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IPAC21 – Poster WEPAB365

CERN BDF PROTOTYPE TARGET OPERATION, REMOVAL AND AUTOPSY STEPS

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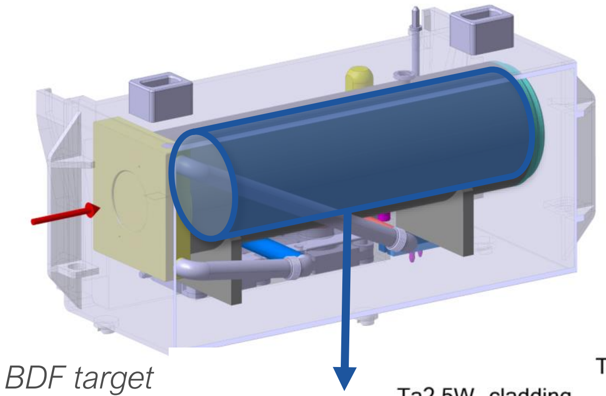
Outline

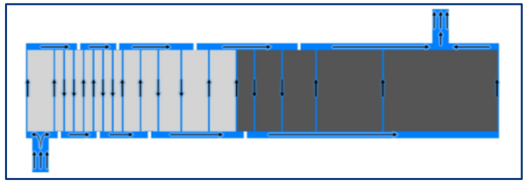
BDF Project & Target

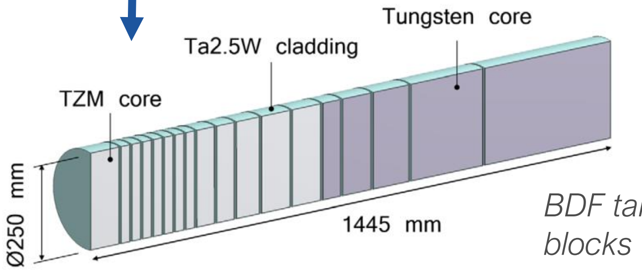
- **Beam Dump Facility (BDF)** project, currently in the study phase, is a proposed general-purpose facility at CERN dedicated to beam dump and fixed target experiments.
- Facility is foreseen to be initially exploited by the **Search for Hidden Particles Experiment (SHiP)**.
- In the core of the facility lays the Target Complex and its Target. The later will be used to absorb and provoke hard interactions of the highest possible number of incident protons (4×10^{19} p^{+} /year at 400 GeV/c), in order to search for feebly interacting particles.



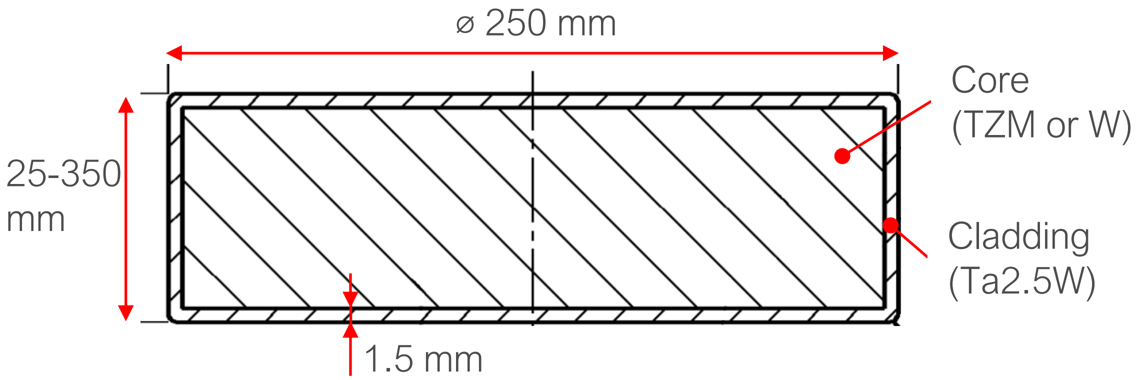
BDF target assembly

Schematic of the water circuit





BDF target blocks

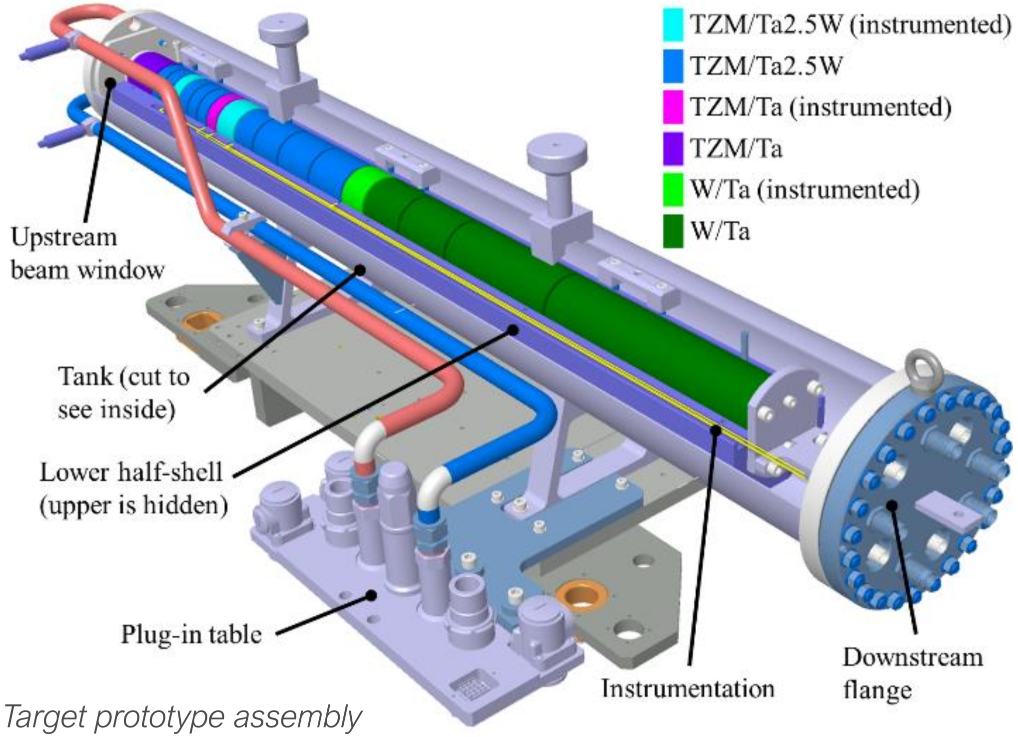


Target blocks. Core-cladding joint via HIP

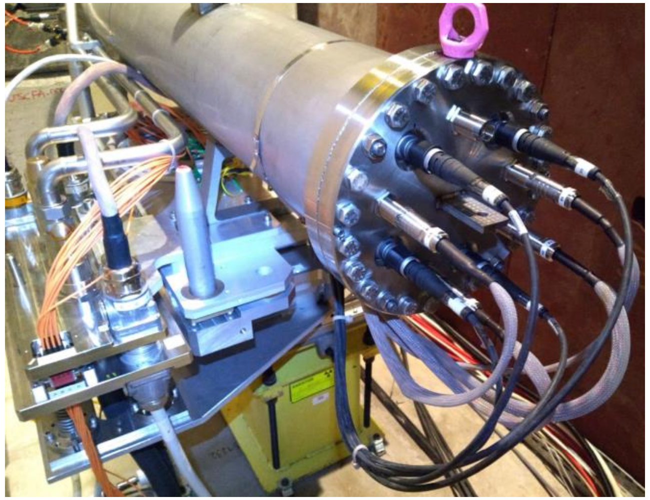
- Assembly of 18 cylindrical blocks cladded with an erosion-corrosion protective layer as well as to avoid hydrogen embrittlement.
- Blocks are **250 mm in diameter** and **25-350mm in length**;
- **Core: TZM** (a molybdenum alloy with titanium and zirconium) or pure tungsten (**W**)
- **Cladding:** tantalum-2.5tungsten (**Ta2.5W**), 1-1.5 mm thickness
- Core-cladding materials are **joint by means of Hot Isostatic Pressing (HIP)** to provided good thermal and mechanical bonding between the materials.
- Target blocks are cooled a demineralized water circuit at 20 bars.

Prototype Target

- In order to **validate the design, material selection, manufacturing of the target's core blocks and thermo-mechanical calculations**, a reduced scale prototype was built.
- Core blocks of **80 mm diameter**, and lengths and materials identical to the final device.



Target prototype assembly



(left) Instrumented target blocks. (right) Connections on the tank flange.

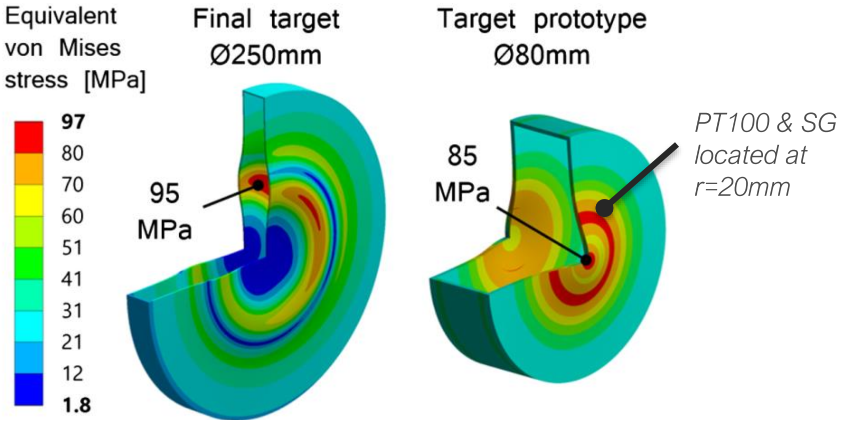
- The **four most representative blocks** in terms of temperatures and thermally induced stresses were **instrumented** with strain gauges and temperature sensors
- Target blocks are entrenched in two half-shell parts which allows free expansion in the axial direction while guiding the 20-bar cooling water.
- The shells assembly is inserted into a cylindrical SS tank. The connections are located on the upstream side of the tank. Downstream, there are the instrumentation connections and a draining port.
- Tank mounted on a collimator-like plug-in table, allowing a fully remote handling of the prototype target. The prototype is designed to **be the first complete remotely dismountable device of its type at CERN**

Beam Tests

- **Irradiated** during the autumn of 2018 upstream the T6 target, located in the **TCC2 primary zone of the North Area at CERN**
- Beam setup to permit having **identical energy densities** and the same or higher level **of temperatures and thermally induced stresses** on the prototype as on the final target

Beam conditions of the final target vs prototype target

	Final target	Target prototype
Proton momentum [GeV/c]	400	
Beam intensity [p+/cycle]	4×10^{13}	$3\text{-}4\times10^{12}$
Beam dilution	four circular sweeps	no
Beam extraction	7.2 s cycle with 1s of beam extraction	
Average beam power [kW]	355	27-35 kW
Average power on target [kW]	300	18-23



Preliminary FEM calculation (with 3×10^{12} p+/cycle on the prototype)

- The most critical measurements of the tests (with Pt100 and strain gauges (SG)) revealed good agreement with the FEA calculations [4]

Final target (at 4 × 10^{13} *p+/cycle) :*

- Expected (FEM) Max von Mises stress of 95 MPa & max T of 160 °C on Ta2.5W. (180 & 150 °C on TZM & W respectively)

Prototype (at *3.75 × 10^{12} p+/cycle*) :

- Expected (FEA) max stress amplitude(σ_a) of 50 Mpa (105 MPa von Mises equivalent) and max temperature of 250 °C on the Ta2.5W
- **σ_a @r=20mm: 37 MPa (FEA) vs 43 MPa (SG)** on the **Ta2.5W**
- **T@r=20mm: 40 °C (FEA) vs 38.8 °C (Pt100)** on the **Ta2.5W**

Maximum[1] temperatures, strains measured (Transverse & Radial) and equivalent stress amplitudes vs calculated via FEA for 3.75 × 10^{12} p+/cycle

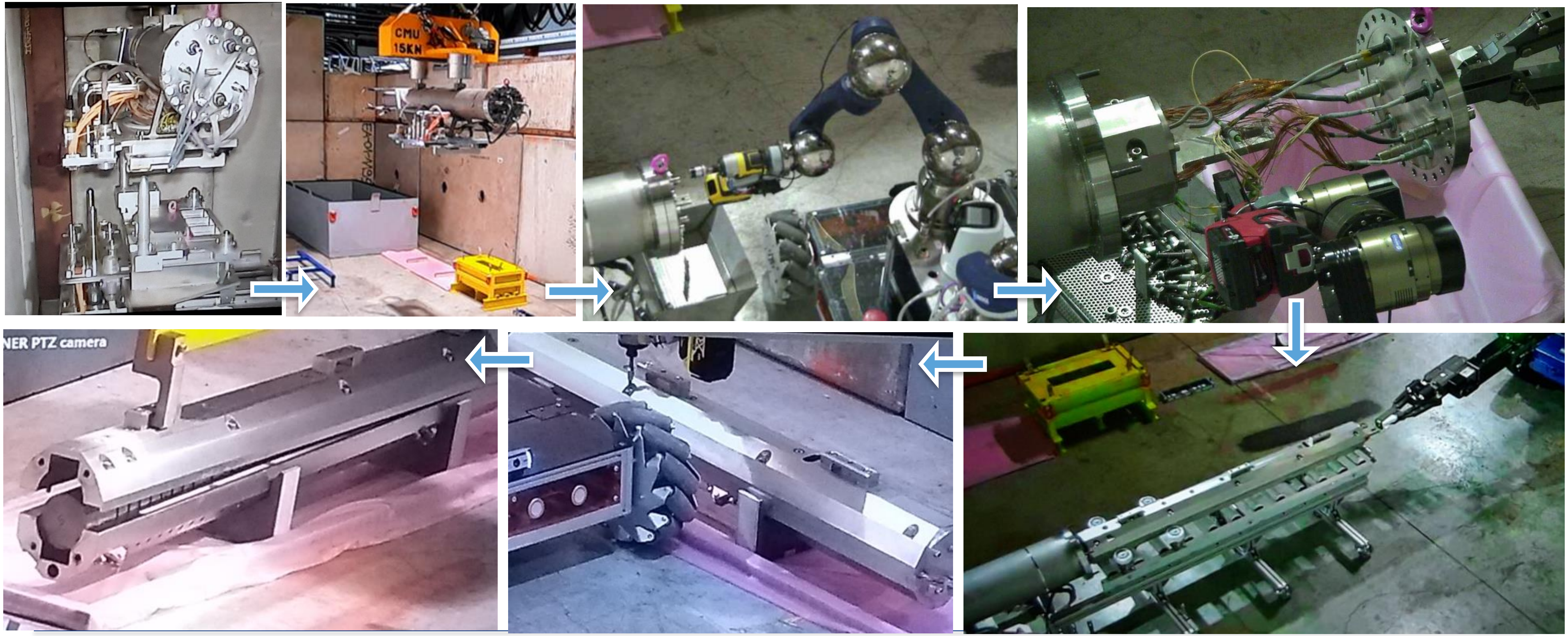
Cladding Material (block)	T_{Pt100} [°C]	T_{FEA} [°C]
Ta2.5W (4)	38.8±0.5	40
Ta (8)	46±0.5	43.8

Cladding Material (block)	$\Delta\varepsilon_{SG}$ [µm/m]	$\sigma_{a,SG}$ [MPa]	$\Delta\varepsilon_{FEA}$ [µm/m]	$\sigma_{a,FEA}$ [MPa]
Ta2.5W (4)	190 |-450	43	170 | 390	37
Ta (8)	100 |-230	22	87 |-250	23

[1] Maximum within all the measured values by the instrumentation. The FEA values are at the same location of the PT100 and SG. The actual maximum temperatures in the blocks are higher but were not directly measured.

Removal intervention

- Unplug-in of the Target ▸ Transport to the bunker ▸ Unscrew of the downstream flange ▸ Instrumentation wire cut & flange removal ▸ Extraction of half-shells core assembly ▸ Unscrew of half-shells ▸ Removal of the top half-shell & first glimpse of the target blocks



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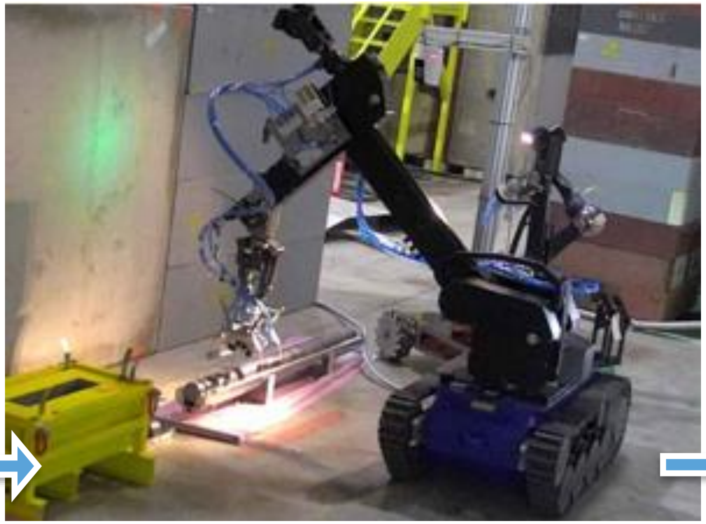
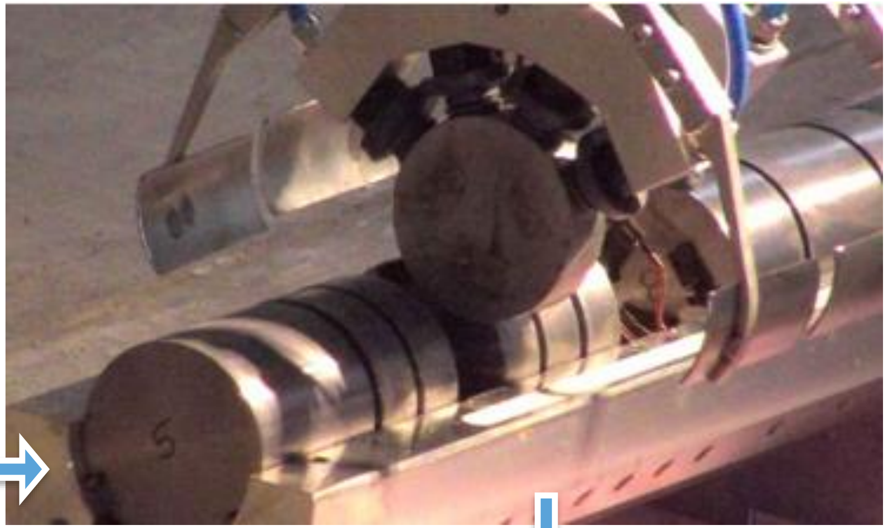
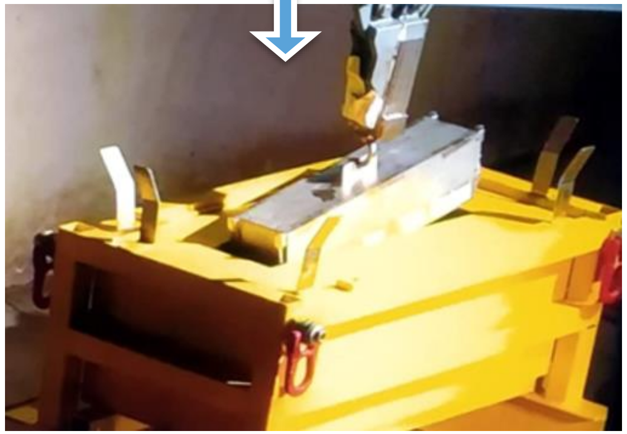
Removal intervention

- Identification of the blocks and angular orientation with respect to the beam with a marker ▸ Removal of the target blocks for the post irradiation examination (PIE) campaign ▸ Storage of the extracted blocks in a shielded container



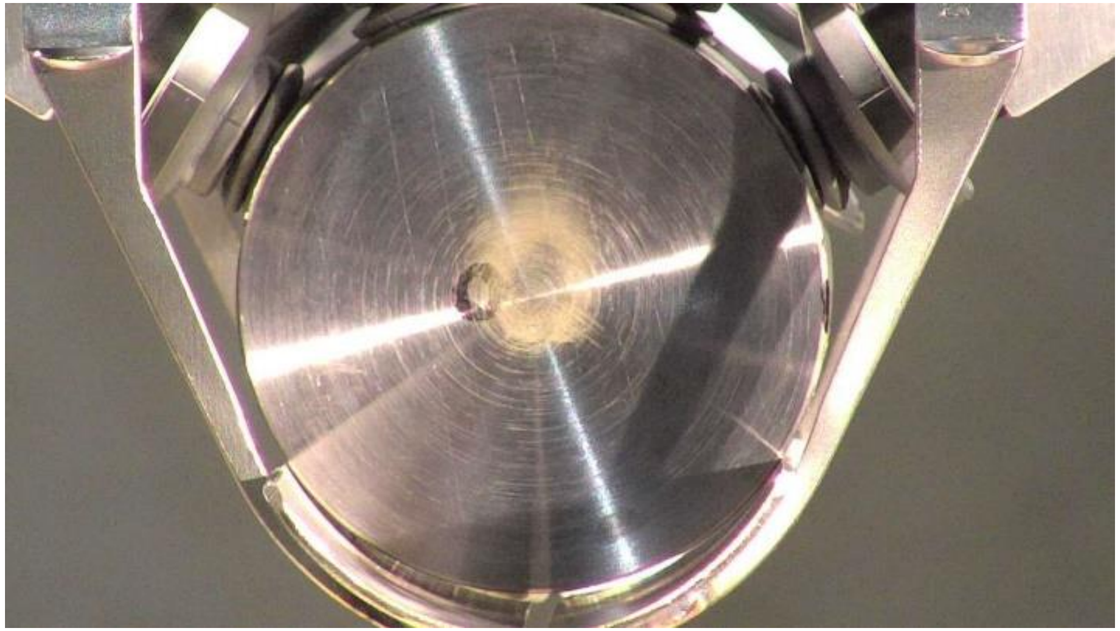




- The measured dose rates on contact with the target blocks were as high as **90 mSv/h (after 1.5 years cool-down)**
- **Design thought for fully remote handling and dismantling with the robotic capabilities of CERN turned into a successful intervention**

Post irradiation examination plans

- **PIE** is currently on going with the purpose of **characterizing six target blocks** (four of which instrumented during the beam tests), particularly the **cladding surface, core-cladding interface, cladding and core bulk materials**:
  - Film dosimetry
  - Optical microscopy (OM)
  - Energy-dispersive X-ray spectroscopy (EDS) of the target blocks flat surfaces.
  - Metrology of the blocks. Dimensions, profilometry and roughness on the flat surfaces.
  - Ultrasonic testing of the cladding-core interface.
  - Microstructural characterization of the bulk core and cladding materials and their interface. Optical microscopy (OM), scanning electron microscopy (SEM), EDS and characterization via Electron backscatter diffraction (EBSD) will be employed.
  - Hardness measurement of the bulk core and cladding materials at various radial and axial distances from the beam axis.
  - Mechanical tensile characterization of the bulk core materials.
  - Mechanical shear characterization of the cladding-core interface.



Visual inspection upon removal intervention revealed surface coloration around the beam impacted area

Conclusion

- A fully remote handling prototype of the BDF target has been built and irradiated at CERN.
- The beam test conditions replicated the temperatures and stresses of the final device, and good agreement was found between the measurements and the FEA calculations.
- In order to analyse the state of the highly radioactive target blocks, their removal took place in a successful fully remote intervention.
- A detailed post irradiation examination is ongoing to characterize and understand the survivability of the target materials

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Thank you for your attention!

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