TRIUMF

ARIEL Target Station and Target Ion Source Technology

TRIUMF-KEK Symposium 2017

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Discovery, accelerated

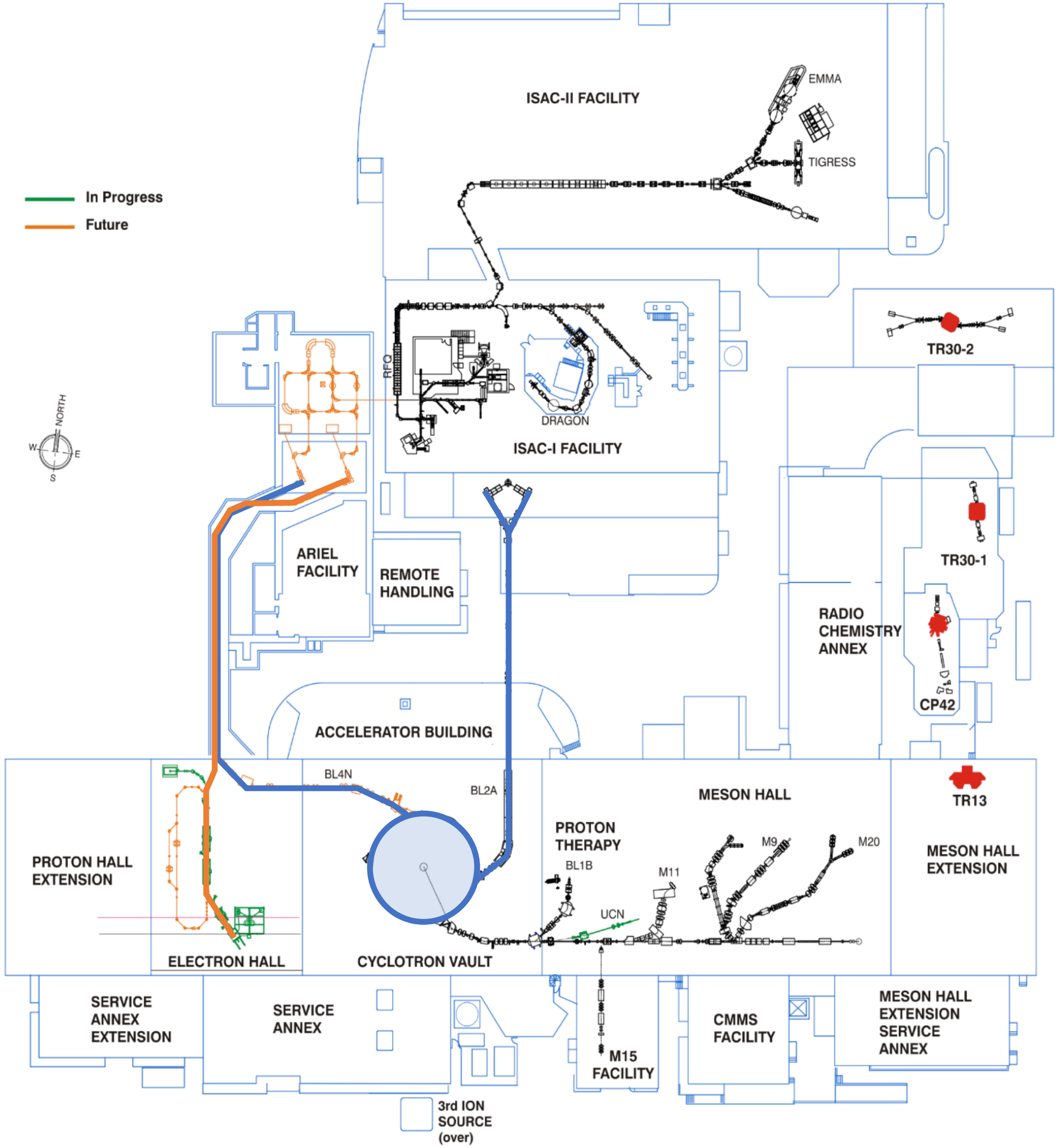
TRIUMF-ARIEL

ISAC (currently):

- 480 MeV, ≤100 μA protons from main cyclotron
- 50 kW is highest-power ISOL target worldwide
- Two target stations (ITE, ITW), alternating operation
- Approx. 5 weeks operation per target
- Target exchange approx. 5 weeks
- Routine target materials: UC_x, SiC, TaC, Ta, NiO, Nb, ZrC, TiC

ARIEL (in development / under construction):

- 480 MeV, ≤100 μA protons from main cyclotron onto APTW
- ≤ 50 MeV, ≤10 mA electrons from e-linac onto AETE
- 100 kW electron beam on ISOL target is fully unprecedented
- Two independent target stations
- RIB beam through beam transport and CANREB system to ISAC experiments
- Optimized design based on lessons learnt and new technology

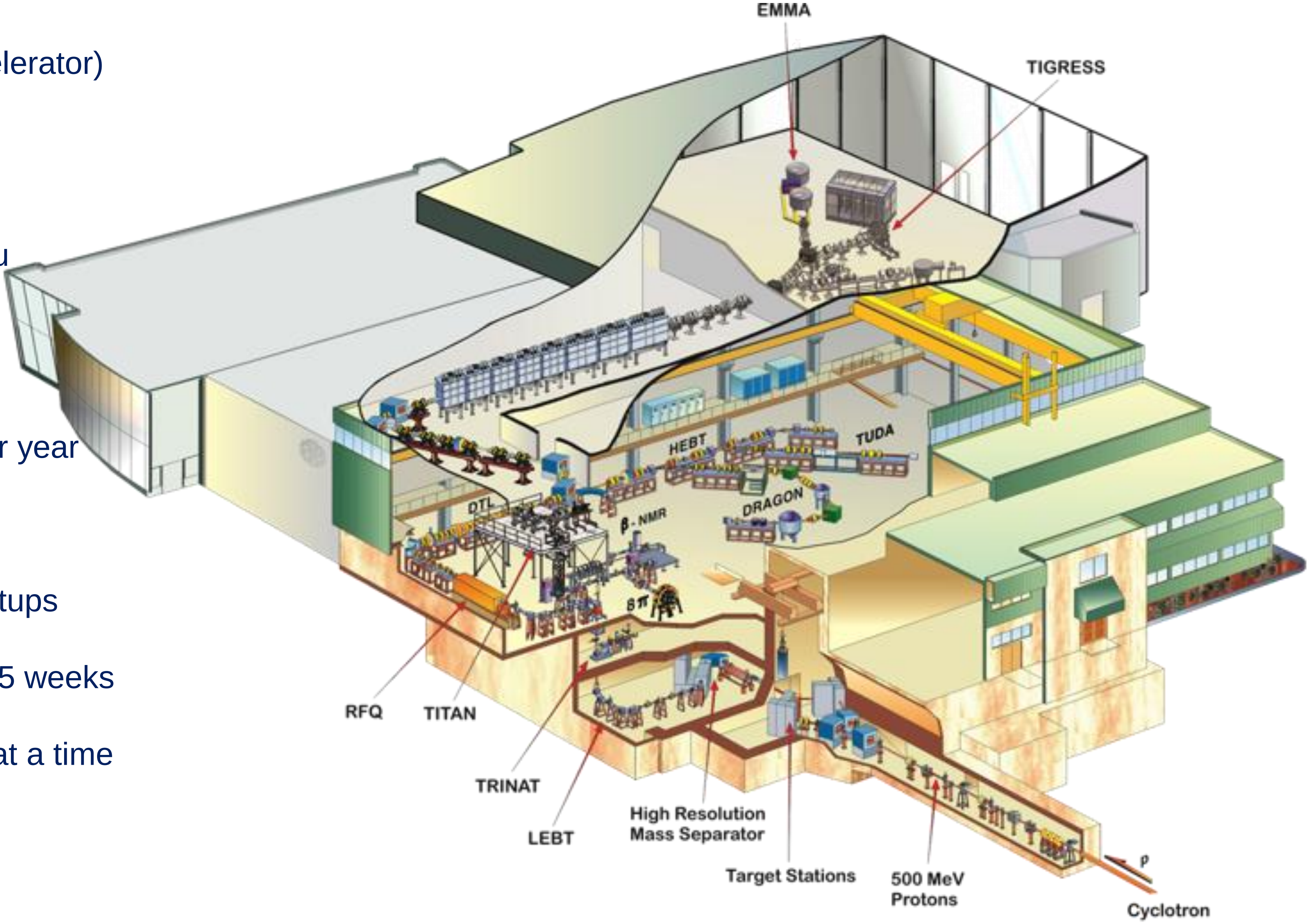


The ISAC Facility

ISAC (Isotope Separator and Accelerator)

ISAC I:
- Low energy: 50 keV
- Medium Energy: up to 1.8 MeV/u

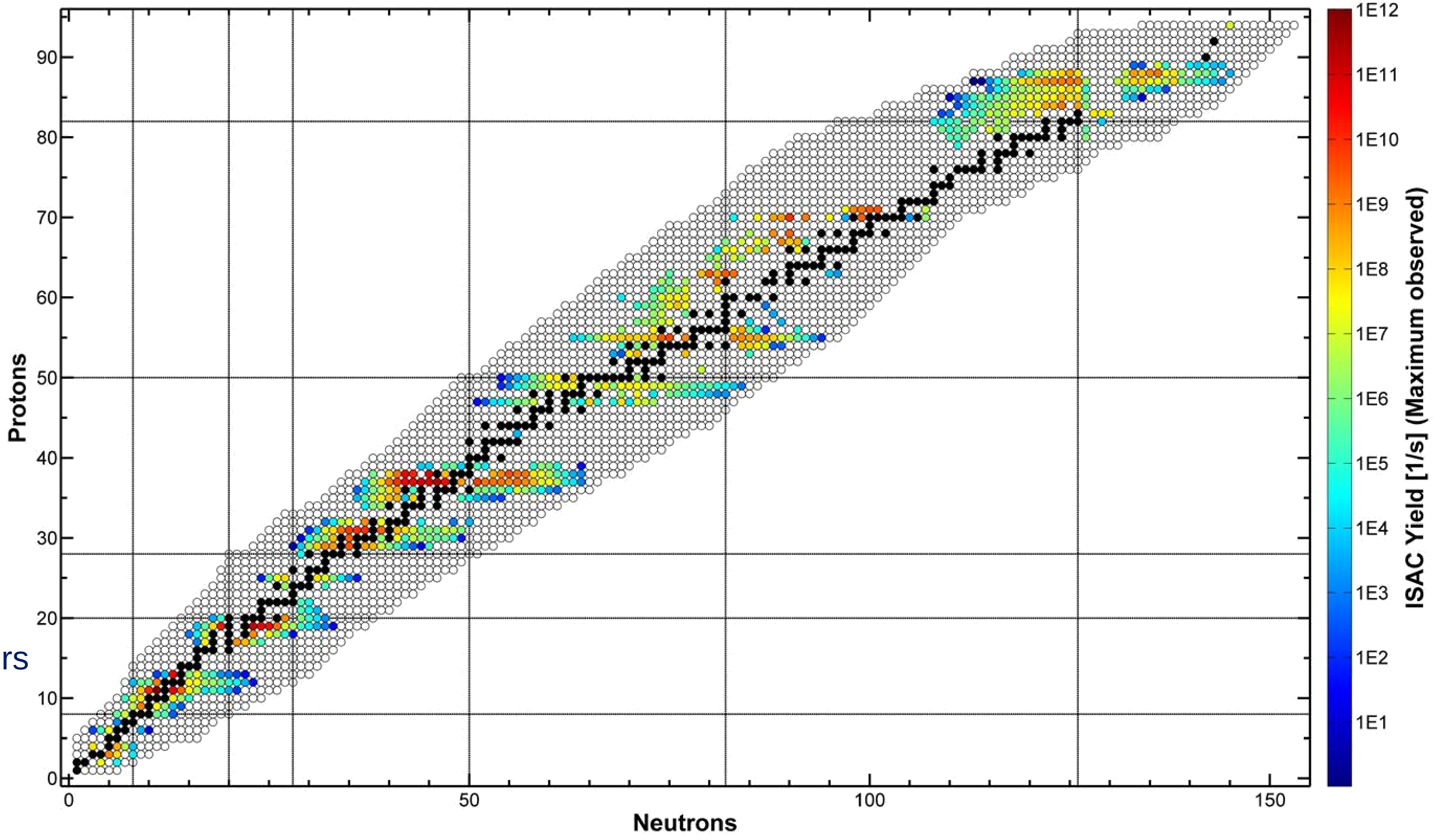
ISAC II:
- Up to 16 MeV/u
- Approx. 2500 h of RIB beam per year
- 700 isotopes extracted
- State-of-the art experimental setups
- Target exchange every approx. 5 weeks
- Operation of one target station at a time



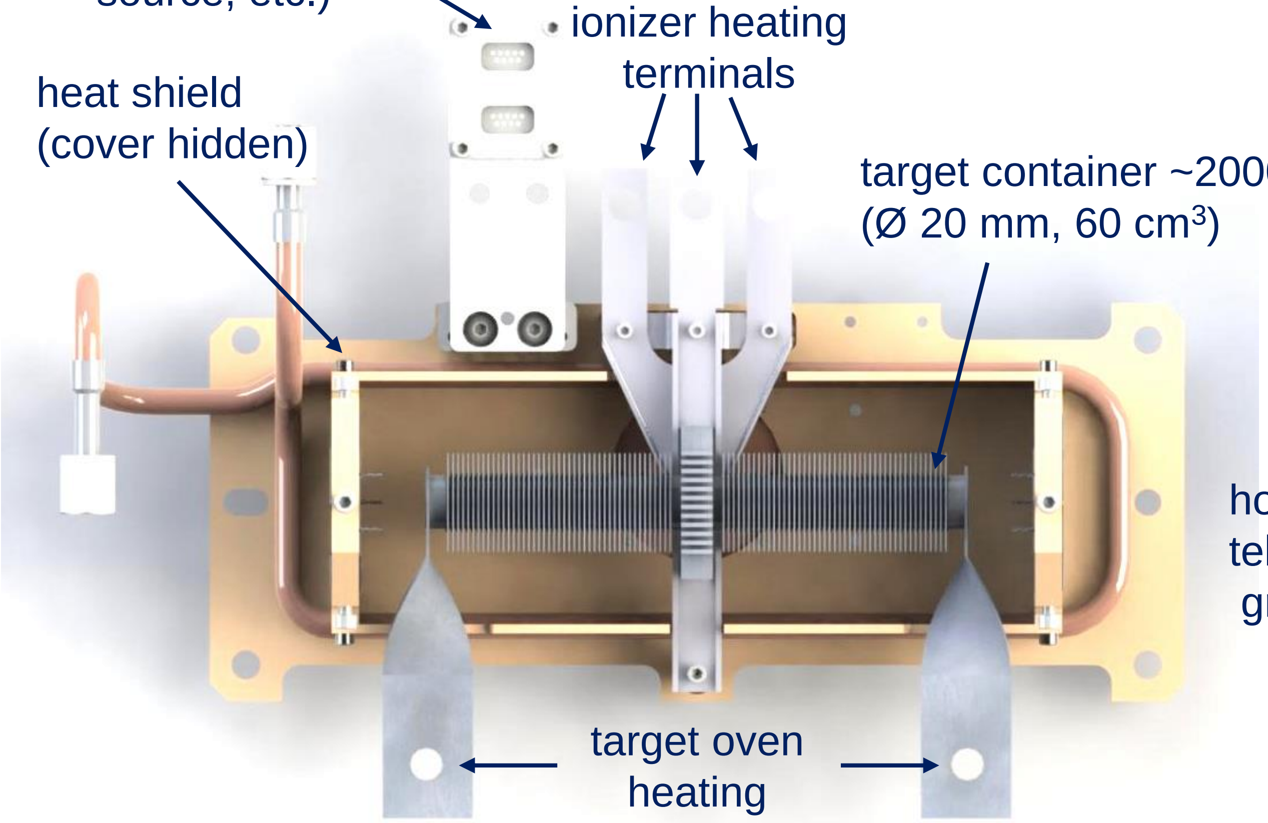
ISAC Radioisotope Beams Since 1998

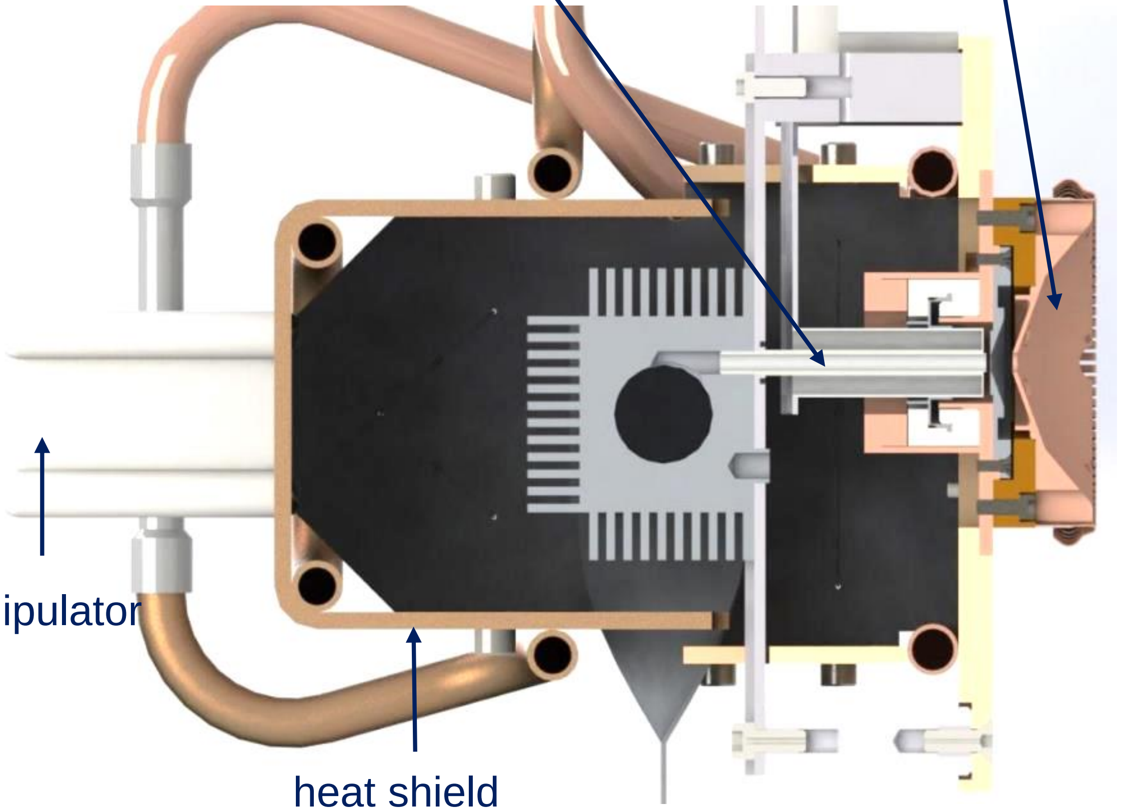
target materials:
- UC_x
- UO_2
- ThO
- Nb
- Ta
- TaC
- NiO
- ZrC
- TiC
- SiC

ion sources:
- surface
- resonant lasers
- FEBIAD
- IG-LIS



ISAC Target Assembly

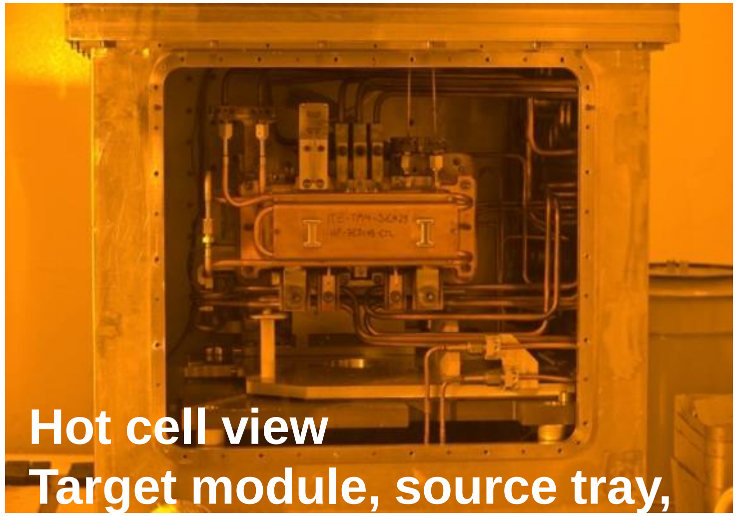


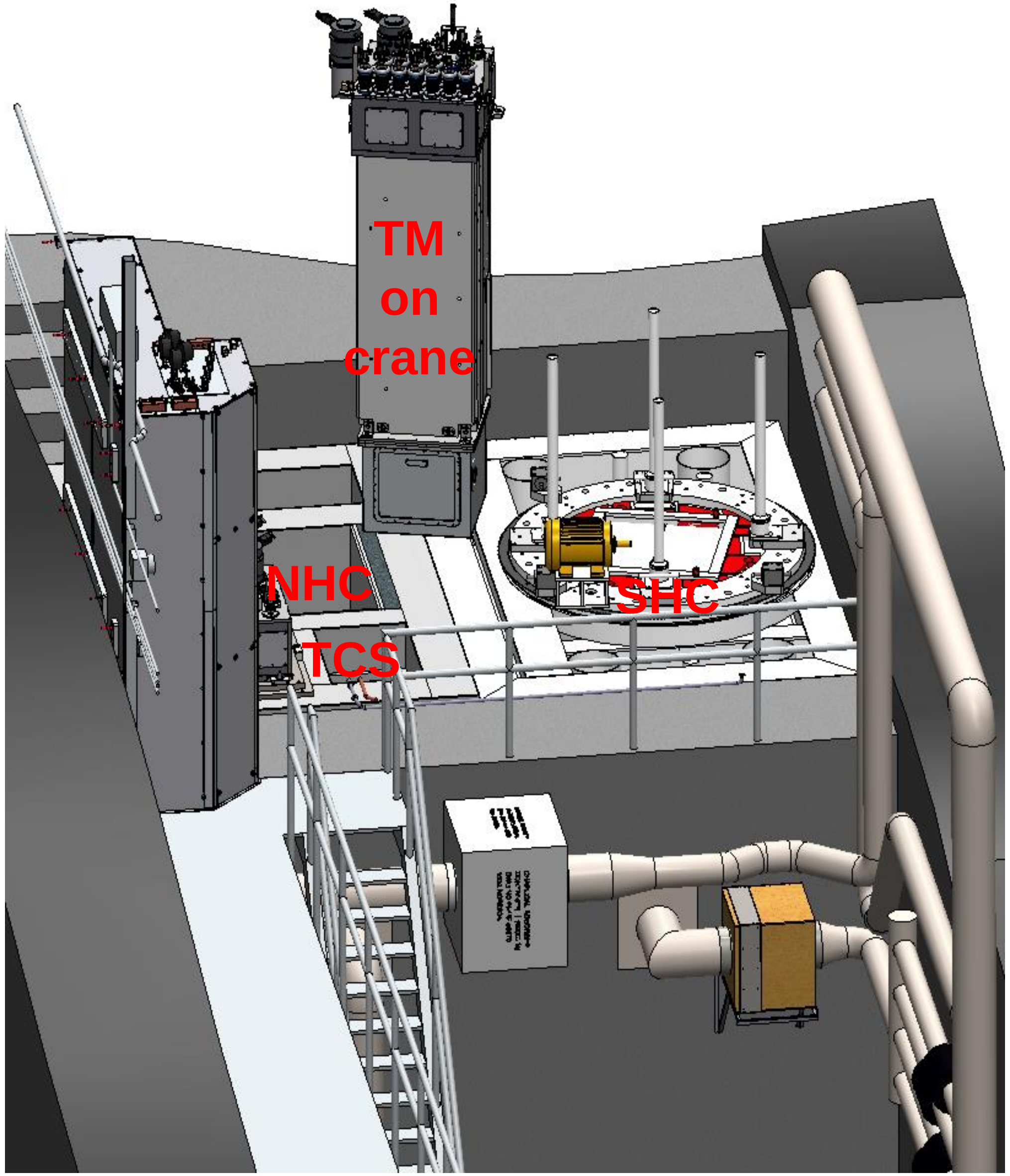


diffusion bonded Ta fins
→ radiative cooling of up to 13 kW
→ 50 kW proton irradiation

ISAC Remote Handling Infrastructure

- 20 t redundant nuclear crane
- Beam and target infrastructure modular on 2m steel shield plugs
- α/β/ɣ hot cell target exchange (SHC)
- α/β/ɣ hot cell for module maintenance (NHC, under construction)
- Shielded target vault for initial radioactive decay before shipment
- Remote module storage area
- Safe module parking with rotating module flange for safe landing of modules in case of crane rotation failure (under construction)



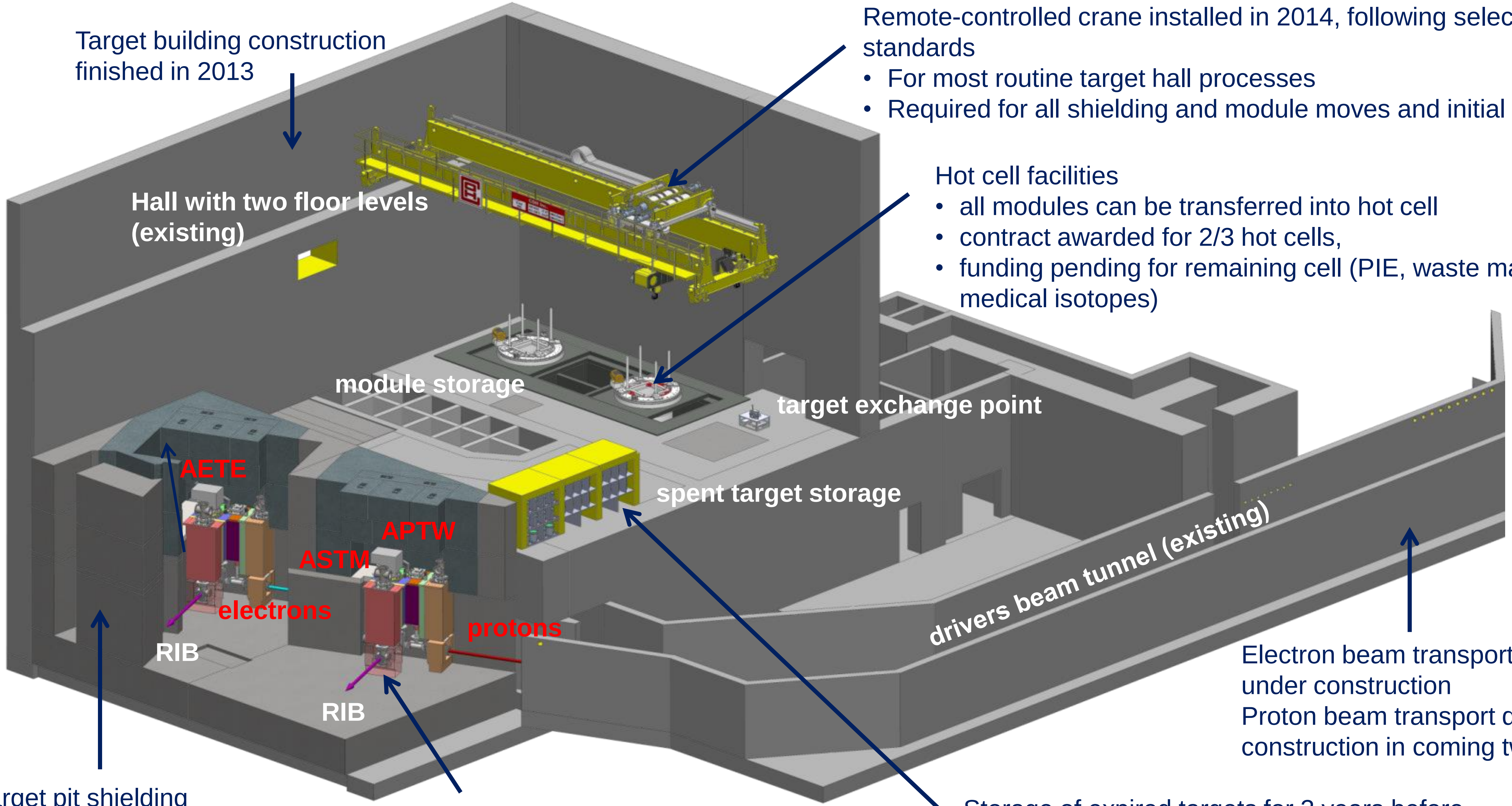


ARIEL Target Infrastructure - Overview

Target building construction finished in 2013

Remote-controlled crane installed in 2014, following selected nuclear standards
- For most routine target hall processes
- Required for all shielding and module moves and initial installation

Hot cell facilities
- all modules can be transferred into hot cell
- contract awarded for 2/3 hot cells,
- funding pending for remaining cell (PIE, waste management, medical isotopes)



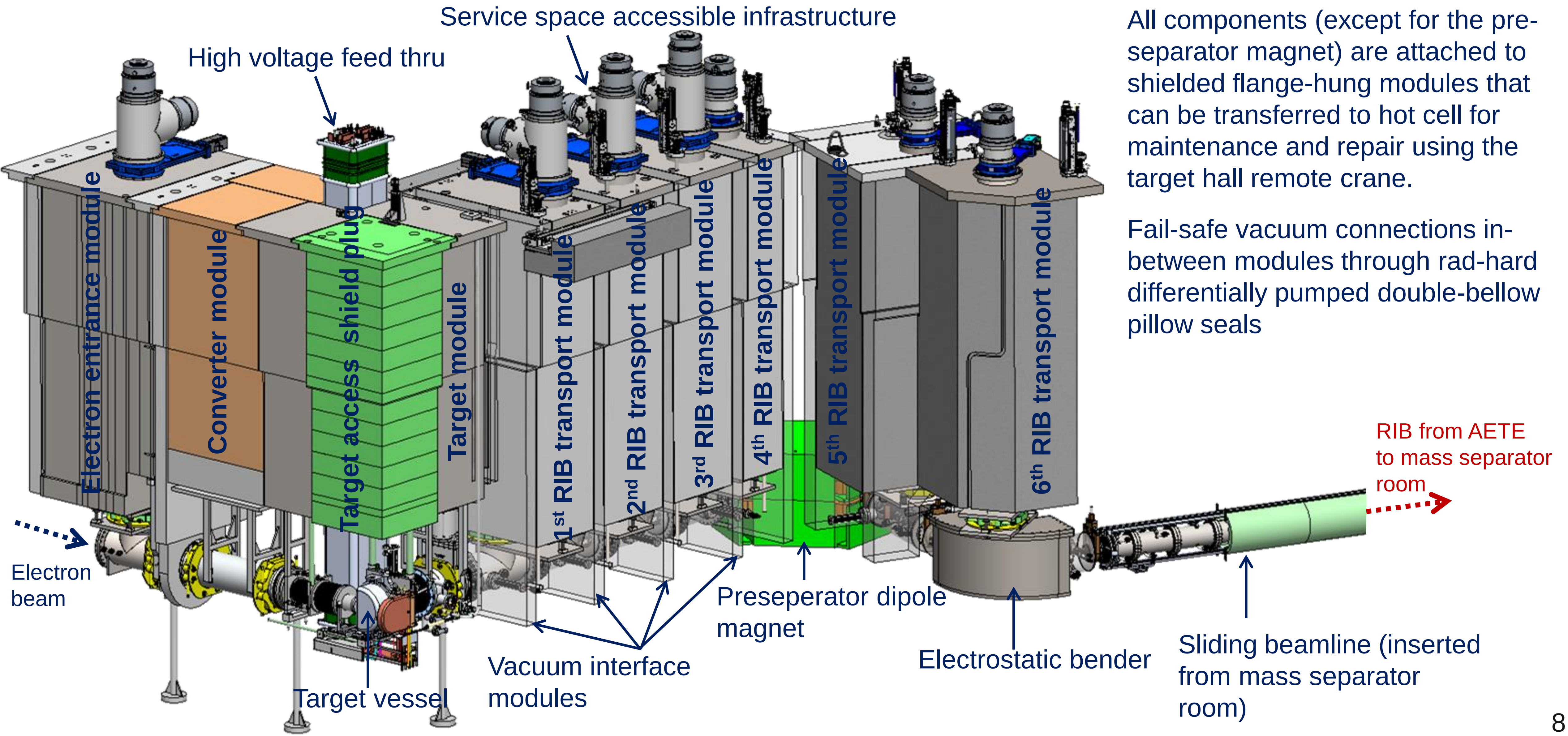
Electron beam transport to target station under construction
Proton beam transport design complete, construction in coming two years

Target pit shielding concept validated through FLUKA simulations

beam-critical components with life-time < 30 years: modular and serviceable in hot cell facility

Storage of expired targets for 3 years before shipment to CNL (as for ISAC targets)

Target Station (Modules and Pre-Separator)

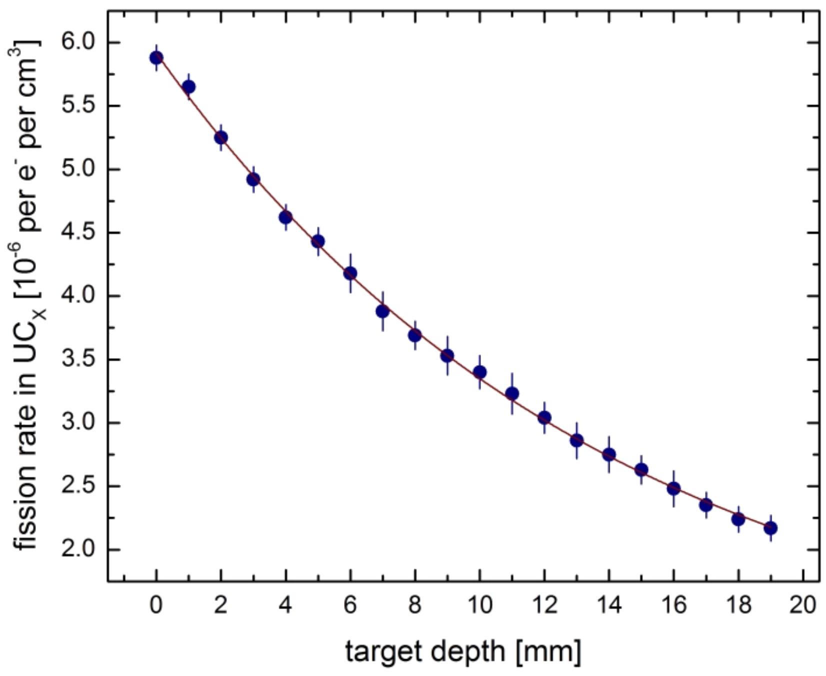


All components (except for the pre-separator magnet) are attached to shielded flange-hung modules that can be transferred to hot cell for maintenance and repair using the target hall remote crane.

Fail-safe vacuum connections in-between modules through rad-hard differentially pumped double-bellow pillow seals

Electron Target Principles

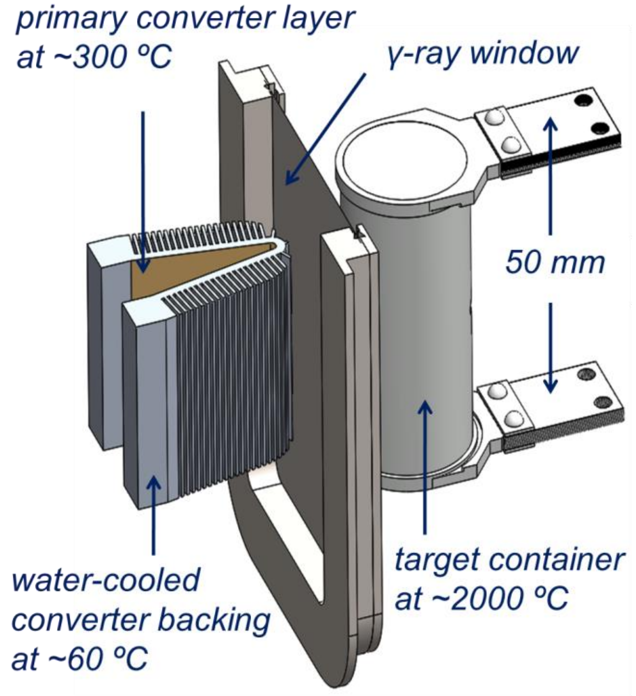
1. The power deposition imposed by the stopping power of 35 MeV electrons in a target container or a target material is unsustainable in an ISOL target
   Consequence: An electron-to-gamma converter is required.
2. The e-linac delivers 100 kW electron beam with FWHM ≈ 1 mm → 1 MW/cm^3 power density inside of the converter, which is unsustainable!
   Consequence: The electron beam needs to be scanned over a larger area and the resulting power needs to be dissipated



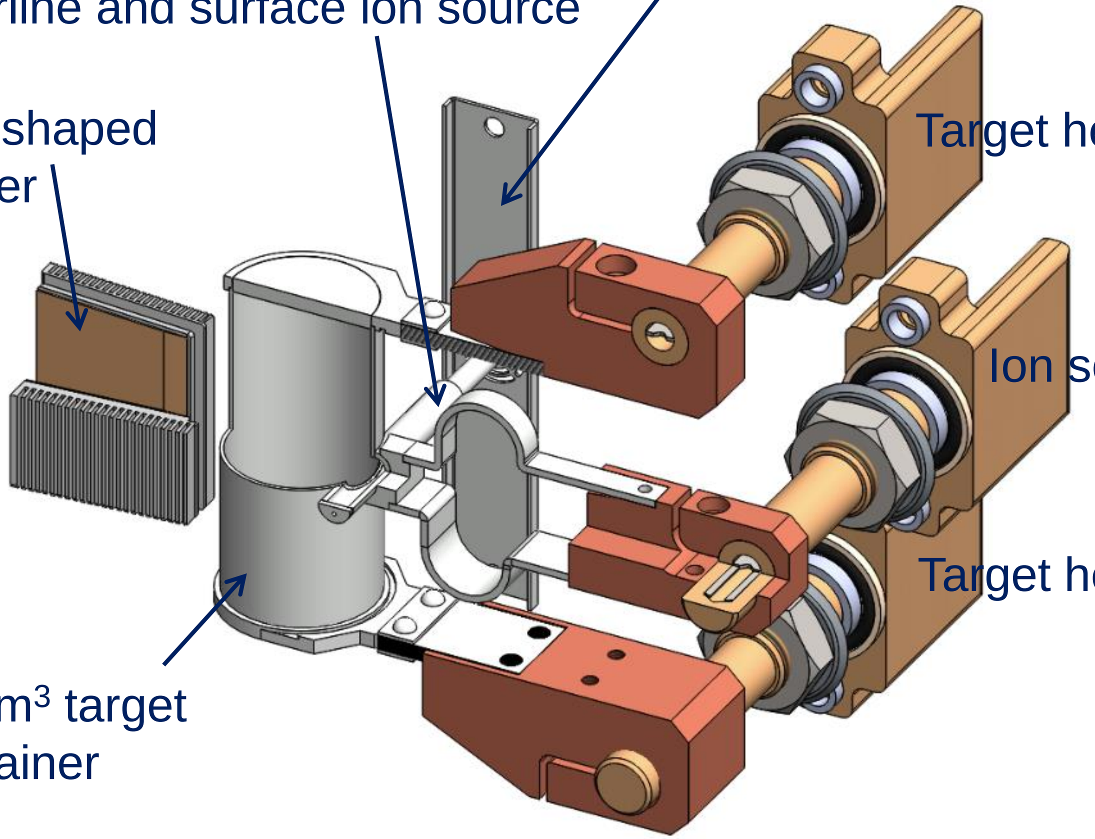
The gamma radiation is strongly attenuated in the target, mostly by e^+-e^- pair production

Consequence: A target thickness beyond ≈10 g/cm^2 is contra-productive

→ At AETE the cylindrical target container is installed vertically and the electron beam is scanned along a vertical rectangle of dimensions (baseline: 50mm x 8 mm).
In order to decrease the beam power deposition further, the converter consists of two faces that are tilted in respect to the electron beam direction.



Electron Target Principles



Assuming 100 kW electron beam:

- Optimized converter absorbs approximately ≈35 kW
- UC_x target absorbs ≈15 kW (>> power required for 2000 °C)

Consequences:

1. Low electron beam power: active heating of target in heat shields required
2. Intermediate electron beam power: natural target container emissivity cools target
3. High electron beam power: no active heating & additional target cooling required

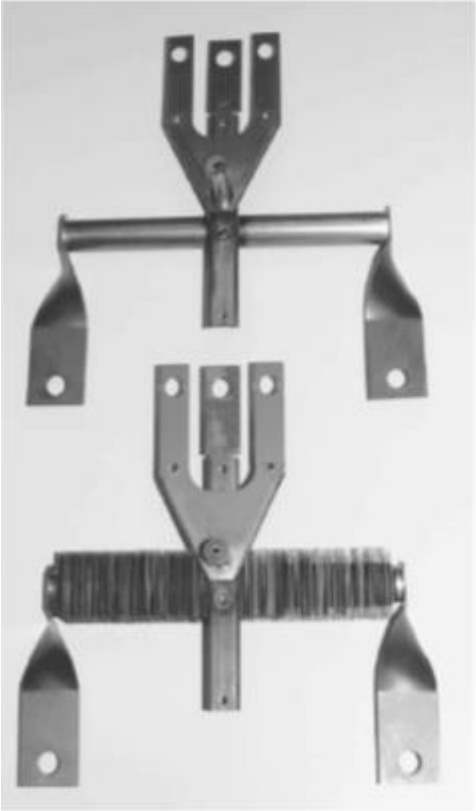
Electron Target Principles

ISAC high-power target strategy:

Diffusion-bonded Ta fins to increase effective emissivity to ≈0.95

In the ARIEL geometry the Ta fins will cause more additional power than they cause additional radiative power dissipation.

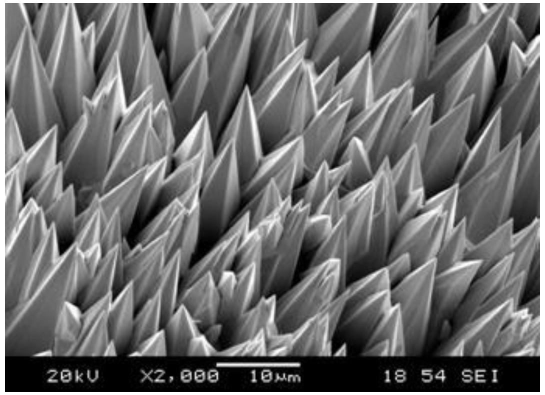
→ Not applicable for AETE



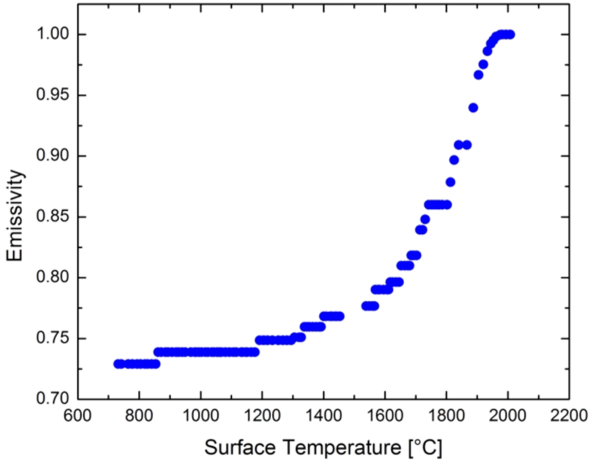
Plan for ARIEL:

commercial 50 µm detrital black rhenium coating

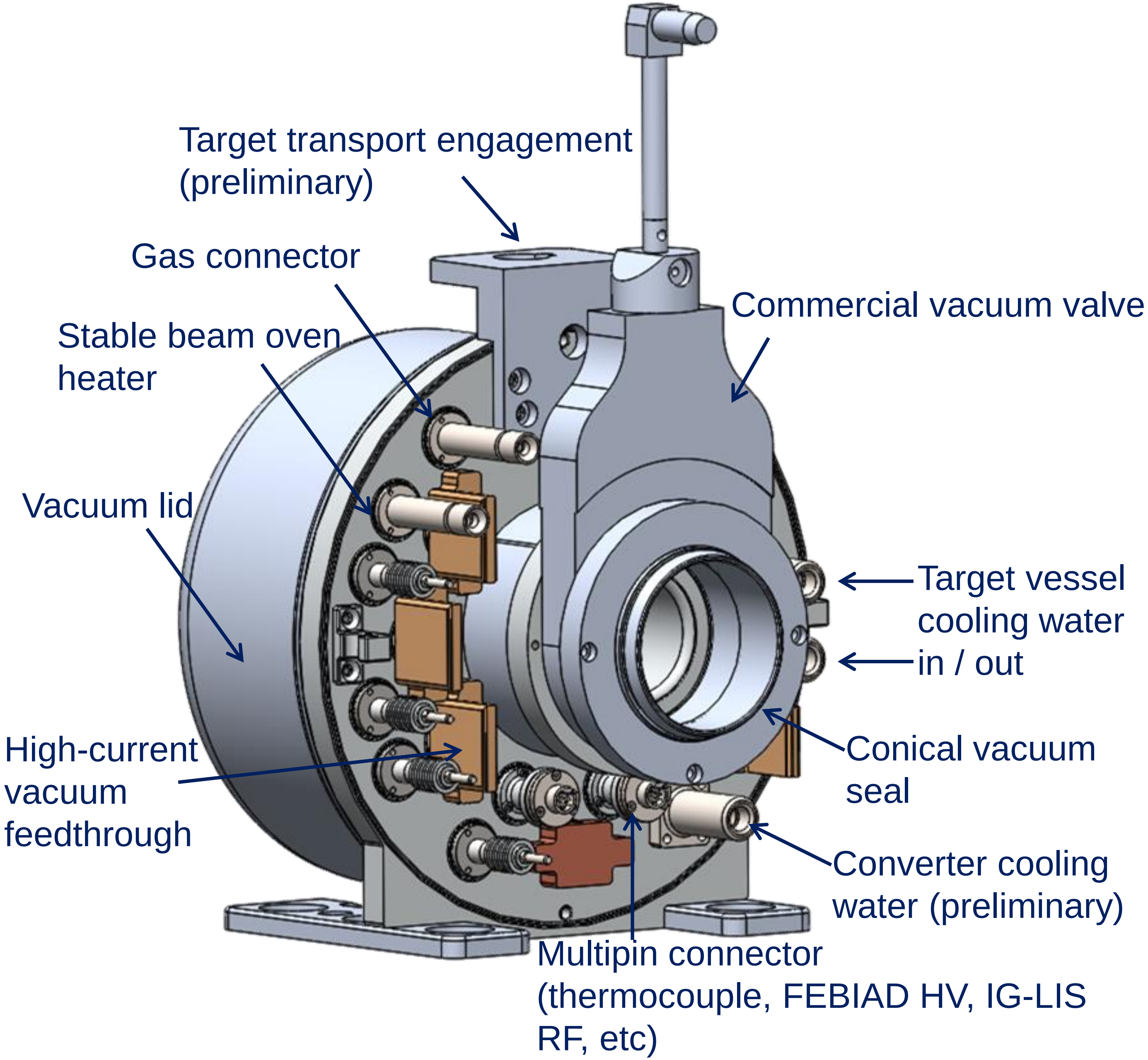
→ Effectively no additional material but emissivity ≈1



Ultramet – Advanced Materials Solutions



Hermetic Target Vessel



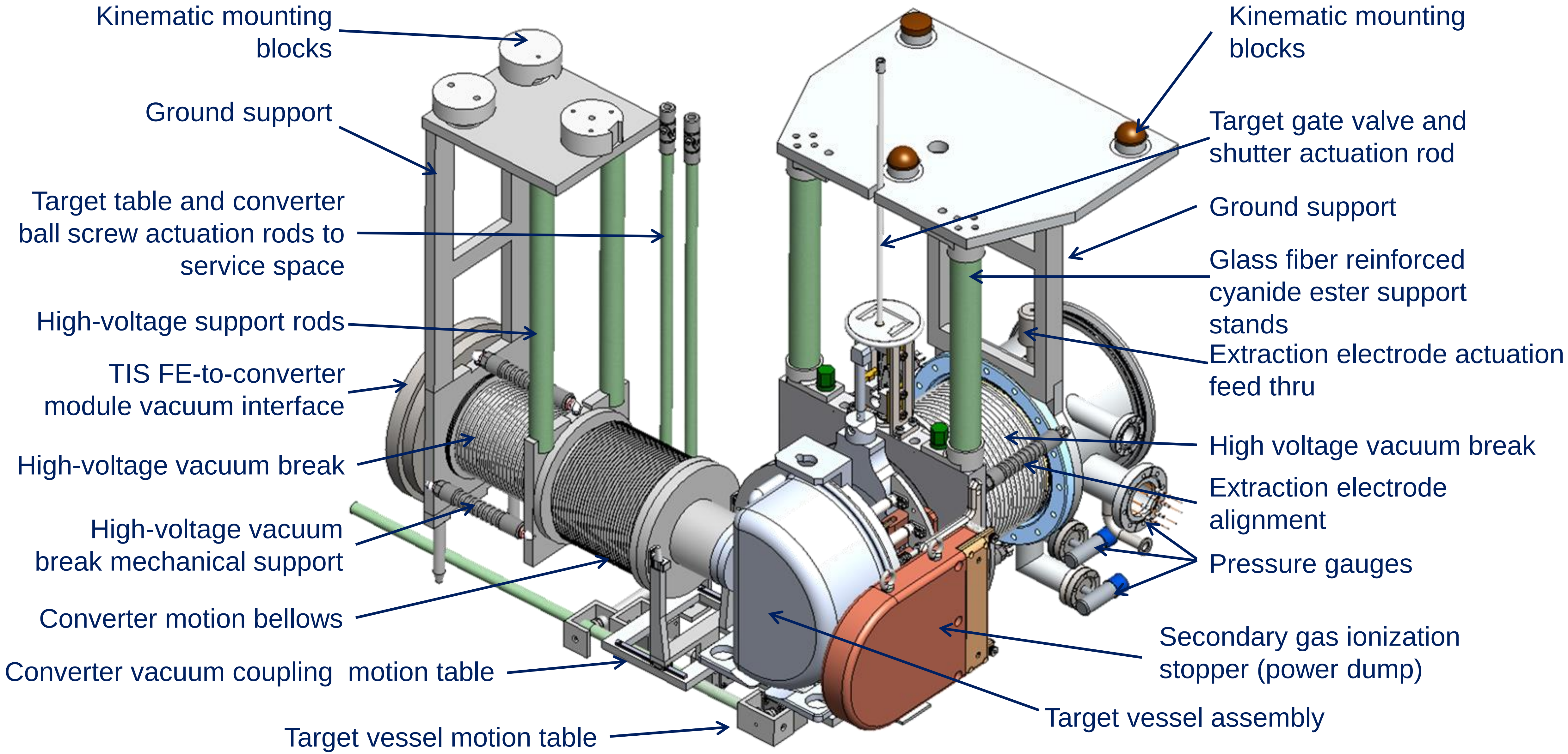
Requirements:

- Full offline conditioning
- Life-time: 5 weeks
- Air sensitive target material
- Converter on target vessel in start-up phase (converter life time unknown and converter-to-target distance critical)
- Service connections compatible with APTW
- Minimizing number of water connections
- Minimize mass and radioactive inventory after irradiation
- Eliminating water-to-vacuum interfaces
- Vacuum pumping through RIB line
- All connector seals shall be upgradable to metal seals for high-power proton operation

- Baseline design based on ISOLDE hermetic target unit
- Deploying new welding techniques
- Using state-of-the-art manufacturing methods

- Service and vacuum coupling tests ongoing

Target Ion Source Frontend – Overview



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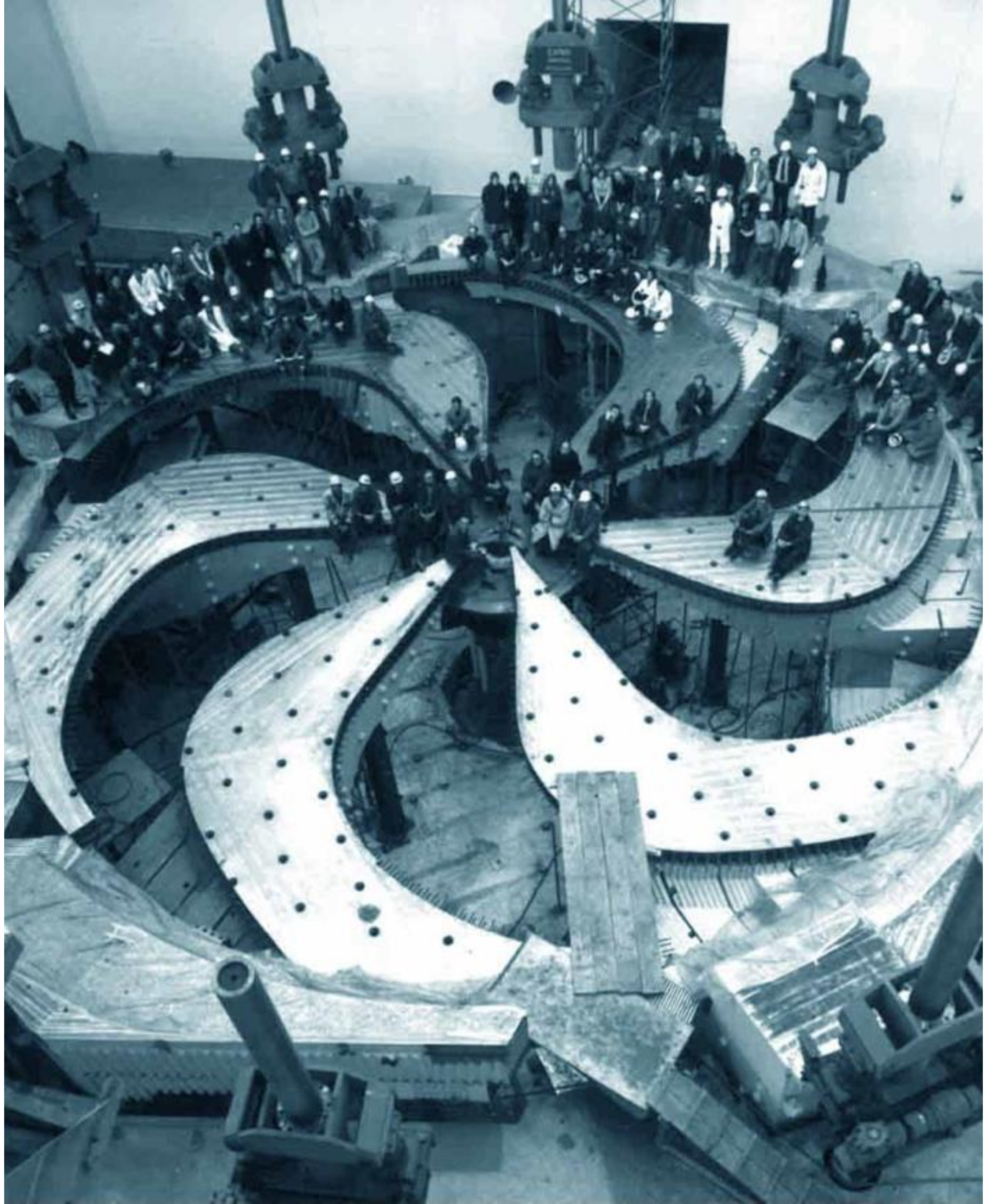
Thank you
Merci



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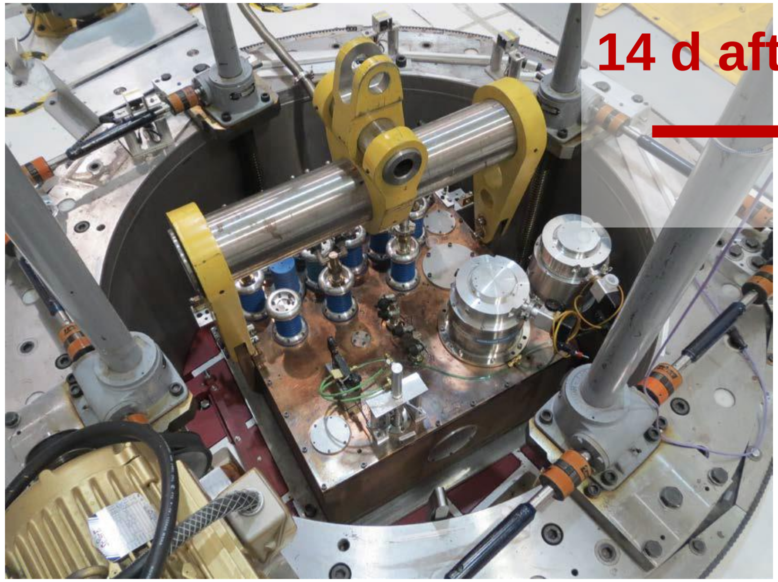
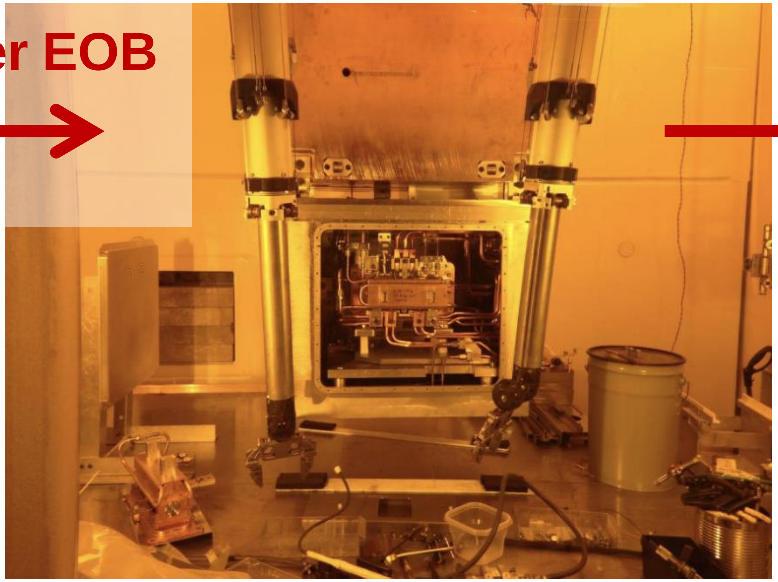
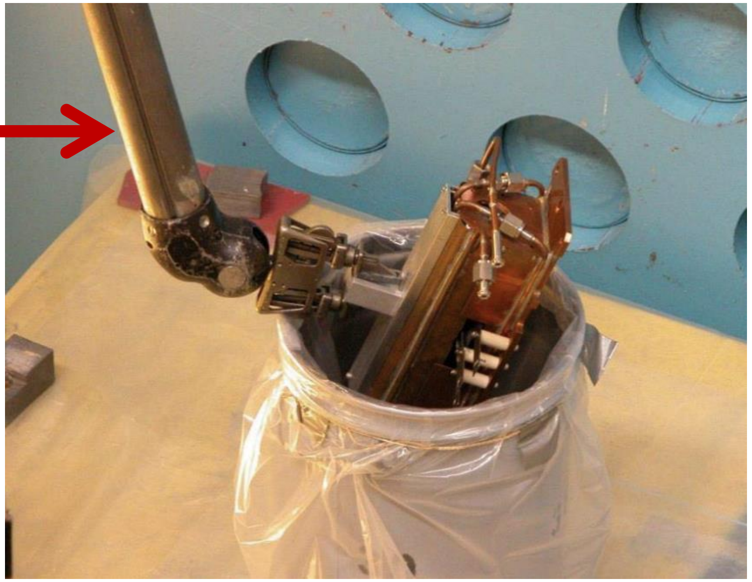
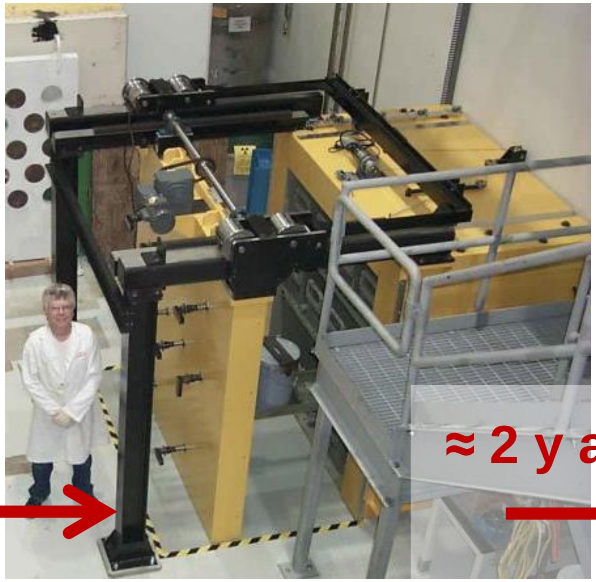
ISAC Spent Target Handling



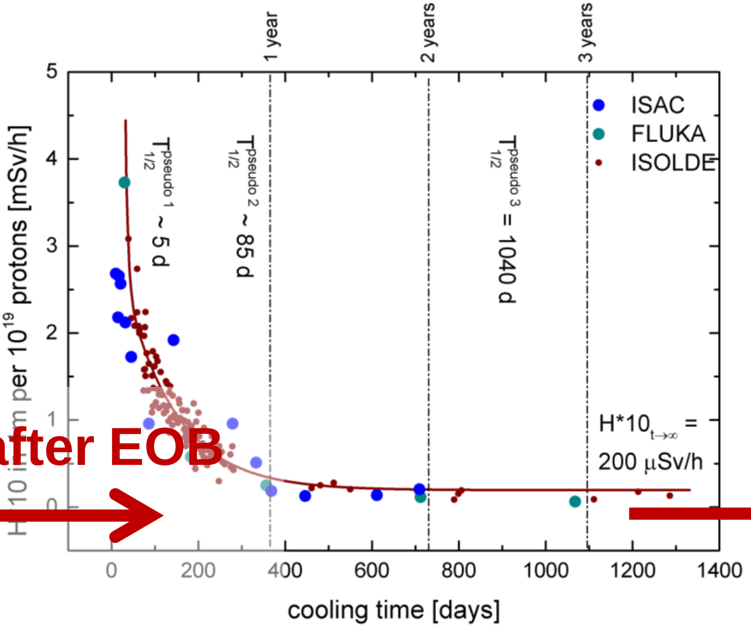
14 d after EOB



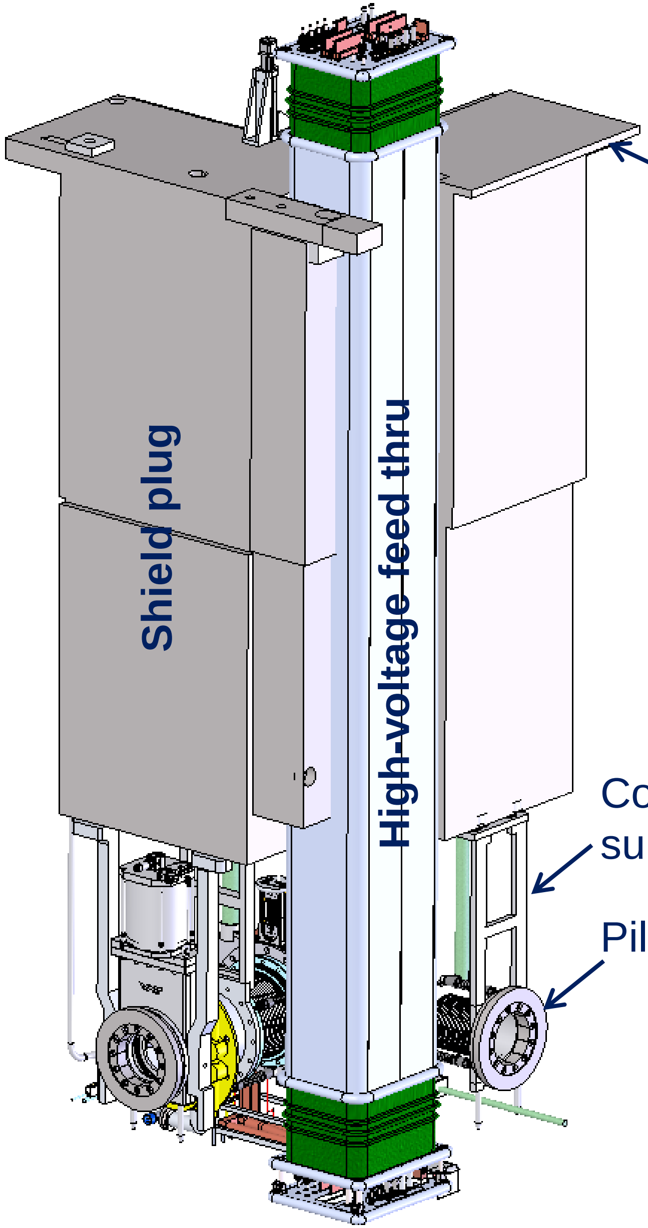


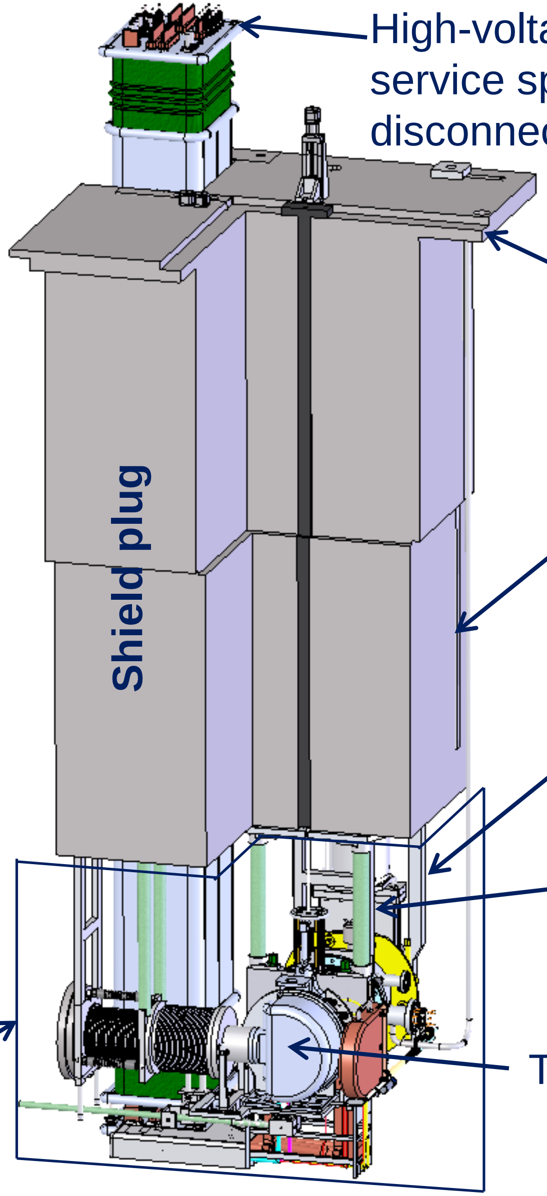


≈ 2 y after EOB

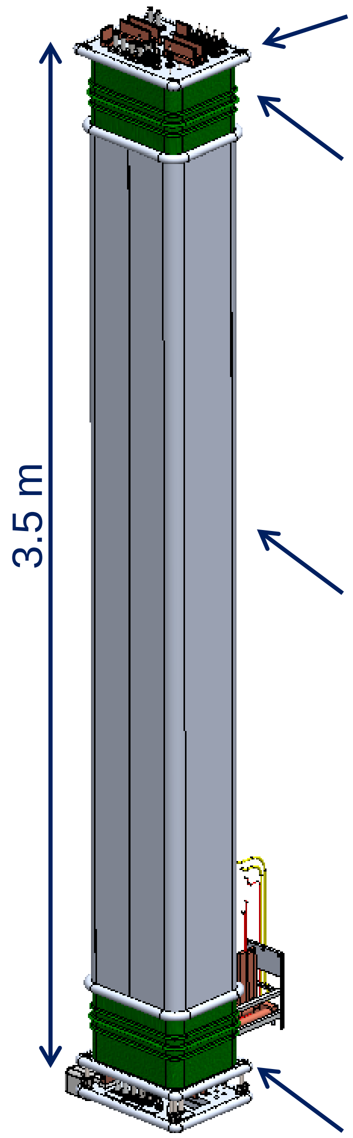


Target Module





High-Voltage Feedthrough



<u>Requirements</u>**:**
- sustainable 75 kV capability at ~ 100 MGy
- replaceability
- compatible with shielding requirements (mostly neutrons)

<u>Solution:</u>
- services (busbars for high current, pipes for everything else)
- vacuum impregnated in radiation-hard resin
- inside of steel pipe on HV potential
- vacuum impregnated in radiation-hard resin
- inside of steel pipe on ground potential

- ground pipe as structural supporting member of assembly

AroCy® L-10 cyanate ester resin (ITER development)
- Dielectric strength: 60 kV / mm at 9 GGy

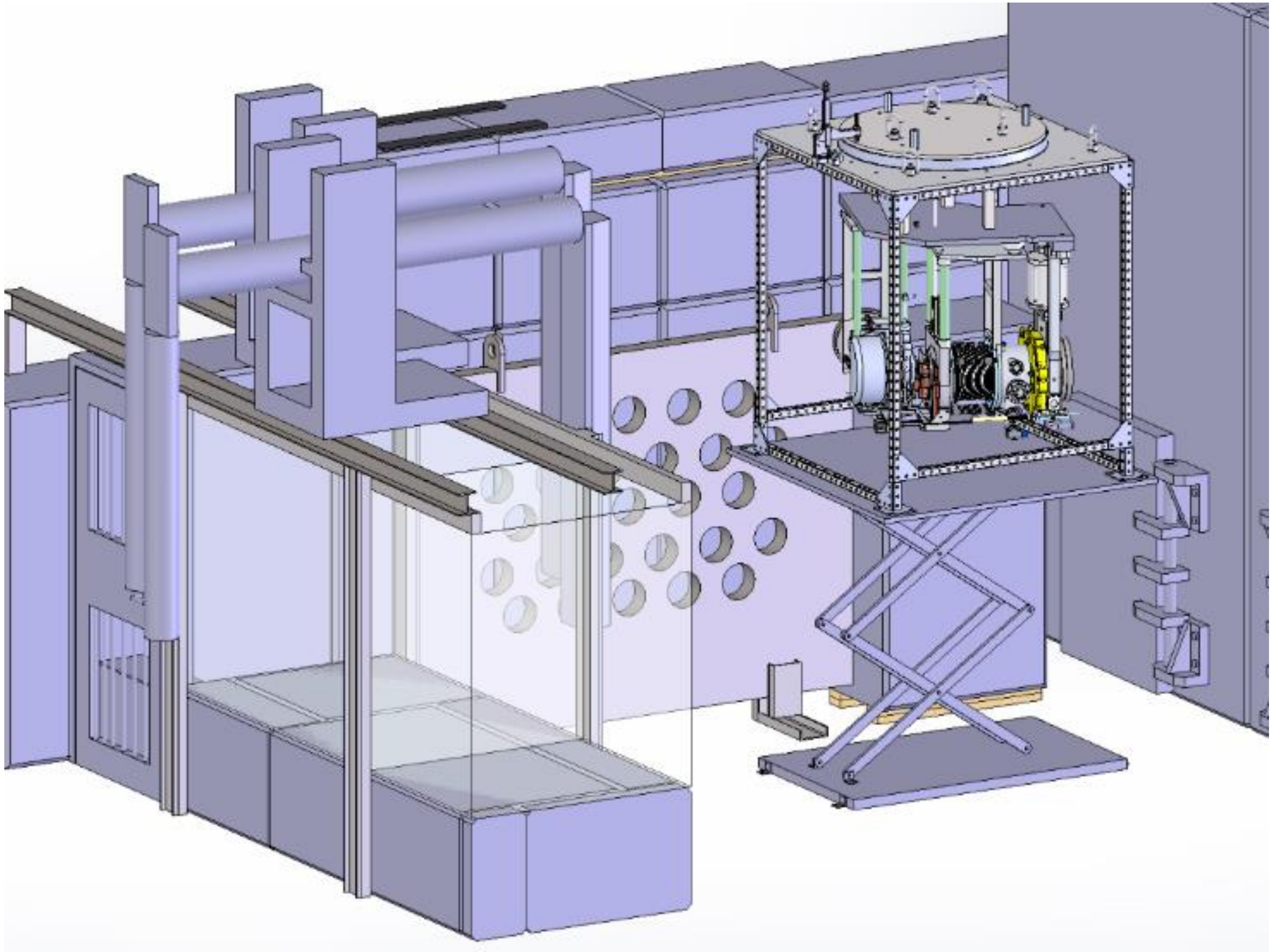
Remote Handling Mock Up

Methodology

- Test stand is mounted onto a lift table inside a warm cell
- Allows the operator 360° range of motion to test disassembly procedures via turntable design
- Lift table allows stand to travel, simulating the environment in the ARIEL hot cell

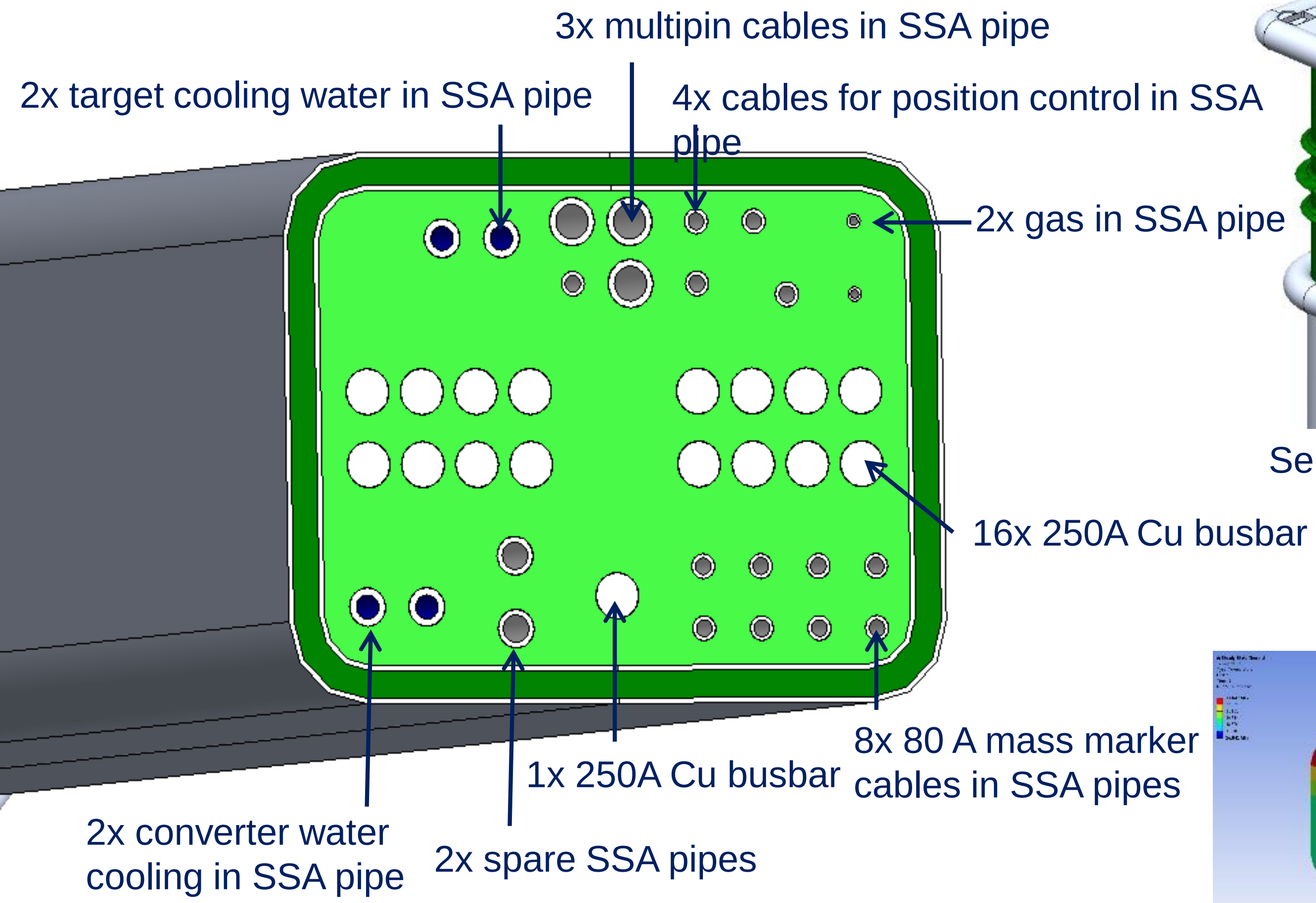
Key Benefits

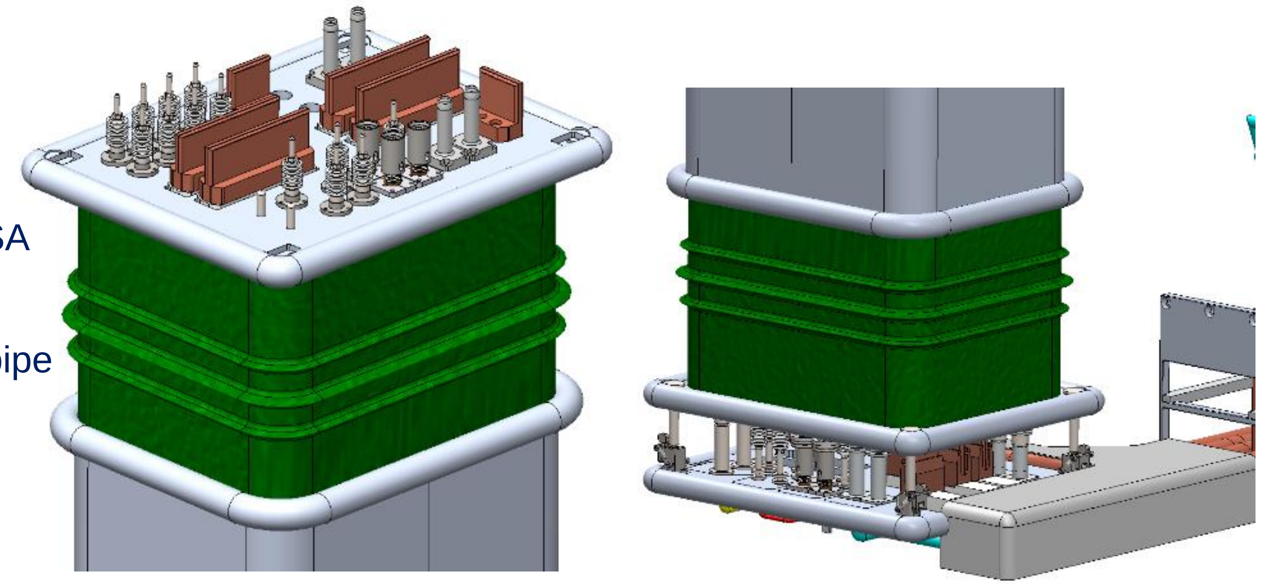
- Allows remote handling feedback into the design process
- Allows development of tools and jigs to happen in parallel with target station design
- Allows design concepts to be proven easily and quickly



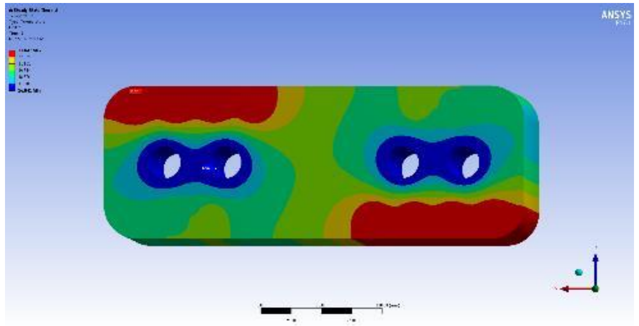
Sectioned View of warm cell with test stand

High-Voltage Feedthrough





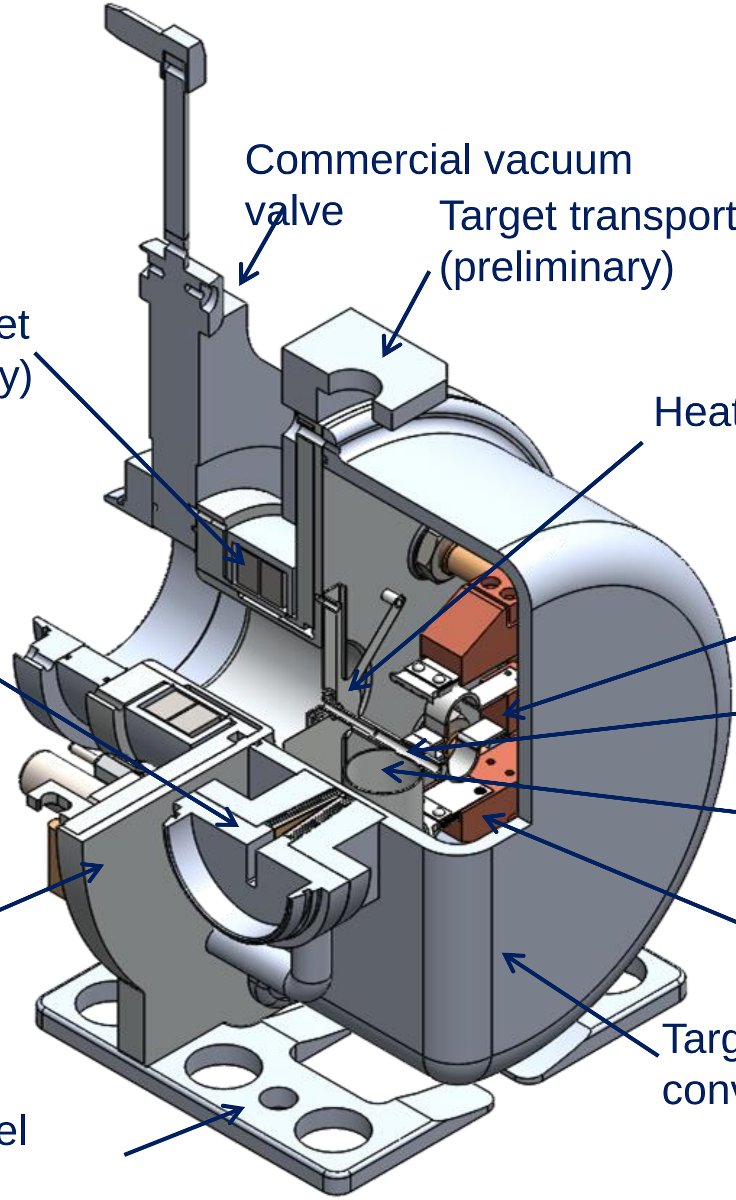
Service space HV remote disconnect Hot cell remote disconnect



Validation steps (by partner VECC):

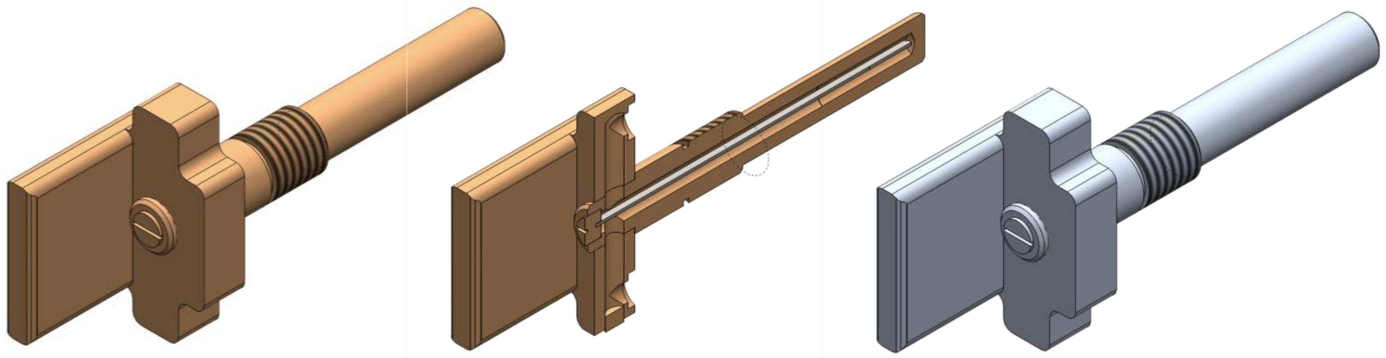
- Thermal simulations ongoing
- Structural simulations
- High voltage simulations
- Vacuum impregnation tests
- 75 kV prototype acceptance tests

Hermetic Target Vessel



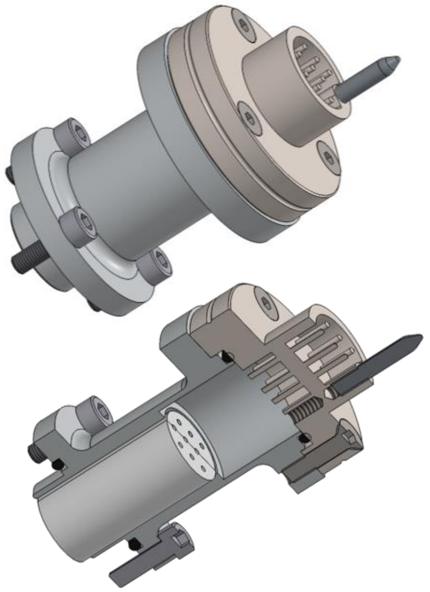
- Increased development space for new ion source and transfer line concepts (cold transfer line, variable temperature transfer line, quartz transfer line, improved FEBIAD, low work function cavity, IG-LIS[2])
- FEBIAD simulations and tests ongoing for defining operational conditions, i.e. magnetic field requirements
- Converter cooling concept developed, prototyping and testing ongoing
- Gamma window thermal simulations and experimental tests
- Full hermetic target vessel prototype and thermo-mechanical test plan being developed
- Converter integrated into target vessel lid allows for routing additional cooling for high power target operation

Hermetic Target Vessel – Vacuum Service Feedthroughs

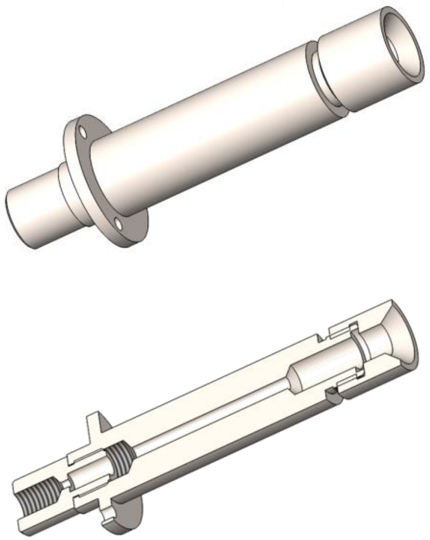


High-current connectors:

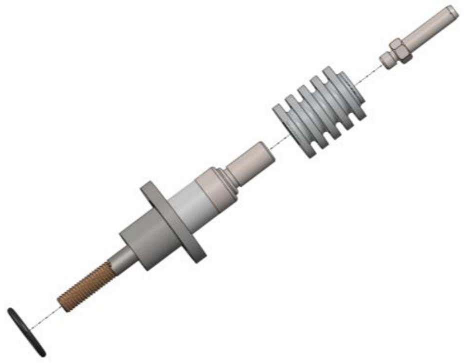
- Modified ISOLDE design
- 2400 A capable
- No brazing or solder joints
- Machined or e-beam welded
- Optimized cooling water separation blade for higher heat transfer coefficient at lower pressure drop
- Increased bus bar connectors
- Upgradable to all-aluminum design



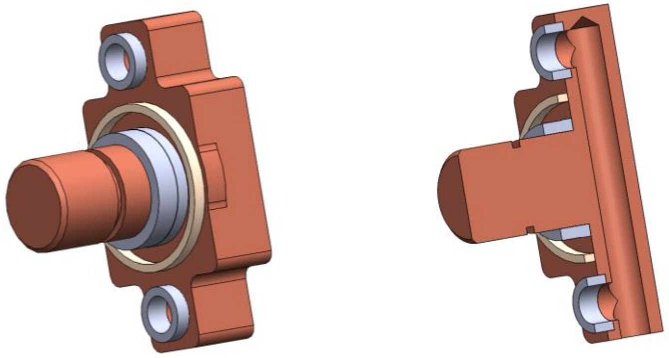
VacTec multipin connector
ISOLDE design but glass instead of ceramic insulation



ISOLDE gas connector

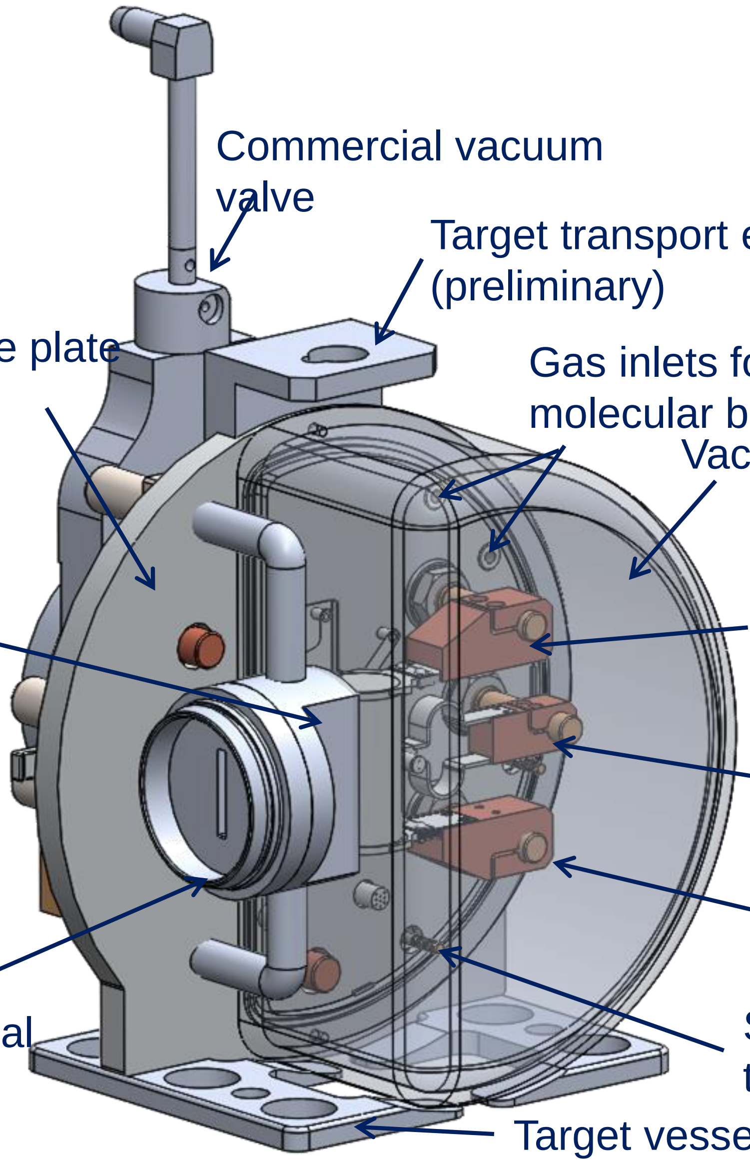


ISOLDE stable beam oven heater



High-current connector port water jumper
Allows to shortcut the water circuit for the AETE / APTW specific high-current connectors

Hermetic Target Vessel



<u>distribution of e-beam power</u>
→ vertical beam scanning, vertical converter, vertical target material container

<u>converter as close to target as possible</u>
→ asymmetric target vessel with target container close to γ-ray window

<u>stable ion source outlet position and temperature</u>
→ current return and mechanical support at ion source tip

<u>target material container and ion source at 2000 °C</u>
→ flexible Ta-sheet electrical and mechanical connectors except for ion source outlet

<u>ion source and transfer line development flexibility</u>
→ space between current ion source and valve

<u>Molecular beams, RILIS tuning, separator tuning</u>
material ovens and calibrated gas leaks connected to ion source

all of these aspects have precedence,
except for converter & γ-ray window