
CERN

Introduction to the BDF target system

1st Beam Dump Facility (BDF) Targetry Systems Advisory Committee (TSAC)

4th – 6th March 2025

Rui F. Ximenes on behalf of WP3 & HI-ECN3 Project team

04/03/2025

Take-home objectives of this talk

- ❑ **Overview of HI-ECN3 project BID's, target complex and target system**
- ❑ What are the main **interfaces** with the **Target system**
- ❑ What are the key **Target requirements & challenges**
- ❑ What **Target design concepts were explored** in the **past**, **last year** and **now**
- ❑ What **material R&D and beam tests were done**, and what were the main **conclusions**
- ❑ What is the **motivation** for the **TDR threads** and for a **new Target design**
- ❑ **Introduction to the following talks**

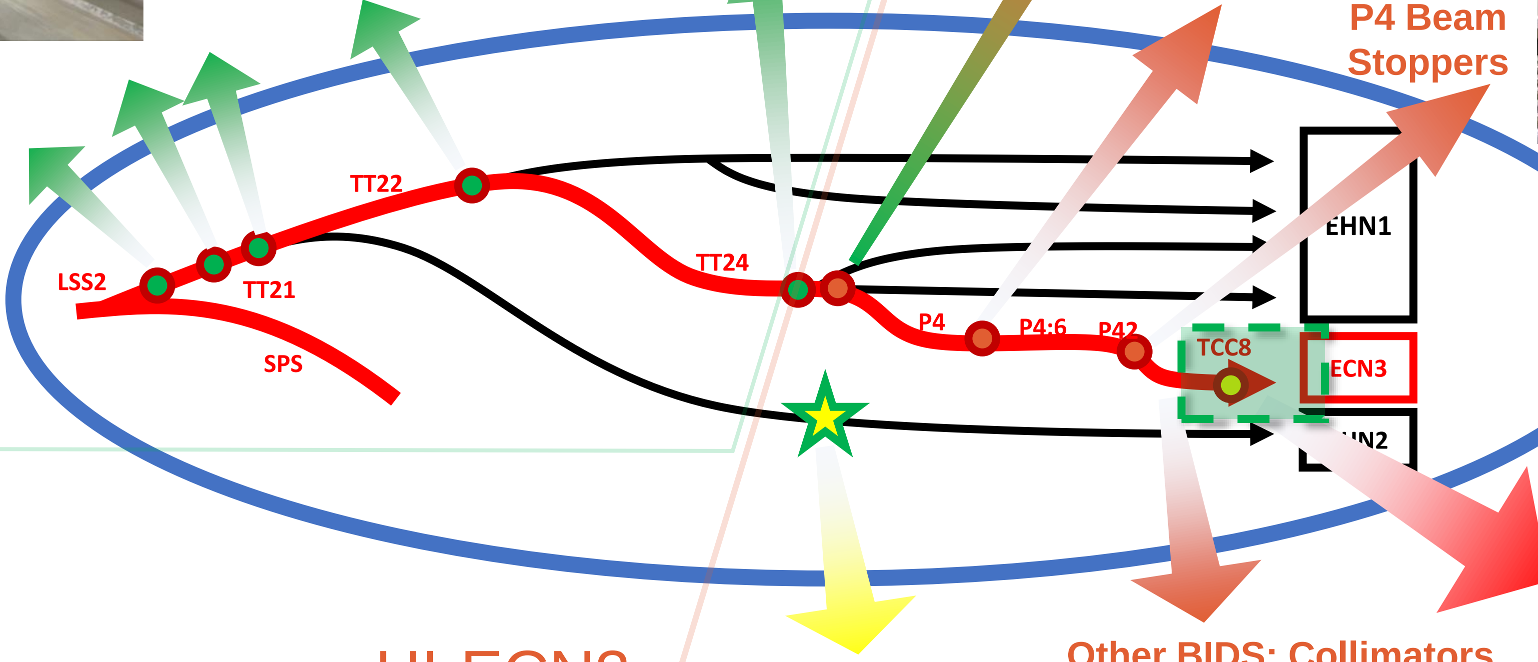
Beam Intercepting devices towards ECN3

TBSE

TCSC

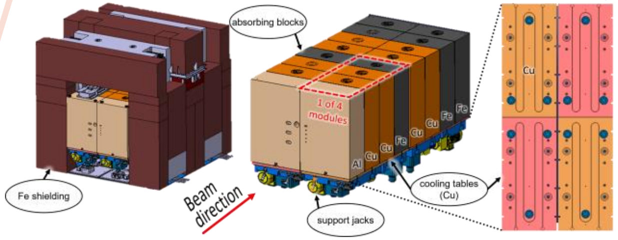
T4 Target

TT20 TED

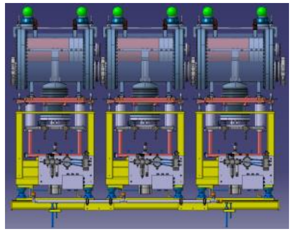


NA-CONS

HI-ECN3

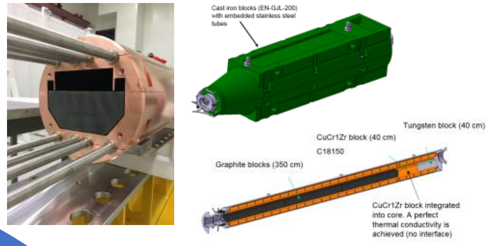


T4 XTAX

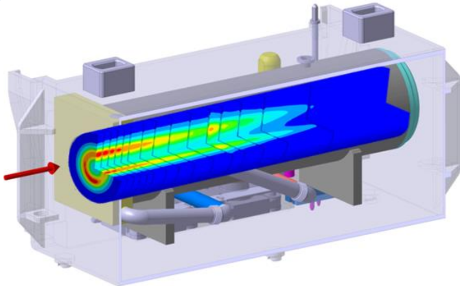


P4 Beam Stoppers

P42 commissioning Dump (TIDVG4)



Target system + beam windows

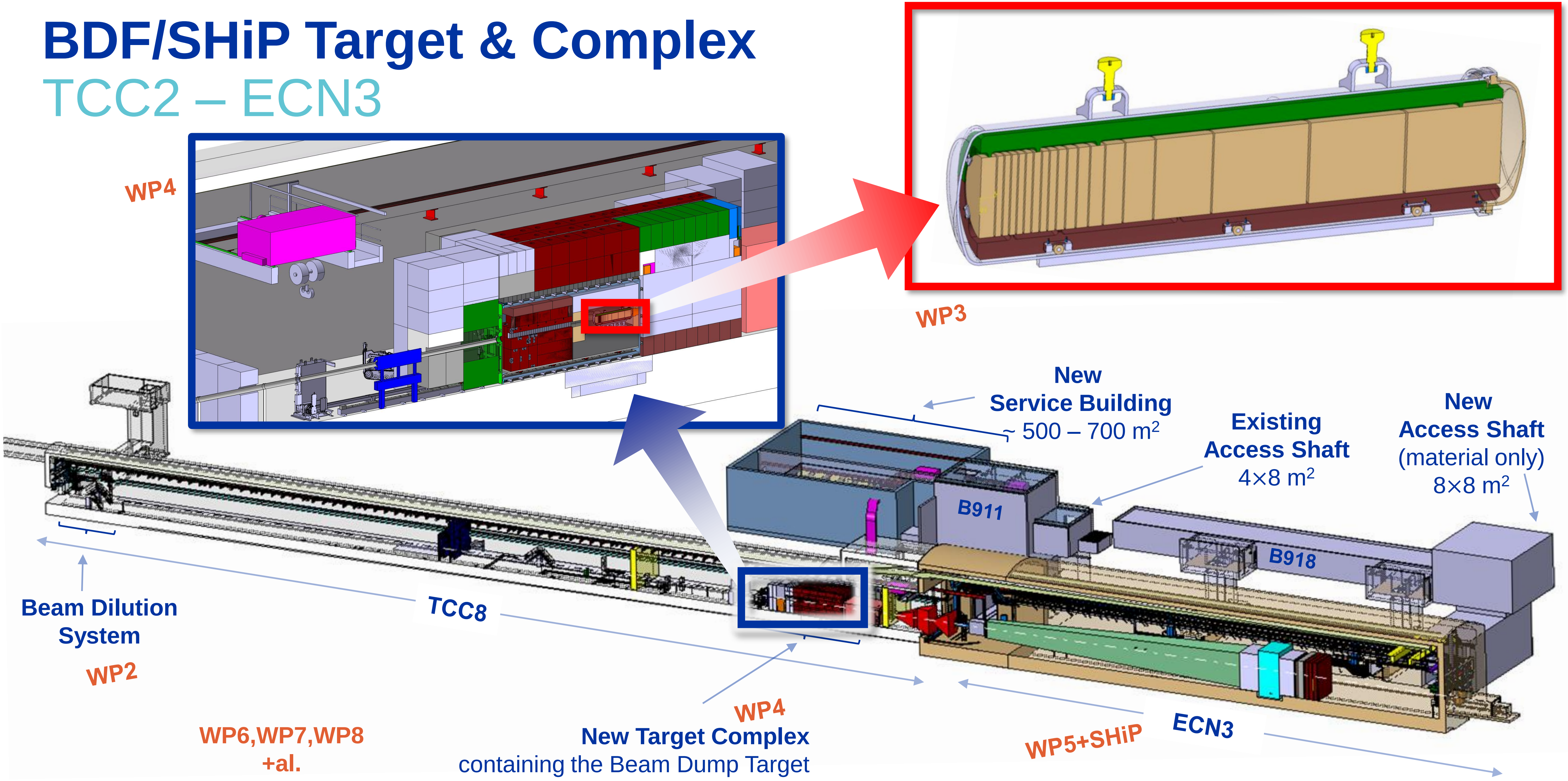


SX-testbench

Other BIDS: Collimators, Masks, etc → To be defined

BDF/SHiP Target & Complex

TCC2 – ECN3



WP4

WP3

New Service Building
~ 500 – 700 m²

Existing Access Shaft
4×8 m²

New Access Shaft
(material only)
8×8 m²

Beam Dilution System

WP2

TCC8

WP4
New Target Complex
containing the Beam Dump Target

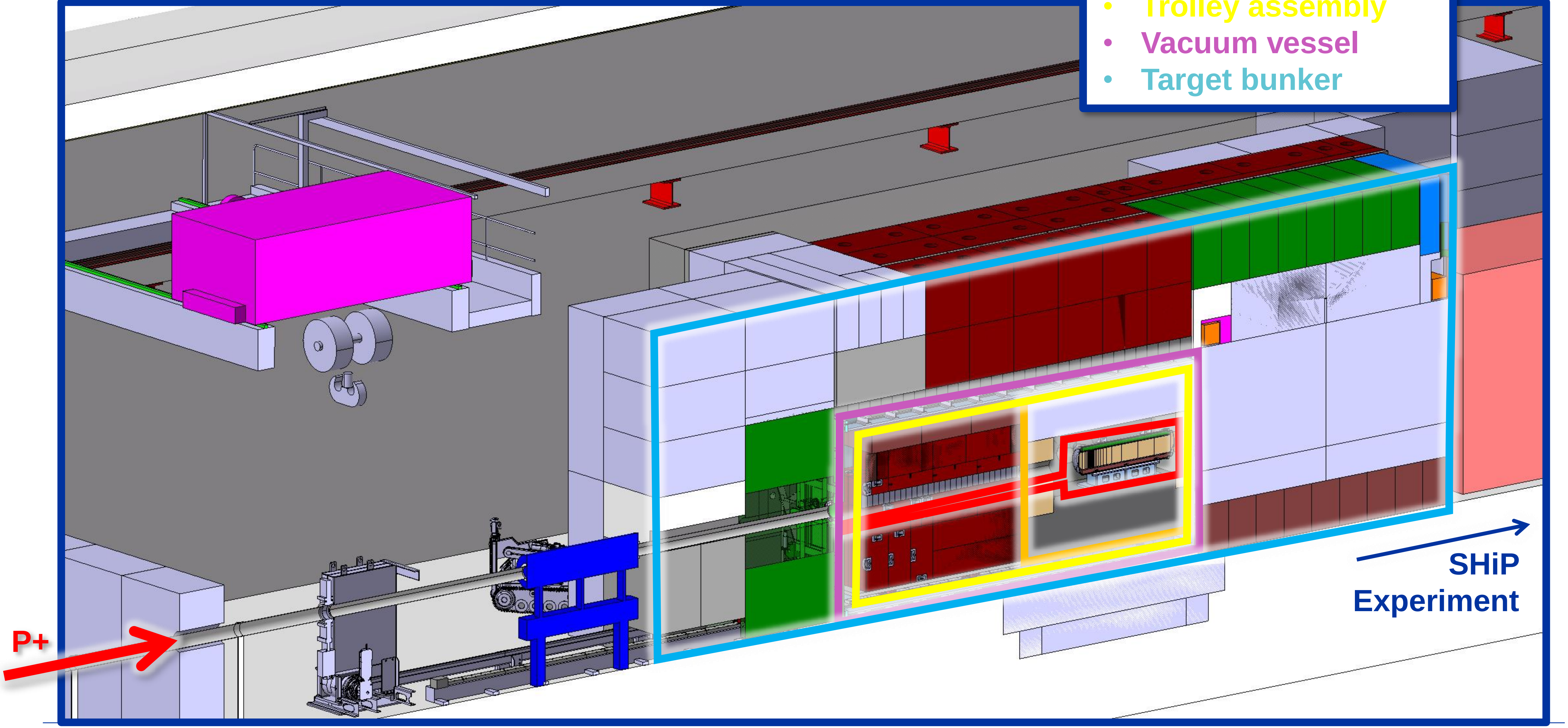
WP6,WP7,WP8
+al.

WP5+SHiP

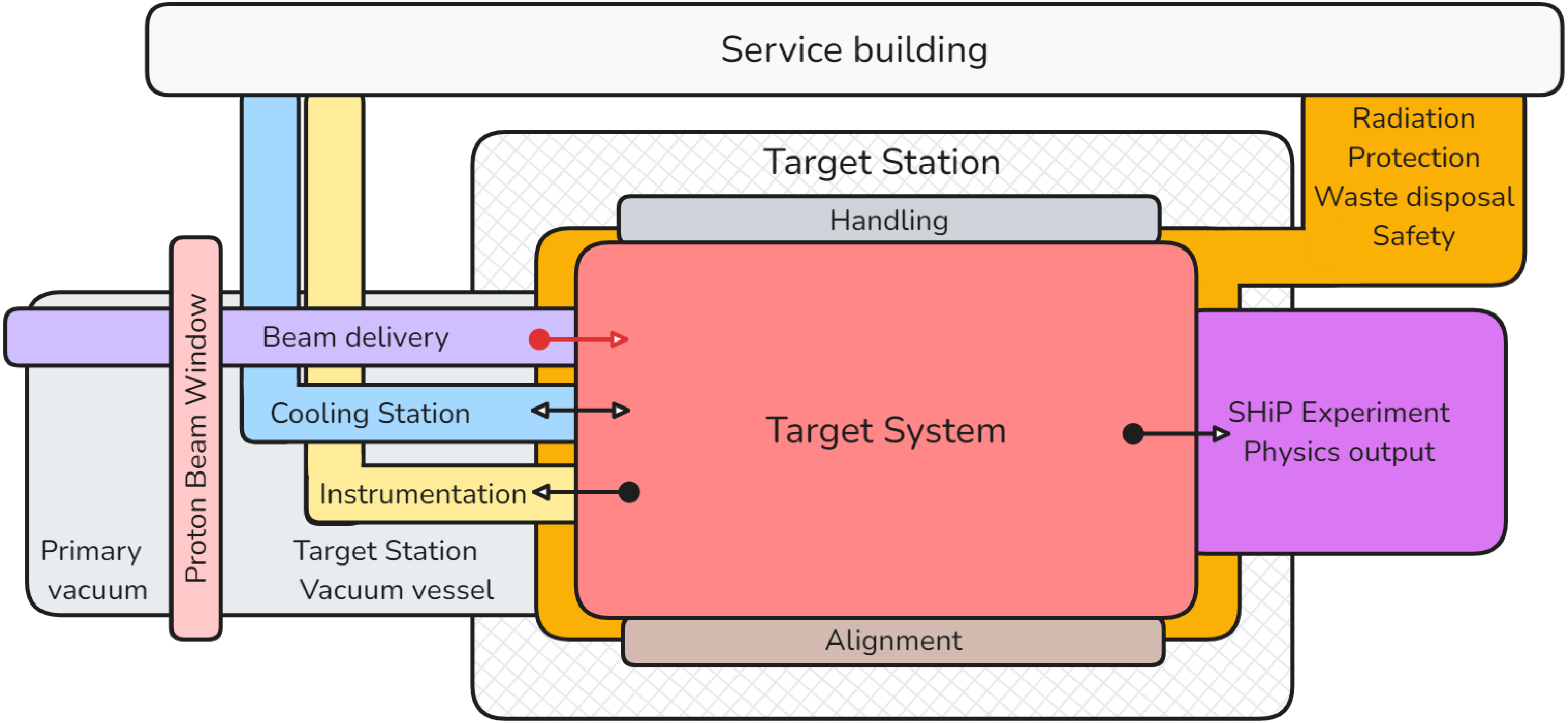
ECN3

Target Complex & Target system

- Target System
- Proximity Shielding
- Trolley assembly
- Vacuum vessel
- Target bunker



Target system key interfaces



From physics requirements to engineering challenges

BDF/SHiP Target

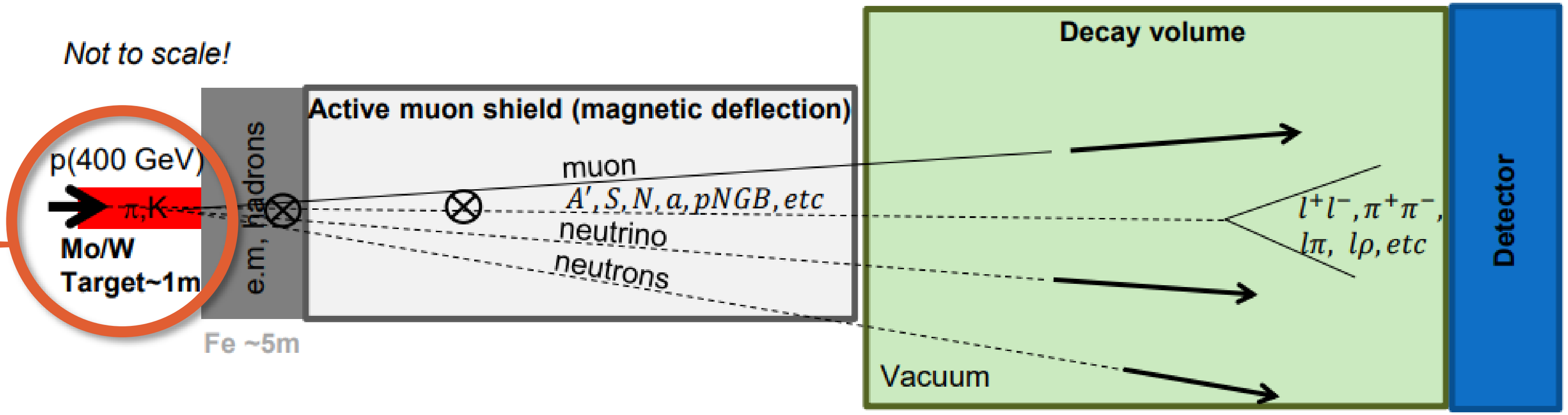
- **Beam Dump Target** / SHiP Target
  - Fully absorbe all p+, maximize production of charm and beauty hadrons & re-absorption of pions, muons and kaons

High energy → production of charmed and beauty mesons

High ppp & POT → overcome small prod cross-section of extra rare events of hidden particles

High ρ, Z & A → Maximize p+ interaction

Shortest λ → Force absorption of K & π to reduce muon & neutrino background



R. Jacobsson

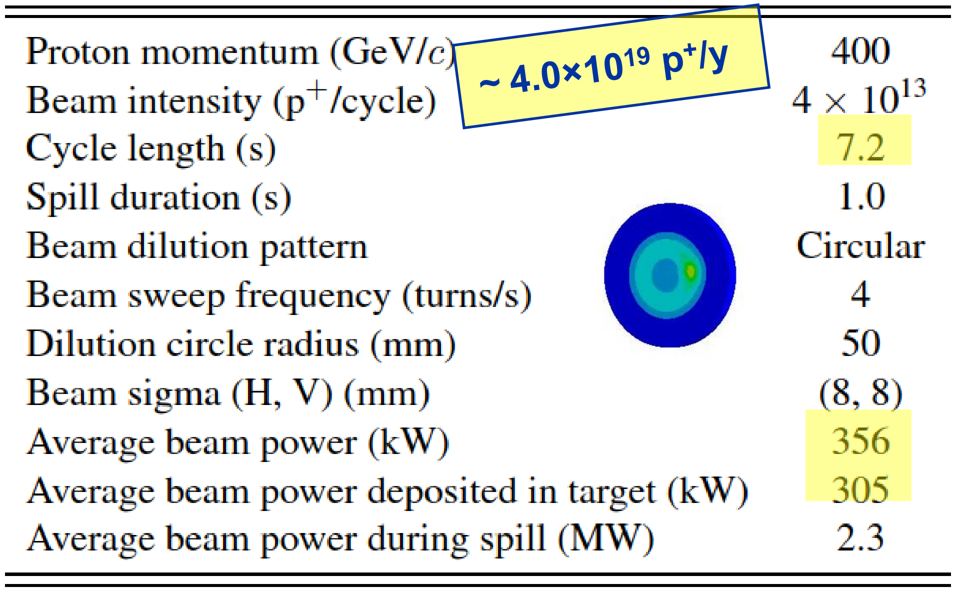
SPS Beam Dump Facility: Comprehensive Design Study, https://doi.org/10.23731/CYRM-2020-002
SHiP Experiment - Comprehensive Design Study report, https://cds.cern.ch/record/2704147

BDF Target

Target requirements

- **Physics**:
  - high-Z material & with short interaction length
  - Fully absorb SPS p+ beam
- **Engineering**:
  - 305kW power → cooling needs
  - 305kW power → temperature & thermal-induced stresses
  - High nr of spills & POT → mechanical fatigue & radiation damage
- **Safety:**
  - High activation → Remote handling, waste disposal considerations, spallation/contamination products…

Baseline beam parameters of the BDF Target operation. *https://doi.org/10.23731/CYRM-2020-002*



Proton momentum (GeV/c)	400
Beam intensity (p^+/cycle)	4×10^{13}
Cycle length (s)	7.2
Spill duration (s)	1.0
Beam dilution pattern	Circular
Beam sweep frequency (turns/s)	4
Dilution circle radius (mm)	50
Beam sigma (H, V) (mm)	(8, 8)
Average beam power (kW)	356
Average beam power deposited in target (kW)	305
Average beam power during spill (MW)	2.3

~ 4.0×10^{19} p^+/y

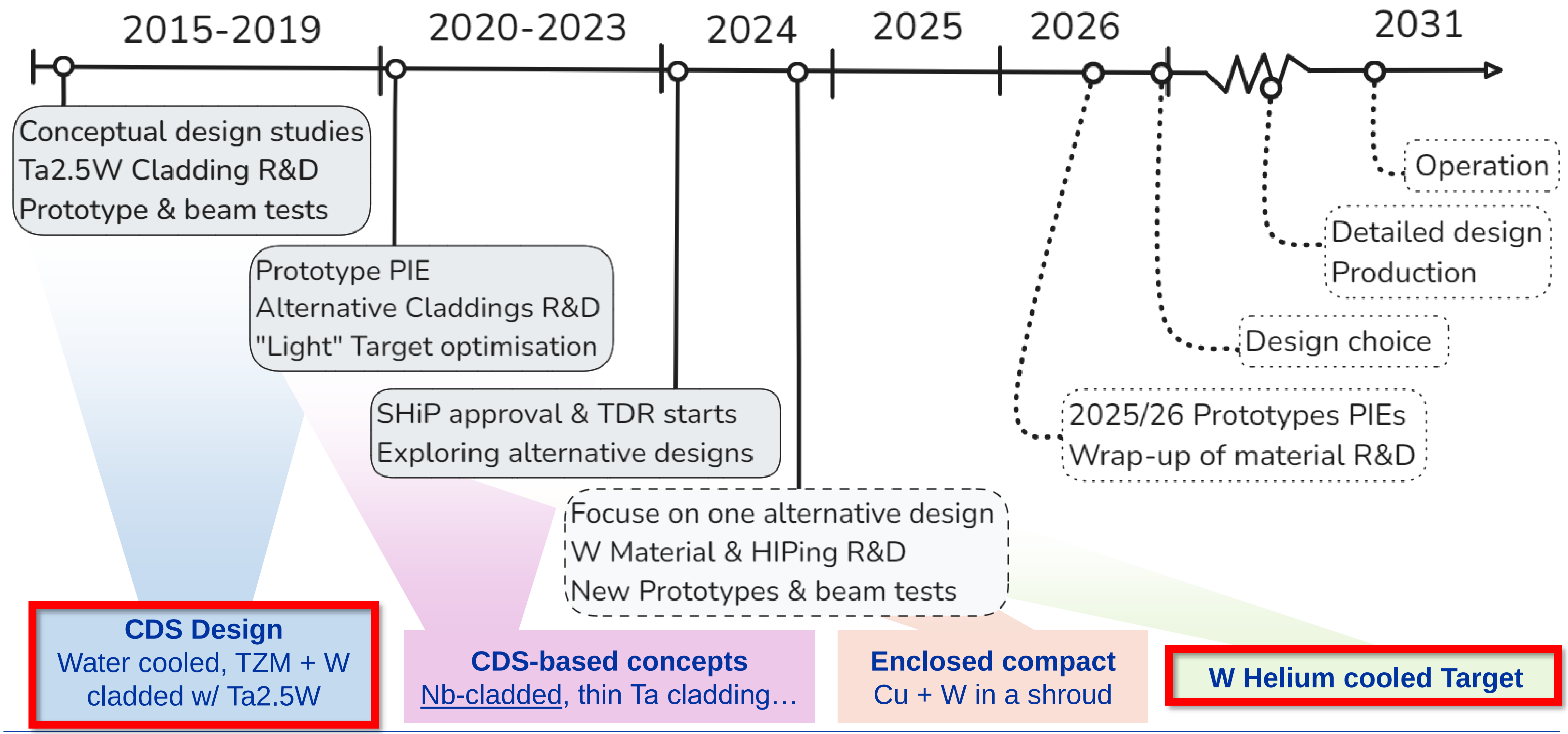
~ 5 years of operation per target Total of ~15 years of operation for the target station

Very similar requirements to a neutron spallation target

Synergies with other labs are being pursued

Overview of the Target concepts

BDF Target designs history (in a nutshell)



Conceptual design studies
Ta2.5W Cladding R&D
Prototype & beam tests

Prototype PIE
Alternative Claddings R&D
"Light" Target optimisation

SHiP approval & TDR starts
Exploring alternative designs

Focuse on one alternative design
W Material & HIPing R&D
New Prototypes & beam tests

2025/26 Prototypes PIEs
Wrap-up of material R&D

Design choice

Detailed design
Production

Operation

CDS Design
Water cooled, TZM + W cladded w/ Ta2.5W

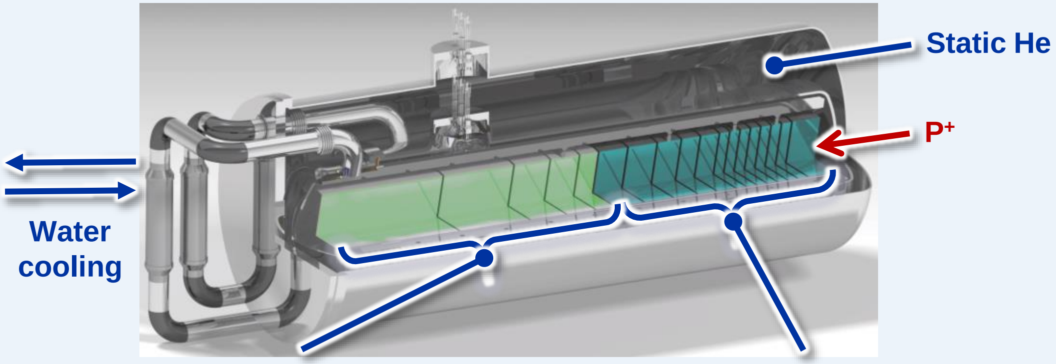
CDS-based concepts
Nb-cladded, thin Ta cladding…

Enclosed compact
Cu + W in a shroud

W Helium cooled Target

https://doi.org/10.1103/PhysRevAccelBeams.22.113001

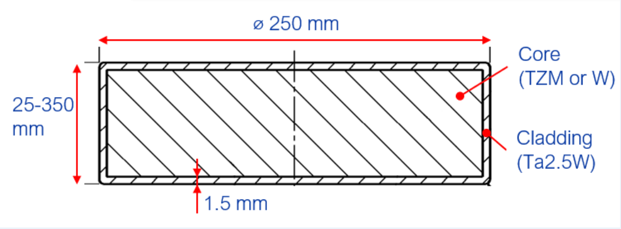
CDS Design



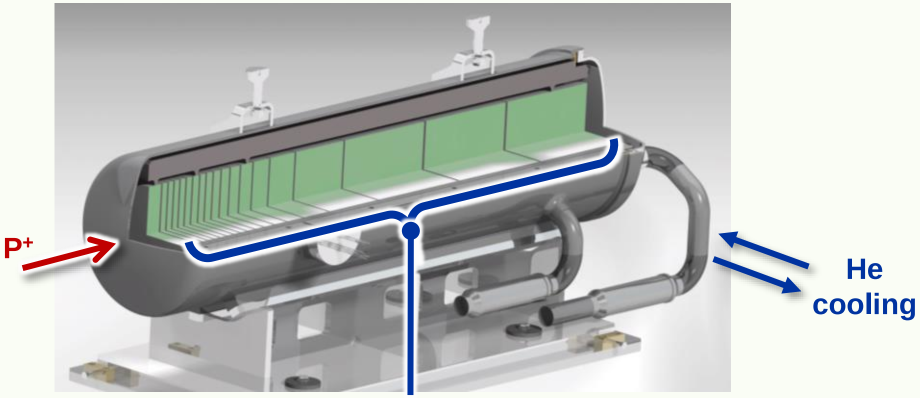
5x W blocks (Z=74, ρ=19.3g/cm^3) **13 x TZM blocks** (Z=42, ρ=10.2g/cm^3)
(L780 mm) (D250 mm) (L580 mm)

Water-cooled, Ta-cladded TZM + W Core

- TZM: Absorbs most of the power. Higher strength, better creep resistance, higher recrystallisation temp wrt Mo.
- W: Good radiation damage resistance. Best for physics.
- Ta2.5W: To avoid corrosion-erosion of the core materials
- Manufacturing: Forged TZM, sintered W (single blocks). Cladding via HIP.
- Cooling: 22 bar, 5 m/s, ~660l/min,



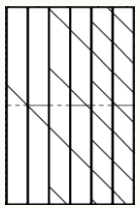
W Helium Cooled Target

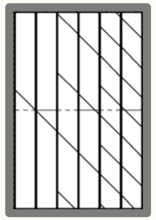


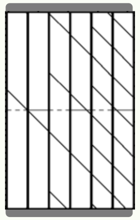
19x W blocks (L1500 mm) (D250 mm)

He-cooled, Pure W Core, potentially cladded (tbd)

- W: All W to improve physics. Hot-rolled for higher strength.
- Cladding (tbd): Ta or Ta2.5W, potentially to reinforce core blocks and/or mitigate oxidation.
- Manufacturing: Multiple W plates per block & cladding bonded via HIP.
- Cooling: 16 bar He, 400g/s


Hiped W plates (no-clad)

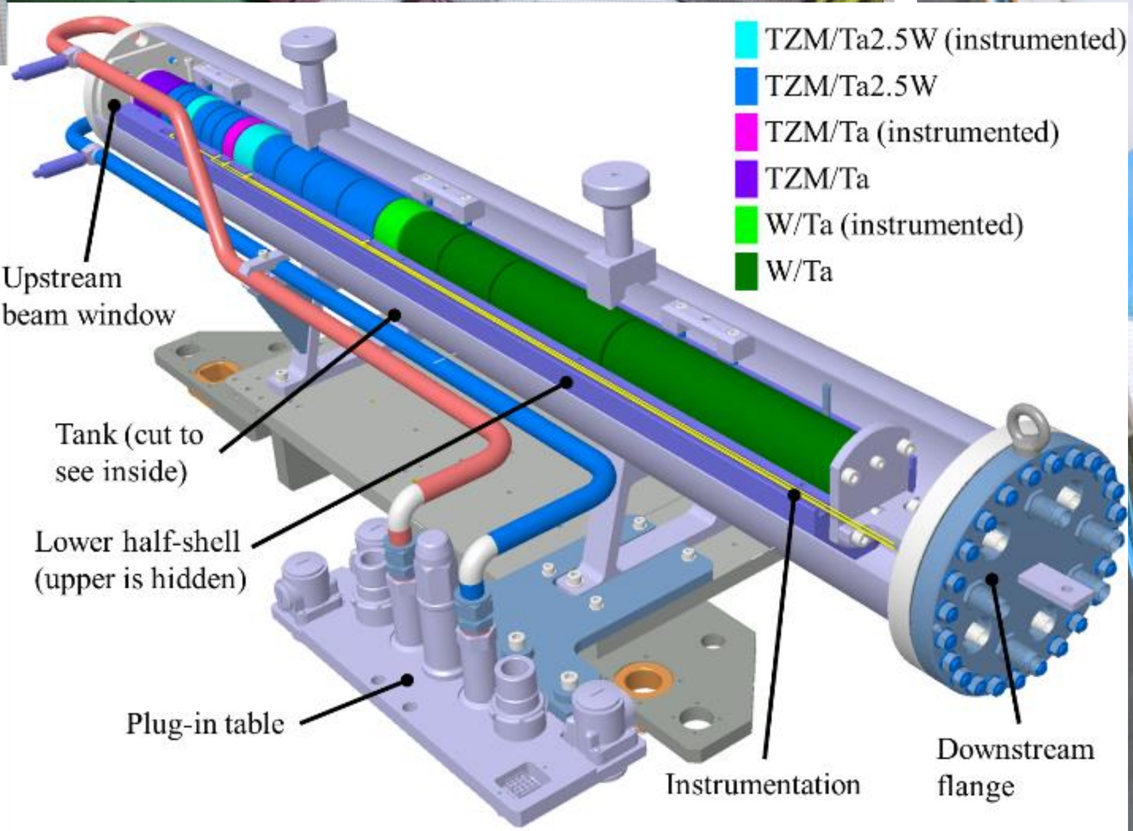

Hiped W w/ cladding


Hiped W w/ partial cladding

Summary of past studies

Prototype & beam tests of the Baseline Target

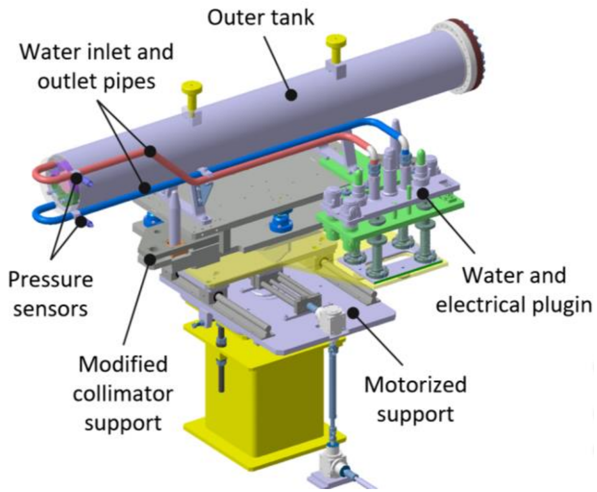
CDS Design
Water cooled, TZM + W
cladded w/ Ta2.5W

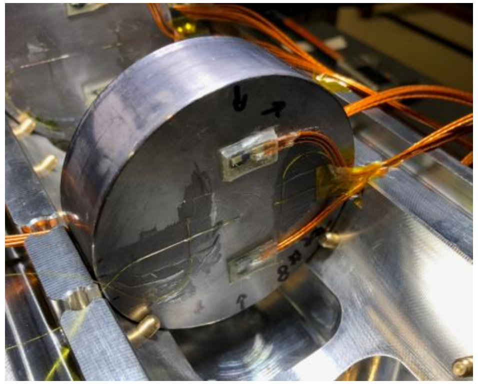

TZM/Ta2.5W (instrumented)
TZM/Ta2.5W
TZM/Ta (instrumented)
TZM/Ta
W/Ta (instrumented)
W/Ta
Upstream beam window
Tank (cut to see inside)
Lower half-shell (upper is hidden)
Plug-in table
Instrumentation
Downstream flange

BDF Baseline Target Prototype + PIE

Prototype Beam tests

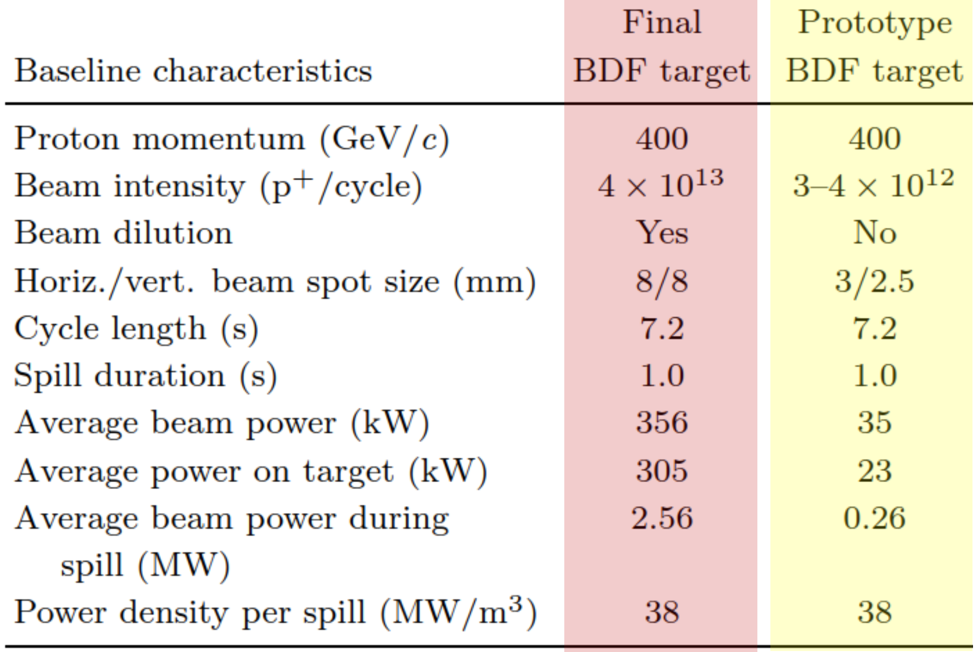
- Validate manufacturing and test operation at identical temperatures & mechanical stresses.
- Reduced diameter (80 mm) prototype.
- Tested in 2018 on a **dedicated slow extraction (SX) testbench** in the T6 primary beam line in TCC2 at CERN. Total of 2.4×10^{16} p^+





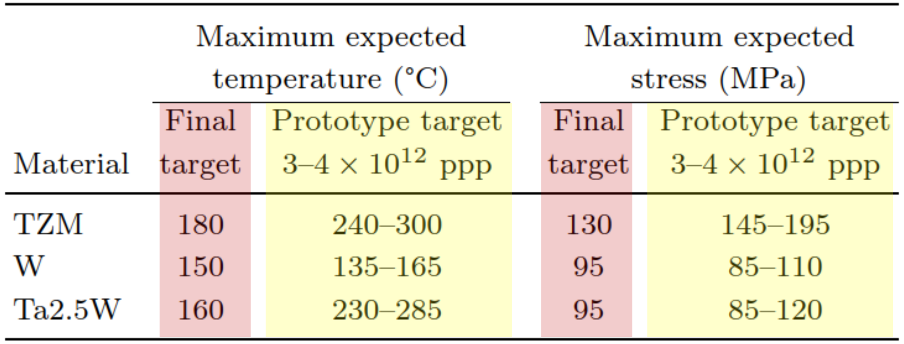
https://doi.org/10.1103/PhysRevAccelBeams.22.123001

Beam parameters



Baseline characteristics	Final BDF target	Prototype BDF target
Proton momentum (GeV/c)	400	400
Beam intensity (p^+/cycle)	4×10^{13}	$3–4 \times 10^{12}$
Beam dilution	Yes	No
Horiz./vert. beam spot size (mm)	8/8	3/2.5
Cycle length (s)	7.2	7.2
Spill duration (s)	1.0	1.0
Average beam power (kW)	356	35
Average power on target (kW)	305	23
Average beam power during spill (MW)	2.56	0.26
Power density per spill (MW/m^3)	38	38

Operational conditions



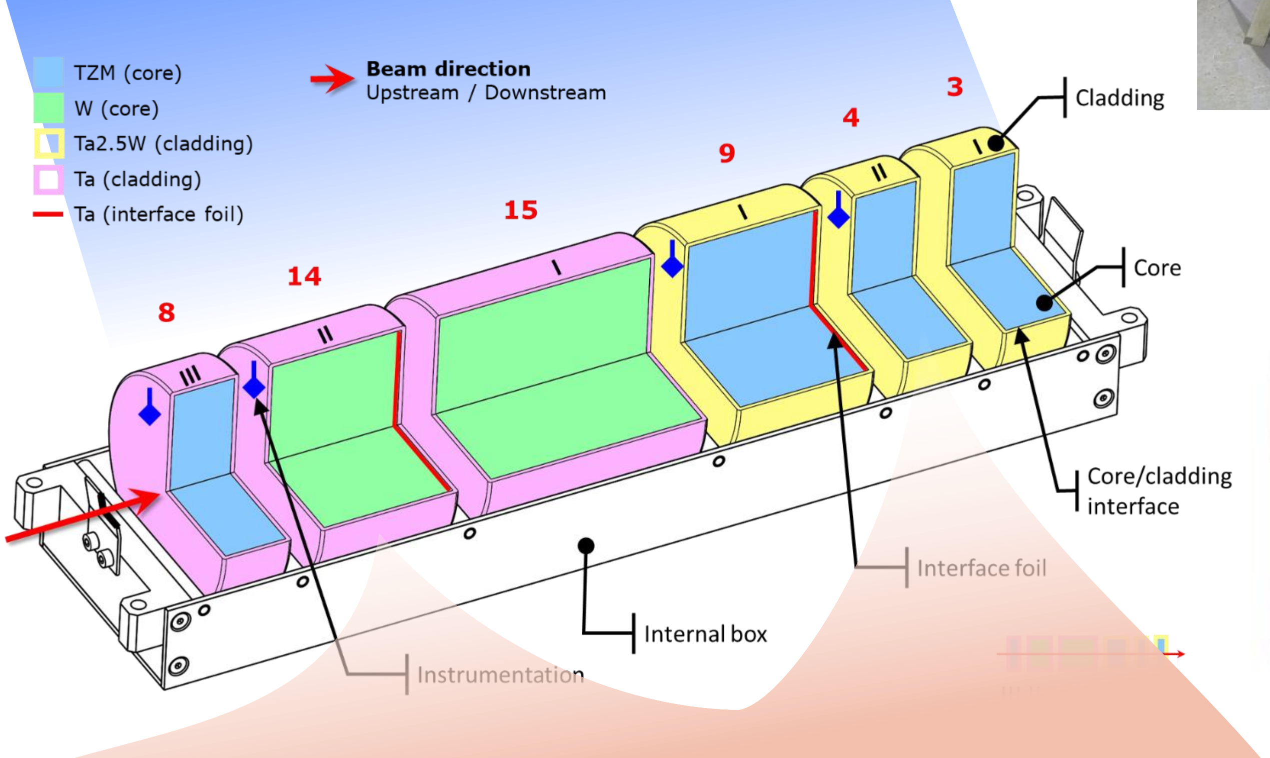
	Maximum expected temperature (°C)		Maximum expected stress (MPa)	
Material	Final target	Prototype target $3–4 \times 10^{12}$ ppp	Final target	Prototype target $3–4 \times 10^{12}$ ppp
TZM	180	240–300	130	145–195
W	150	135–165	95	85–110
Ta2.5W	160	230–285	95	85–120

PIE activities & samples

I. Film Dosimetry

II. Metrology & Microscopy

III. Ultrasonic Testing

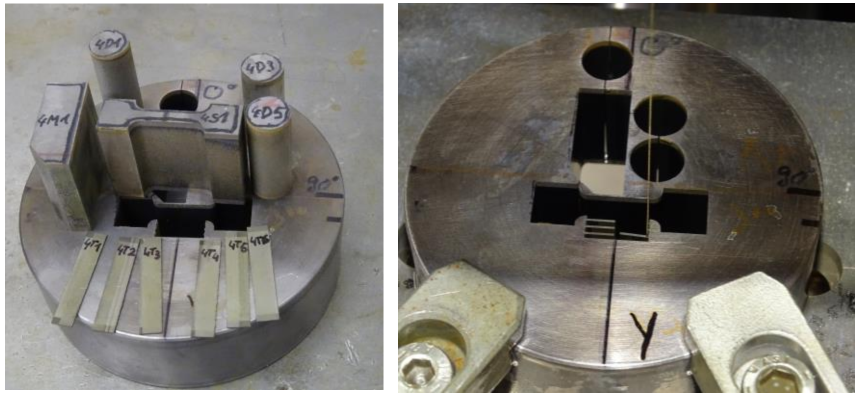


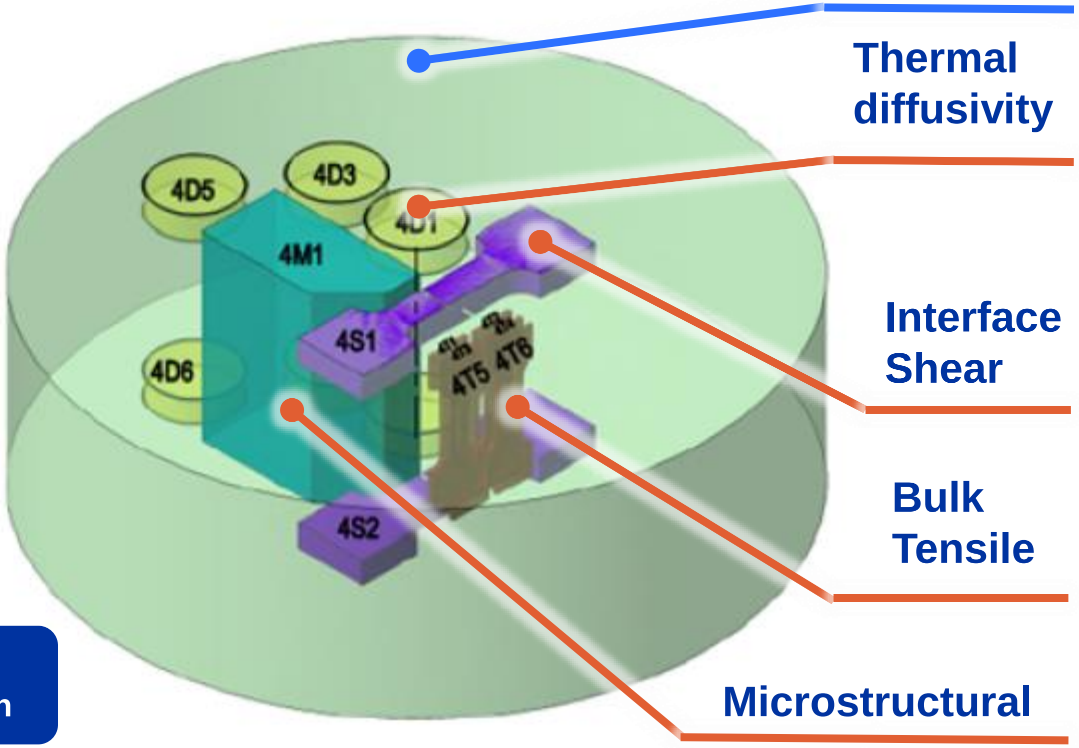
IV. Specimen Extraction

V. Microstructural Characterization

VI. Mechanical Characterization

VII. Thermal Characterization





PIE – Nondestructive testing

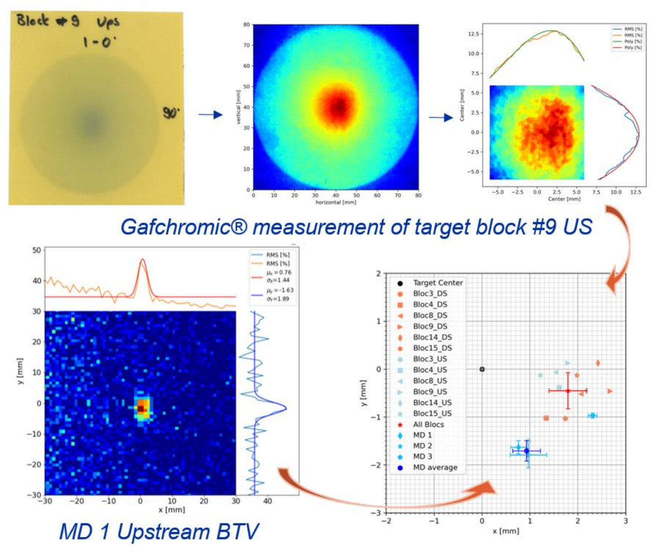
I. Film Dosimetry

II. Metrology and Microscopy

III. Ultrasonic Tests

I. Film Dosimetry

→ BTV and gafchromic imaging consistent (< 1mm)
→ Blow up of the beam downstream.



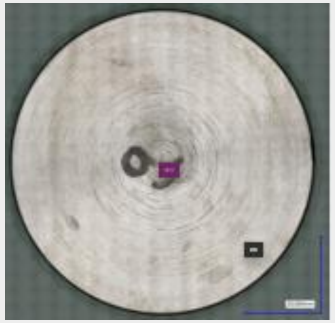
Gafchromic® measurement of target block #9 US

MD 1 Upstream BTV

II. Metrology and Microscopy

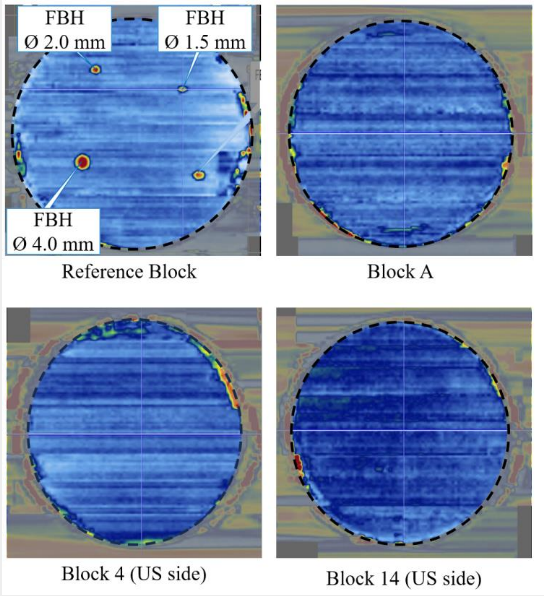
→ No relevant geometrical changes nor swelling and **no corrosion, cracks, or melting** visible

- Better cleaning of lubricant necessary
- Strong turning grooves in the centre



III. Ultrasonic Tests

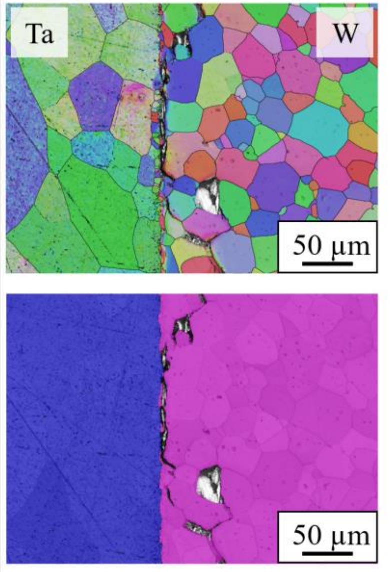
→ **No signs of damages** in the bonding interface!



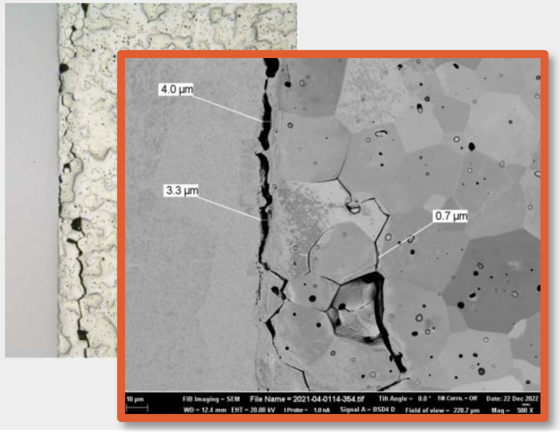
PIE – Microstructure analysis

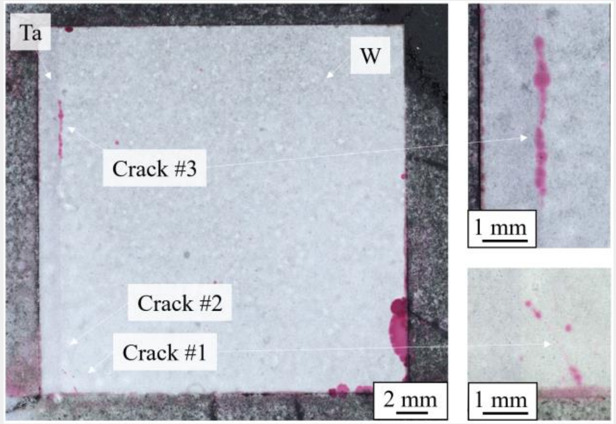
V. Microstructural Characterization

Cracks in irradiated W Block



EBSD and SEM images show **cracks inside W**
→ No delamination of the interface





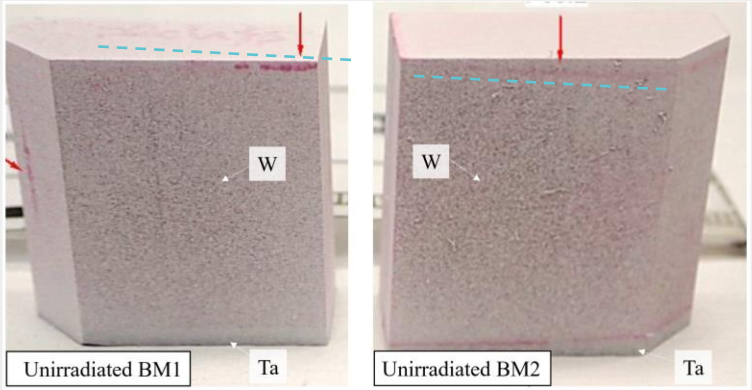
Dye penetrant testing (PT) show superficial cracks (1&3) and Crack 2 was not detected

TZM: → Tantalum & TZM → No damages)

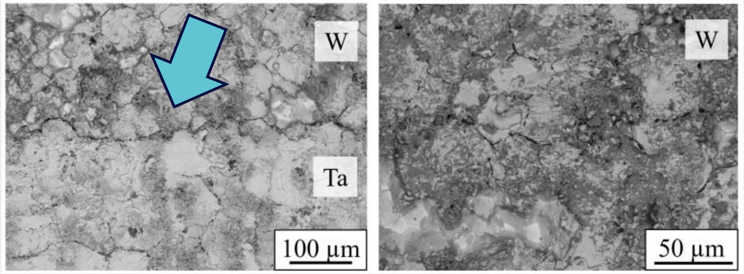
W: → Cracks → Beam-induced?

- Cracks did not exist before EDM cutting (UT Testing)
- **No differences** between unirradiated and irradiated microstructure
- Reason: Cracks superficial, release of high residual stresses during EDM cutting, brittle W (porosity & fully recrystallized). Attributed to **quality of sintered W**

Testing of unirradiated W Block



PT Testing indicated cracks in unirradiated W

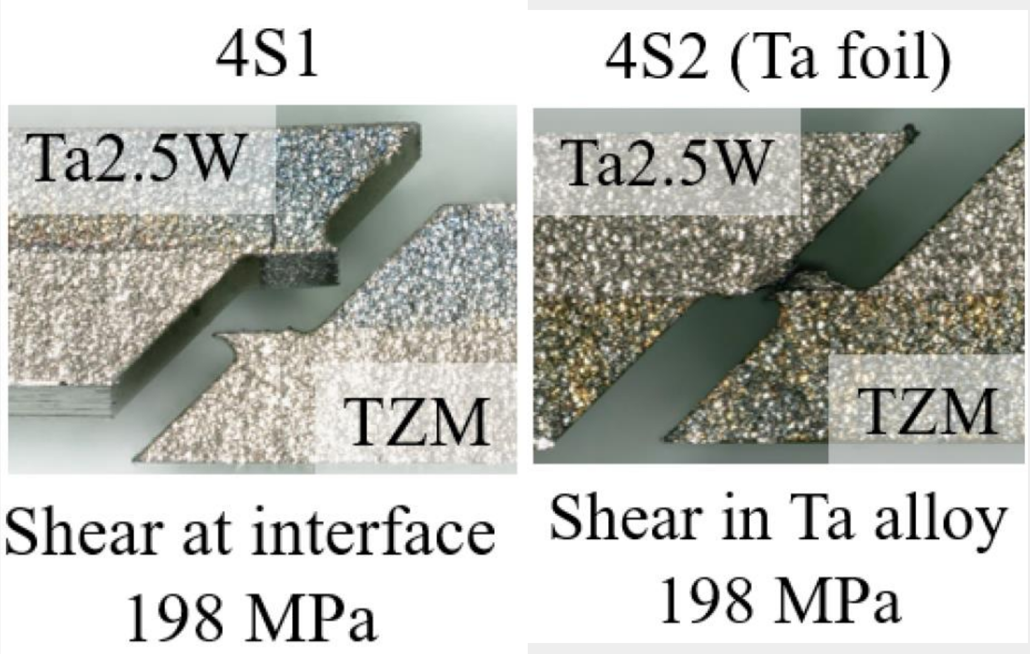


SEM shows similar cracks as in irradiated sample

PIE - Shear testing

Irradiated TZM-Ta2.5W

- Ta clad: Higher shear breaking strength than bulk Ta (150 MPa) (un-irradiated block)
- Ta2.5W clad: Close to shear breaking strength of bulk Ta2.5W (215 MPa) (irradiated, w/ and wo Ta foil)

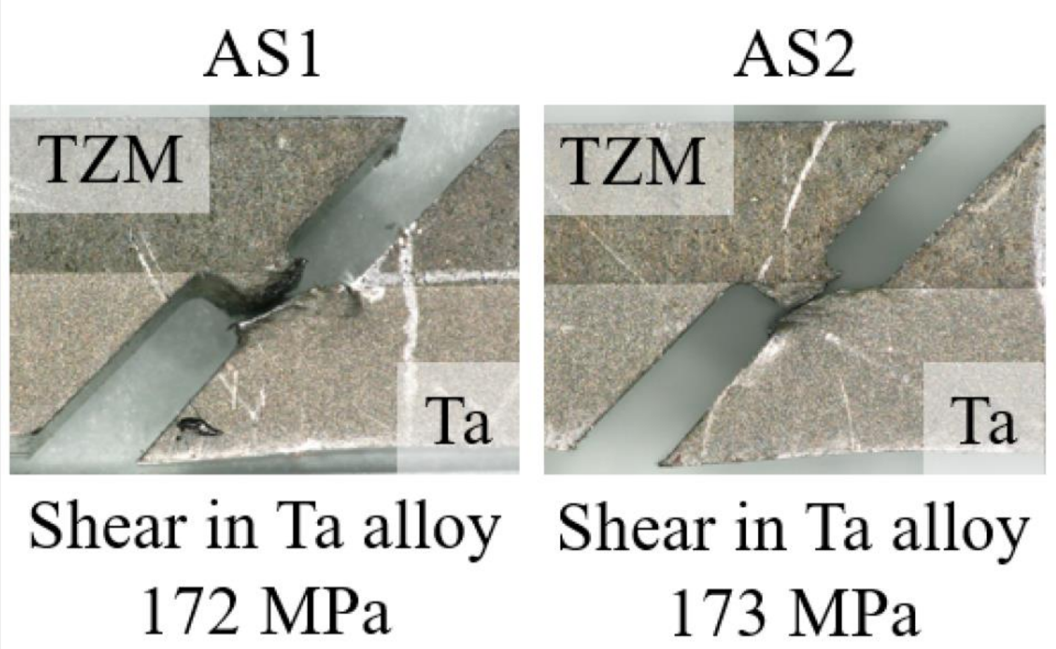


Shear at interface
198 MPa

Shear in Ta alloy
198 MPa

Un-irradiated TZM-Ta

- Fracture in shear neck region
  - 1 at the interface, 3 in the Tantalum
  - 80-750um extension (slightly higher in un-irradiated)



Shear in Ta alloy
172 MPa

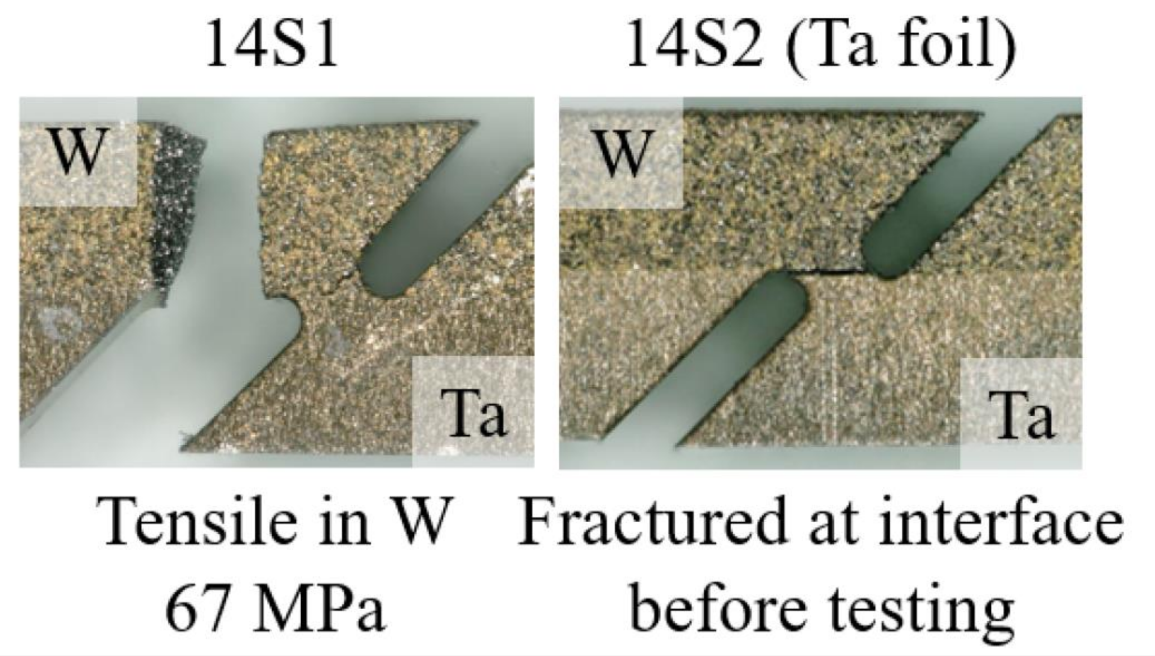
Shear in Ta alloy
173 MPa

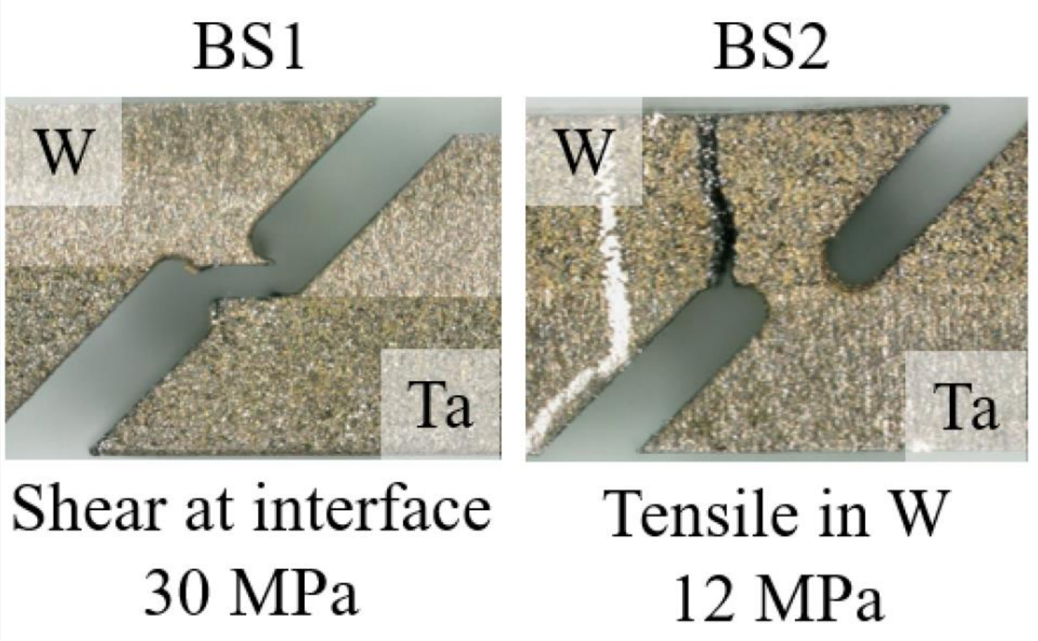
PIE - Shear testing

Irradiated W-Ta

Un-irradiated W-Ta

- Fracture outside necking indicating very brittle W (both irradiated and un-irradiated) – weaker than interface itself
- Small extension before fracture
- 14S2 fracture before test

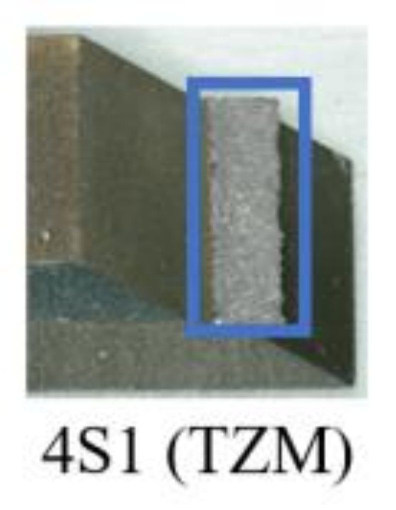




PIE - Shear testing

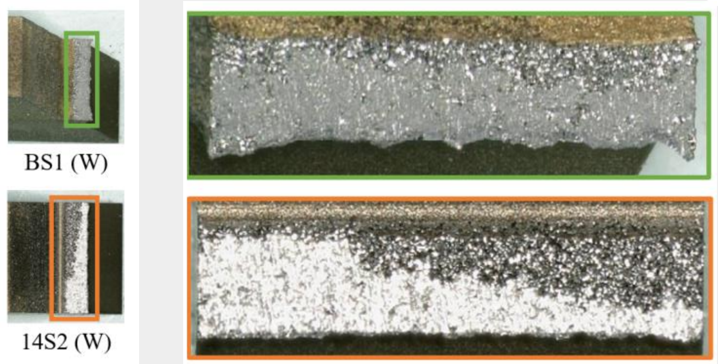
TZM block

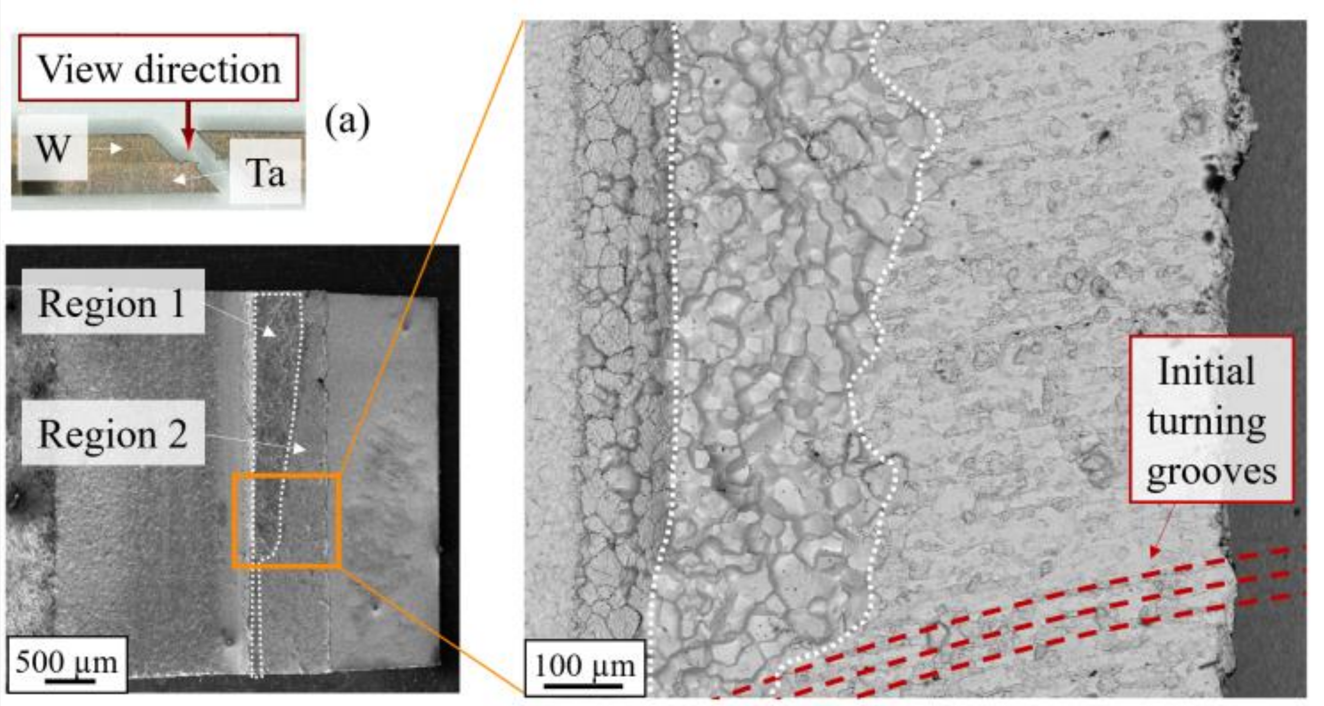
- Uniform fracture, always on Ta and Ta2.5W (with and without Ta foil)



W block

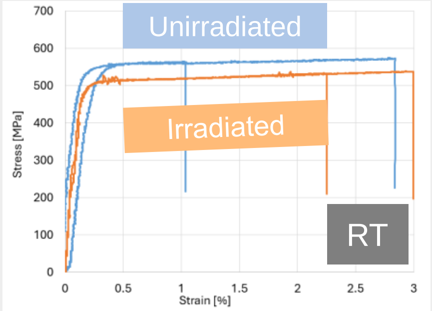
- Both Intragranular fracture & no distinct fracture on both irradiated and un-irradiated

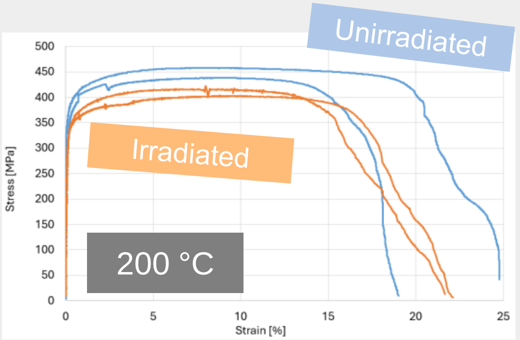


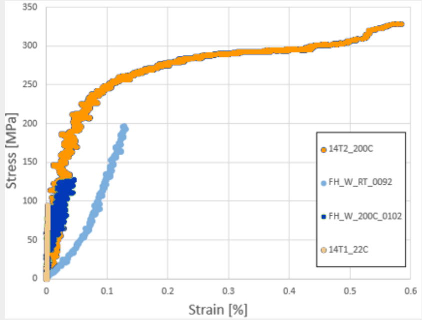


PIE: Mechanical testing

Tensile Testing







TZM : Lower mechanical properties of irradiated samples
→ low PoT → no irradiation damage
→ No differences in microstructure detected
→ No faults in testing set up found

W
Tensile specimens very error prone for brittle material such as W
→ 4-pending test better

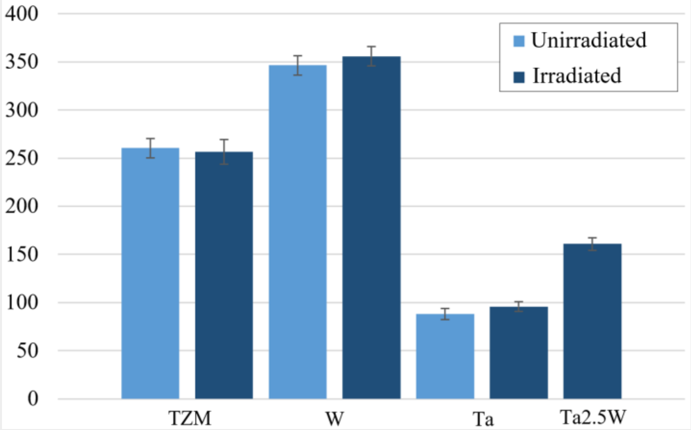
	TZM (AT)		TZM (4T)		W (14T)	
	YS	UTS	YS	UTS	YS	UTS
22 °C	552	569	511	535	–	84
200 °C	376	448	343	409	288	334

Thermal Testing

- Two-layered specimens of core and cladding material from irradiated Block #4 and #14
- Negligible thermal contact resistance of all interfaces
- No dependencies of proximity to beam impact axis or usage of Ta interlayer detected
- No irradiation effects detected (compared to prior studies)

Vickers Hardness [HV 0.5]

- **TZM, Ta, Ta2.5W**: as annealed materials
- **W** as fully recrystallized
- ➢ **No differences** unirradiated and irradiated



	Literature	Prototype capsules	Unirrad.	Irrad.
TZM	235–250^{a}	240^{e}, 215^{f}	260 ± 10	257 ± 13
W	350^{b}	435^{e}, 355^{f}	346 ± 10	356 ± 10
Ta	75–105^{c}	80^{e}, 70^{f}	88 ± 6	96 ± 5
Ta2.5W	160–240^{d}	140^{e}, 120^{f}	–	161 ± 7

Summary of past studies

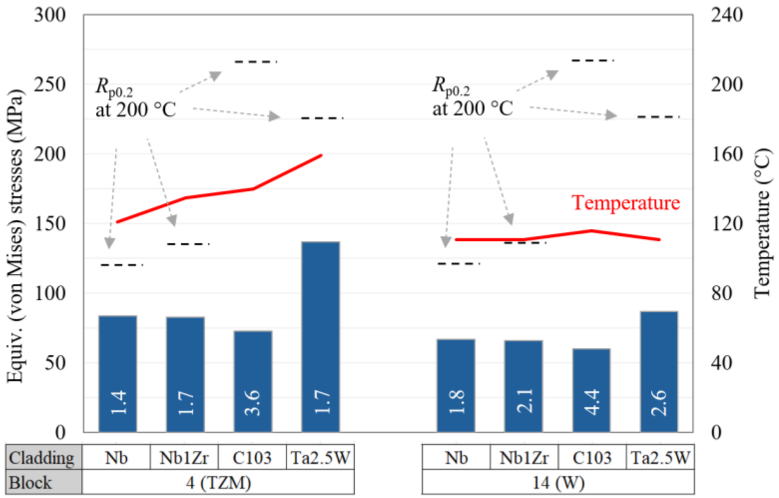
Niobium Cladding R&D

CDS-based concepts
Nb-cladded, thin Ta cladding…

Nb-cladded baseline target

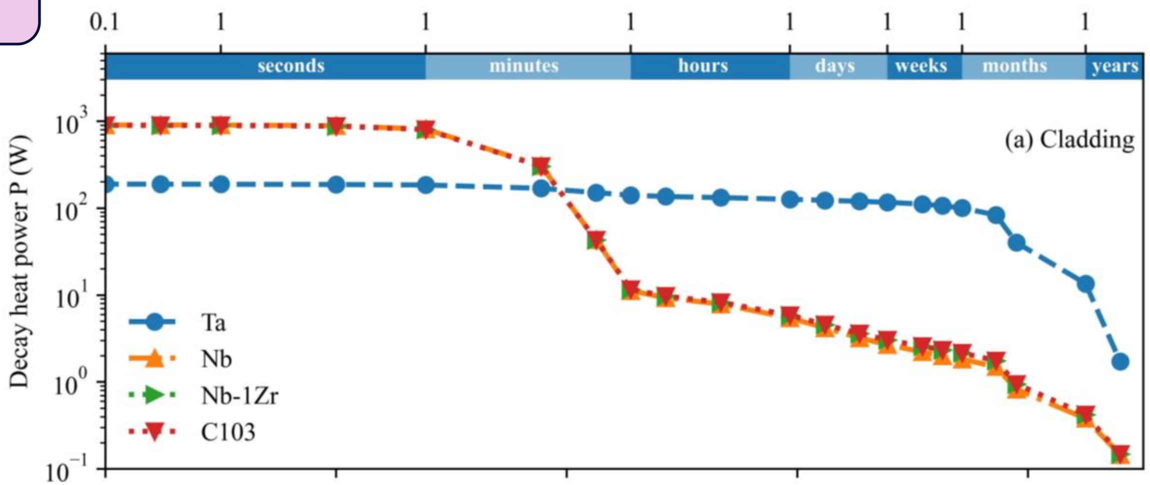
Selection of Nb-alloys:

- **Promising LOCA improvement**
- **Compliant with Thermo-mechanical conditions**



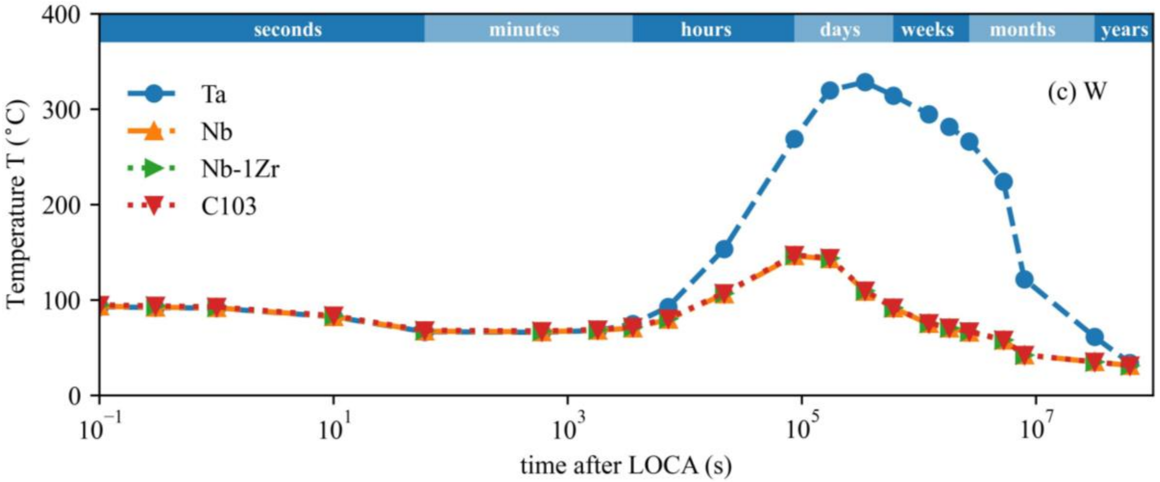
- **Likely HIP "bondable"**
  - **Phase diagrams:** Good solubility no critical intermetallic phases
  - **Diffusivity**: as much diffusivity into W and Mo as Ta.
  - **Ductility**: Nb identical to Ta

Decay heat power



Temperature after LOCA

Assuming htc=1W/m2.K



Nb alloy cladding R&D - Prototype capsules

I. EBW of Capsules

II. Helium Penetrant Test

III. 1st HIPing Cycle (1200 °C)

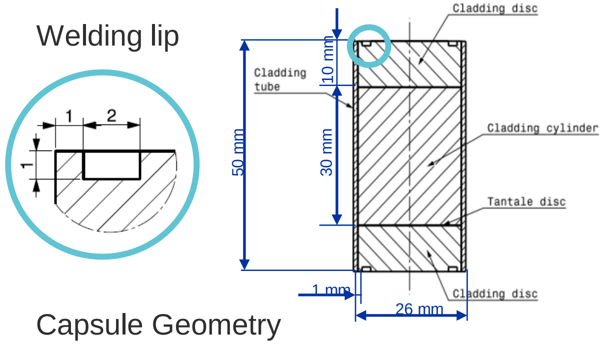
IV. 2nd HIPing Cycle (1400 °C)

V. Ultrasonic Testing

VI. Cutting & OM at interface

VII. Thermal Characterization

VIII. Mechanical Characterization



Welding lip

Capsule Geometry

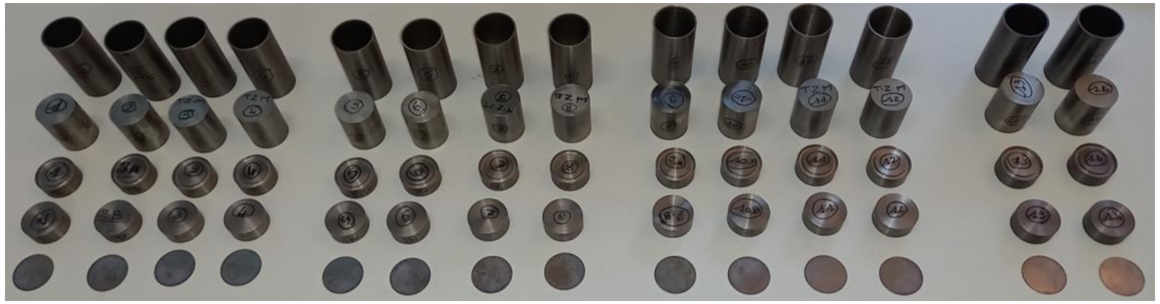
Capsules after EB welding

1st batch after HIPing

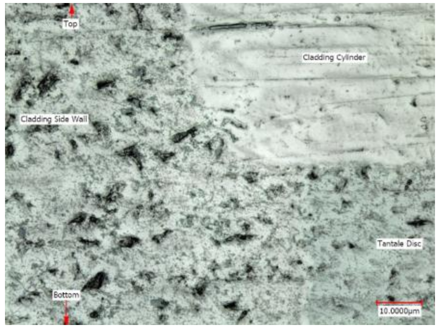
HIPing Furnace at Nuclear AMRC

Successfully bonded capsule

Single failed UT capsule fell apart when cut open



W | TZM	W | TZM	W | TZM	W
Nb	**Nb1Zr**	**C103 (Nb10Hf1Ti)**	**Ta**



OM of Nb//W

OM to visually check the bonding interface
→ **Bonding visually ok**

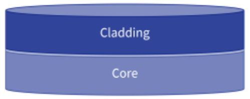
Nb-cladded baseline target

However, long-lived Nb isotopes pose challenges for waste disposal

I. EBW of Capsules | **II. Helium Penetrant Test** | **III. 1st HIPing Cycle (1200 °C)** | **IV. 2nd HIPing Cycle (1400 °C)** | **V. Ultrasonic Testing** | **VI. Cutting & OM at interface** | **VII. Thermal Characterization** | **VIII. Mechanical Characterization**

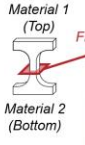
Thermal diffusivity specimens

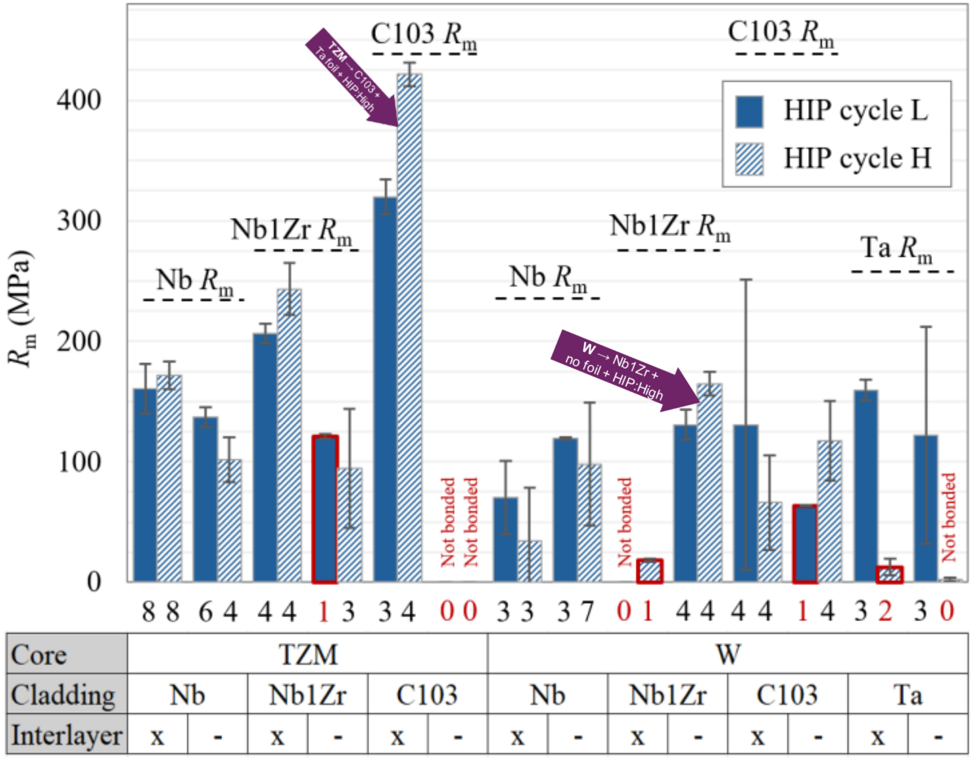
- Excellent thermal contact has been confirmed for all Niobium alloys (Nb, Nb1Zr, C103)



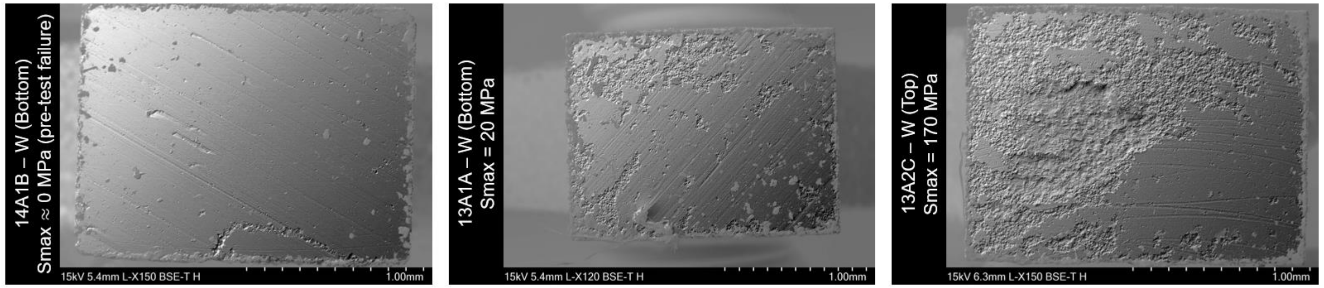
Tensile specimens

- Interface strength for Nb alloys higher for TZM than W
- TZM core :
  - Ta foil + HIP: High increased the strength
  - C103 did not bond without the foil
- W core
  - Higher variation, but it seems no foil increases interface strength





Core	TZM						W							
Cladding	Nb		Nb1Zr		C103		Nb		Nb1Zr		C103		Ta	
Interlayer	x	-	x	-	x	-	x	-	x	-	x	-	x	-



SEM: Increase of successful diffusion bonding / maximum stresses

Why and what during the TDR?

Highlighting key issues with Baseline Design

CDS Design
Water cooled, TZM + W cladded w/ Ta2.5W

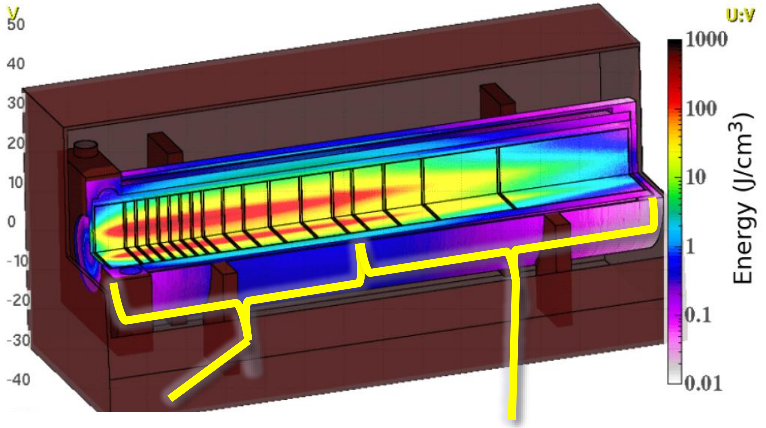
→

W Helium cooled Target

In search of an alternative design

Main motivations

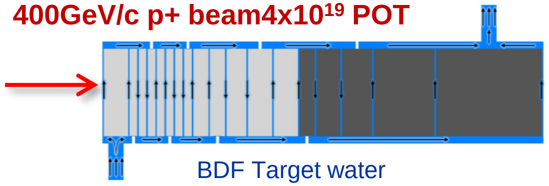
- Most of the shower develops on TZM and not on W → core could be further optimized for physics
- Water in-beam promotes formation of radicals → safety concerns to be addressed or water removed
- Decay heat on baseline target is considerable & driven by cladding. Possibility of LOCA (Loss Of Coolant Accident) poses a critical safety risk → Reduce Ta cladding
- PIE revealed W quality to be poor → Look into more robust W supply



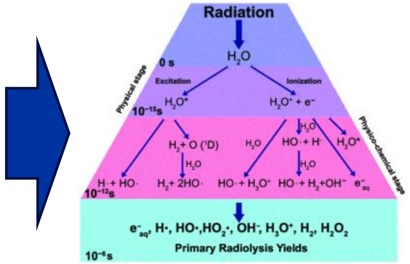
13 x TZM blocks (580 mm)

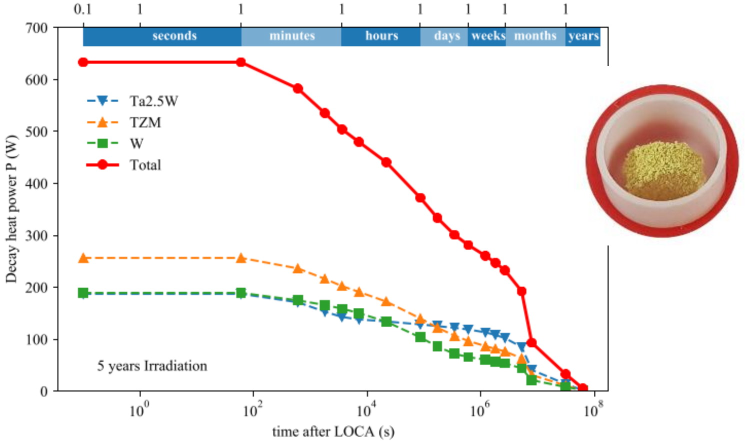
5x W blocks (780 mm)

400GeV/c p+ beam4x10^{19} POT



BDF Target water cooling layout (20bar, 5m/s)





BDF Target TDR – main threads

✓ **We start with a solid background from PBC studies with the CDS Design. Yet, many things still to be addressed:**

- ☐ Address safety aspects such as LOCA, radiolysis & retrofit it into the target design → need for alternative design studies & their validation with a prototype w/beam → Only opportunity will be 2025 & 2026
- ☐ Need to detail the mechanical design of the Target, instrumentation & integration
- ☐ In depth Target physics optimization & review beam delivery/sweep optimization on target
- ☐ Define the manufacturing technology specification & material QA (taking the PIE lessons learnt) necessary to go ahead with procurement in a Production phase
- ☐ Identify the other required BIDs. Design and engineer them.
- ☐ → **Overall, getting ready for a project/production phase**

What lies ahead today?

(short) Specific questions on the Target system

…and where to look for answers

• Any showstopper in **FEA** ? Under-evaluated aspects? • Are the target **blocs design(s) reliable** ? Consider alternative options? • Are **operational and accident scenarios addressed**? Others to consider?	**Mike (1) & Giuseppe & Francesco V**
• Does **R&D** support the design efforts? Any missing threads?	**Stefano & Rui (1)**
• Are the **design(s) feasible for production and assembly**?	**Luca**
• Is the **prototype beam testing useful** ? Explore other tests?	**Rui (2) & Mike (1)**
• What **risks** exist in the proposed designs? areas for optimisation?	**(All)**
• Is the **instrumentation package** suitable for diagnosing operational/accident scenarios? Additional target instrumentation needed?	**Mike (2)**
• Is the **cooling system** adequate? Are safety concerns addressed and mitigated?	**Francesco D**
• Are **radiation protection** aspects (operation & waste) properly considered?	**Claudia & Gerald**

Thank you

home.cern

Reviewers questions (detailed)

Do you see any feasibility issues in the proposed designs (target core, pressure vessel, vacuum vessel, shielding system etc.) in view of their future production and assembly?

Do you see any potential showstopper in the FEA / thermo-mechanical calculations, for both nominal and for degraded scenarios? Are there specific topics which have been under evaluated?

Are the most important operational considerations and accident scenarios being fully addressed? Shall other situations be considered?

Do the target block R&D plans adequately support the design efforts? Do you see any potential missing aspects that would need to be considered at this stage?

Are the present target block design options appropriate for long-term reliability – should options be included or eliminated?

Are the plans for target prototype proton beam testing appropriate and useful to support the target development plans? Shall other complementary tests be explored?

Do you identify any specific risks in the proposed target designs? Do you see areas for optimisation?

Is the proposed target instrumentation package suitable for diagnosing operational and potential accident scenarios? Is there any other instrumentation you would suggest?

Is the current target station design in line with best operational and maintenance practices from the international community? Are there any specific improvements or design options that should be considered at this stage?

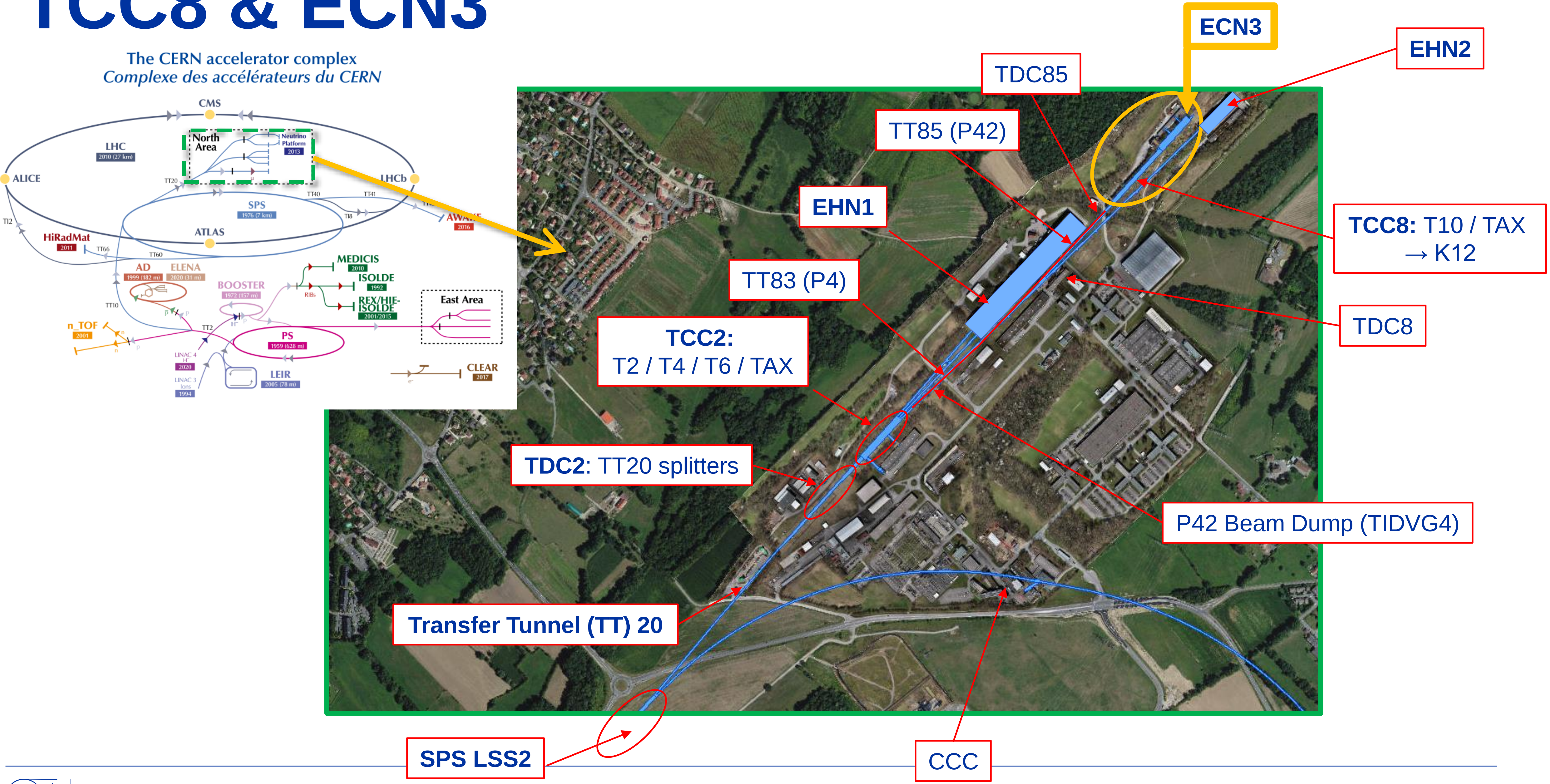
Is the design of the cooling and ventilation systems adequate for the needs of the target systems? Are the safety concerns associated with such a cooling system being addressed and mitigated in the current design? Including maintenance scenarios of the cooling system

Are radiation protection aspects adequately considered in the design of the complex, both in terms of operation as well as waste management?

Is the concept for the service cell in the target service building appropriate to tackle the challenges of maintenance and waste packaging of the target systems?

Did we have to consider additional failure scenarios?

TCC8 & ECN3



The CERN accelerator complex
Complexe des accélérateurs du CERN

ECN3

EHN2

TDC85

TT85 (P42)

EHN1

TCC8: T10 / TAX
→ K12

TT83 (P4)

TDC8

TCC2:
T2 / T4 / T6 / TAX

TDC2: TT20 splitters

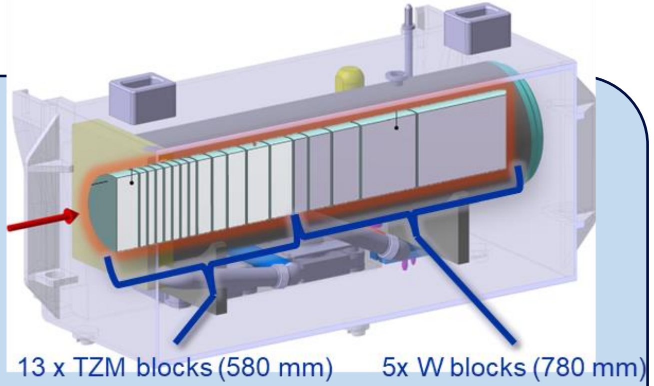
P42 Beam Dump (TIDVG4)

Transfer Tunnel (TT) 20

SPS LSS2

CCC

Overview of BDF Target design options

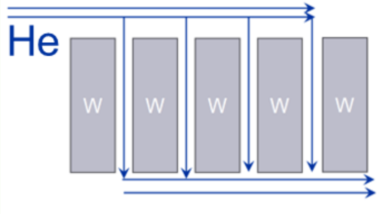


CDS Design – Water cooled, W + TZM cladded w/ Ta2.5W

- Pursued during the conceptual design phase
  https://doi.org/10.1103/PhysRevAccelBeams.22.113001
- Prototype + test with beam + Post irradiation examination
- Still some safety aspects to be addressed
- Could be further optimized for physics

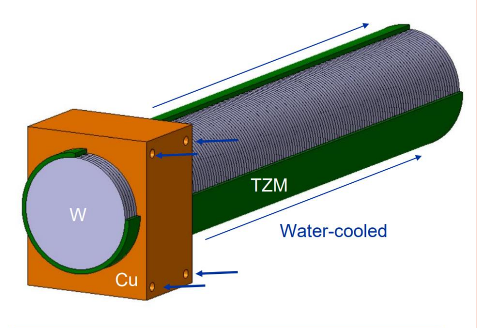
Alternative designs currently being studied in the TDR

CDS-based concepts: with W rolled material, Nb-cladded Target, thin Ta cladding…



W Helium cooled Target
- Removes water from beam
- Better physics performance
- Reduces decay heat & residual stresses
- Conceptually different system!

Enclosed compact Cu + W Target
- Removes water from beam
- Keeps physics performance
- Reduces decay heat
- Increases T and stress



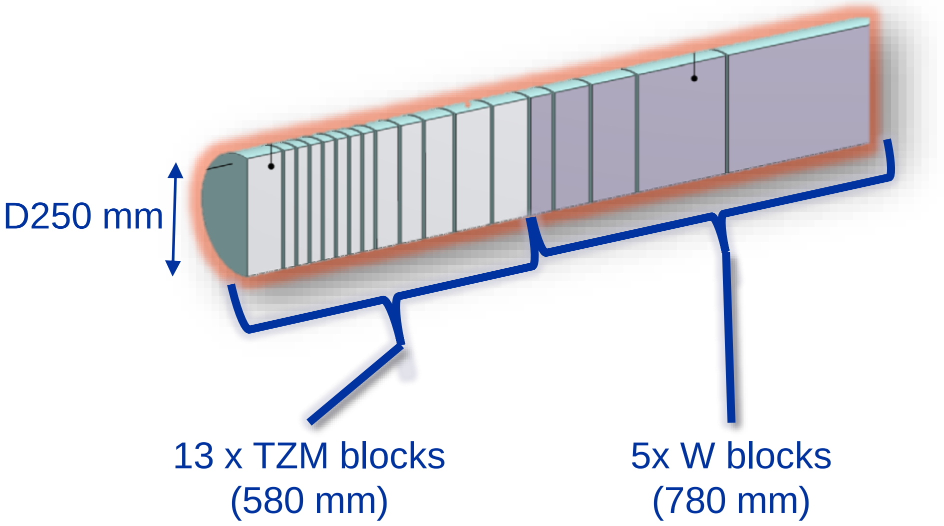
This is just a conceptual design. It is not optimized

https://doi.org/10.1103/PhysRevAccelBeams.22.113001

BDF Target CDS design

Core geometry & materials

- **250 mm Diameter Target**
- **580 mm of TZM (13 blocks)**
  - Reasonable high density & Z (Z=42, ρ=10.2g/cm^3)
  - Higher strength, better creep resistance, higher recrystallisation temp wrt Mo.
  - Absorbs most of the beam power.
- **780 mm of W (5 blocks)**
  - High Z and density (Z=74, ρ=19.3g/cm^3)
  - Good radiation damage resistance
- **95 mm of water (5 mm * 19 channels)**
  - Required to cool the blocks
- **54 mm of Ta2.5W cladding (1.5 mm * 2 * 18 blocks)**
  - To avoid corrosion-erosion of the core materials



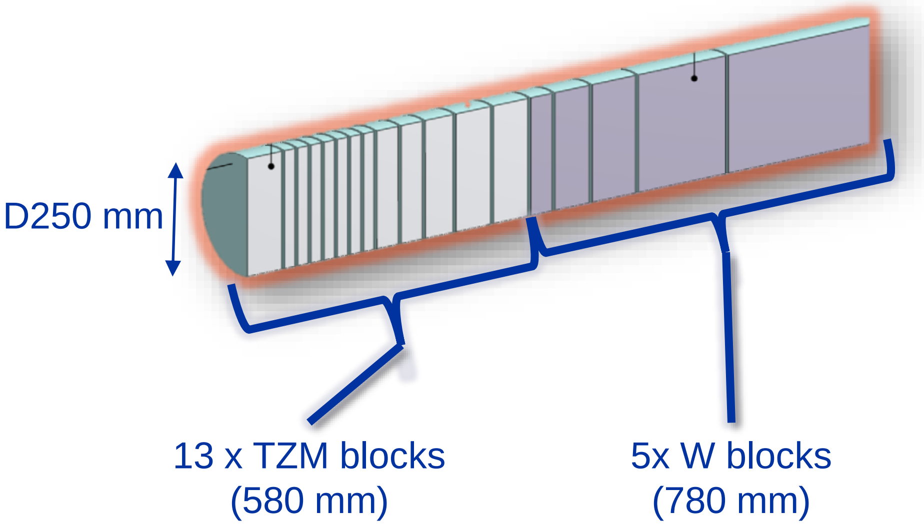
Target Core with reasonable physics performance & that allows diluting (longitudinally) the energy deposition

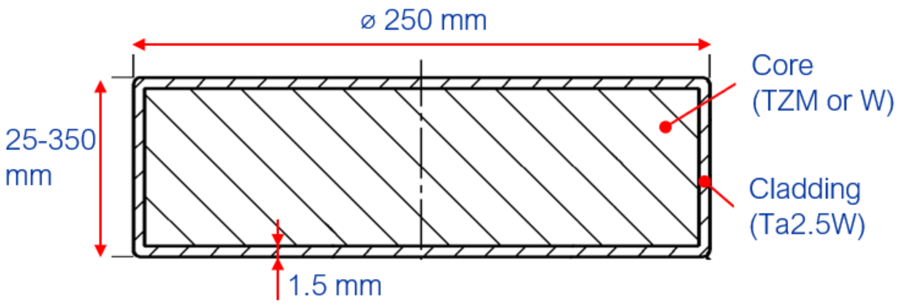
https://doi.org/10.1103/PhysRevAccelBeams.22.113001

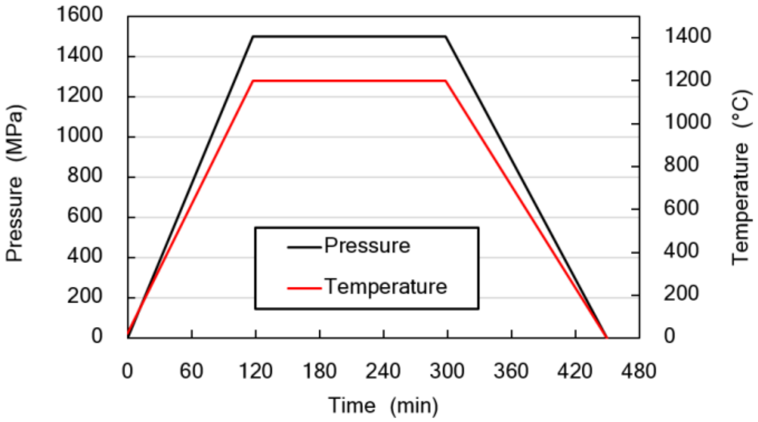
BDF Target CDS design

Manufacturing technology

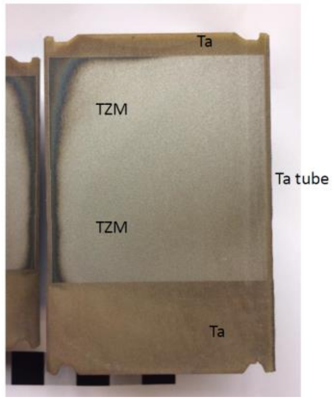
- Water-cooling circuit → Corrosion-erosion → Core cladded with Ta2.5W (1-1.5 mm thickness) by means of Hot Isostatic Pressing (HIP)
- HIP (Hot Isostatic Pressing)
- Diffusion bonded at High pressure and high temperature
- Key manufacturing feature. Essential for good heat transfer to the water circuit (cooling)







TZM containing capsule (electro eroded)

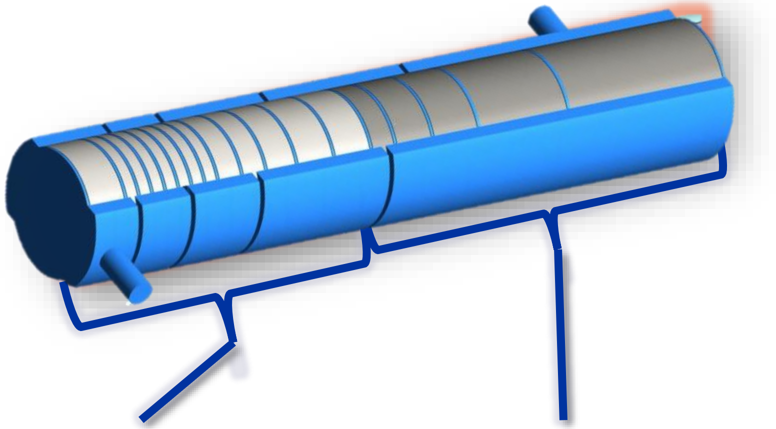


https://doi.org/10.1103/PhysRevAccelBeams.22.113001

BDF Target CDS design

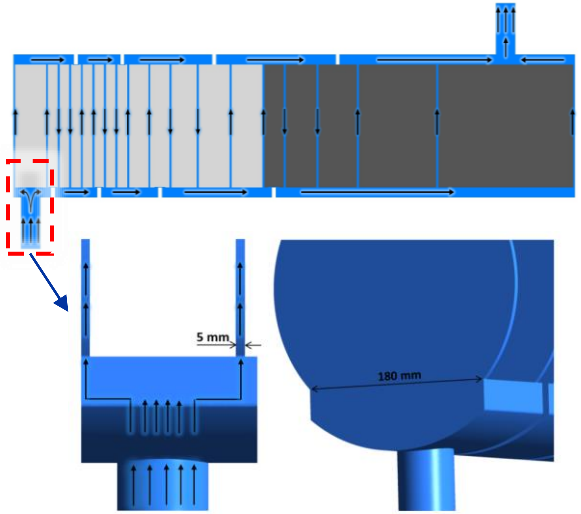
Cooling

- **95 mm of water (5 mm * 19 channels)**
  - Water → better cooling for identical flow rate wrt He, Air.
  - 22 bar → higher boiling threshold
  - 5 m/s → high heat convection coefficient and limited erosion
  - ~660l/min → To extract ~305kW of heat.
  - Circuit Serpentine configuration with 2 parallel channels
    - Serpentine → high speed at moderate flow rate
    - 2 parallel channels → pressure drop reduction & reduce failure in case 1 channel is blocked.



13 x TZM blocks (580 mm)

5x W blocks (780 mm)



CDS Design

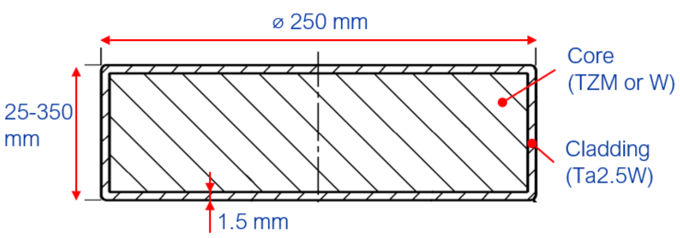
https://doi.org/10.1103/PhysRevAccelBeams.22.113001

Water-cooled, Ta-cladded TZM + W Core

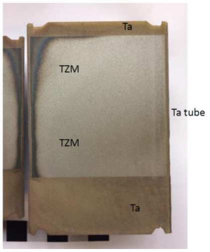
- TZM: Absorbs most of the power. Higher strength, better creep resistance, higher recrystallisation temp wrt Mo.
- W: Good radiation damage resistance. Best for physics.
- Ta2.5W: To avoid corrosion-erosion of the core materials
- Cooling: 22 bar, 5 m/s, ~660l/min, ~305kW of heat.

Manufacturing

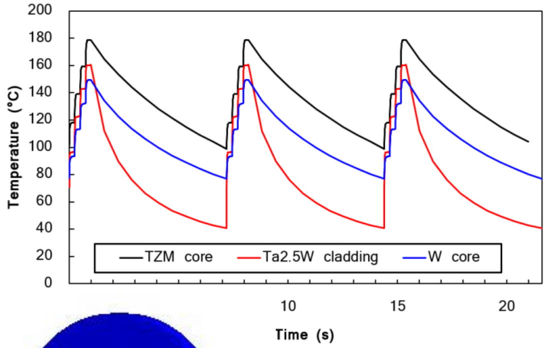
- Forged TZM and sintered W (single blocks)
- Diffusion bonding with cladding via Hot Isostatic Pressing

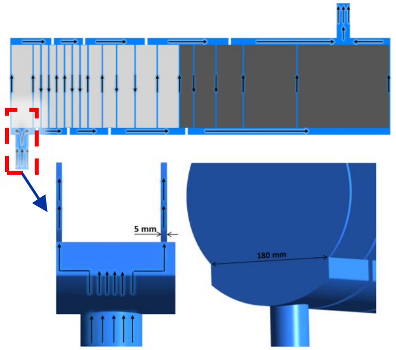


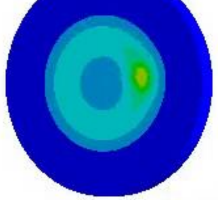
TZM containing capsule (electro eroded)



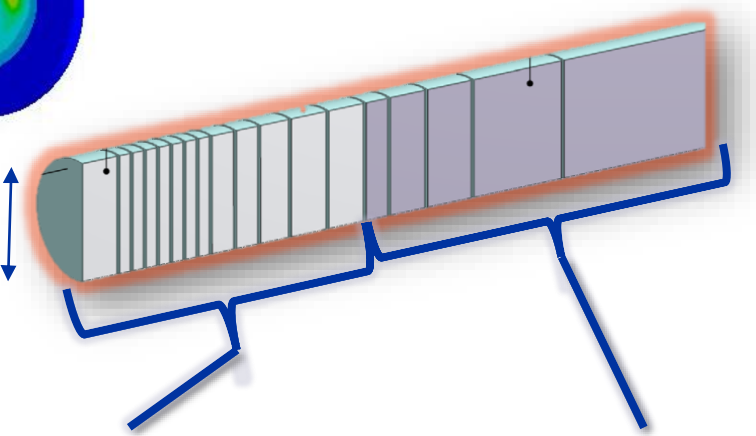
Target Core with reasonable physics performance & that allows diluting (longitudinally) the energy deposition







D250 mm



13 x TZM blocks (Z=42, ρ=10.2g/cm^3)
(580 mm)

5x W blocks (Z=74, ρ=19.3g/cm^3)
(780 mm)

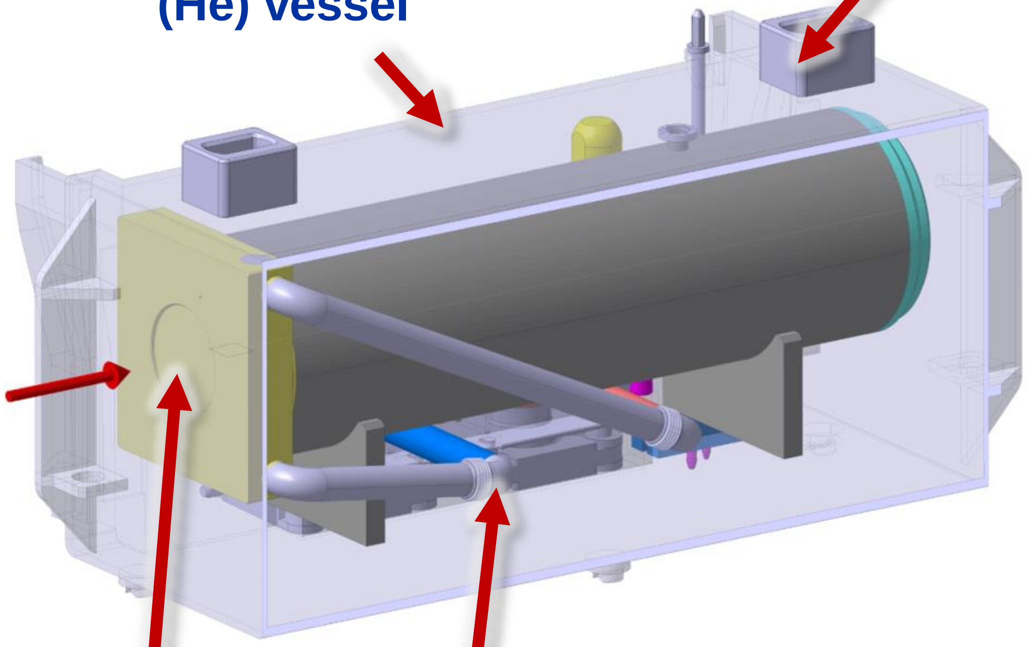
Key components

Remote handling & waste disposal features

Cooling

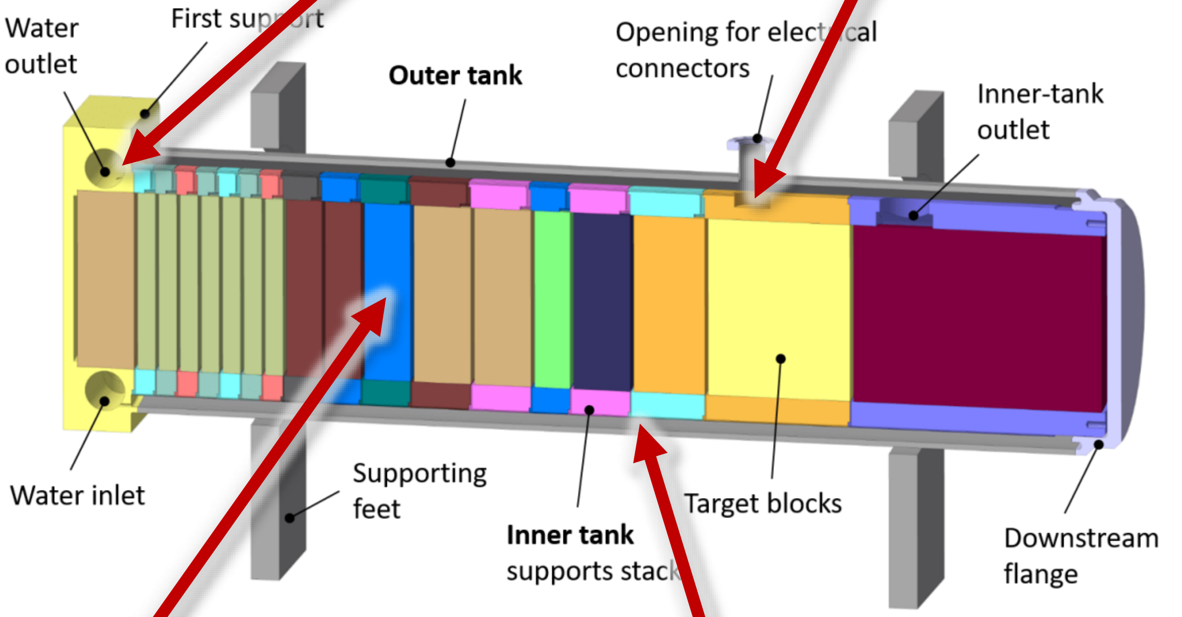
Instrumentation & integration

2nd outer Target (He) vessel



Beam windows

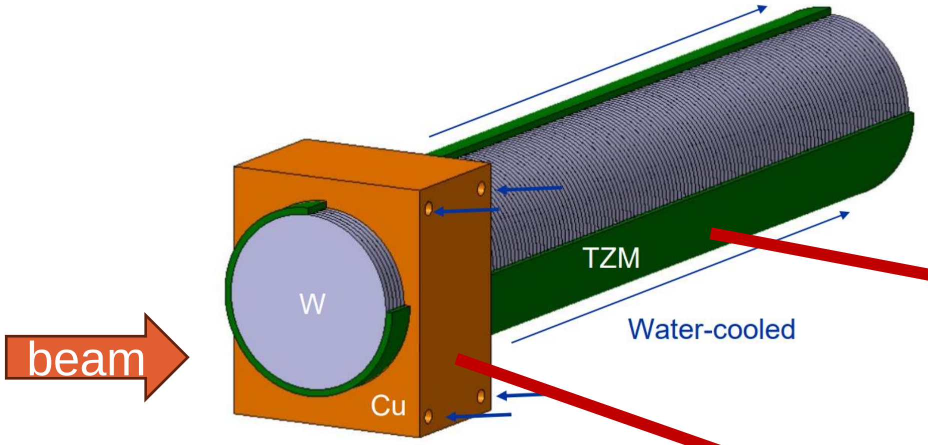
Services connections



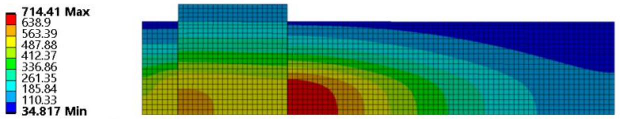
Target core

Target inner vessel

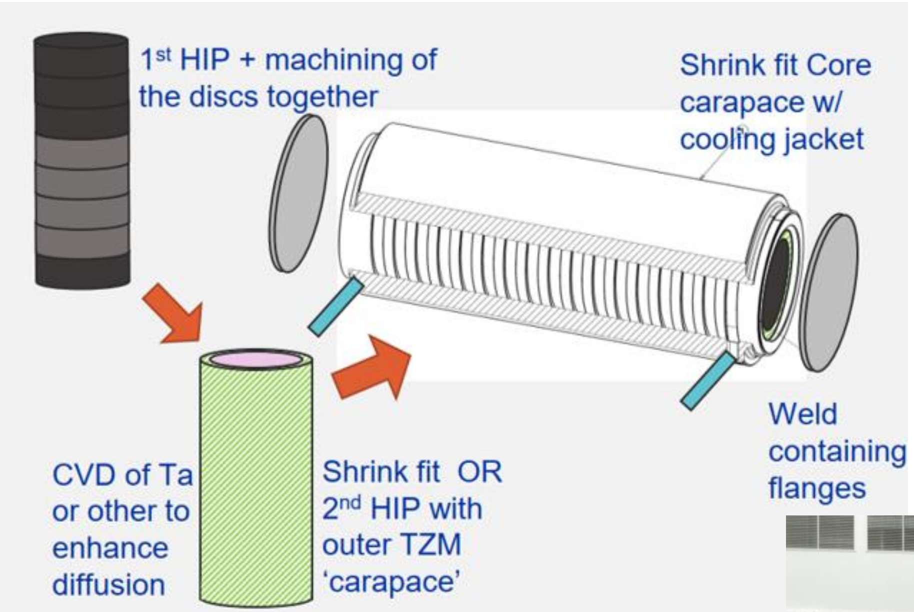
Enclosed compact Cu + W Target



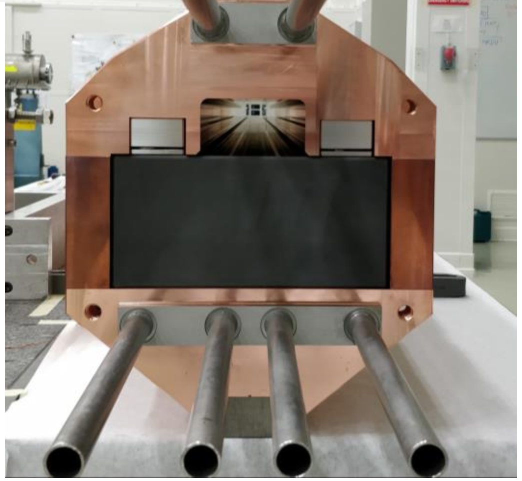
This is just a conceptual design. It is not optimized



Temperature [C°]



Cu-SS HIP bonding for the SPS internal dump (TIDVG5)



Cu+W target :

- Removes water from beam path (radiolysis)
- Keeps physics performance
- Reduces decay heat
- **Increases T and stress**

Hot isostatic pressing assisted diffusion bonding for application to the Super Proton Synchrotron internal beam dump at CERN, S. Pianese, A. Perillo Marcone et al, https://doi.org/10.1103/PhysRevAccelBeams.24.043001

Ta2.5W cladding

Manufacturing know-how

Ta2.5W cladding

Tantalum

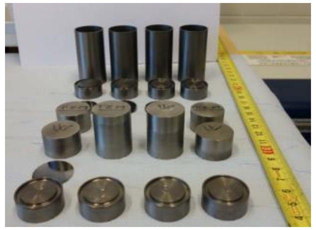
- ✓ Refractory with high melting point, conductivity, strength and ductility
- ✓ High density
- ✓ Low CTE
- ✓ Full solubility with Molybdenum and Tungsten
- ✓ Very good corrosion-erosion resistance in water medium
- ✓ Sound experience in other Targetry applications (ISIS, LANSCE, KENS…)

Ta-2.5W: Solution strengthened Ta alloy with W

- Higher strength yet still ductile
- Enhanced hydrogen embrittlement resistance

- **Preliminary HIP and SPS Cladding trials w/ Ta2.5W & core materials**
- **Prototype manufacturing**
- **Extensive material & HIPed cladding characterization**
- **Prototype beam tests**
- **Post Irradiation Examination**

Ta2.5W cladding



Preliminary HIP and SPS Cladding trials w/ Ta2.5W

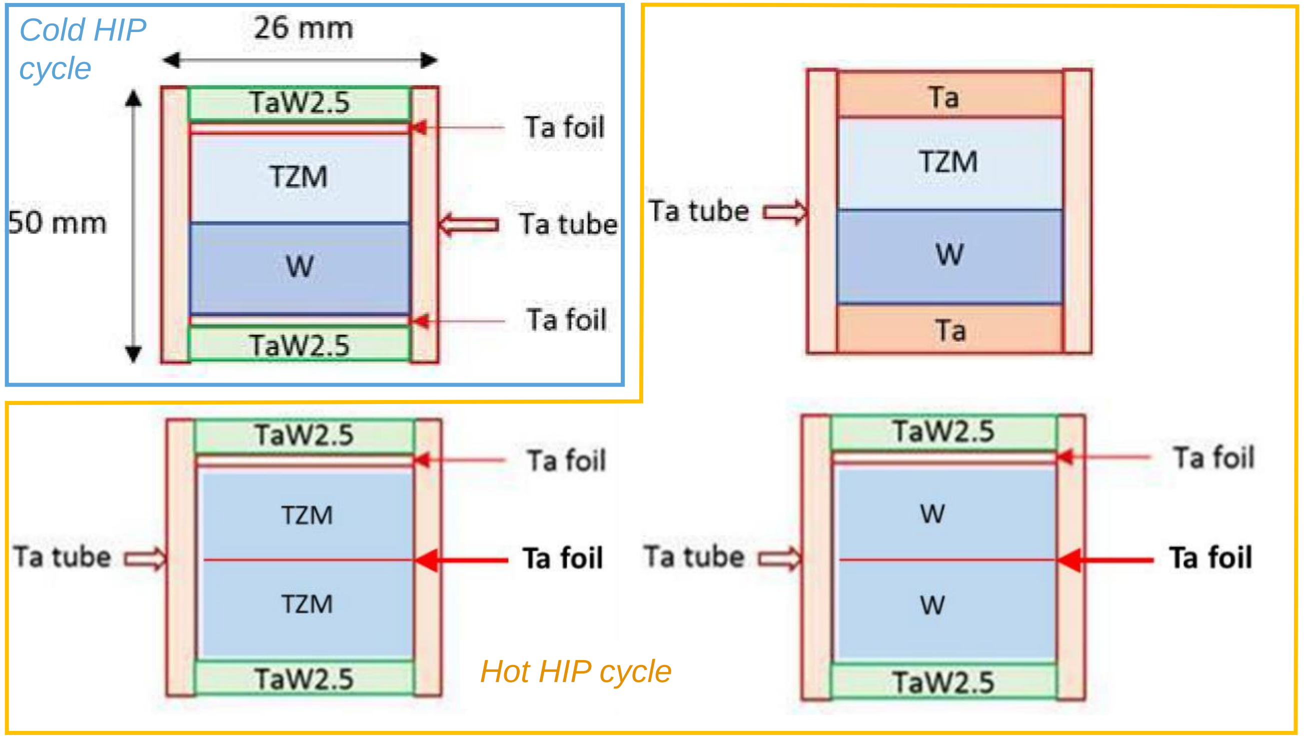
- Assembly with EBW & joining via hot isostatic pressing (HIP)

Scope

- Comparing two Heating cycles (1200°C/150MPa 1400°C/200MPa)
- TZM//TZM & W//W via HIP w/wo interface Ta Foil
- Ta2.5W vs Ta cladded on W and TZM, w/wo interface foil

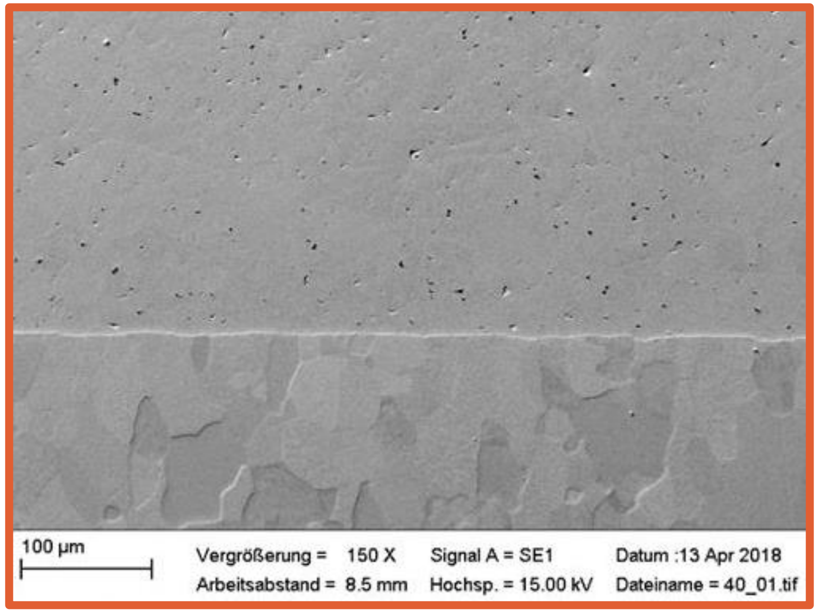
Methodology

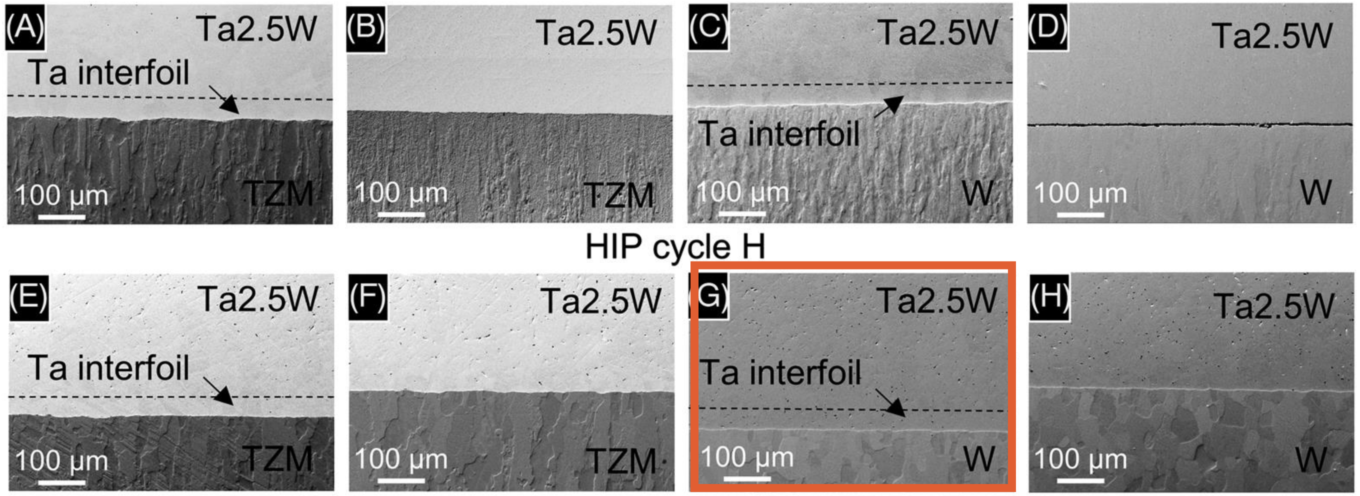
- Microstructure w/ optical and electron microscopy
- k (RT-300°C) and ρ measurements
- Mechanical characterization of interfaces

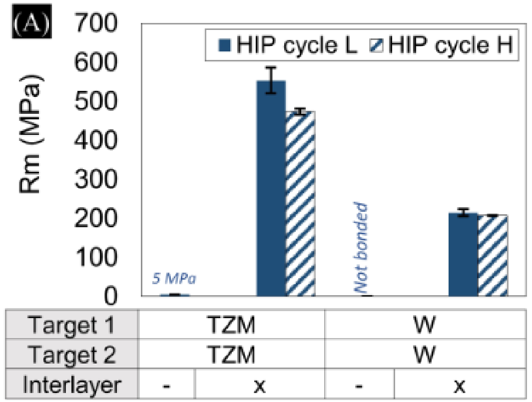


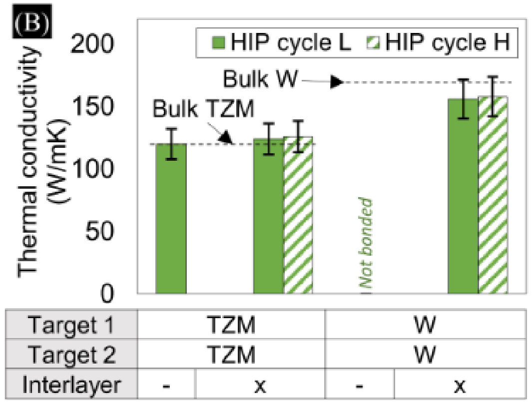
Ta2.5W cladding

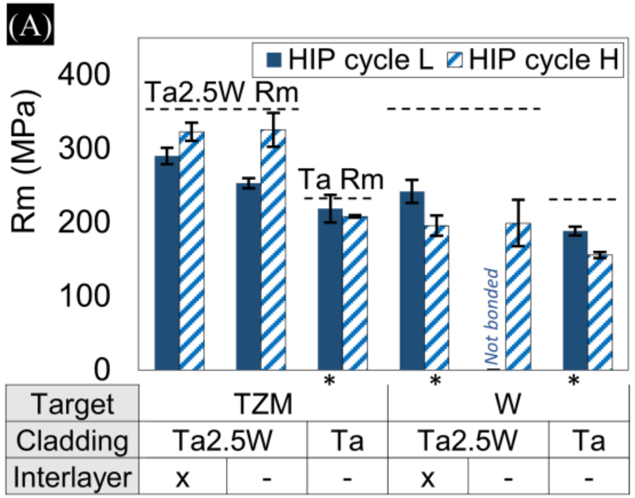
Very difficult to see any diffusion layer !

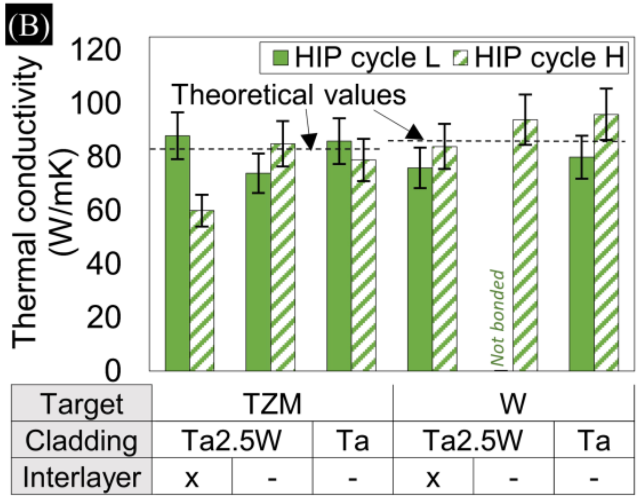












Microstructural observations, tensile strength and conductivity measurements for some of the studied interfaces (https://doi.org/10.1002/mdp2.101)

Ta2.5W cladding – LOCA

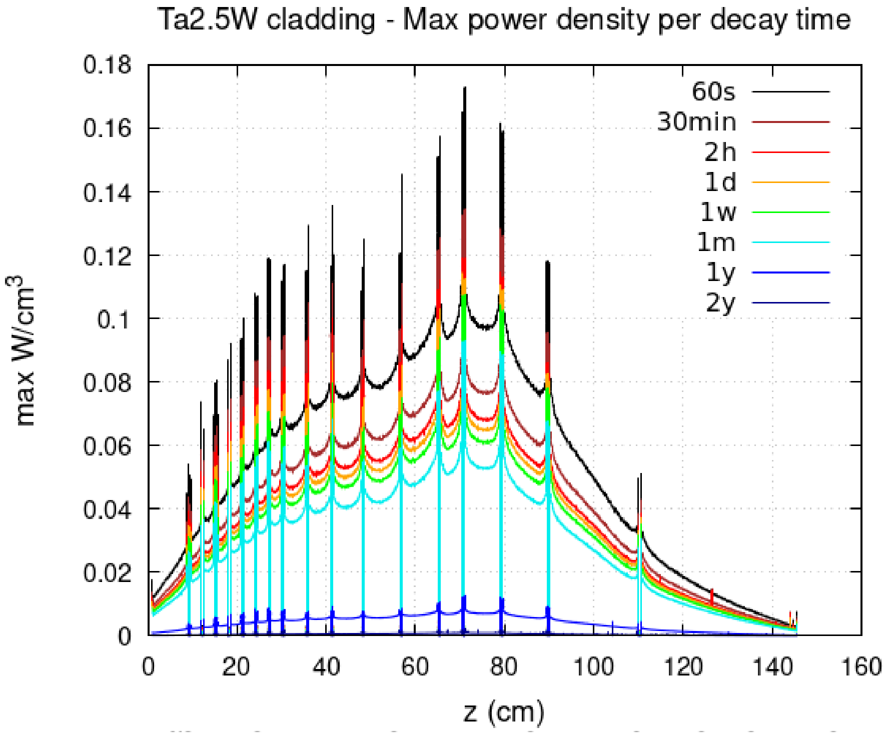
- (Loss-of-Coolant Accident scenario) LOCA hypothetical scenario used as a criterion for assessing the safety of a nuclear installation during its design phase.

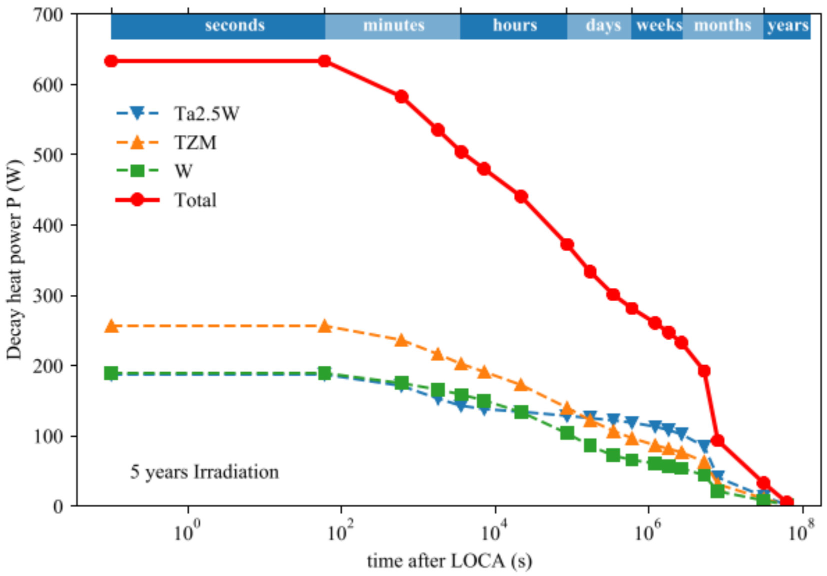
→ Strong implications on the classification of the facility.

- Thermo-mechanical simulations to determine the temperature evolution of the target in a 2 years scenario after the accident.

- Depending on the assumptions, T > 300 C may be reached for prolonged periods ((O)weeks)

Mena R., Ximenes R.F. and Calviani M. (2022), Loss-of-Coolant-Accident study for the Beam Dump Facility at CERN, NURETH-19 Conference



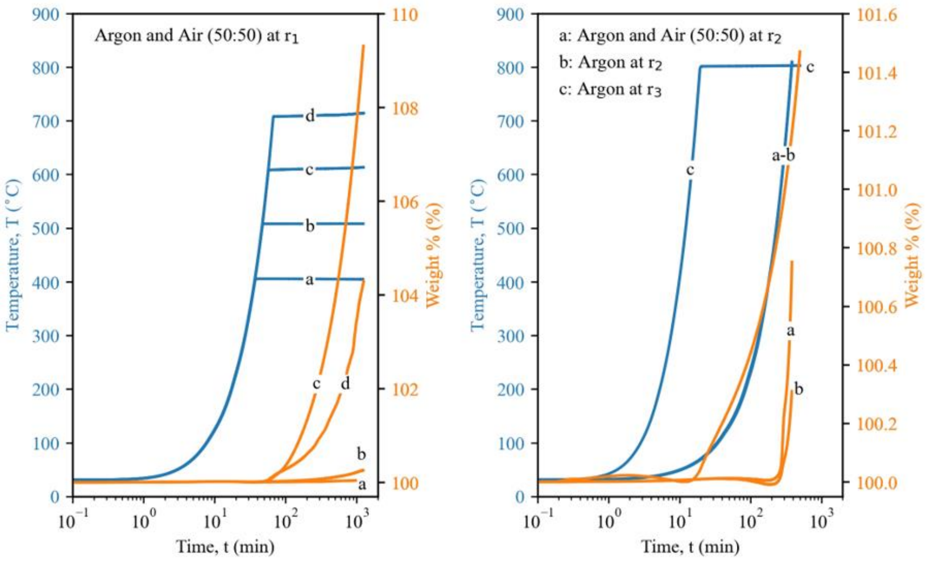


Ta2.5W cladding – LOCA

- Potentially degradation of the material through oxidation with LOCA.

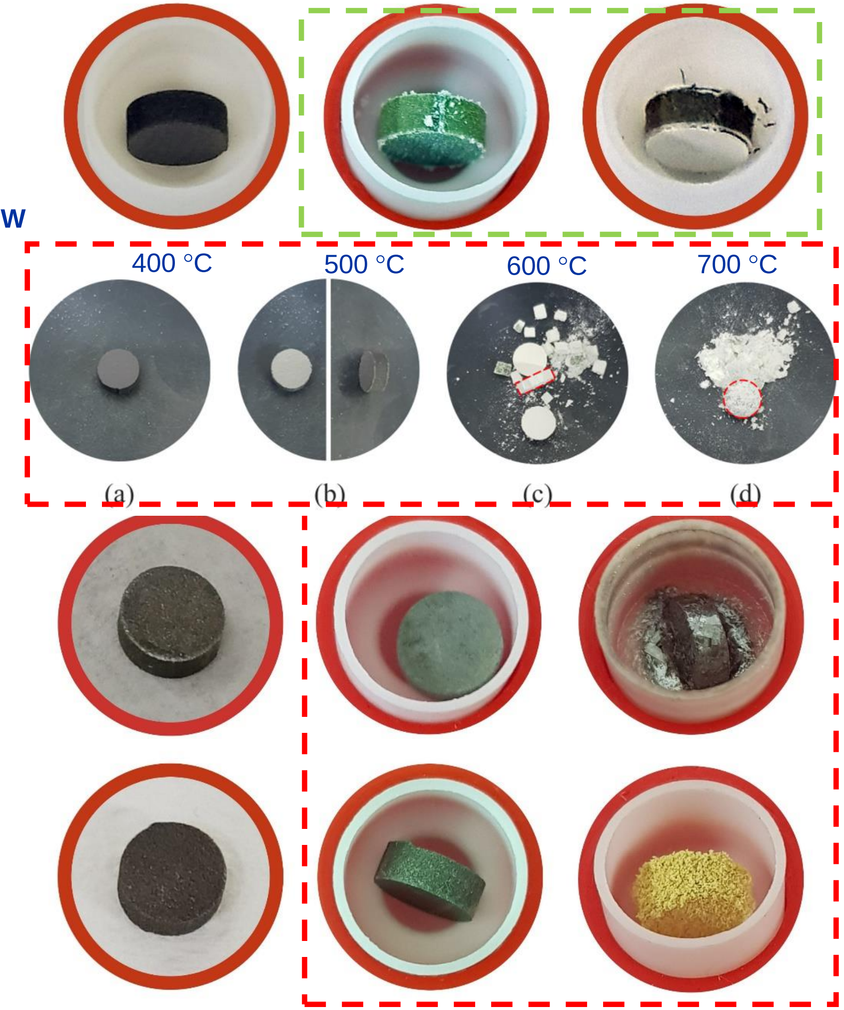
→ Campaign to assess the onset for extensive oxidation and formation of volatile oxides

- Thermogravimetric analyses (TGA) performed for Ta2.5W, TZM and W in the range of 400-800 C under active and inert atmospheres.



r1 = 10
r2 = 2
r3 = 40
[°C/min]

Visual inspection of the samples before and after oxidation for different temperatures.



Raw sample

800 °C at 2 °C/min

800 °C at 40 °C/min

Inert Atmosphere (argon 6.0)

Ta2.5W

400 °C

500 °C

600 °C

700 °C

TZM

W

Active Atmosphere (50% argon: 50% air)

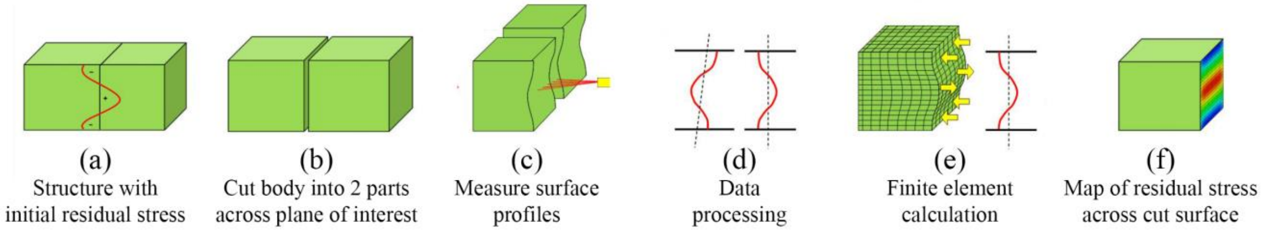
400 °C at 10°C/min x 7 days

800 °C at 2°C/min

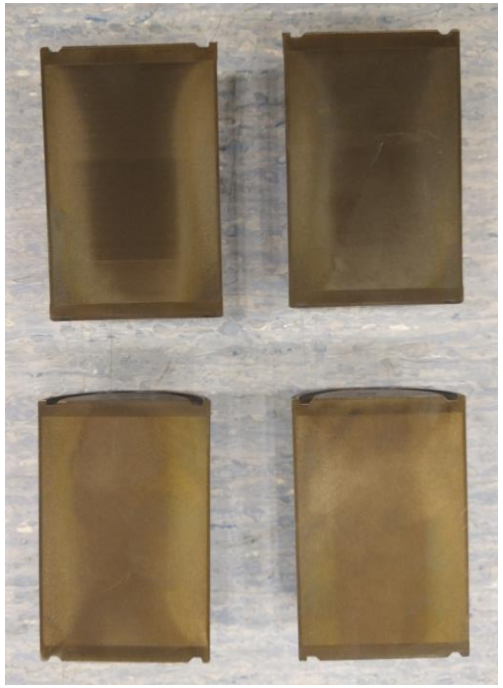
Nb-alloys cladding R&D

Residual stress

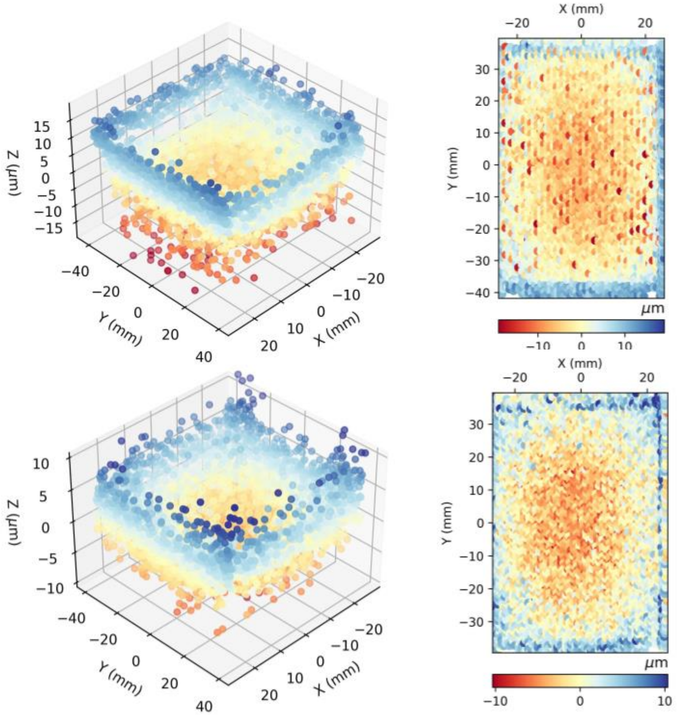
- Presence of residual stresses (RS) during the manufacturing of the target blocks via Hot Isostatic Pressing (HIPing).
- RS defines the onset for plastic deformation and eventually material failure
- **Purpose:** quantify the RS in the BDF target blocks
- Contour method* employed to measure the RS in the BDF target blocks. Ongoing FE model calibration.


(a) Structure with initial residual stress
(b) Cut body into 2 parts across plane of interest
(c) Measure surface profiles
(d) Data processing
(e) Finite element calculation
(f) Map of residual stress across cut surface

The contour method and its different steps to obtain the residual stresses. Adapted from [StressMap 2018]



Resulting left and right parts after EDM cutting (Top) Block 3 and (Bottom) Block 4



Average flatness measurements of the resulting surfaces (Top) Block 3 and (Bottom) Block 4

* Prime, M. B., 2001, Cross-sectional Mapping of Residual Stresses by Measuring the Surface Contour After a Cut, *Journal of Engineering Materials and Technology* 123(2):162–168