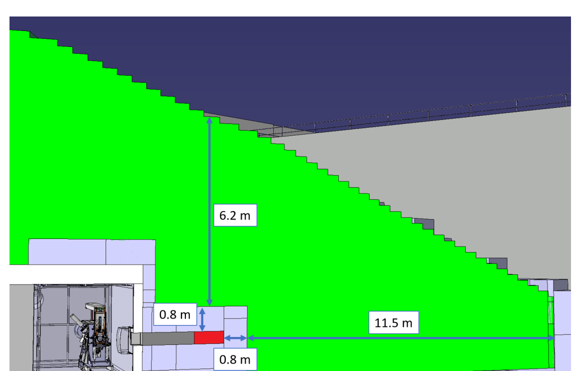

Figure 3: Section showing the HRS dump in red, the concrete blocks surrounding it in grey, and the soil in green.

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Therefore, a flexible handling strategy will be necessary to remove the different blocks shapes.

- The outer layer of blocks contains a waterproofing layer, which could contain asbestos. The treatment of this material should be performed by a specialized contractor to reduce any contamination risk.
- The future dump design should take into account its entire lifetime: from conception to final dismantling.

FUTURE DUMP DESIGN

A design for the new dumps is hereby proposed. The lifetime of the new dumps should be approximately 25 years of operation. To comply with any possible scenario that might develop during that lifetime, the beam parameters have been conservatively estimated and are reported in Table 2.

Table 2: Beam Parameters for Future Dump Design

Parameter	Value
Beam energy	2.0 GeV
Max beam intensity per extraction	1×10^{14} ppp
Number of bunches	4
Bunch length	250 ns
Bunch spacing (center to center)	552 ns
Total pulse length	1906 ns
Repetition period	1.2 s
Beam intensity	13.4 μA
Beam power	26.7 kW
Minimum beam size (1σ,H × V)	1.5×1.5 mm^2

The dump geometry has been inspired by the Proton Synchrotron Booster (PSB) dump [8], which was installed in 2013 with similar beam parameters and requirements. The proposed dump geometry is a 1500 mm-long, 400 mm-diameter Copper-Chromium-Zirconium (CuCr1Zr-UNS C18150 [9]) cylinder, with a 600 mm-long, 200 mm-diameter graphite (isostatically pressed graphite [10]) cylinder which acts as a diluter. The length of the dump has been selected to contain most of the prompt radiation generated in the beam interaction process and minimize leaking of radiation downstream. The copper alloy has been selected due its high density, high thermal conductivity, and high strength. The diluter has been added as a direct beam impact on the copper alloy would have increased the temperatures close to the melting point; the graphite however can withstand a direct hit due its lower density and good thermo-mechanical properties. A series of stainless-steel water-cooling pipes are inserted in the copper in order to cool it. They will be bonded to the copper alloy using Hot Isostatic Pressing (HIP) [11]. The graphite diluter will be shrink-fitted into the copper alloy assembly.

Finite Element Modelling and Results

The simulation setup was similar to the one explained in the previous section: FLUKA Monte Carlo simulations [3], imported into ANSYS® Mechanical™[4] for

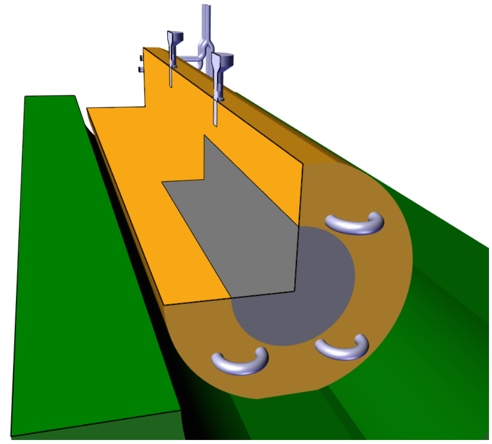

Figure 4: Quarter view of the proposed dump design.

thermo-mechanical finite element analyses (FEA). The scenario considered for design was direct beam impact on the dump, until a steady-state was reached, plus an additional single pulse (composed of 4 bunches). The thermal contact resistance between the CuCr1Zr and the cooling pipes was considered as zero due to the perfect bonding during the HIP process. The TCC between the CuCr1Zr and the graphite has been computed based on semi-empirical formulations [7], using the contact pressure derived from the shrink-fitting parameters. The HTC was calculated using the Dittus-Boelter equation [12] and additionally checked by running a simulation with ANSYS® FLUENT™.

The maximum temperatures for the design scenario are showed in Table 3. The failure criteria for the CuCr1Zr is the Von Mises criterion (based on a material yield strength of 230 MPa [8]), while the Christensen criteria [13] was used for the graphite using the material properties found in its datasheet [10].

Table 3: Results for the Future Dump Design

Parameter	CuCr1Zr	Graphite (R4550)
Temperature (steady-state + 1 shot)	76 °C	119 °C
Von Mises stress (safety factor)	21 MPa (11)	-
Christensen criteria (safety factor)	-	0.27 (3.7)

CONCLUSIONS AND FUTURE WORK

The current operation of the ISOLDE beam dumps has been evaluated. The finite-element model developed shows good initial agreement with the data from the thermocouples. As more data becomes available, the model will be refined and used to predict the behaviour of the dumps with higher energy and intensity. A future dump design has been proposed, compatible with the expected future ISOLDE operation. Its design should be further evaluated in terms of fatigue strength, ease of manufacture, handling, and instrumentation.

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