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# CHALLENGES WITH THE BEAM DESTINATIONS FOR THE ESS LINAC

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*Abstract*

For the ESS linac commissioning, twelve compact beam destinations were designed in place of bulky beam dumps, in order to dump [0.075, 250] MeV protons. The beam destinations were either Faraday Cups (FC) for the NCL commissioning or Insertable Beam Stops (IBS) for the SCL commissioning. Both FC and IBS are beam-intercepting devices installed in the ESS proton linac, operated under vacuum, water cooled and movable by means of a pneumatic actuator. The FC and IBS manufacturing relied on high-precision machining. The limited installation space and vacuum requirements required strict tolerances, complex welding of small components and vacuum brazing of compact cooling pipes. The installation of the devices themselves, their radiation shielding and portable cleanrooms were particularly challenging due to the limited space not only outside but also inside the beamline. The main challenge during the operation was posed by the beam power density. Radiation transport calculations allowed to minimize residual dose rates. Thermo-mechanical simulations allowed to define the operational limits thus avoiding damage to the beam destinations themselves and linac components nearby. This paper addresses some FAQs about the ESS beam destinations.

## WHAT IS A BEAM DESTINATION?

The high-power proton accelerator of the ESS [1] has been incrementally commissioned since 2018 [2]. The beam destinations have been essential to safely dump the beam at the end of each section under commissioning. Twelve compact beam destinations were tailored to the ESS linac, in place of bulky beam dumps. The most demanding beam modes are: slow tuning (62.5 mA, 50 μs, 1 Hz) and fast tuning (62.5 mA, 5 μs and 14 Hz). Each beam destination is operated under vacuum, water-cooled and movable in/out of the beam pipe by means of a pneumatic actuator. In the ESS Normal Conducting Linac (NCL), the beam destinations are Faraday cups measuring the proton beam current and pulse length. In the ESS SuperConducting Linac (SCL), the beam destinations are movable beam stops for protons up to the nominal energy of either 100 or 250 MeV.

The design, fabrication, cleaning, assembly, handling and installation phases are subject to the vacuum requirements.

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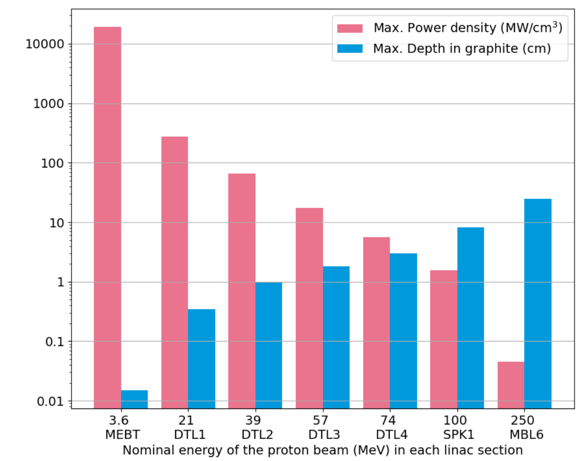


Figure 1: Maximum beam power density and beam's penetration depth in the graphite core of each ESS beam destination (assuming the ESS nominal proton current of 62.5 mA).

The closest beam destination to the ESS proton source [3] relies on a copper collector for stopping 75 keV protons up to 14 kW/cm$^2$, whereas graphite is the only suitable material for the core of all the other destinations, given the thermo-mechanical and radiation protection aspects. Details about the design and initial performance of the beam destinations can be found in [4–7]; this short paper summarizes the main challenges in the manufacturing, installation and operation of the ESS beam destinations. All challenges stem from the demanding beam power density to be dissipated within the limited space inside as well outside the vacuum beam line. Figure 1 points out that the higher the proton energy, the less the beam power density, but more space along the beam path is needed to fully stop the proton beam.

## WHY IS MANUFACTURING TAKING SO LONG?

Manufacturing a beam destination for the ESS linac has never taken less than seven months. There exists no company that can perform all the manufacturing steps between the detailed design and the final acceptance tests. Therefore, global sourcing and compliance with international regulations are unavoidable. On top of this, the materials, assembly procedures and rigorous tests have to be customized for the ESS accelerator environment. Four manufacturing steps are

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crucial in order to withstand the mechanical loads, the high temperatures and the radiation environment in the ESS linac:

- High-precision machining of UHV-compatible components: to fit into the tight space inside the beam pipe, maintain the alignment and ensure a reliable operation under the high-power ESS proton beam.
- Welding of small components which is a highly operator-dependent process, requiring testing on dummy/expensive components, and testing to a leak rate better than $2{\cdot}10^{-10}$ mbar·L/s in the case of the ESS beam stops. At the end of the welding process, all vacuum surfaces have to be free from visible defects such as pitting, cracks and indentions. This is especially complicated for the small cooling pipes of all the ESS beam destinations (see the example in Fig. 2).
- Vacuum brazing of the cooling pipes onto the heat sink. In particular, the unconventional brazing of steel pipes onto TZM for the ESS beam stops was the most challenging one due to the thermal expansion mismatch between TZM (a molybdenum allow) and SS (stainless steel), requiring tests/selection of the brazing fillers and multiple furnace runs above 950 °C. The brazing was performed by Reuter Technologie GmbH (in Germany) for the SPK1 beam stops, and by TWI (in the UK) for the MBL6 beam stops.
- Heat treatment of an entire beam destination (at ≈120 °C or within the limits posed by e.g. the bellows). The graphite core was baked for hours (if not days), in order to minimize the outgassing prior to installation into the ESS beam pipe.

The manufacturing process is followed by the Factory Acceptance Tests to fulfill the vacuum, motion, electrical and cooling requirements. Site Acceptance Tests are performed upon delivery to the ESS site and prior to installation in the ESS linac. In particular, rigorous control of particulate contamination is mandatory for the beam destinations to be installed in the superconducting section of the ESS linac by means of a temporary ISO5 cleanroom, in order to achieve and sustain high accelerating gradients in the superconducting cavities. A dedicated installation cart that is ISO5 compatible was designed and manufactured in order to transport and lift into the beam pipe the heavy beam stops.

## HOW DO YOU INSTALL A BEAM DESTINATION IN THE ESS LINAC?

Installing a beam destination in the ESS linac requires preparations, tests, and joint efforts from various ESS teams (see Table 1). The preparations at the ESS are usually performed in parallel to the manufacturing phase. The time as well as the space for installation in the ESS linac tunnel is limited due to the overlapping installations, tests and commissioning phases. The device and the installation location

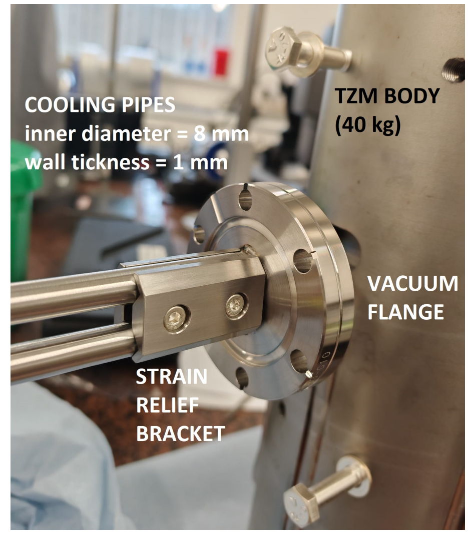


Figure 2: SS316L Tube strain relief added on the small cooling pipes of the MBL6 beam stop which has a 40 kg heavy beam-interceptive body (courtesy of Allectra Ltd).

are prepared prior to the installation which usually mainly involves the Diagnostics, Vacuum and Rigging teams. Verifications without beam are performed once again to cross-check the intended performance including the long-haul cables, the hardware and the EPICS-based control systems [8, 9].

Table 1: ESS Teams Involved During, Before and After the Installation of a Beam Destination

| | BEFORE | DURING | AFTER |
|---|---|---|---|
| Diagnostics | ⊗ | ⊗ | ⊗ |
| Vacuum | ⊗ | ⊗ | ⊗ |
| Metrology | ⊗ | | ⊗ |
| Mech.Eng. | ⊗ | ⊗ | |
| Rigging | ⊗ | ⊗ | |
| Linac | ⊗ | ⊗ | |
| Rad.Prot. | ⊗ | | ⊗ |
| Piping | ⊗ | | ⊗ |
| Cabling | ⊗ | | ⊗ |
| Controls | ⊗ | | ⊗ |

## WHERE IS THE BEAM?

Once the installation, verification and documentation are completed, tests with beam are performed in the ESS control room. The beam destinations have to be 24/7 up and running in order to make sure that the beam is safely dumped down to the end of the linac section being commissioned, and to minimize the overall linac activation. The EPICS-based control system is fundamental for the motion, HV, cooling, beam current measurements, timing synchronization, alarms and interlocks. For example, the first particle-free beam stop [7] of the ESS linac includes four thermocouples to monitor the temperature on the entrance window (see Fig. 3).

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The overall outgassing is monitored, too, and it remained below the limit of $10^{-7}$ mbar while dumping up to 6 mA onto the SPK1 beam destination during spring 2025.

It is worth noticing that measurements of the beam energy, emittance and size were not always possible during the linac commissioning phases, therefore Monte Carlo [10] and thermo-mechanical simulations were performed to define the operational limits and the corresponding linac settings. This allowed to avoid damages not only to the beam destinations themselves but also to the linac cavities nearby.

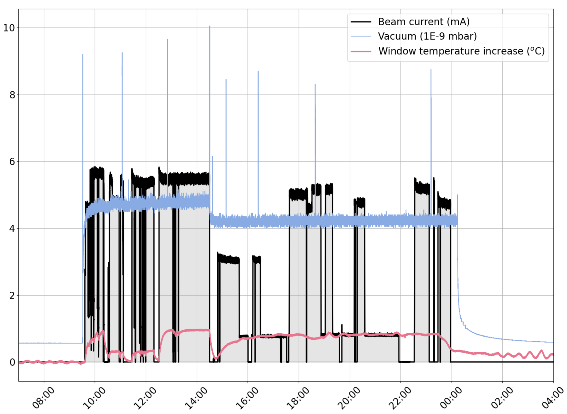


Figure 3: Total outgassing from the SPK1 beam destination and temperature increase in the surface of the SPK1 while dumping up to 6 mA proton current on the SPK1 beam stop.

## WHAT'S NEXT?

To maintain safety, beam control and flexibility, multiple beam destinations were installed along the ESS high-power linac. These devices allow for: controlled beam extraction, gradual acceleration over increasing distances, NCL commissioning in parallel to the SCL installation, and also tuning of upstream sections while downstream sections are being conditioned. Table 2 provides the status overview and the remaining tasks, including the tests with nominal beam parameters and the spare beam destinations to be manufactured. The continuous bombardment of the beam destinations by the high-intensity ESS proton beam poses challenges in the operation and maintenance. Therefore, the corresponding author can be contacted in reference to R&D projects for:

- Additive manufacturing of crucial structural components for the ESS beam destinations.
- Radiation damage studies to quantify the displacement of atoms, gas production and signal degradation.
- Advanced cooling technologies, feasible in the limited space and radiation environment of the ESS linac.

## ACKNOWLEDGMENTS

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Table 2: Status of the ESS Beam Destinations as of August 2025, (TBD = To Be Done)

| | INSTALLATION | BEAM TEST | SPARE |
|---|---|---|---|
| LEBT | ✓ | ✓ | ✓ |
| MEBT | ✓ | ✓ | ✓ |
| DTL1 | ✓ | ✓ | Not needed |
| DTL2 | ✓ | ✓ | TBD |
| DTL4 | ✓ | ✓ | Not needed |
| Upgraded DTL4 | TBD | TBD | TBD |
| SPK1 | ✓ | ✓ | ✓ |
| MBL6 | ✓ | TBD | ✓ |

## REFERENCES

[1] R. Garoby *et al.*, "The European Spallation Source design", *Phys. Scr.*, vol 93, p. 014001, 2018. doi:10.1088/1402-4896/aaecea

[2] R. Miyamoto *et al.*, "ESS Low Energy Beam Transport Tuning During the First Beam Commissioning Stage", in *Proc. IPAC'19*, Melbourne, Australia, May 2019, pp. 1046–1049. doi:10.18429/JACoW-IPAC2019-MOPTS084

[3] L. Bellan *et al.*, "Space Charge and Electron Confinement in High Current Low Energy Transport Lines: Experience and Simulations From IFMIF/EVEDA and ESS Commissioning", in *Proc. LINAC'22*, Liverpool, UK, Aug.-Sep. 2022, pp. 618–621. doi:10.18429/JACoW-LINAC2022-TUPORI29

[4] A. Rodríguez Paramo *et al.*, "Design of the ESS MEBT Faraday Cup", in *Proc. IBIC'19*, Malmö, Sweden, Sep. 2019, pp. 106–110. doi:10.18429/JACoW-IBIC2019-MOPP014

[5] E. Donegani *et al.*, "Design and performance of the compact DTL1 Faraday cup for the high-power ESS NCL", *Nucl. Instrum. Methods Phys. Res. A*, vol. 1047, p. 167827, 2023. doi:10.1016/j.nima.2022.167827

[6] E. Donegani *et al.*, "Design and performance of the shielded DTL4 Faraday cup for the commissioning of the high-power ESS proton linac", *Nucl. Instrum. Methods Phys. Res. A*, vol. 1057, p. 168727, 2023. doi:10.1016/j.nima.2023.168727

[7] E. Donegani *et al.*, "Design and initial performance of the beam stop for the first spoke section of the ESS superconducting proton linac", *Nucl. Instrum. Methods Phys. Res. A*, vol. 1081, p. 170848, 2026. https://doi.org/10.1016/j.nima.2025.170848

[8] M. Serluca, T. Friedrich, A. Jansson, and C. Plostinar, "The development of aggregation diagrams for high-level planning at the ESS", in *Proc. IPAC'23*, Venice, Italy, May 2023, pp. 2305–2308. doi:10.18429/JACoW-IPAC2023-TUPM048

[9] EPICS - Experimental Physics and Industrial Control System, https://epics.anl.gov/

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[10] E. Donegani *et al.*, “First Attila4MC simulations for the high-power proton accelerator of the European Spallation Source”, presented at IBIC’25, Liverpool, UK, Sept. 2025, paper MOPMO07, this conference.