An Overview of ISIS Neutron Spallation Targets

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AHIPS-2024

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40 Years of ISIS Neutron and Muon Source

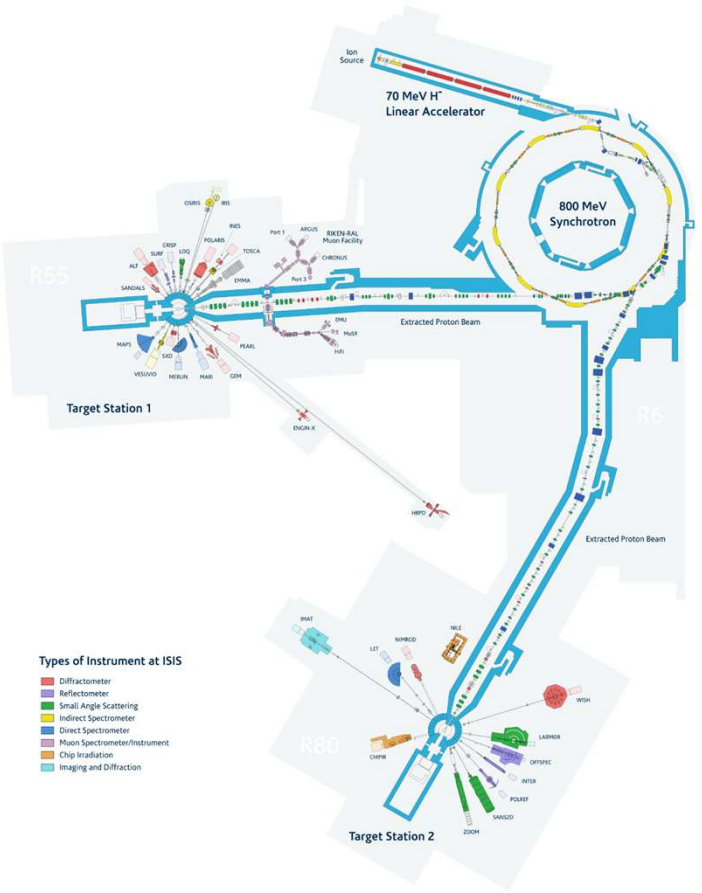
Science and Technology Facilities Council

ISIS Neutron and Muon Source

Introduction

- ISIS Facility – 40th year
- Overview of TS1 Target - History & Evolution
- Overview of TS2 Target - History & Evolution
- Target Plate design and manufacturing
- ISIS Target Manufacturing Facility
- ISIS 2….
- Summary

ISIS Neutron and Muon Source



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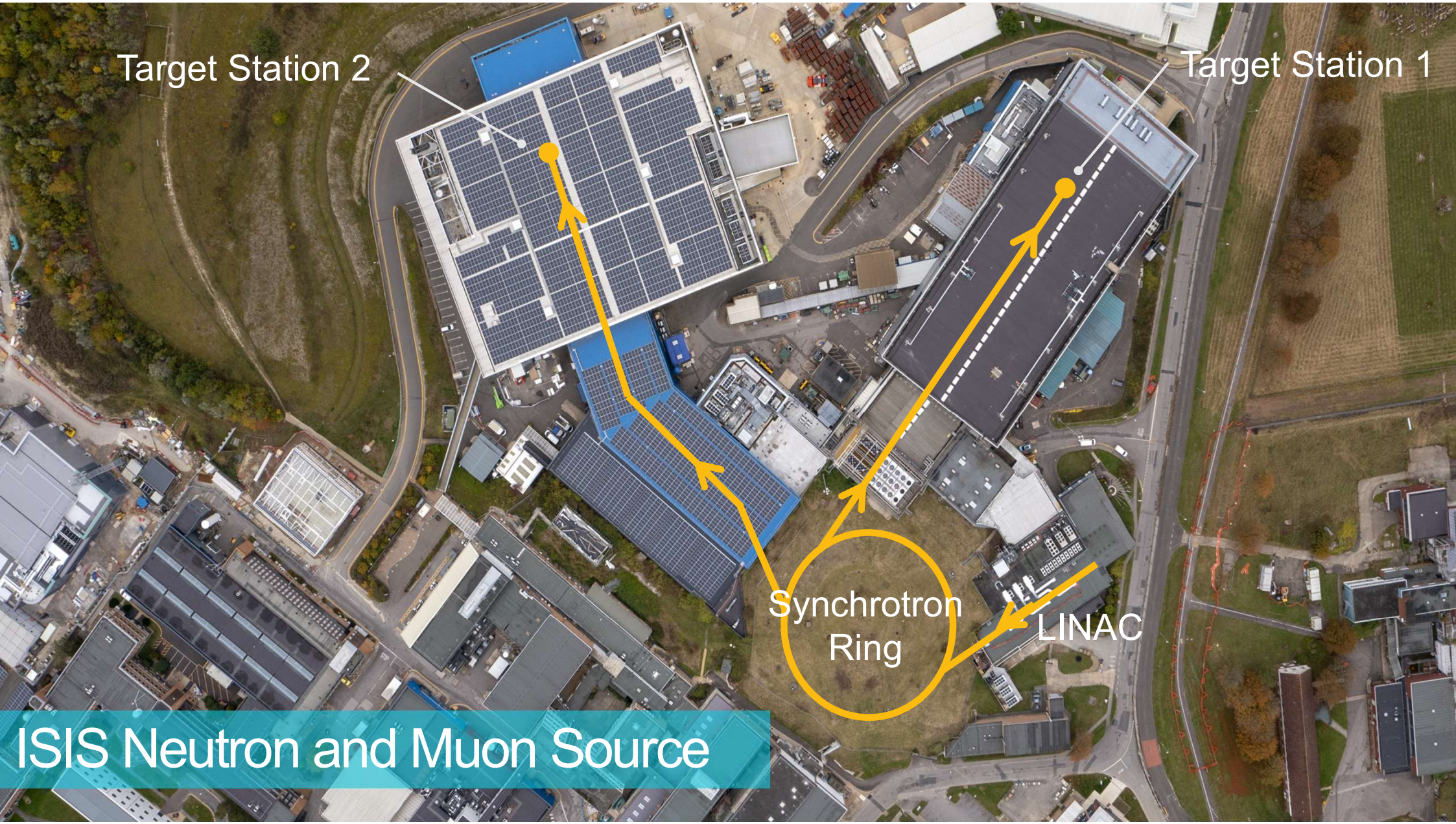
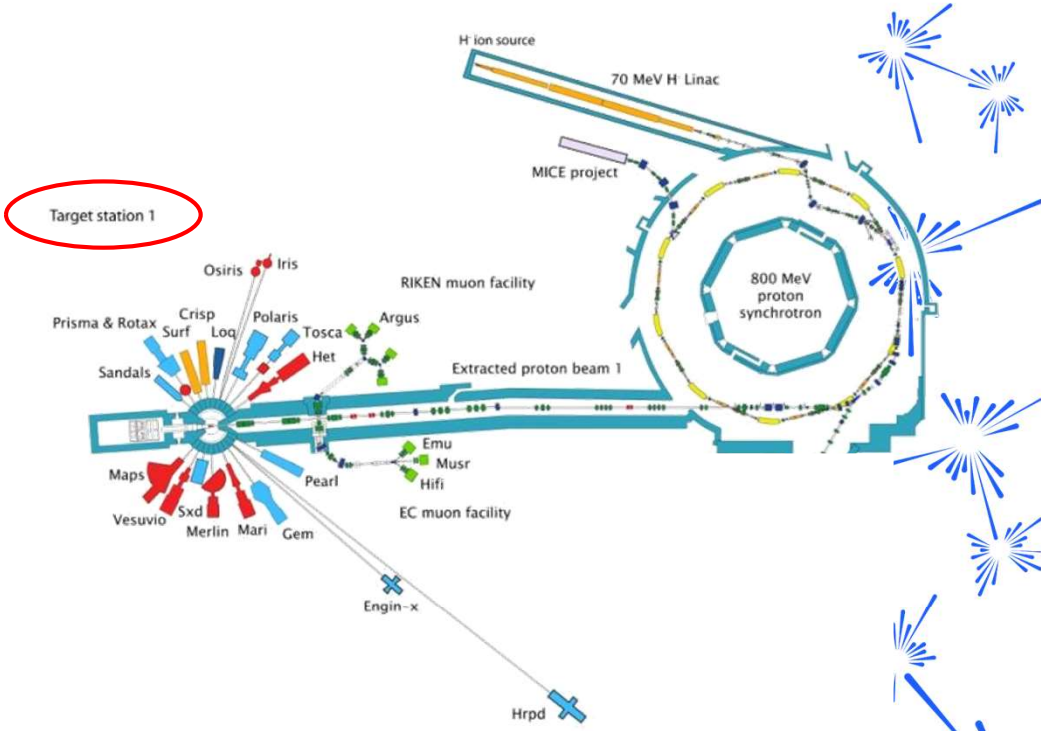

Target Station 2
Target Station 1
Synchrotron
Ring
LINAC
ISIS Neutron and Muon Source

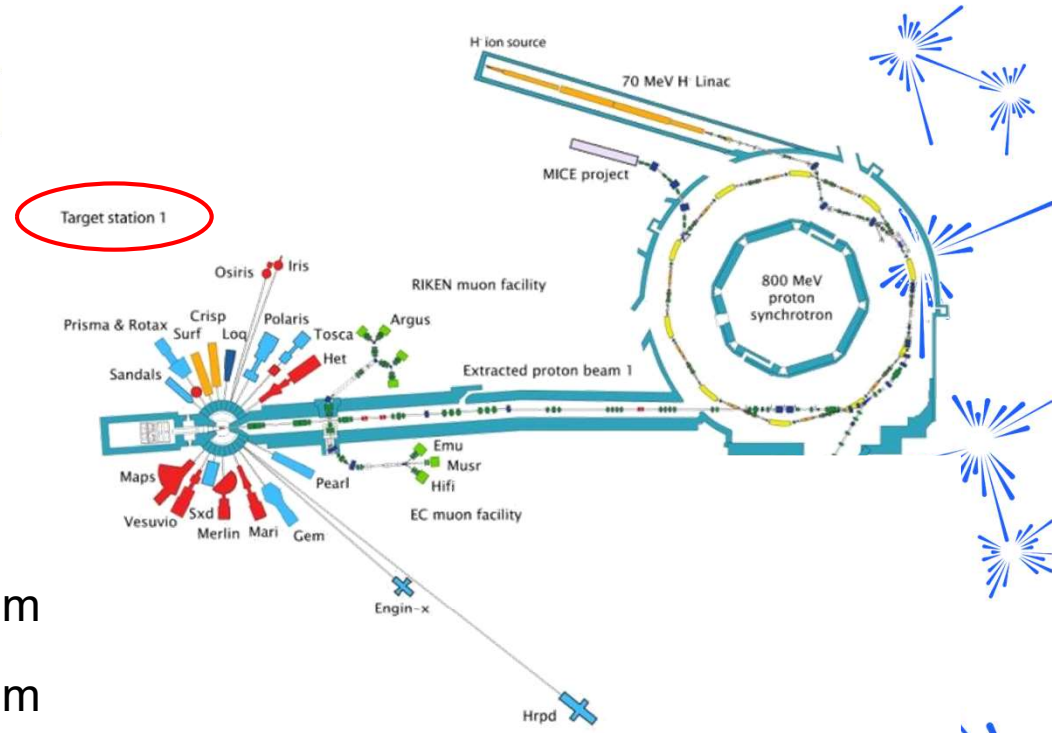
ISIS Overview – Synchrotron

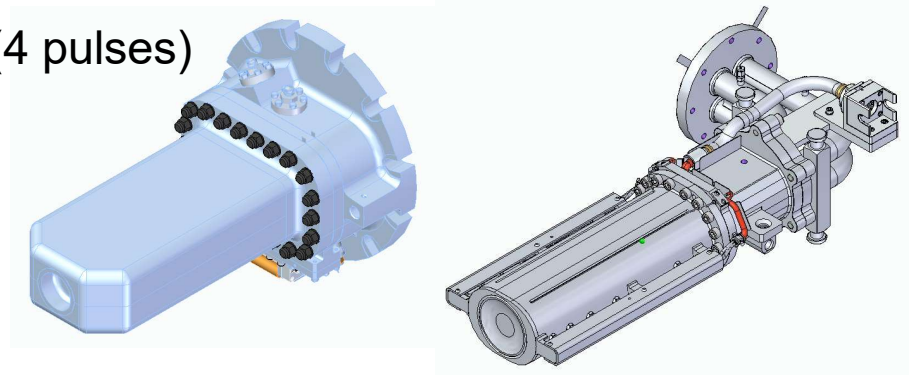
- 800 MeV, 50 Hz, 200μA (170 KW) proton beam
- Operated with single Target Station for 25 years.
- TS1 Target was designed to provide tight-pulse shapes and high-flux of epi-thermal neutrons.
- Built to service a broad science programme.
- Second Target Station operational since 2009
- 160μA to TS1 (4 pulses), 40μA to TS2 (I pulse)
- Upgrades to synchrotron give the potential for 300μA
- Continue to operate @ 200μA (target limited – TS2)
- Briefly operated @ 245μA before long shutdown.



ISIS Overview – Target Station 1

- TS1 fully operational since 1985 through 4 generations of target design
- Gen 1 - U/Zr Alloy – 24 plates
- Gen 2 – Tantalum – 24 plates
- Gen 3 - W/Ta – 12 Tungsten plates clad in Tantalum
- Gen 4 - W/Ta – 10 Tungsten plates clad in Tantalum
- Operates @160μA (128 KW), 800 MeV, 40 Hz (4 pulses)
  >5-year service life (latest design just installed)

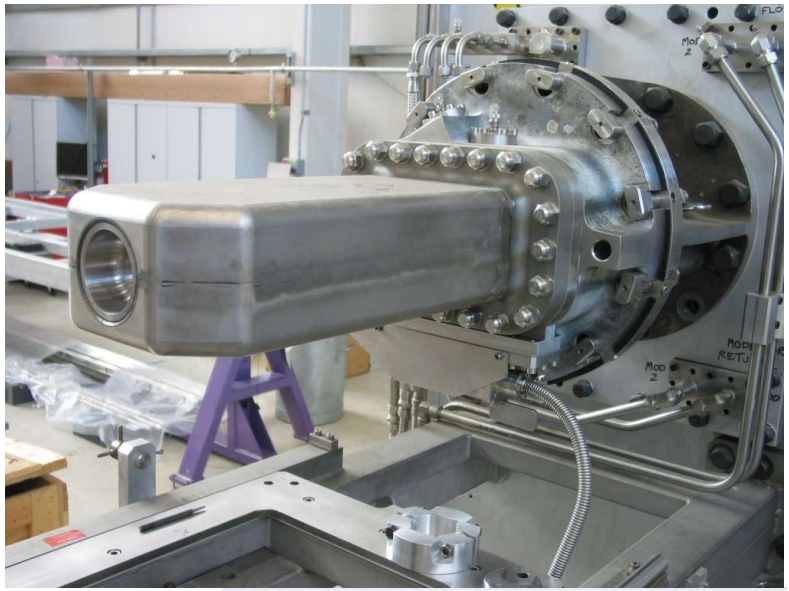




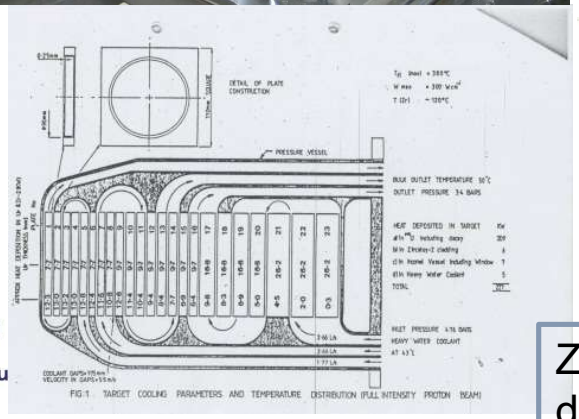
Generation 1-3

Generation 4

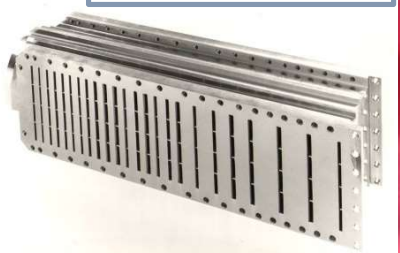
ISIS TS1 Targets



- Uranium targets (#1 to #9)
  - 1984 to 1995
  - Total of 9 Uranium targets all run for very short periods of time due to failure by radiation damage
  - Neutrons ☑ Lifetime ☒



Target Module



Zircaloy clad Uranium discs in st. st. frames

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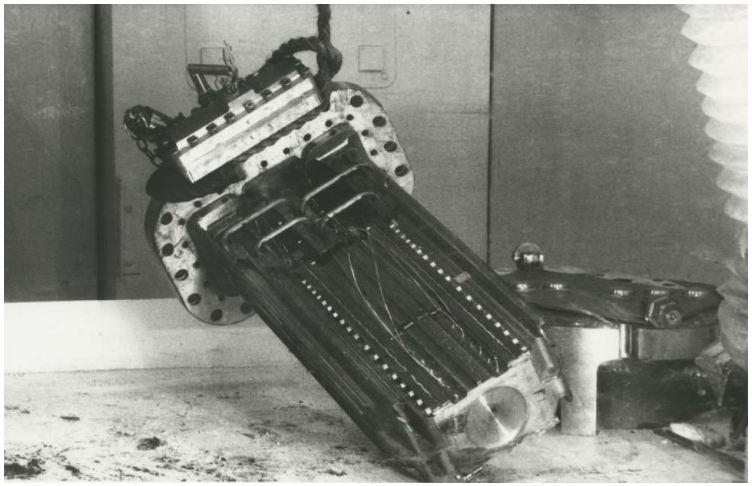
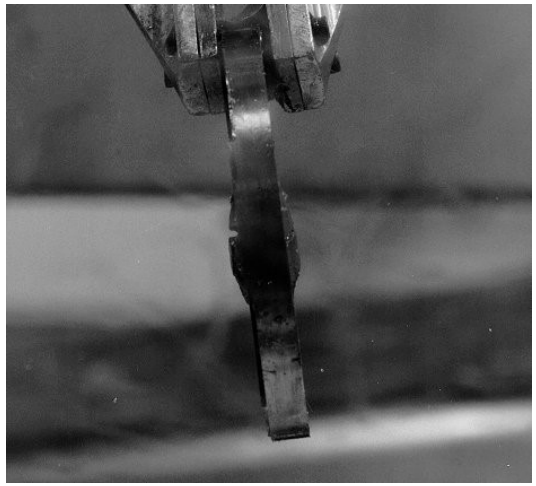
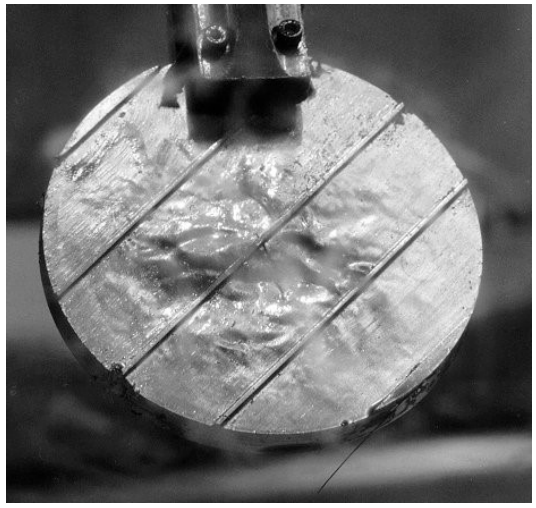
ISIS TS1 Targets

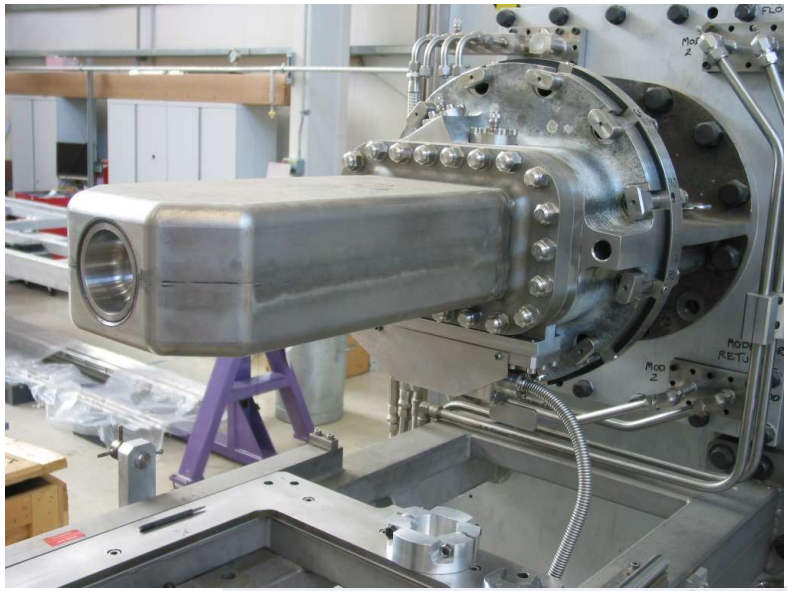




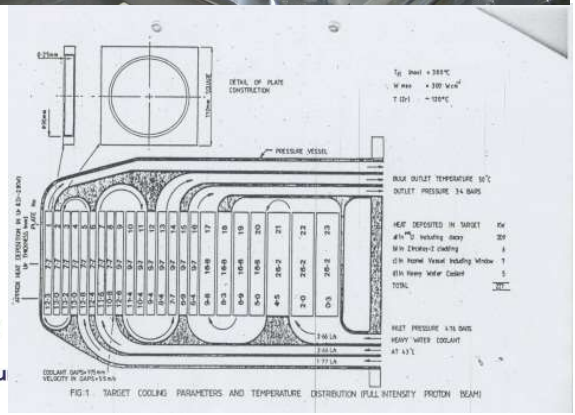


TS1 TARGET PIE clearly shows swelling of the Uranium causing the plates to deform

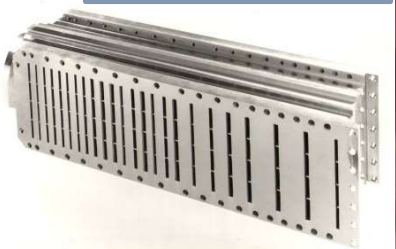
ISIS TS1 Targets



- Tantalum Targets (#1 to #4)
  - Tantalum targets #1 and #2 used at various times as a stop gap between Uranium targets
  - 1995 to 2001 Tantalum only running
  - A total of 4 Tantalum targets
  - Neutrons ☒ Lifetime ☑
  - Issue with decay heat



Target Module



Tantalum discs in st. st. frames

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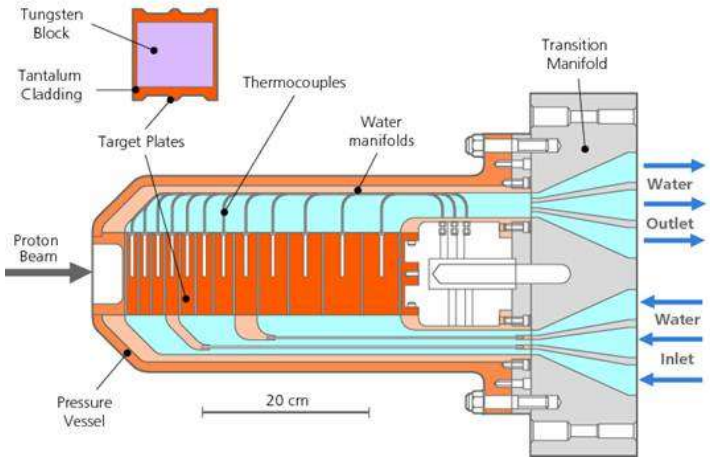
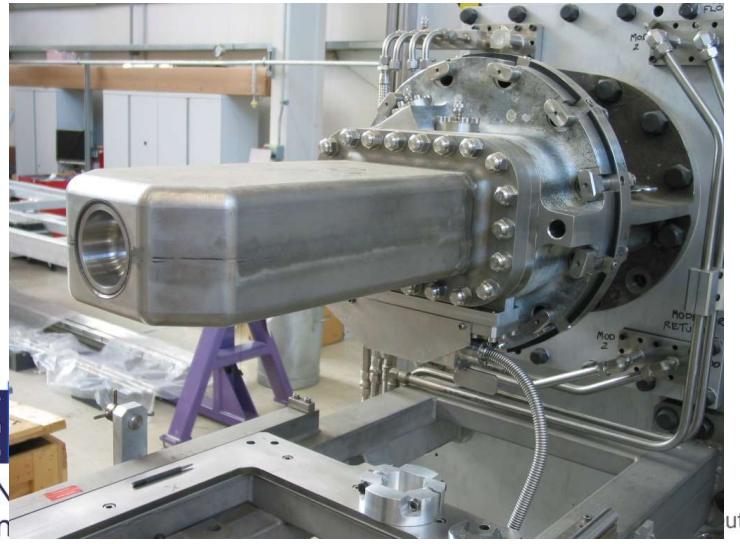
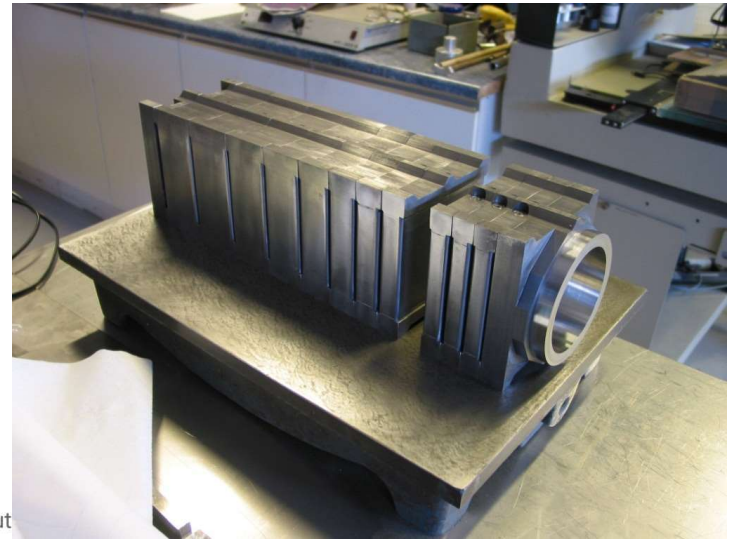
ISIS TS1 Targets



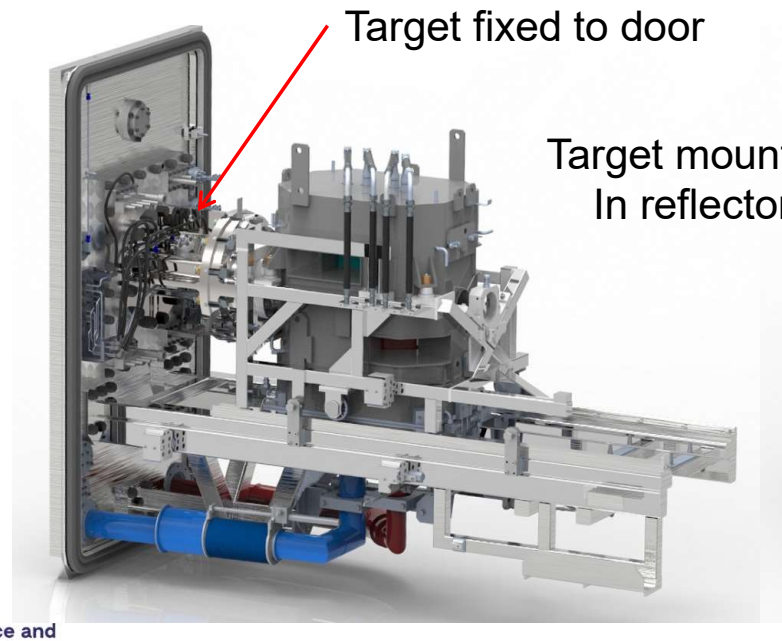
- Hybrid Targets #1 to #4
  - 2001 to 2020
  - 12 target plates – tungsten clad with tantalum
  - Neutrons ☑ Lifetime ☑



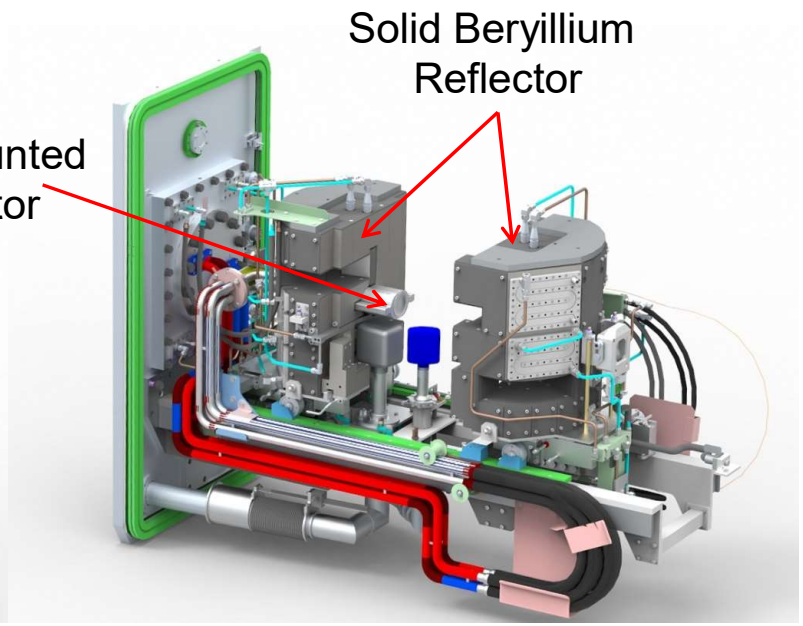


TS1 TRaM Upgrade Project

To enable the reflector to move apart, the target can no longer be attached to the TRaM door – now moves with the reflector.

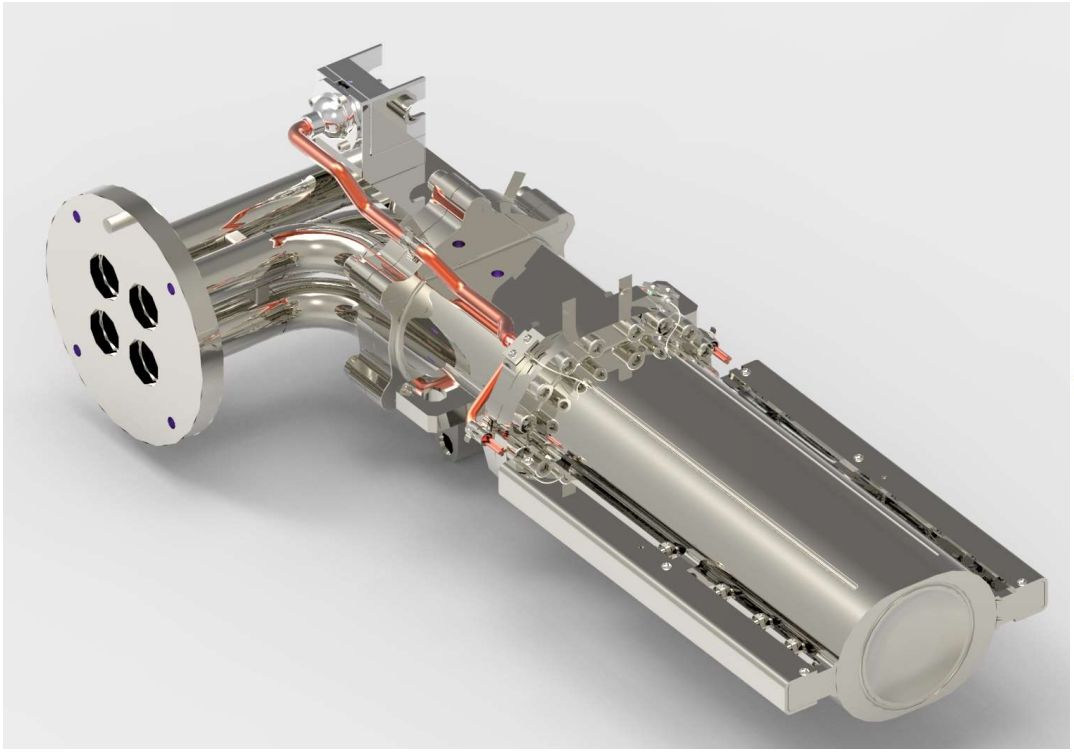


TS1 Old Design



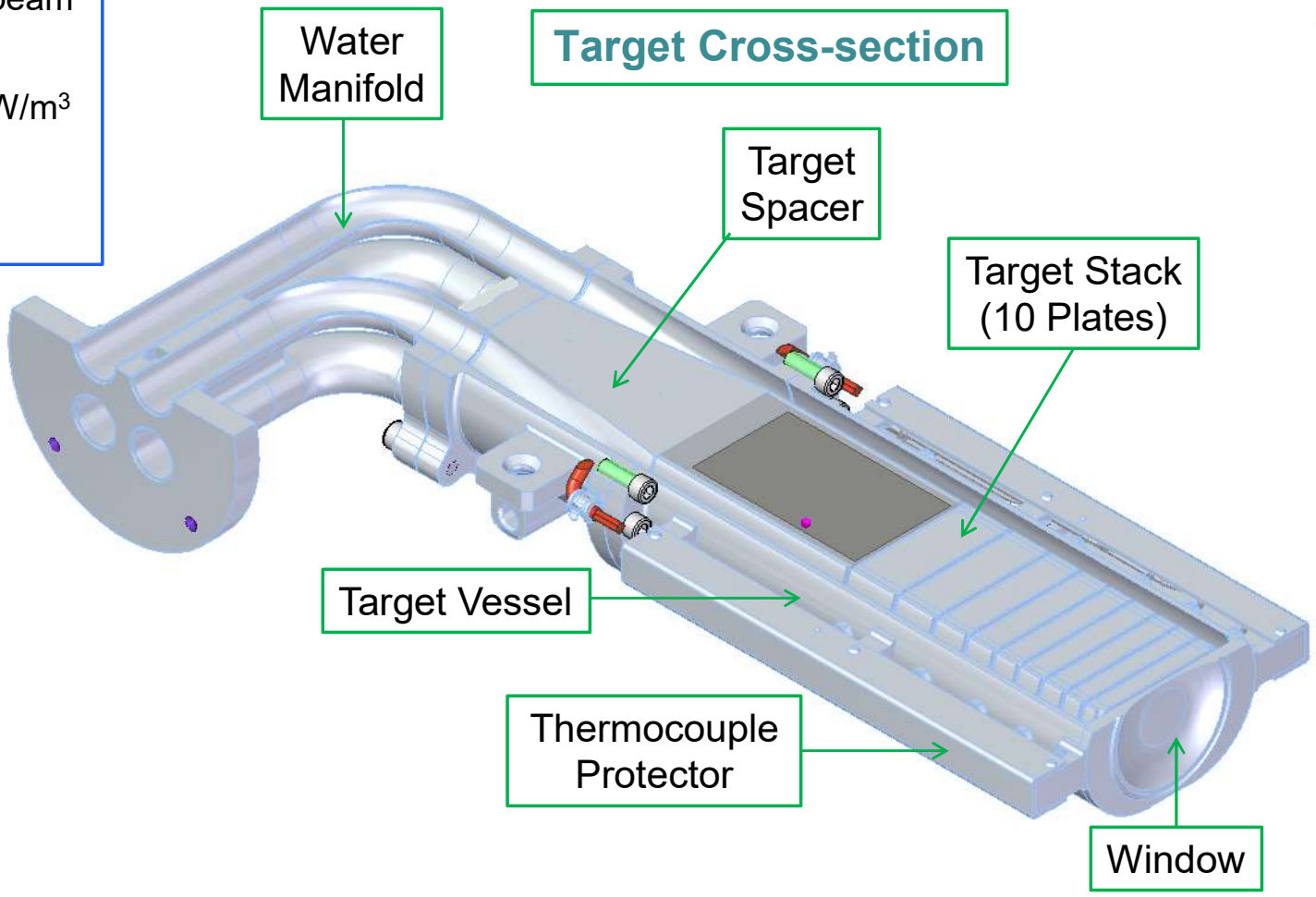
TS1 Project Design

ISIS TS1 Project Target – installed 2021



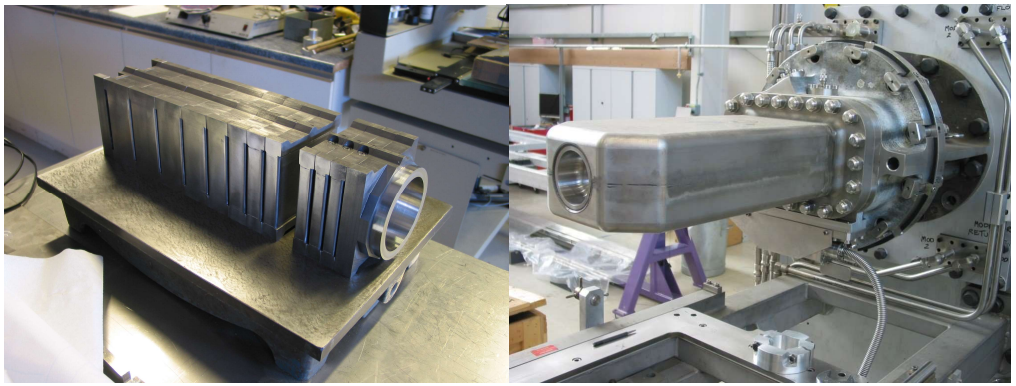
ISIS TS1 Project Target – installed 2021

- Beam sigma of ~17mm (overall beam spot diameter ~70mm)
- Maximum power density ~400MW/m^3
- Peak energy ~11MJ/m^3/pulse



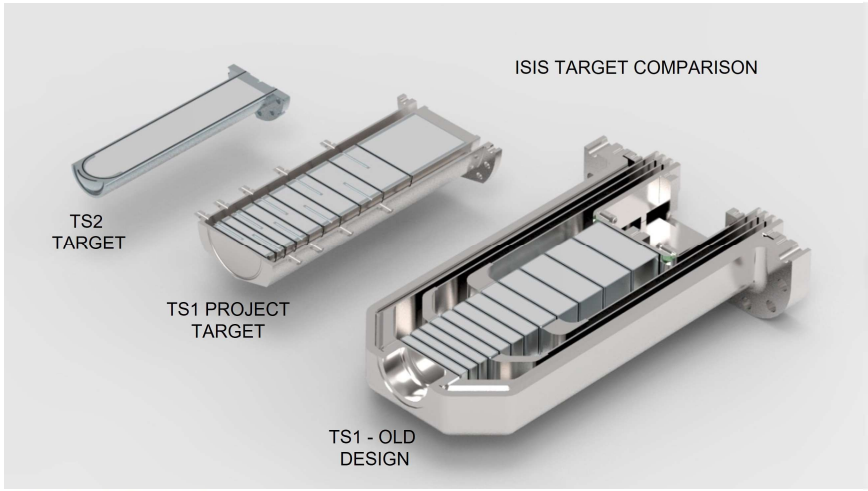
TS1 Neutron Spallation Targets

TS1 TARGET – OLD DESIGN



- <u>Basic elements of the new target design:</u>
- 10 target plates of varying thicknesses
- Tungsten Ø98 mm, Ta Cladding 1.5 mm, water channel width 2 mm
- Target Stack length 368mm
- 316L Target Vessel

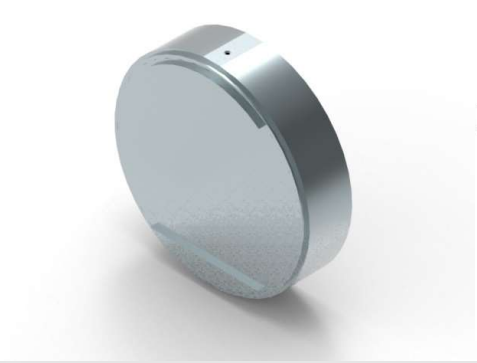
Mass of material (kg)	Current TS1	TS1 Project	Reduction
Stainless Steel	73.8	12.6	82.9%
Tantalum	32.7	14.5	55.7%
Tungsten	47.3	46.4	1.9%
Total	153.8	73.5	52.2%

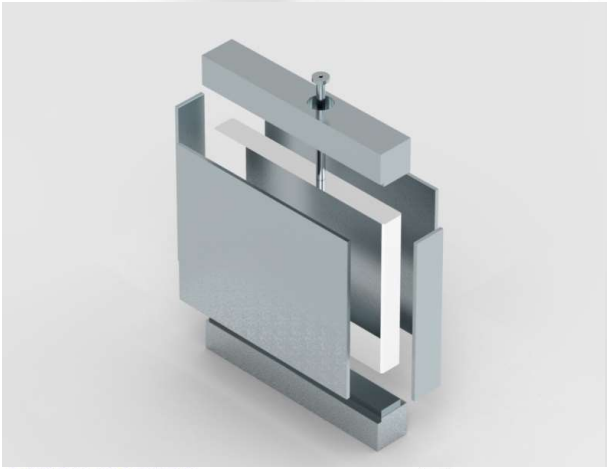


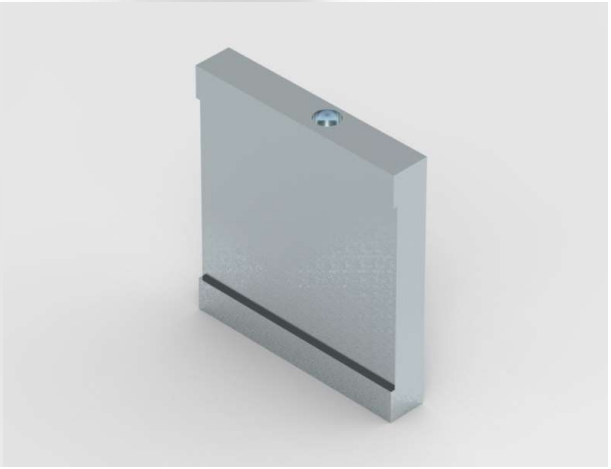
- Tungsten volume closely matches old design
- Tantalum reduced
- Stainless massively reduced

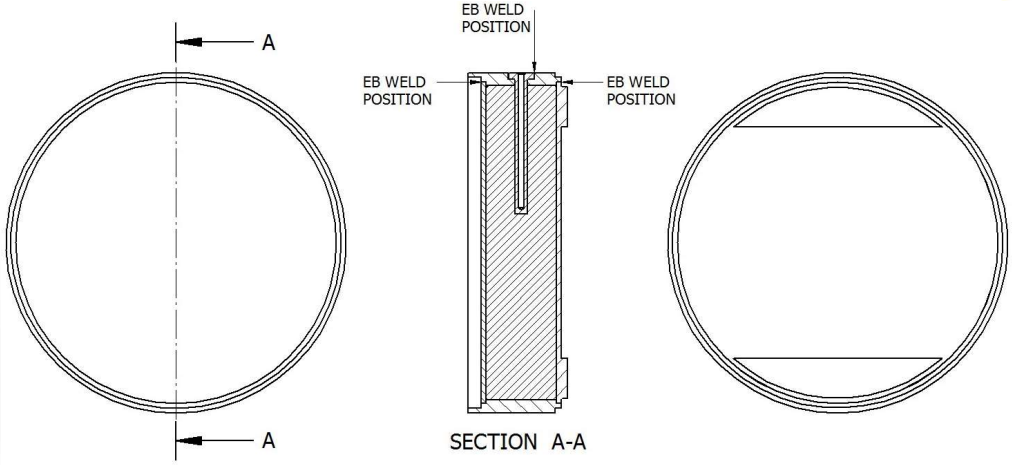
Manufacturing Target Plates

- Construction principle of **Target Plates** same as previous TS1 target
- Round profile reduces no of welds from 13 to 3









Meticulous surface preparation and cleaning required before EB welding in vacuum

Note: Welds are carefully positioned to receive minimal skimming during post HIP machining operations

Manufacturing Target Plates

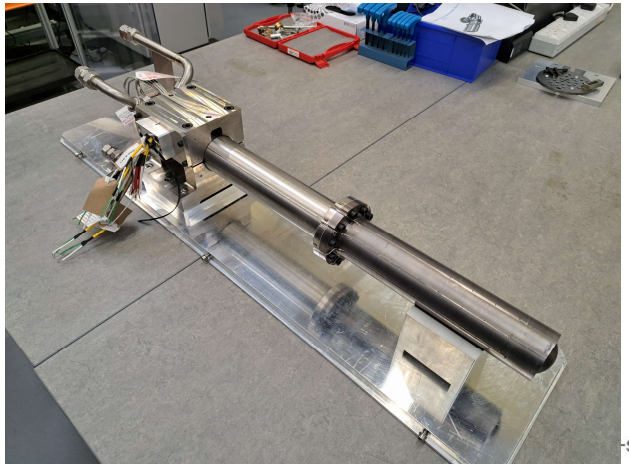
Target Plates Machined After HIP

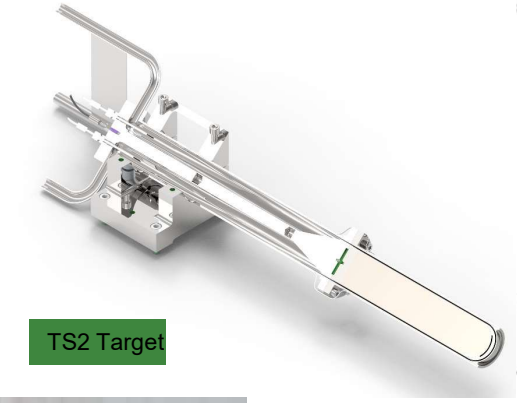
ISIS Overview – Target Station 2

A low repetition rate, low-power target station optimised to produce long wavelength neutrons.

Extending the facilities capabilities in the fields of biology, soft matter, and advanced materials.

- TS2 operational since 2009.
- The Target is a single Tungsten rod clad in Tantalum and water cooled.
- Operates @40μA (32 KW), 800 Mev, 10Hz 2-year service life (Avg. 250 MA hrs)





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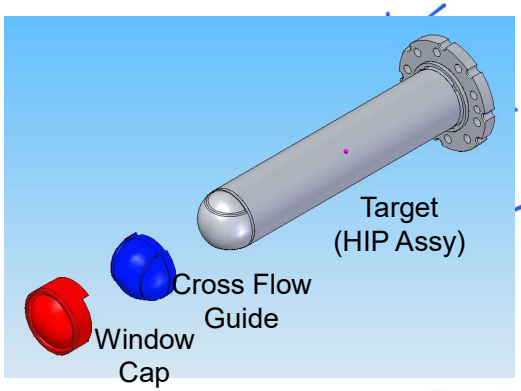
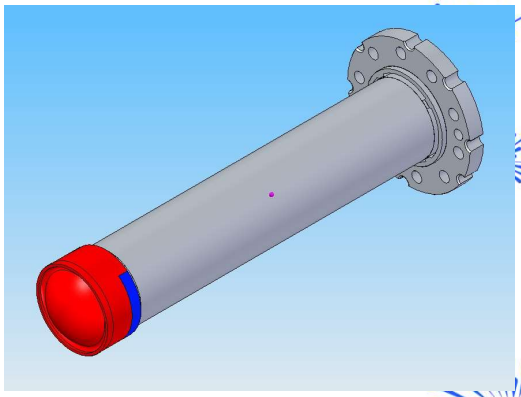
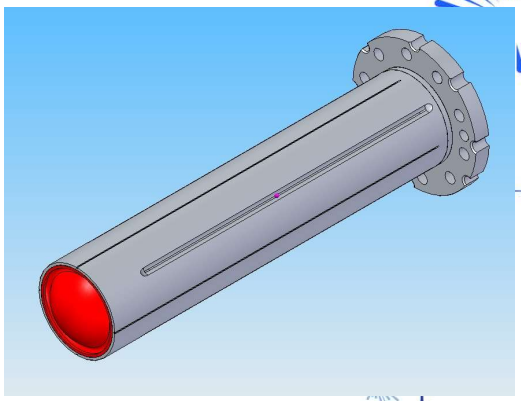
-source

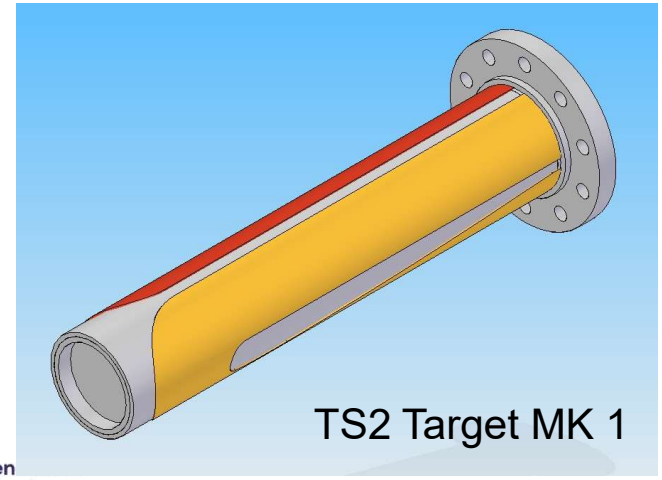
TS2 Target MK1 & MK2

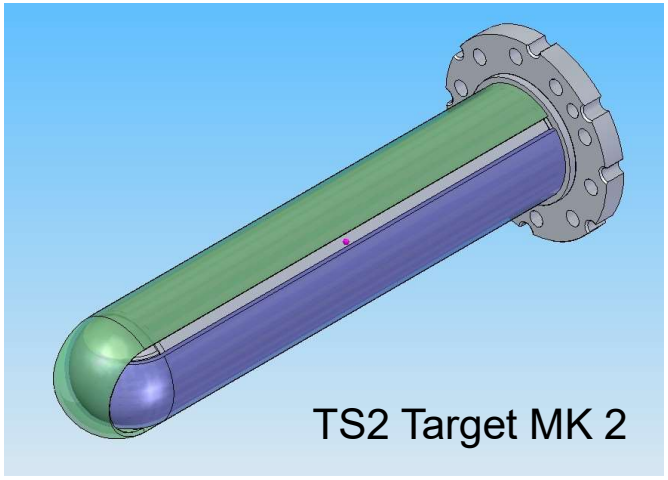
- MK1 failed in service due to Intergranular Corrosion from overheating tantalum front face.
- MK2 introduced front face cooling to cure the problem
- Cross Flow Guide and Window Cap direct water across the front face.











Cooling Sleeves removed for clarity

TS2 Target – Manufacturing (MK2)

*Requires final Machining After HIP

Raw Materials

Ta Tube + W Core

Ta Flange

Ta Flange
+
W Core

Ta Flange
+
W Core
+
Ta Tube

Ta Flange
+
W Core
+
Ta Tube
+
Ta Cap

EB Welded
+
HIP
1250 °C
1400 MPa

TS2 Target – Assembly

Target HIP Assembly
(after final machining)

Machined from
solid Ta rod

Final Assembly
(ALL COMPONENTS FITTED AND
THERMOCOUPLE GROVES MACHINED)

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TS2 Target MK2

- The MK 2 Target solved the original problem of the front face oxidising and extended the service life of the target - then presented a new problem!
- Short lived isotopes Ta 182 & W 187 detected in the cooling water.
- Early analysis suggested a breach in the Ta cladding in the location of an EB Welded joint in the Target HIP Assembly.

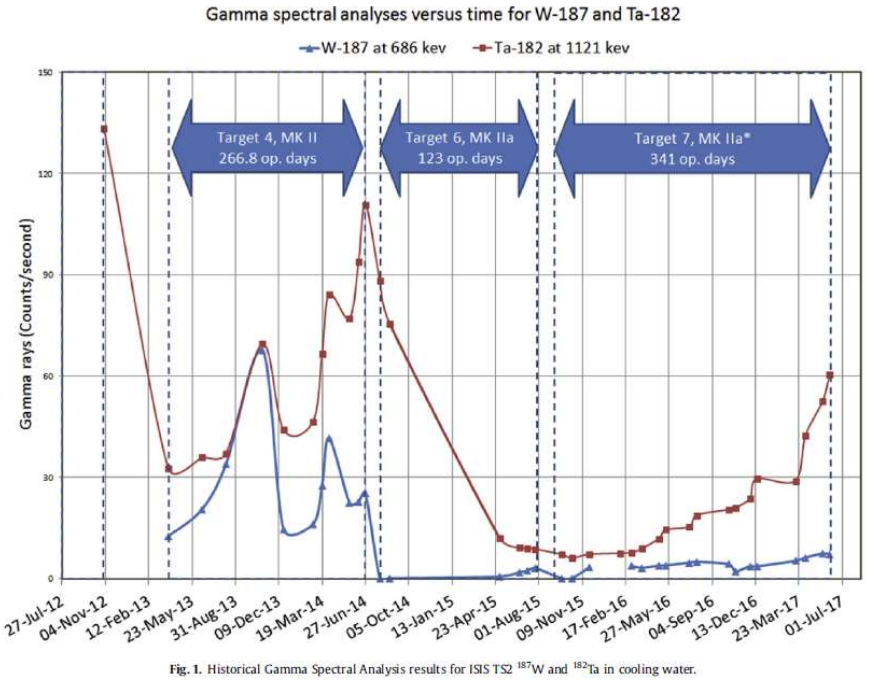
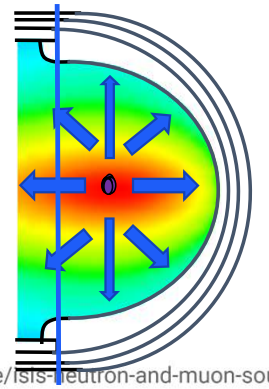


Fig. 1. Historical Gamma Spectral Analysis results for ISIS TS2 ^{187}W and ^{182}Ta in cooling water.

Reasoning

- *Arghya Dey, Leslie Jones. (2018). Strategies to improve ISIS TS2 target life.*
- *Journal of Nuclear Materials*

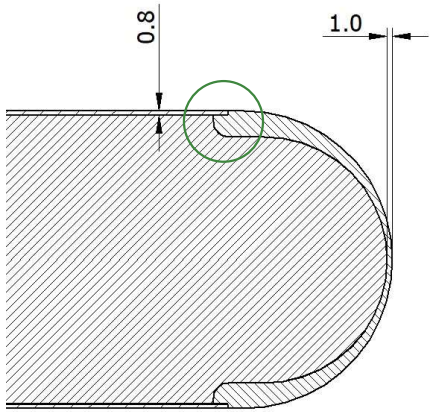
EB Weld Line



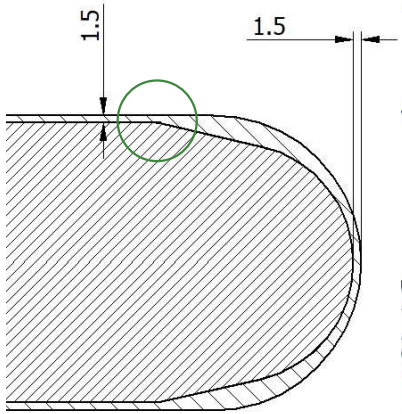
- 32 KW Energy deposited causes the core to expand in all directions
- Electron Beam welding creates large grains in HAZ
- The weld joint is in a vulnerable position
- Tantalum and Tungsten have different material expansion rates.
- In the cooldown after HIP Tantalum shrinks more and is in tension.
- Potential for stress crack at the weld joint

TS2 Target MK3 & 3a

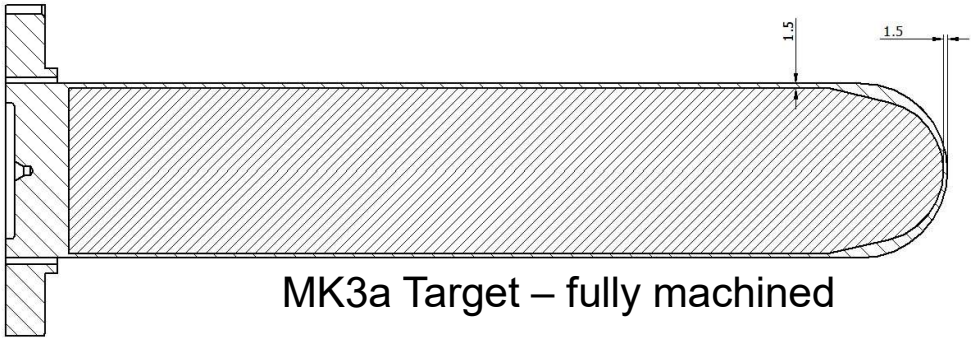
- The MK 3 Target had a reprofiled front on the W Core – small improvement in service life.
- Cladding thickness has been increased from 0.8 mm to 1.5 mm (MK3a).
- If erosion and/or corrosion are a big factor this should help prolong the service life of the target.
- The first MK3a is in service now.



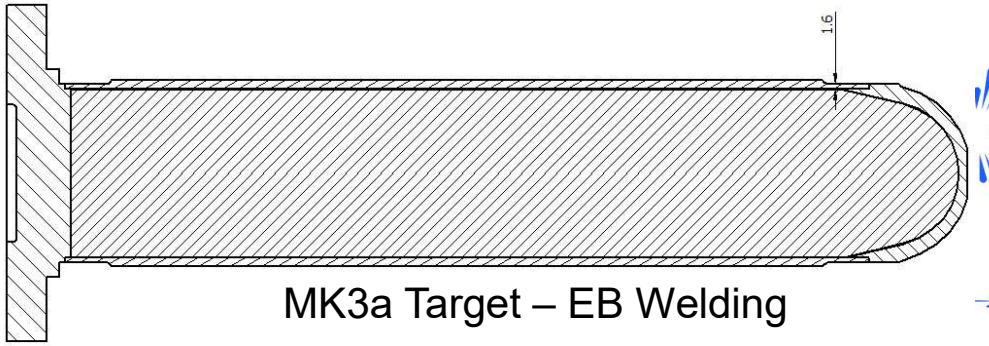
MK2 Target



MK3a Target



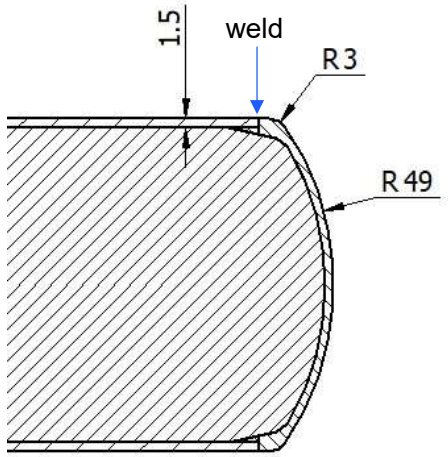
MK3a Target – fully machined

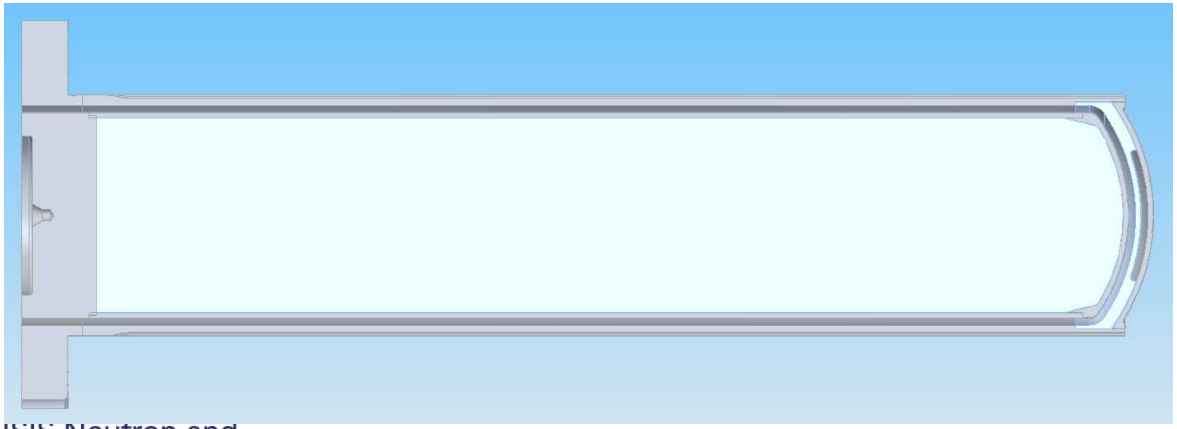


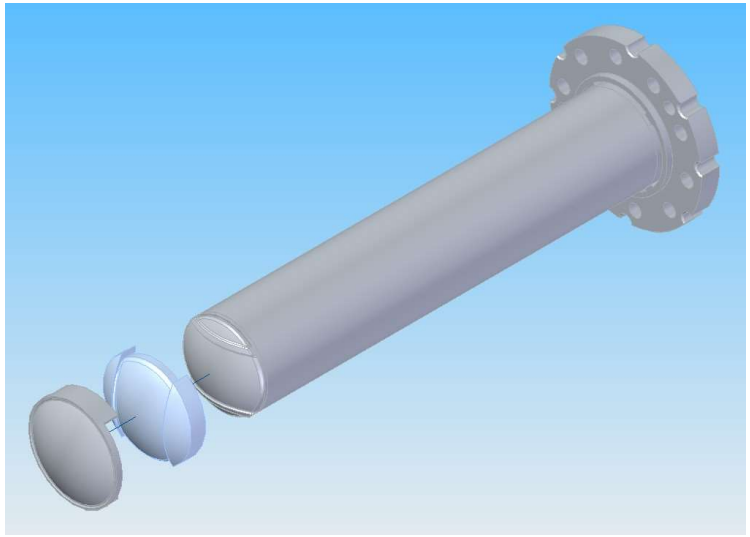
MK3a Target – EB Welding

TS2 Target MK4, single plate, semi-dome

- Key features:
- EB weld moved as close to the front as possible to reduce stress in the weld
- Combination of semi-dome front and R3 corner radius gives best compromise for flow
- Cladding thickness 1.5 mm for increased erosion/corrosion resistance
- Attention to detail regarding flow channel shape ensuring good match up where components meet







Target Manufacturing Facility

ISIS N
Muon

The future for ISIS….

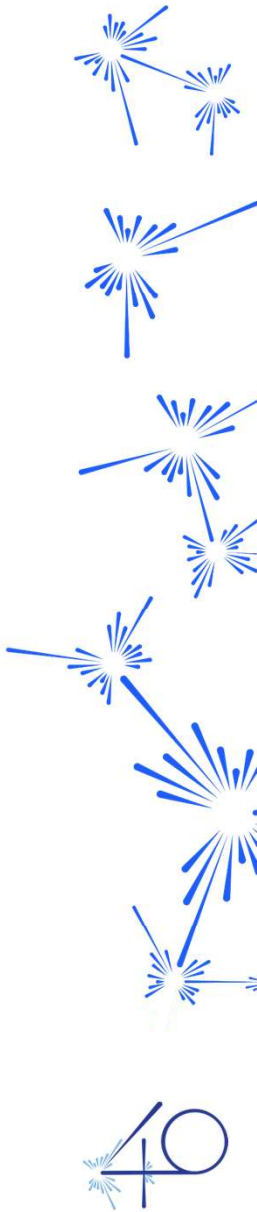
- A feasibility study is underway to decide what an ISIS-2 facility should be.
- Community consultation is helping develop the science case.
- What does the user community need?
- Conceptual stage….

- ISIS 2 Target Design….?

Summary

- ISIS Facility – 40th year
- Overview of TS1 Target - History & Evolution
- Overview of TS2 Target - History & Evolution
- Target Plate design and manufacturing
- ISIS Target Manufacturing Facility
- ISIS 2….

Thank you



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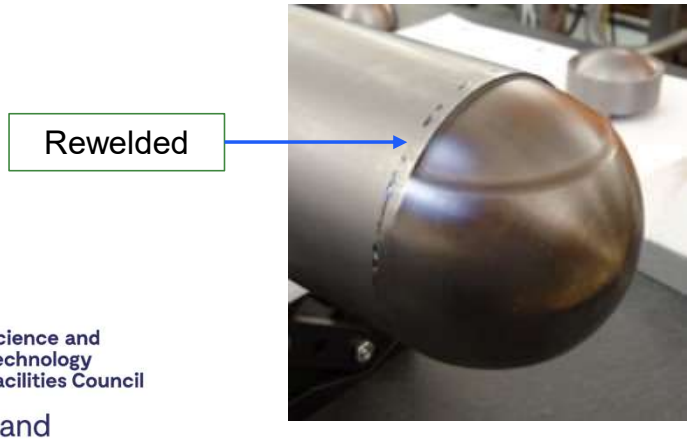
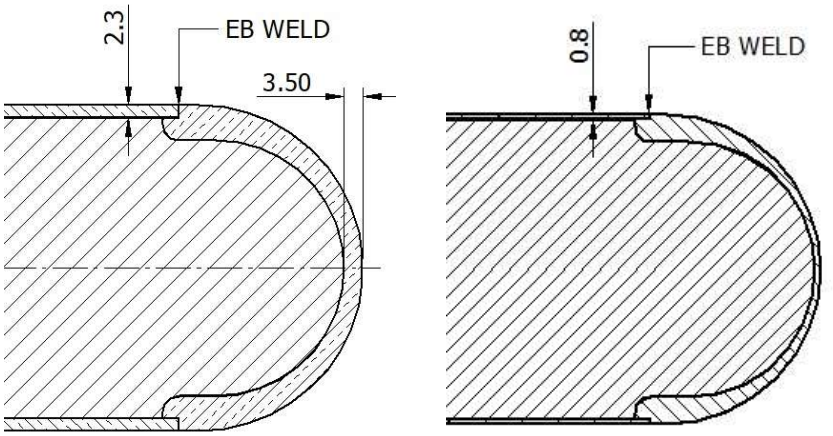
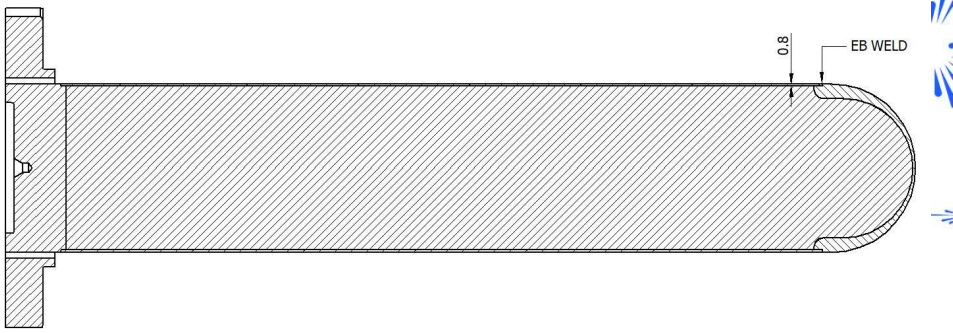
TS2 Target MK2

- Now manufacturing targets in-house.
- EB Weld trials concluded insufficient weld penetration.
- Tantalum has extremely high density and melting point (3000°C).
- Post HIP machining operation reduces cladding thickness to 0.8 mm, likely removing most/all the weld.

- Target no. 7 was rewelded after HIP/Machining and lasted longer







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