DESIGN AND DEVELOPMENT OF THE NEW ISOLDE BEAM DUMPS AT CERN

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Abstract

New beam dumps have been developed for the Isotope mass Separator On-Line facility (ISOLDE) at CERN, as part of the ISOLDE Beam Dump Replacement and Sustainability (IBDRS) project. The new design is engineered to ensure an operational lifetime of 30 years, additionally, to accommodate the planned quadrupling of beam power. The absorber assembly consists of water-cooled plates of cladded CuCr1Zr as well as pure copper. The cladding consists of an encapsulation of 316LN stainless steel, diffusion bonded to the cuprous core by means of Hot Isostatic Pressing (HIP). The cladded blocks are enclosed within a 316LN stainless steel vessel, which allows the use of pressurised water to cool the dump.

Extensive Monte Carlo and thermomechanical studies were conducted to evaluate temperature and stress distributions under nominal and accidental beam conditions, as well as the fatigue lifetime and cooling requirements. Prototyping of the cladded blocks has been carried out successfully. This contribution presents the final design, which employs advanced manufacturing methods to provide a sustainable and robust solution for the future ISOLDE beam dumps.

INTRODUCTION

The Isotope mass Separator On-Line (ISOLDE) facility at CERN produces a variety of Radioactive Ion Beams (RIB) for a comprehensive nuclear, medical and solid state physics program [1]. The ISOLDE Beam Dump Replacement and Sustainability (IBDRS) project aims to facilitate the increase of beam power (2.8 kW to 13 kW) at ISOLDE whilst mitigating existing concerns for radiation protection, with an improved life-cycle management [2, 3]. This is done by replacing the current beam dumps and increasing the surrounding shielding during CERN's Long Shutdown 3 (LS3, 2026-2028). Compared to the existing dumps installed in 1991, which consist of stacked steel blocks with no active cooling, the new beam dumps deploy Copper-Chromium-Zirconium (CuCr1Zr) and local water cooling for efficient heat extraction. To avoid corrosion-related issues like the observed corrosion at the n_TOF facility [4], erosion of copper in demineralised water [5], and radiolytic corrosion [6], the copper alloy is cladded with 316LN stainless steel.

Facility

Figure 1 depicts the overview of the two beam dumps for the General Purpose Separator (GPS), and the High Resolution Separator (HRS), in the post-LS3 configuration. The beam is supplied by the Proton Synchrotron Booster (PSB) through the PSB-to-ISOLDE (BTY) transfer line. The beam dumps are positioned 3 meters downstream from the RIB producing target. As opposed to the former beam dumps which had concrete shielding buried in soil, the new beam dumps will be surrounded by a steel shielding, with access from the top for interventions and endoscopy inspection.

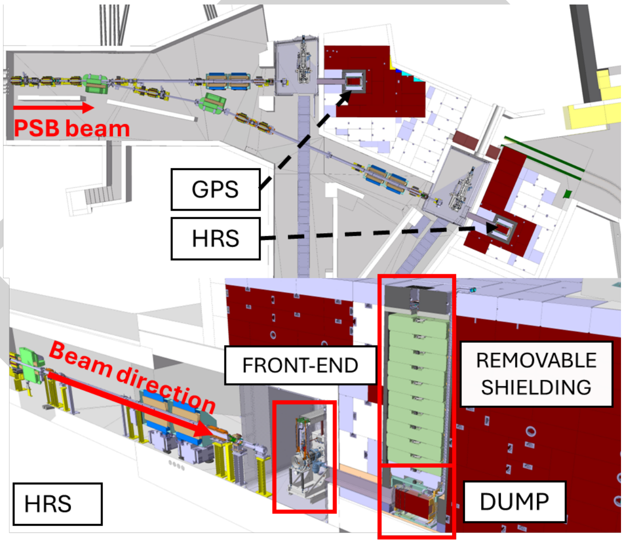

Figure 1: Overview of the ISOLDE complex depicting the HRS and GPS beam dump area and integration.

WATER-COOLED CUCR1ZR DUMP

The beam dump absorbers consist of 4 CuCr1Zr plates, of variables thicknesses, where the deposited energy density is highest, followed by a pure copper block. The cross section of the blocks is 420×420 mm^2 to sufficiently absorb the beam within its "stay-clear" region (+/-135 mm), with margin for initial alignment in the difficult to access area and no realignment until the end of the device's life. The combined length of the absorber blocks is limited to the material that needs active cooling (800 mm).

The dump core is enclosed within a 5 mm thick 316LN pressure vessel and is supported by stainless steel supports within the tank, designed to allow for thermal expansion. The material of the vessel is chosen due to its strength and

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ductility. The thickness is chosen to satisfy structural requirements [7] while limiting beam energy deposition.

Demineralised water is delivered to the dump at 5 barg, a safe operating pressure for the vessel that accounts for the pressure drops in the cooling circuit and increases the boiling point of the water. The beam dump is cooled with water circulating in 10 mm channels, allowing to guide the flow over the front endcap and absorber faces. The mass flow rate of the water is 2 kg/s , reaching a maximum speed of 3 m/s, a safe value to avoid erosion-corrosion of stainless steel. The design of the ISOLDE beam dump is shown in Fig. 2.

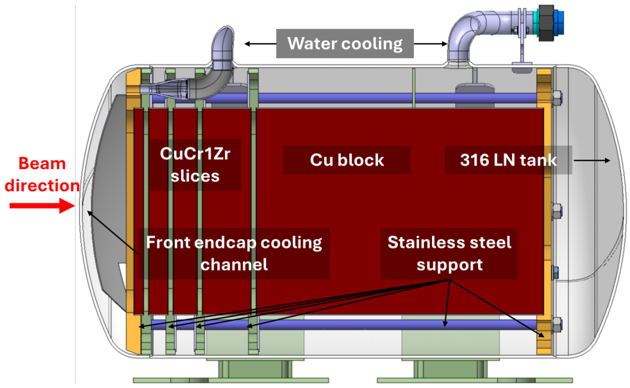

Figure 2: Side cross-section view of the water cooled sliced CuCr1Zr beam dump for the ISOLDE facility at CERN.

316LN Stainless Steel Cladding

Hot Isostatic Pressing (HIP) can be used as a method to bond dissimilar metals together by means of inter-diffusion [8, 9]. In this application, the CuCr1Zr plates and the Cu block are encapsulated by 1 mm thick 316LN. This material was selected as it is a high-strength, corrosion and erosion resistant material, with similar Coefficient of Thermal Expansion (CTE) to Cu, to avoid high residual stresses after HIP and post-HIP heat treatments (required for CuCr1Zr).

As seen in Fig. 3, the cladding acts as the vacuum capsule. Consequently, the presence of interfacial gaps shall be avoided to minimise large geometrical distortion. Even though this technique was used in the past [8,9], the cladding is usually removed after HIP. Hence, prototypes were produced to validate the method.

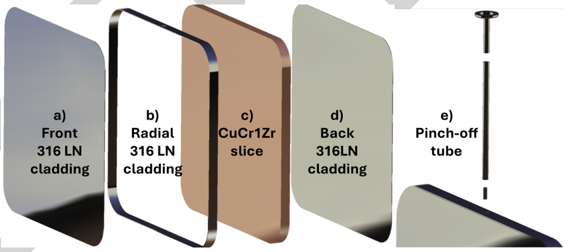

Figure 3: 316LN welded together to make a leak-tight vacuum capsule around the CuCr1Zr.

Operational Beam Conditions

ISOLDE consumes more than half of all protons produced at CERN [10]. Due to the nature of the facility, a variety of operational scenarios are possible. Two scenarios are chosen as representatives to design and dimension the dump: nominal, and accidental; both reflect the maximum operation at ISOLDE, with beam parameters as shown in Table 1. In the nominal scenario, a low-density nano-structured uranium carbide target (nano-UC_x) [11, 12] is considered. While the conventional UC_x is primarily used at ISOLDE (60% of operation), the nano-target provides a conservative estimate of nominal operation due to its lower density and the resulting higher energy density in the downstream dump. In contrast, the accidental scenario assumes a broken target, which leads to a significant reduced beam size due to the absence of a target-induced scattering.

Table 1: Beam parameters for nominal and accidental scenarios [12]

Parameter	Nominal	Accidental
Beam momentum	2 GeV/c	
Beam intensity	1 × 10^{14} protons per pulse	
Average beam intensity	6 µA	
Beam sigma	**32.7 mm**	**6.2 mm**
Beam pulse length	1906 ns	
Max. consecutive pulses	8	
Min. pulse-to-pulse period	1.2 s	
Min. period inc. 8 consecutive pulses	19.2 s	
Beam power	13 kW	

Thermomechanical Response

Monte Carlo FLUKA simulations were conducted to determine beam energy deposition of the 2 GeV beam in the dump [13].

The variable thickness of the plates are optimised for reducing temperature in the system, decreasing the thickness in the upstream part of the absorbers where deposited energy density is highest. The beam creates a stress distribution, where in steady-state conditions shows compressive stresses dominating the centre of the slices, whilst slight tensile stresses are observed in the outer edges and cladding.

Despite higher energy deposition in the absorbers, the highest temperature (120°C) and von-Mises stresses (190 MPa) is expected at the front endcap of the tank, as seen in Fig. 4. This is due to the fact that only one side is cooled and subjected to internal pressure. Subsequently, the fatigue life of the dump is determined by this component. Under nominal operating conditions, it is found to have effectively unlimited fatigue life, while under accidental scenarios, the fatigue resistance is assessed to comfortably exceed the foreseen operational lifetime of 30 years [14].

Apart from the front endcap, the first slice is expected to see the highest temperature and stresses in both scenarios. With a beam pulse length of just under 2 µs, dynamic effects are expected. As seen in Fig. 5, the von-Mises stresses are close to an order of magnitude higher in accidental scenario than those in the nominal operation. The dynamic response

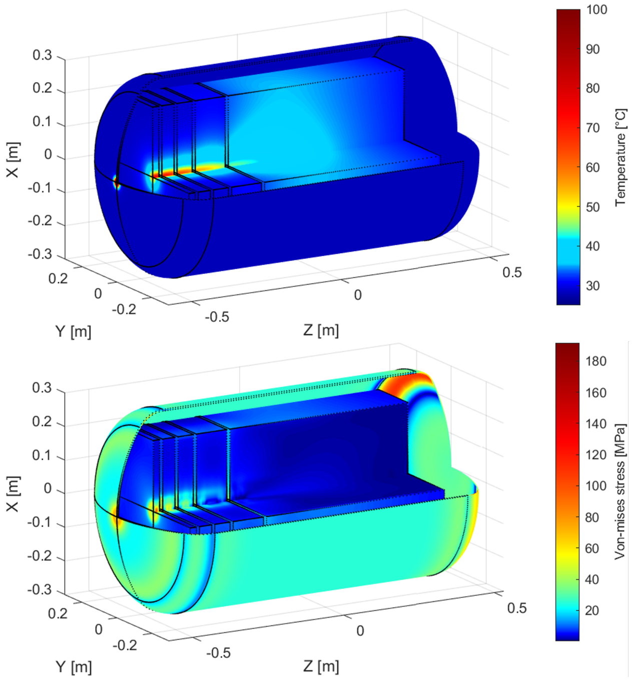

Figure 4: Maximum transient beam-induced temperatures and von-Mises stresses of the beam dump during failure scenario.

shows brief stress oscillations, but the maximum stress remains below the initial peak, and well below the material yield at elevated temperatures [15–17]. Between the beam cycles, the plates return to their steady-state behaviour. This indicates an elastic and recoverable response.

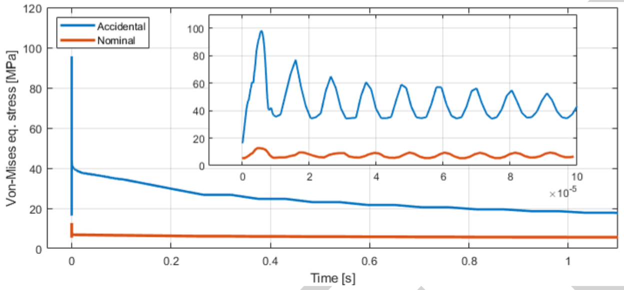

Figure 5: Comparison of von-Mises stresses in 1st CuCr1Zr slice after 1 pulse (with steady-state boundary conditions) for nominal and accidental scenario.

PROTOTYPING

Three prototypes of the first plate were produced to validate the cladding design and manufacturing method: two with 316LN cladding and one with Inconel 625. The Inconel 625 was included as an alternative due to some increased thermal properties [18]. At the start of prototyping, 0.5 mm cladding was required, but 0.5 mm 316LN sheets were not readily available. Accordingly, one prototype was tested by machining 1 mm plates down to 0.5 mm before HIP, while the other explored machining the cladding after HIP. Further analysis allowed to conclude that the cladding thickness of 1 mm will be used for the production of the beam dumps.

To recover the mechanical properties of CuCr1Zr lost in the HIP, post-HIP treatments were performed. The HIP cycle is described in Fig. 6 and post-HIP heat treatments are described in Table 2.

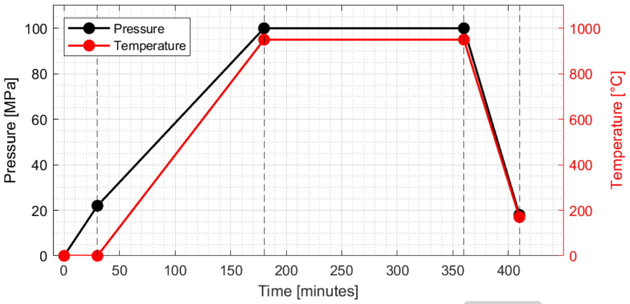

Figure 6: HIP cycle of the beam dump absorber slices.

Table 2: CuCr1Zr post-HIP heat treatments

Description	Temperature	Time
1 Solution annealing	1000 [°C]	30 min
2 Water quenching	Water at room temperature	-
3 Straightening of blocks	Room temperature	N/A
4 Precipitation hardening	480-490 [°C]	2 hours
5 Slow cooling in air	Cooling to room temperature	Not constrained

Ultrasonic testing by immersion showed no bonding defects in any of the three prototypes [19]. Measuring of residual stresses shows equibiaxial compressive residual stresses in the cladding [20]. The 316LN prototypes show significantly less residual stress (200 MPa) compared to the Inconel 625 prototype (400 MPa), which could be explained by the larger difference of CTE between the latter and CuCr1Zr. While some compressive residual stress is beneficial in limiting surface cracking, its interaction with beam-induced stresses will be evaluated, though no critical impact on feasibility is expected.

CONCLUSIONS

The proposed water-cooled CuCr1Zr beam dump provides a robust solution for the next decades of operation at ISOLDE. The sliced design enables localised cooling for efficient heat extraction, enhancing thermal performance and long-term operability. Cladding with 316LN addresses erosion and corrosion concerns, improving long-term structural integrity. Thermomechanical analyses indicate reliable operation within the expected operational scenarios. Prototyping activities have demonstrated the feasibility of manufacturing the sliced design and provided valuable insight into production challenges. Future work will focus on incorporating residual stresses into the thermomechanical model to assess their combined effect with beam-induced loading.

REFERENCES

[1] R. Catherall *et al.*, "The ISOLDE Facility", *J. Phys. G: Nucl. Part. Phys.*, vol 44, p. 094002, Aug. 2017. `doi:10.1088/1361-6471/aa7eba`

[2] M.A. Fraser *et al.*, "Upgrade of the PS Booster-to-ISOLDE beam transfer line to facilitate an increase in proton driver

energy", in *Proc. IPAC'24*, Nashville, TN, USA, May 2024, pp. 3552-3555.
doi:10.18429/JACoW-IPAC2024-THPR28

[3] A-P. Bernardes *et al.*, "IBDRS Summary Report", CERN, Geneva, Switzerland, Rep. EDMS#2875087, Apr. 2023.

[4] R. Catherall, "Isolde and n_TOF consolidation", in *Proc. Chamonix 2014: LHC Performance Workshop*, Chamonix, France, 2015, pp. 265-269.
doi:10.5170/CERN-2015-002.265

[5] H. Schöler and H. Euteneuer, "Corrosion of Copper by Deionized Cooling Water", in *Proc. 1st European Particle Accelerator Conference*, Roma, Italy, Jun. 1988, pp. 1067.

[6] F. E. Hoyer, M. Bourgès, and R. Deltenre, "Radiolytic corrosion and related problems in the cooling water circuits of high-energy particle accelerators", CERN, Geneva, Switzerland, Rep. CERN-68-02, Jan. 1968.
doi:10.5170/CERN-1968-002

[7] *Unfired pressure vessels*, EN 13445, 2021.

[8] S. Pianese *et al.*, "Hot isostatic pressing assisted diffusion bonding for application to the Super Proton Synchrotron internal beam dump at CERN", *Phys. Rev. Accel. Beams*, vol 24, p. 043001, Apr. 2021.
doi:10.1103/PhysRevAccelBeams.24.043001

[9] A. R. Francia *et al.* "Design and early operation of a new-generation internal beam dump for CERN's Super Proton Synchrotron", *Phys. Rev. Accel. Beams*, vol 27, no. 4, p. 043001, Apr. 2024.
doi:10.1103/PhysRevAccelBeams.27.043001

[10] D. Cotte *et al.*, "Proton and duty cylce sharing for the CPS and SPS destinations", Presented at the Joint Accelerator Performance Workshop, CERN, Geneva, Switzerland, Dec. 2022.

[11] A. Gottberg, "Target materials for exotic ISOL beams", *Nucl. Instrum. Methods Phys. Res. B*, vol. 376, pp. 8-15, Jun. 2016.
doi:10.1016/j.nimb.2016.01.020

[12] M. Fraser *et al.*, "ISOLDE beam dump upgrade", CERN, Geneva, Switzerland, Rep. EDMS#2891725, Jan. 2026.

[13] L. Esposito, "FLUKA simulation: IBDRS dump including air and casserole effects", CERN, Geneva, Switzerland, Rep. EDMS#3355459, Oct. 2025.

[14] E. Kubilay, "Thermomechanical fatigue analysis of the ISOLDE beam dump end cap", CERN, Geneva, Switzerland, Rep. EDMS#3430083, Feb. 2026.

[15] L. Blanchi, O. Sacristan, "Thermophysical and Mechanical characterization of cuprous materials", CERN, Geneva, Switzerland, Rep. EDMS#1771731, Mar. 2017.

[16] K. Zhang *et al.*, "Development of the material property handbook and database of CuCrZr", *Fusion Eng. Des.*, vol 144, pp.148-153, Jul. 2019.
doi:10.1016/j.fusengdes.2019.04.094

[17] Y. Xiong *et al.*, "Tensile Deformation Temperature Impact on Microstructure and Mechanical Properties of AISI 316LN Austenitic Stainless Steel", *J. Mater. Eng. Perform.*, vol. 27, pp.1232-1240, Feb. 2018,
doi:10.1007/s11665-018-3234-9

[18] Special Metals Corporation, *"INCONEL alloy 625"*. `https://www.specialmetals.com/documents/technical-bulletins/inconel/inconel-alloy-625.pdf`

[19] K. Geisler, "Ultrasonic Testing by immersion", CERN, Geneva, Switzerland, Rep. EDMS#3323283.

[20] D. Thuliez, O. Sacristan, "Residual stress measurements on Orbital Welds", CERN, Geneva, Switzerland, Rep. EDMS#3353256.