FRIB Remote Handling – Operations Experience and Future Plans

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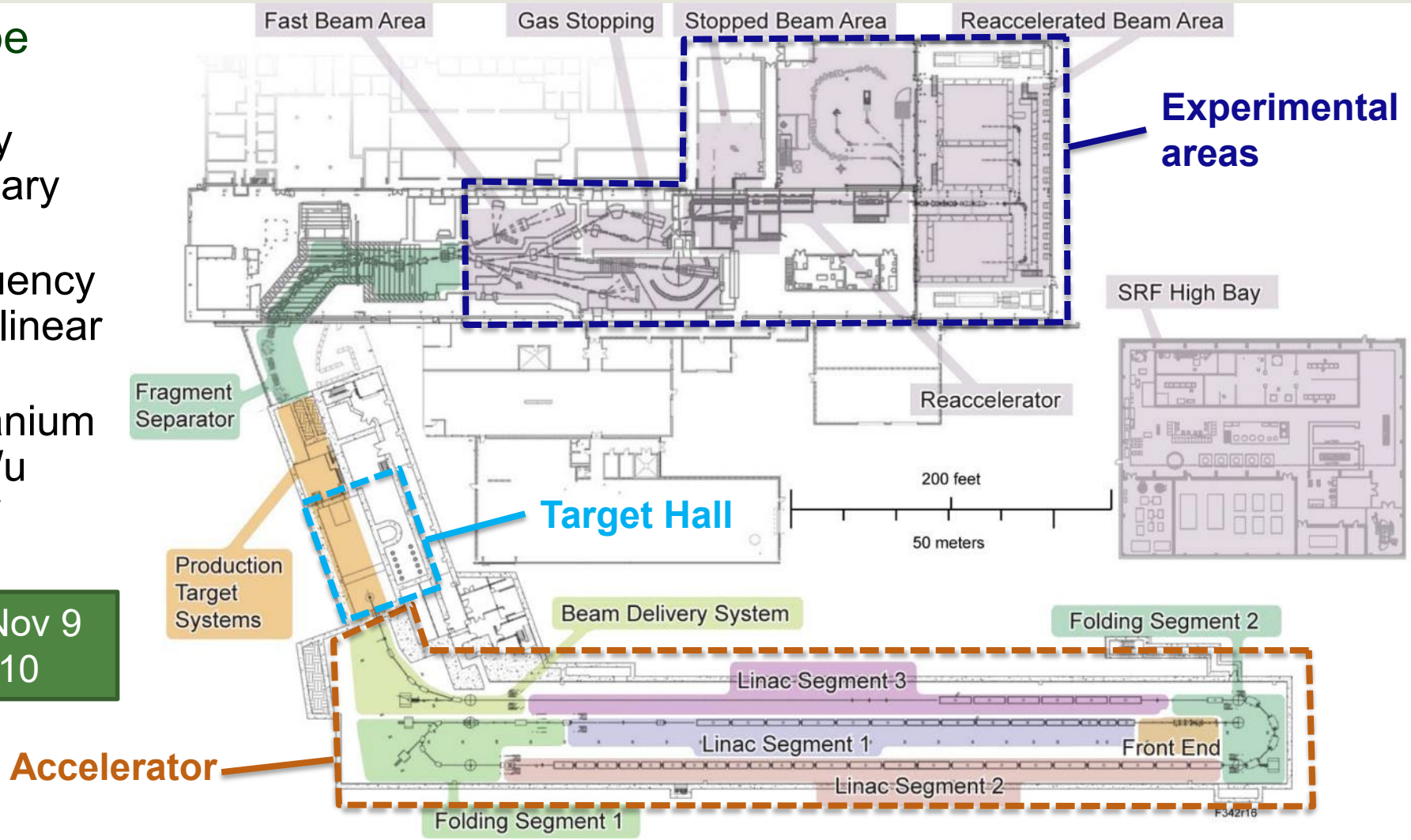
Outline

- FRIB Overview
- Equipment
- Beam Dump Maintenance
- Target Reconfiguration
- Current Operational Status
- Operational Experience
- Future Requirements

FRIB Overview

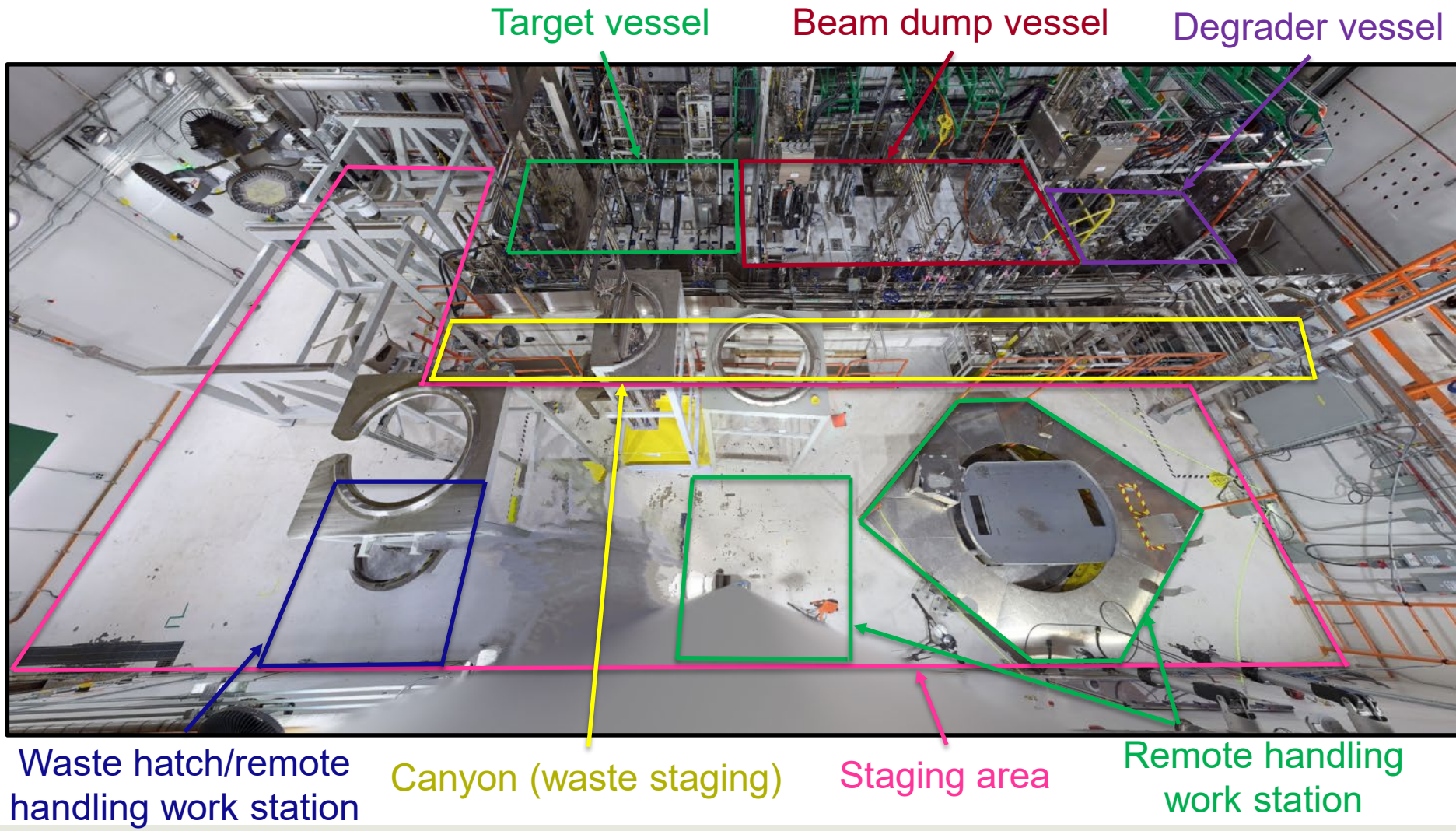
- The Facility for Rare Isotope Beams
  - Heavy ion accelerator facility aiming to reach 400kW primary beams
  - Superconducting radio frequency continuous-wave heavy-ion linear accelerator
  - Accelerate all ions up to Uranium to energies above 200 MeV/u
  - Currently operating at 10kW

T. Maruta, 10:15-10:30am, Thur, Nov 9
J. Song, 10:15-10:30am, Fri, Nov.10

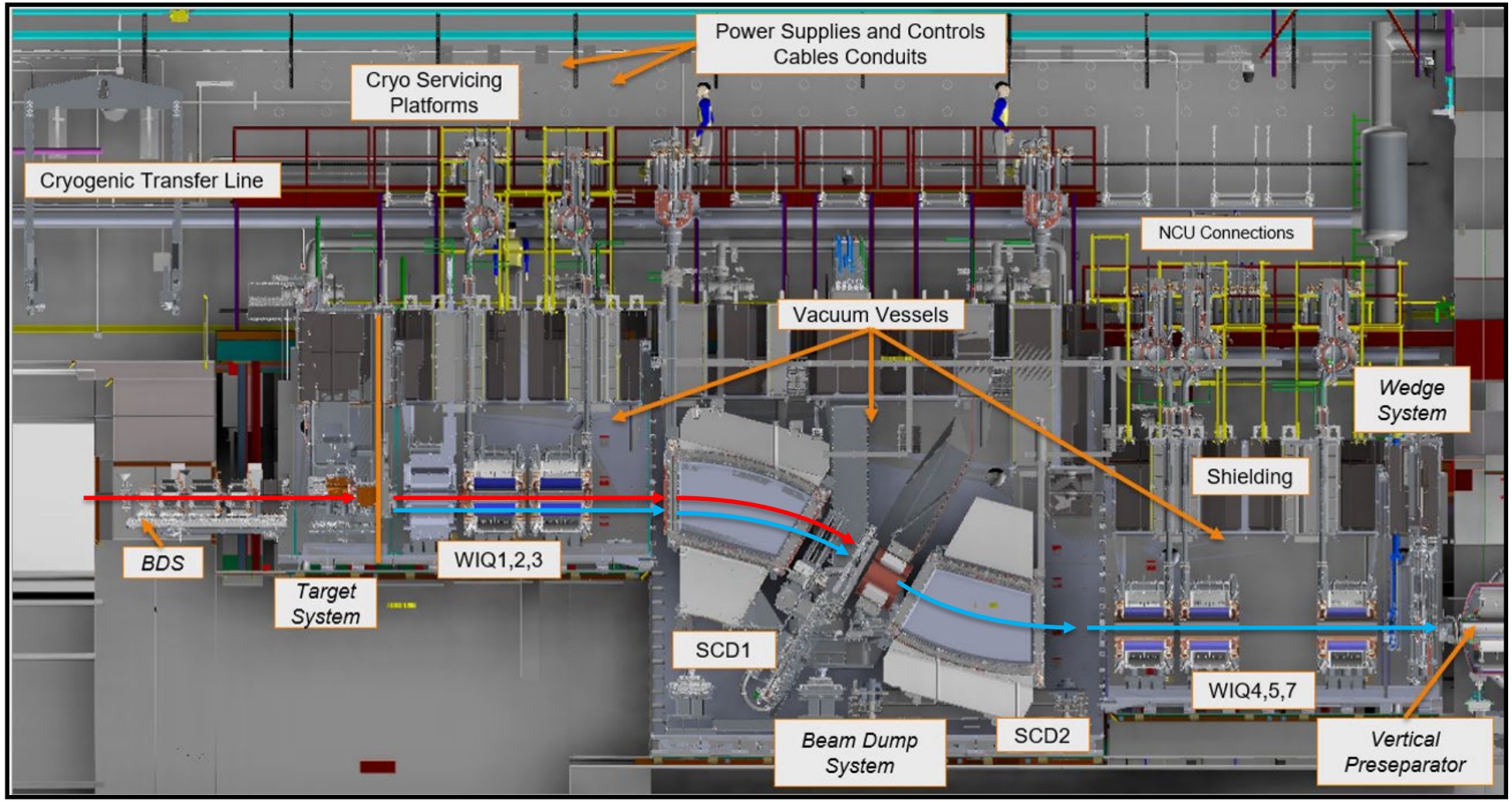


Target Hall Layout

- Target hall allows for hybrid approach of both hands on and remote work to be completed
- Three remote workstations with shield windows and through-wall-manipulators
- Waste hatch to load liners into cask

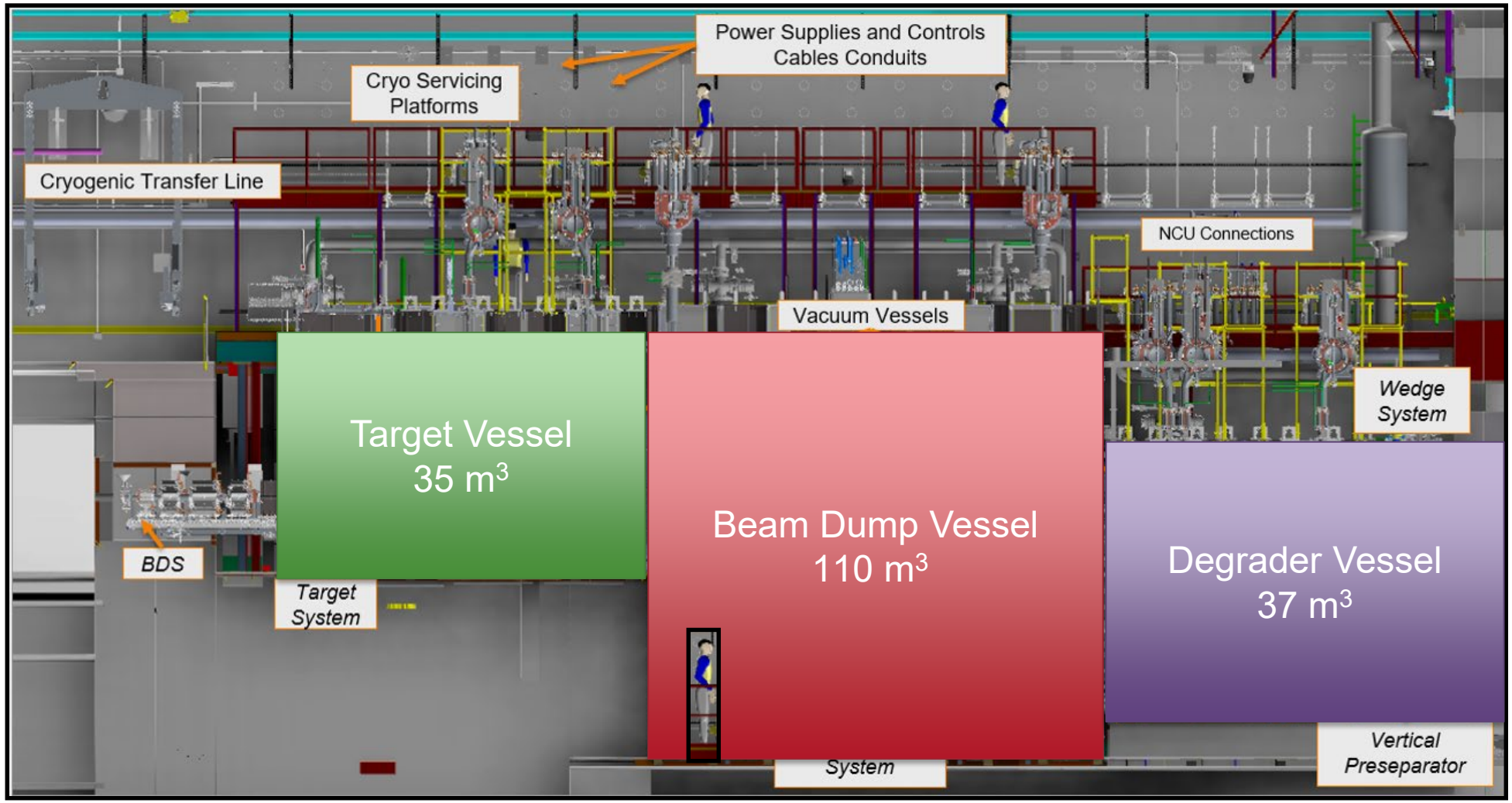


Target Hall Vacuum Vessels [1]



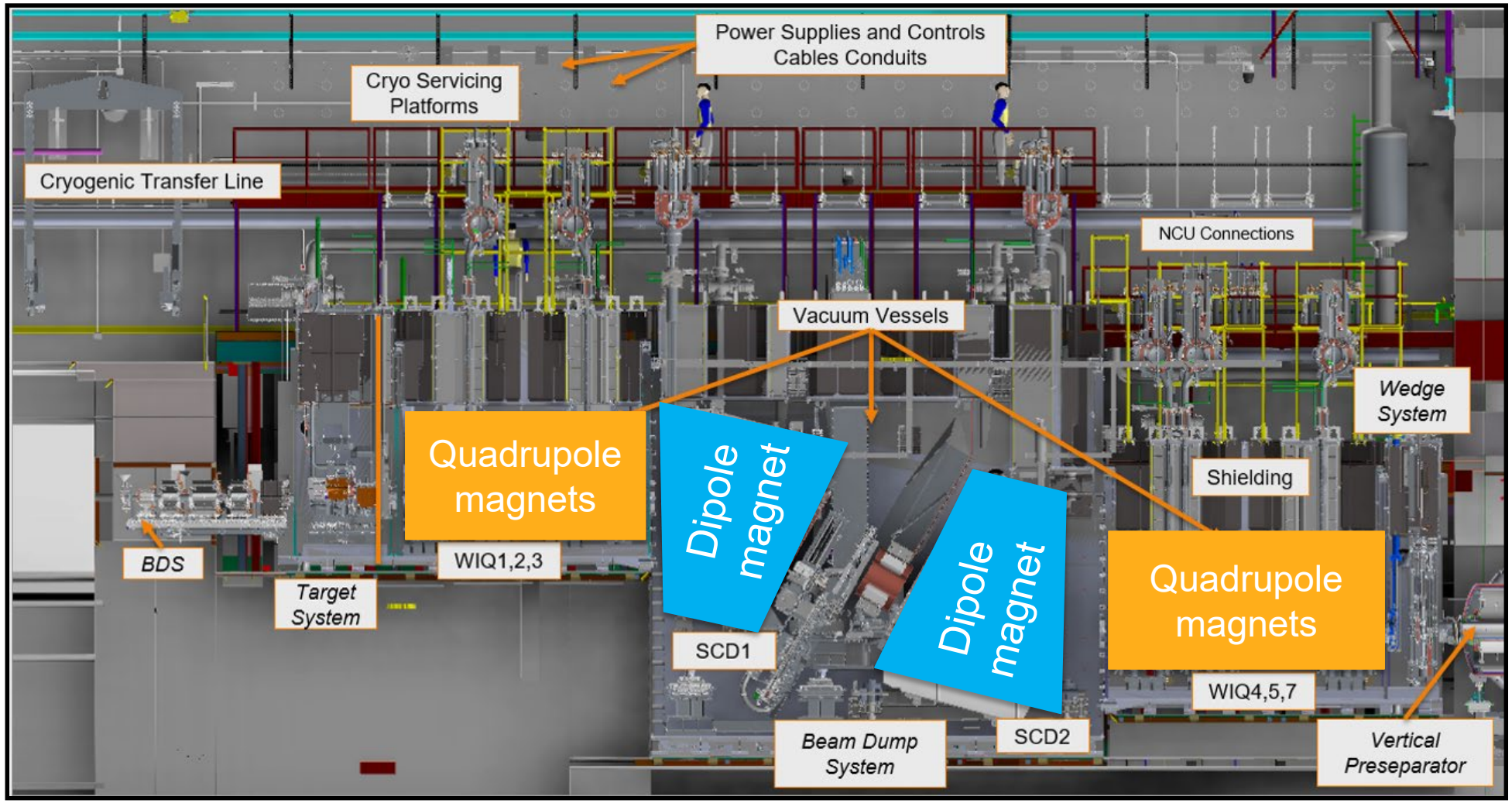
Target Hall Vacuum Vessels [2]

- Three main vessels
  - Target vessel
  - Beam dump vessel
  - Degrader vessel



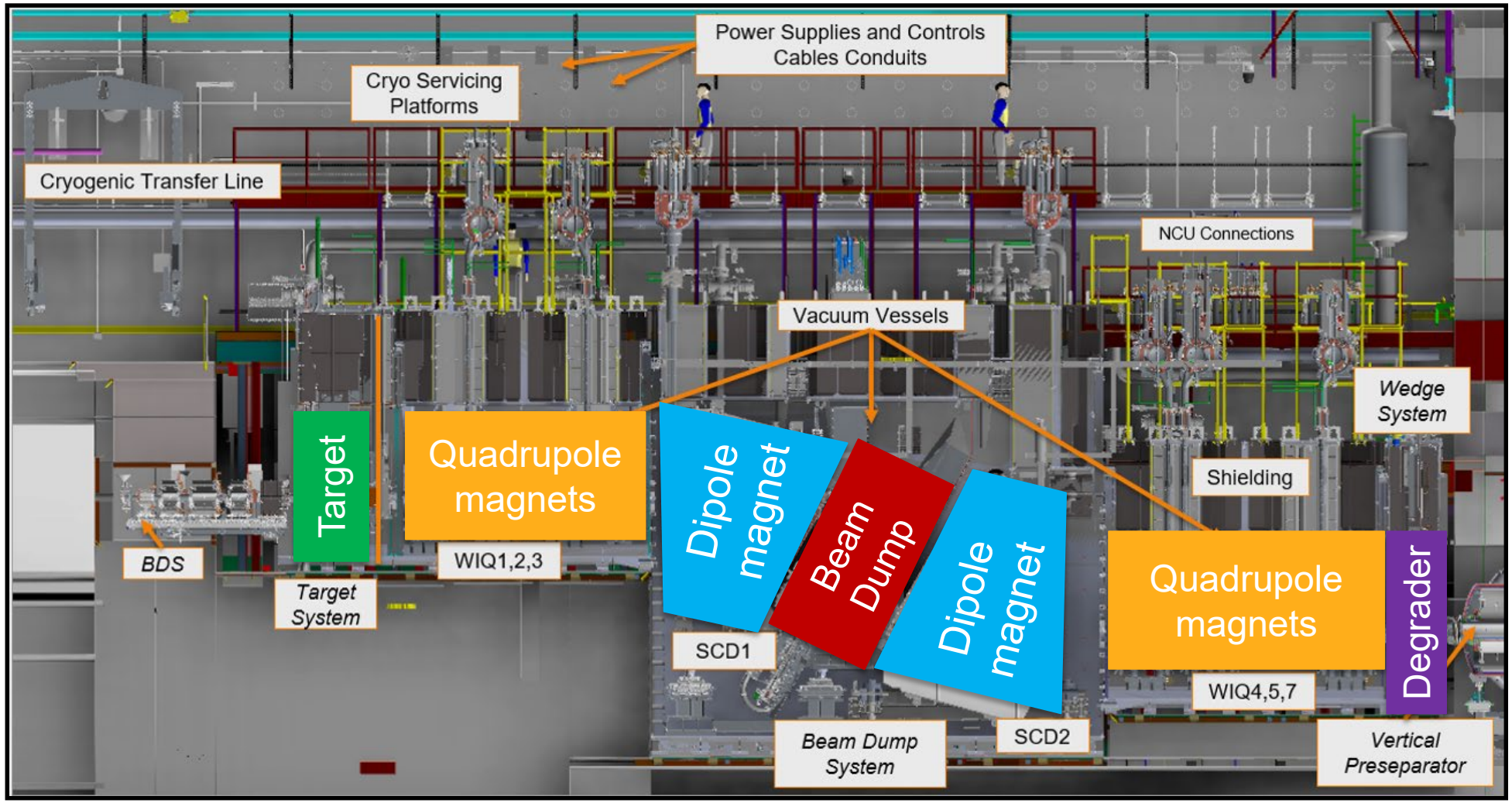
Target Hall Vacuum Vessels [3]

- Three main vessels
  - Target vessel
  - Beam dump vessel
  - Degrader vessel
- Two magnet types
  - Quadrupole
  - Dipole



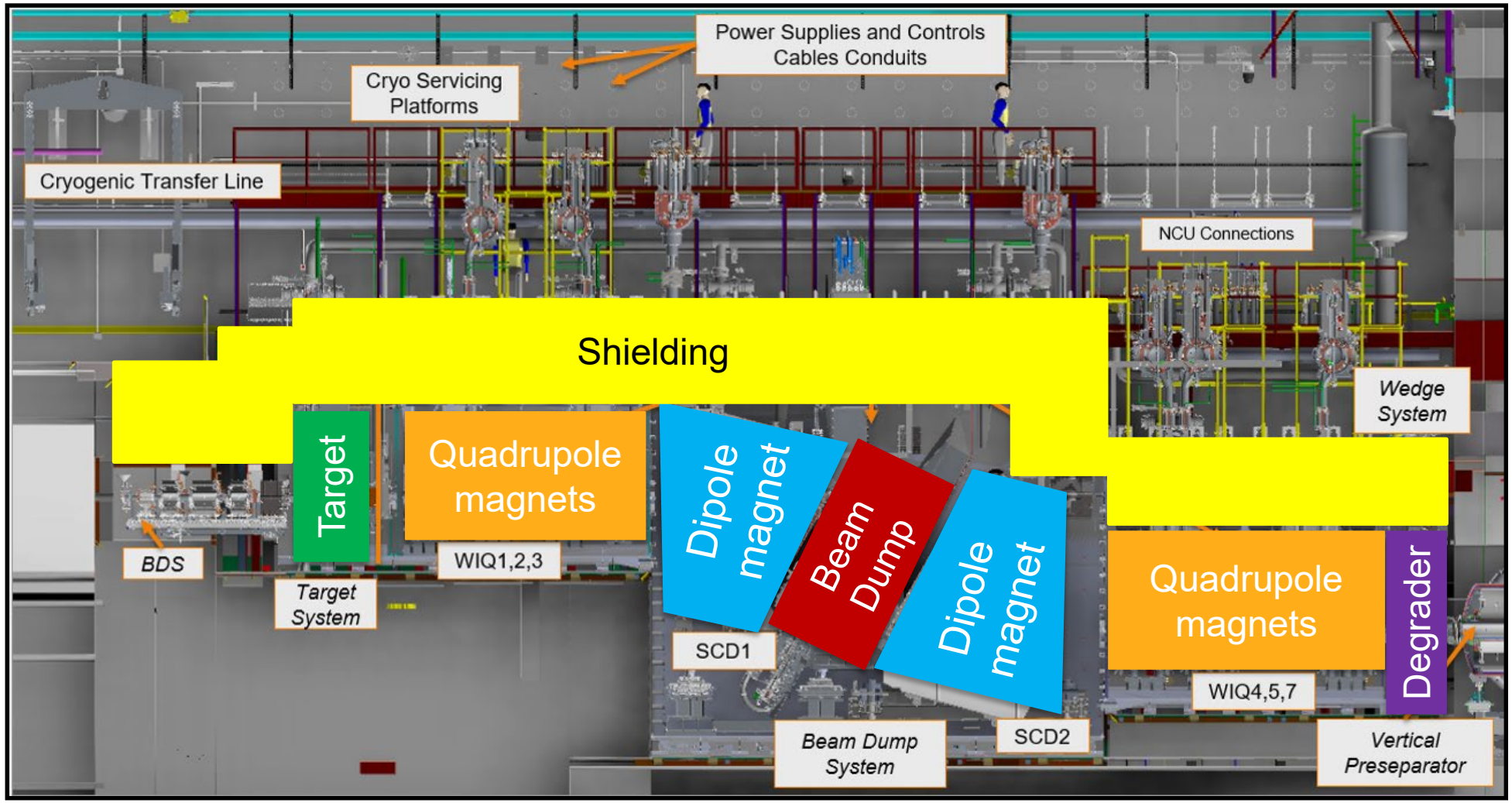
Target Hall Vacuum Vessels [4]

- Three main vessels
  - Target vessel
  - Beam dump vessel
  - Degrader vessel
- Two magnet types
  - Quadrupole
  - Dipole
- Three key devices
  - Target
  - Beam dump
  - Degrader



Target Hall Vacuum Vessels [5]

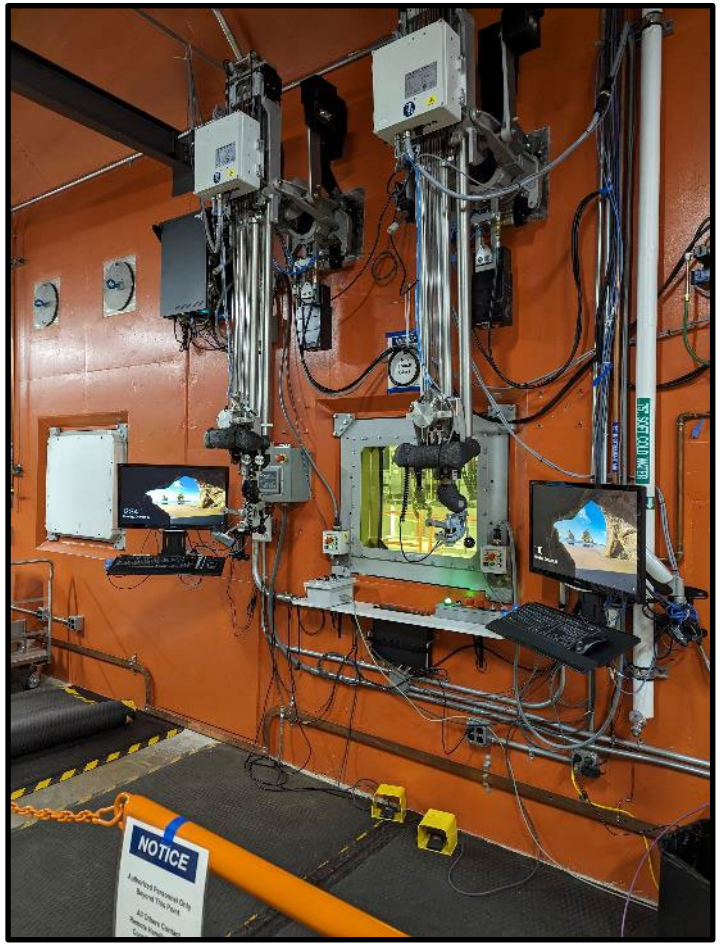
- Three main vessels
  - Target vessel
  - Beam dump vessel
  - Degrader vessel
- Two magnet types
  - Quadrupole
  - Dipole
- Three key devices
  - Target
  - Beam dump
  - Degrader
- Shielding
  - Allows hands-on Target hall access



Equipment [1]

- Crane
  - 20t capacity, PLC converted
  - Fully automated 4 axis of motion
  - Redundancy for recovery
- Workstation window
  - Lead window, 22”x28” viewing area
  - 100lb capacity manipulators
  - Ø100” table x 26’ travel x 28,000lb cap. Lift
- Fixturing and tooling
  - DC nutrunner torque tools
  - Specialized fixturing and tooling for each device
- Vision/Lighting
  - PTZ camera system
  - Lutron LED “Star” light system

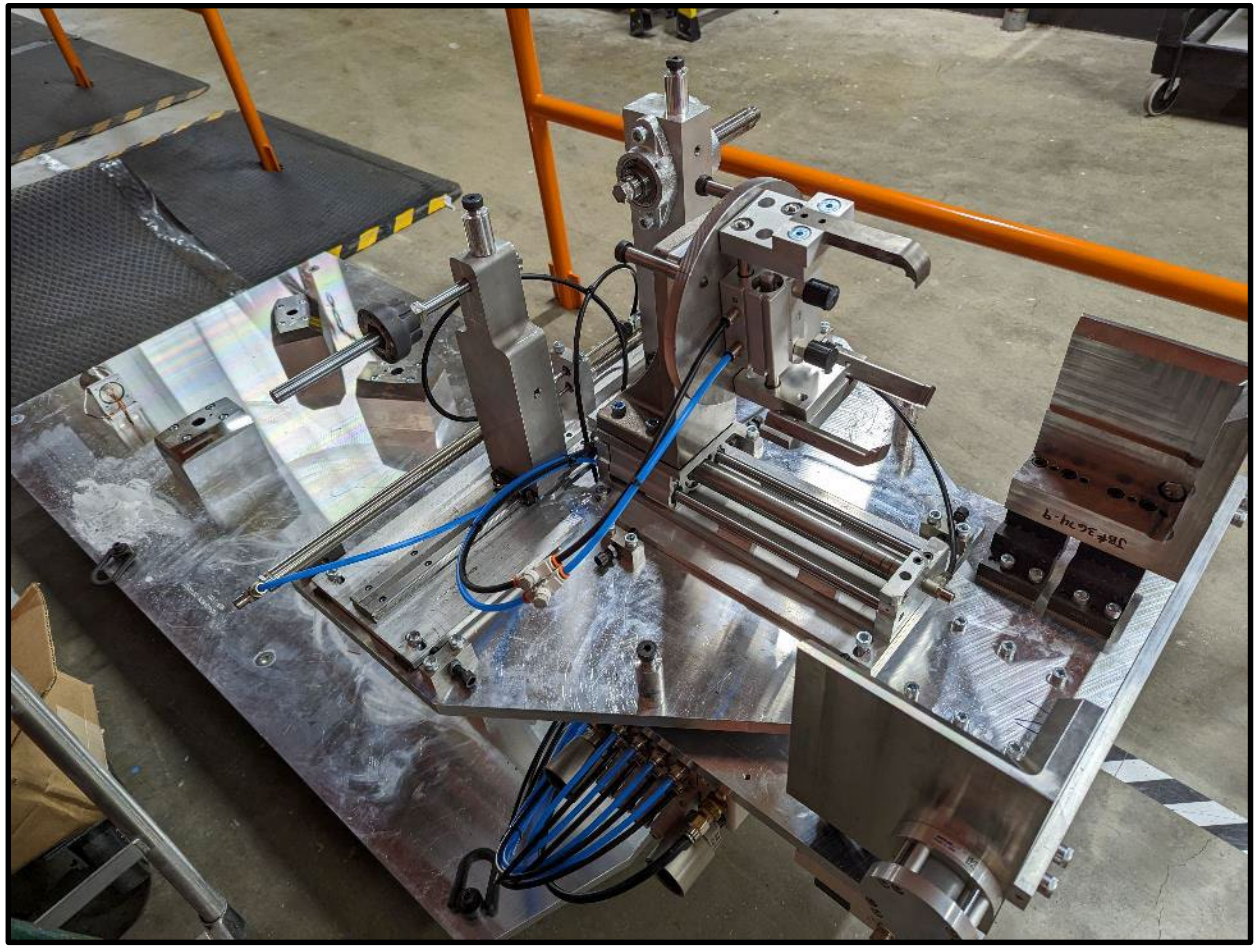
Window workstation target hall side



Window workstation operator side

Equipment [2]

Remote handling control room

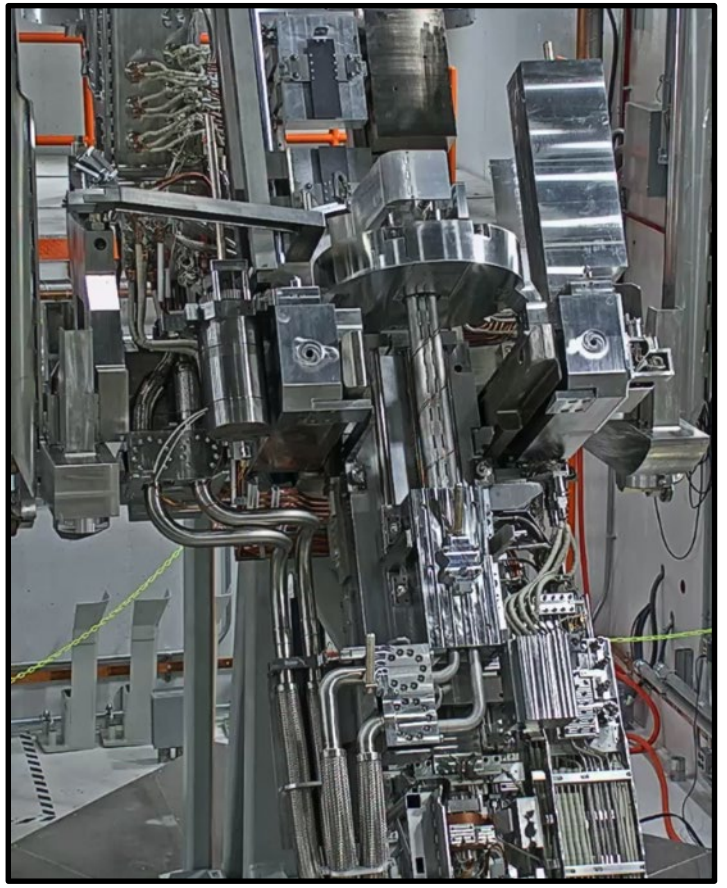


Target graphite disk change fixturing/tooling

Target Hall Key Beamline Devices

- Target
  - Rotating Ø12” graphite disk, max 5,000rpm
  - Will absorb up to 100kW beam power
  - Change graphite thickness for experiments at a frequency of up to weekly
- Beam dump
  - Currently using a static dump head
  - 400kW operations requires rotating .5mm wall titanium drum, max 600rpm
  - Will absorb up to 300kW primary beam
  - Will perform maintenance yearly replacing drum, modules, and motors
- Energy degrader
  - Series of aluminum “wedge” shaped plates
  - Will absorbs up to 6kW of beam power
  - Change thickness and angle of wedge for experiments at a frequency of up to weekly

Target assembly



Beam dump assembly

Degrader assembly

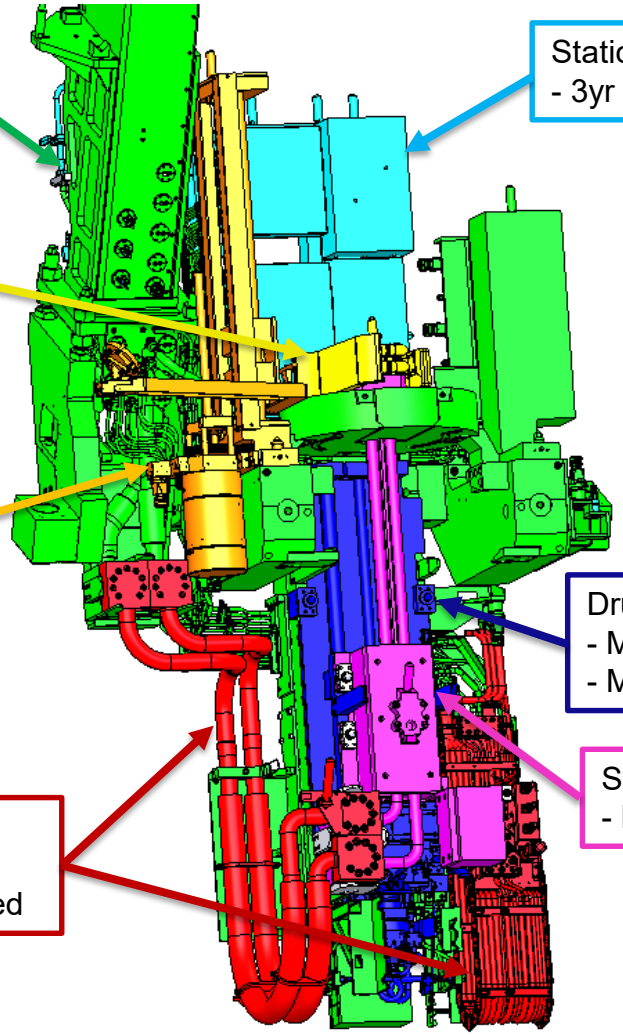
Beam Dump Maintenance, Yearly

Utility chase, integration frame, fixed harnesses
- Life of facility
- Will require size reduction for disposal

Beam dump head
- 1yr life expectancy

Mirror module
- Motor and mirror, 1yr life expectancy
- Module 3yr life expectancy

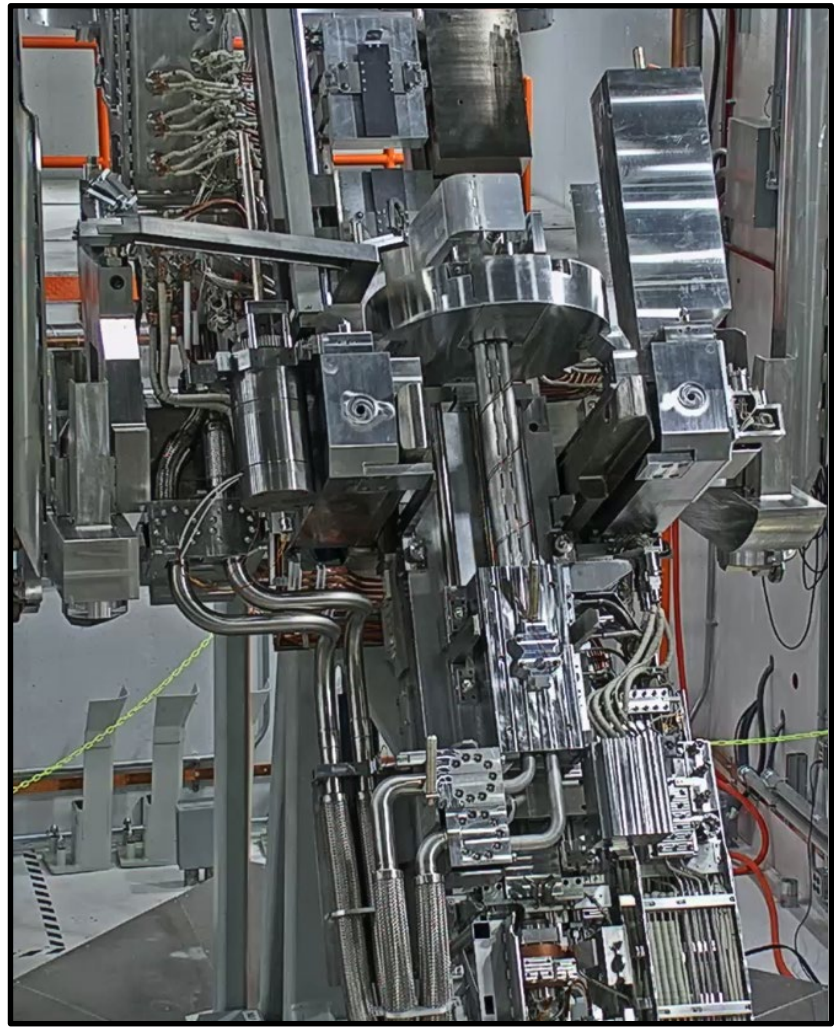
Flexible harnesses
- Estimated as life of facility
- Can be remotely replaced if needed



Static fragment catcher
- 3yr life expectancy

Drum translation module
- Motor, 1yr life expectancy
- Module, 3yr life expectancy

Static rotation module
- Life of facility

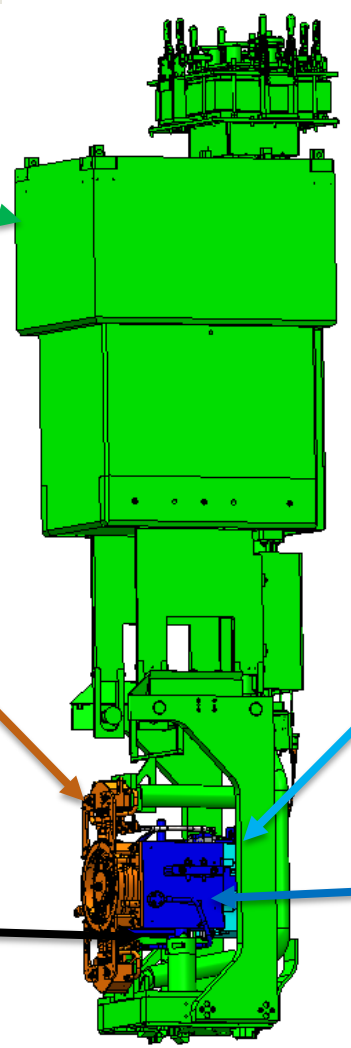


Target Maintenance, Weekly

In-vacuum shielding and cradle
- Life of facility
- Will require size reduction for disposal

Target disk module
- Disks and heat exchanger, changed weekly for user experiments

Mirror module
- Mirror, life expectancy TBD

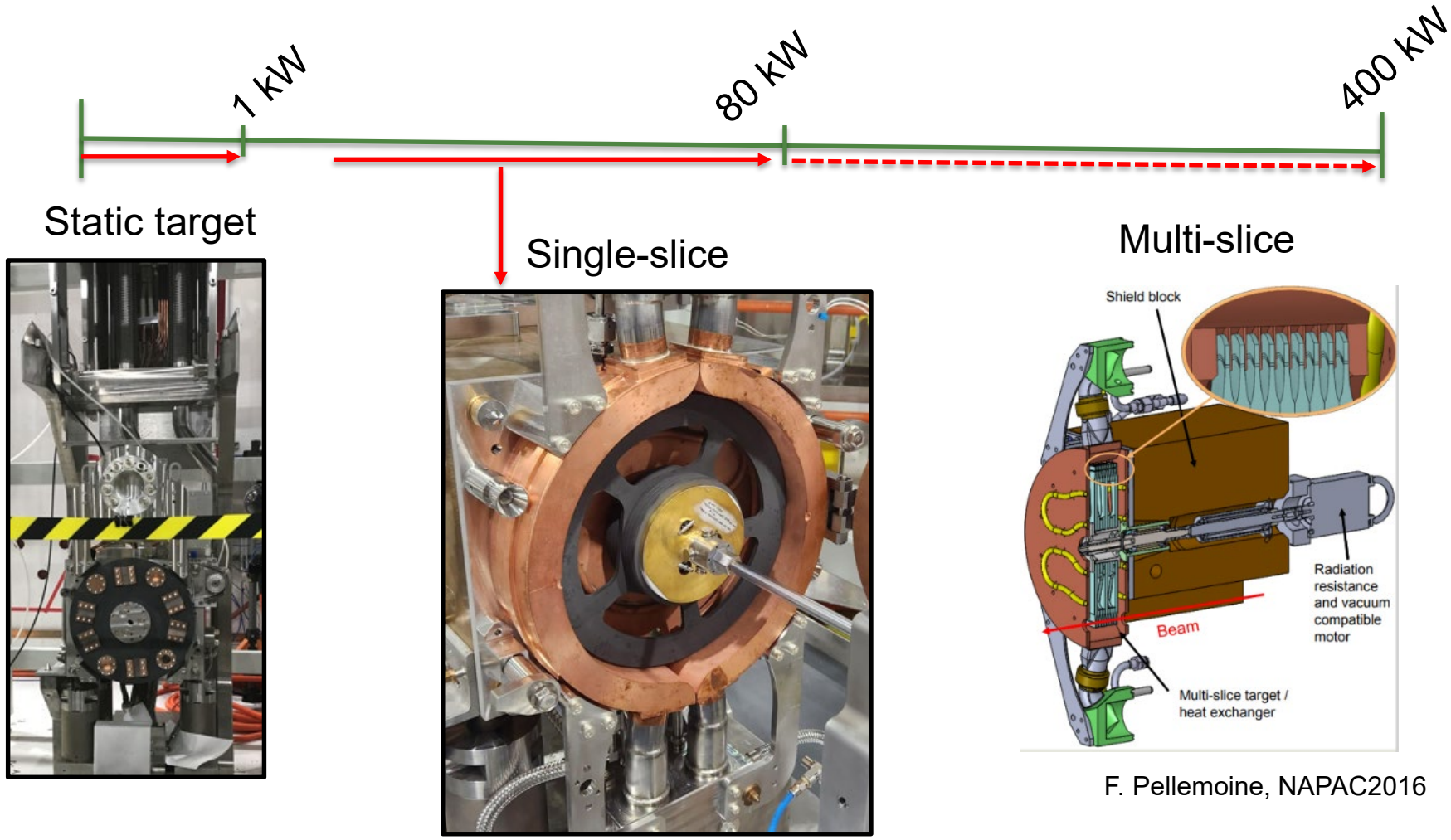


Motor drive module
- Motor, 1-3yr life expectancy

Shield block module
- Estimated life of facility
- Can be replaced and disposed

Target Power Ramp Up Path

- Target
  - Will follow power ramp up strategy with mechanical design
  - Remote handling will require iterations as target design evolves
  - Will incorporate remote handling experience into higher power target designs
  - Static target for was used for commissioning up to 1kW

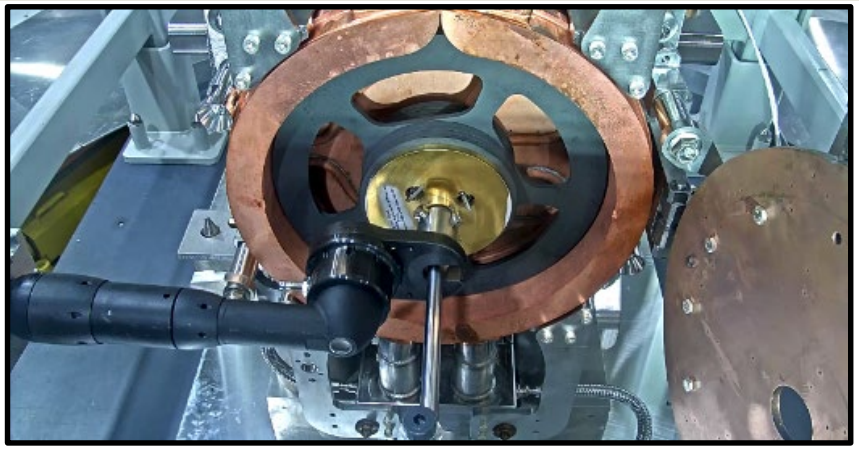


F. Pellemoine, NAPAC2016

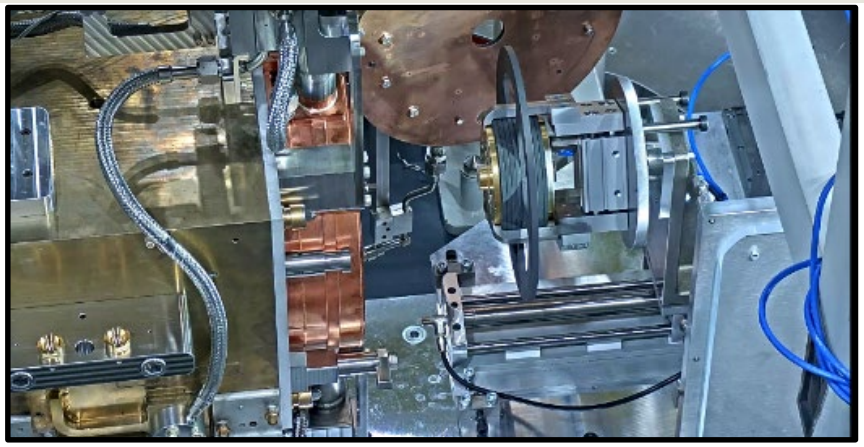
Current Status

- Successfully completed target changes since start of operations in May 2022
  - Total time from beam off to system ready for operations is currently 24hrs (assuming target is the only system scheduled for reconfiguration)
    - » Improved from 13 working days in September 2022

- Completed two successful beam dump head changes
  - Total time from beam off to system ready for operations is 25 working days
    - » Improved from 29 working days in August 2022



Torque tool removing shaft hub nut



Gripper removing old graphite disk

Torque tool removing old 20˚ static dump

Grapple lift putting dump head in container

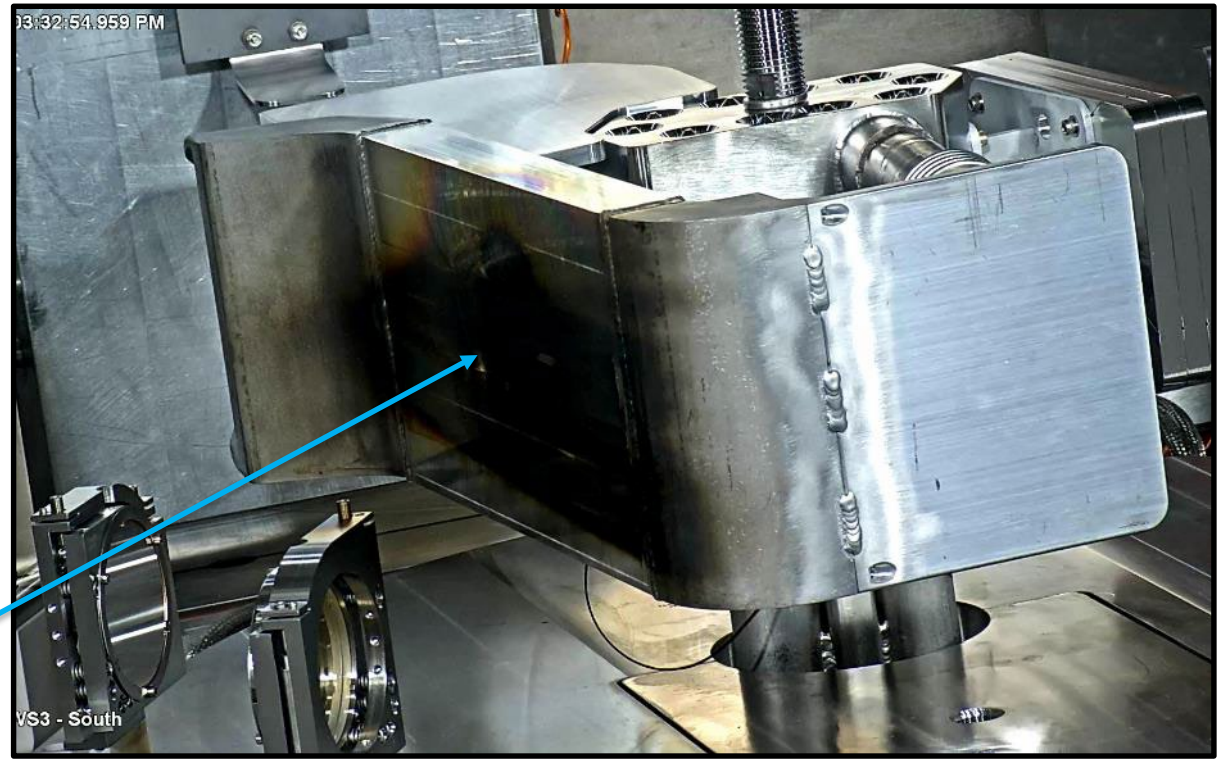
Current Radiation Levels

- Measured radiation levels at the end of 5kW operations
  - Will ramp up to 400kW, 80x higher than current power
  - Remote handling will become more critical to reconfigure and maintain beamline devices

Target after start of operations through 5kW

20 mSv/h at exit aperture of heat exchanger door

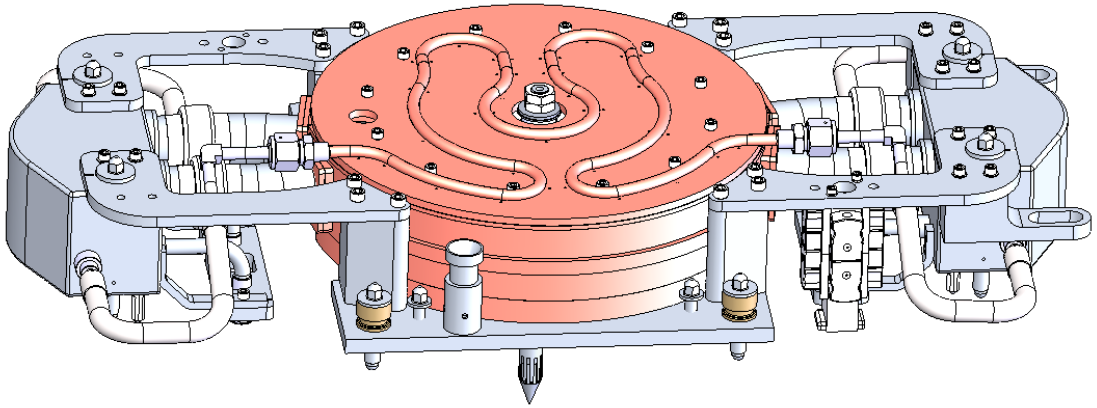
400 mSv/h on dump head



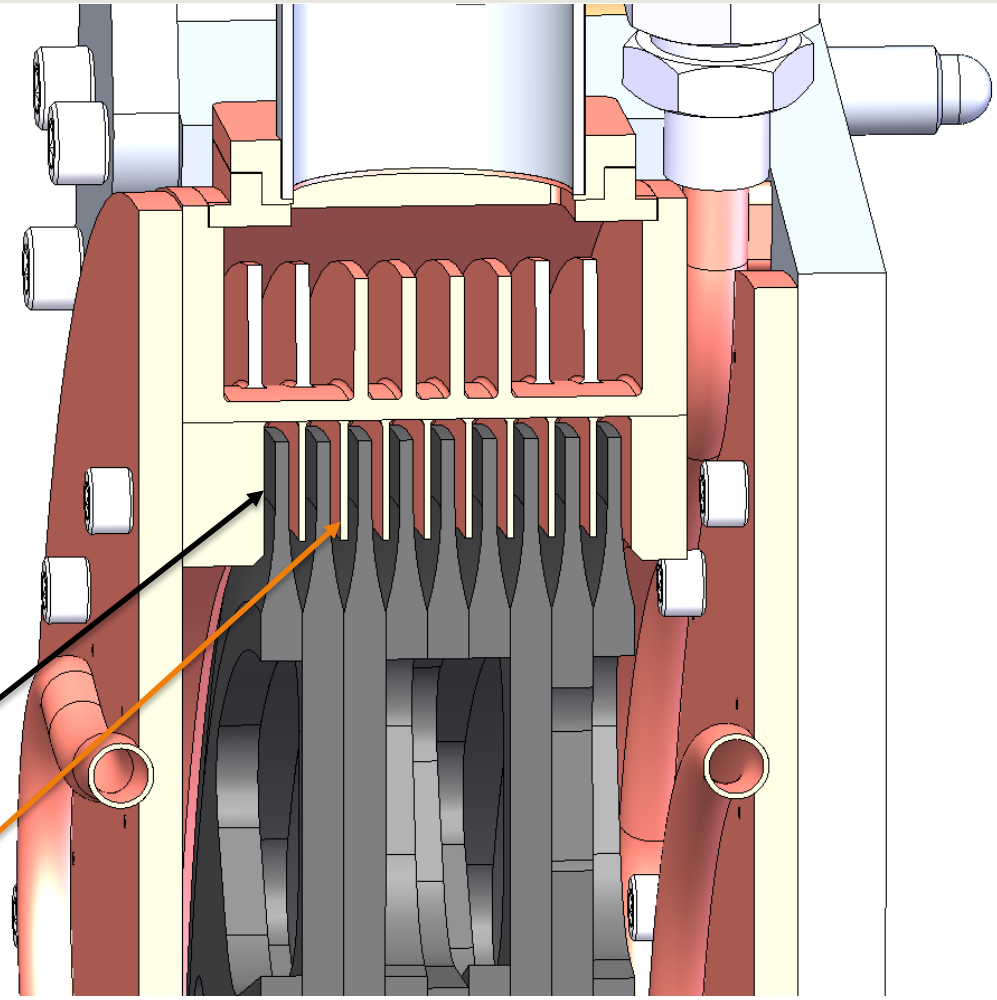
6˚ static dump head after 1 year 5kW operation

Original Target Design

- Modifications to target heat exchanger were found to be beneficial
  - Original design included replacement of heat exchanger and bearing cartridge assembly during disk change
    - » Proved to be costly and time/resource consuming to fabricate heat exchangers
    - » Increases waste volume for disposal
    - » Requires separation of water cooling connections which need to be re-validated
    - » Cooling fins did not allow for disk removal



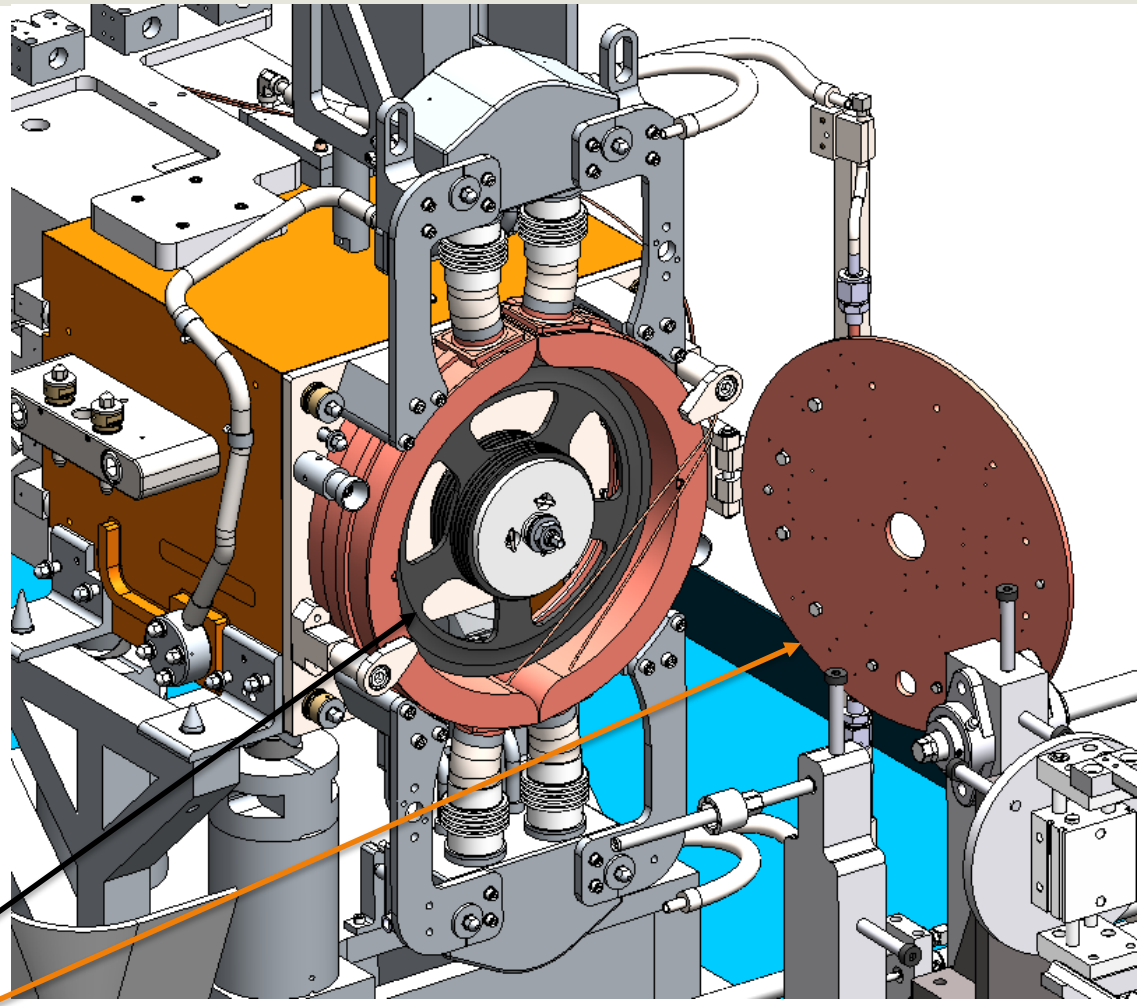
Heat exchanger assembly with disk and bearing cartridge



Original multi-disk heat exchanger design

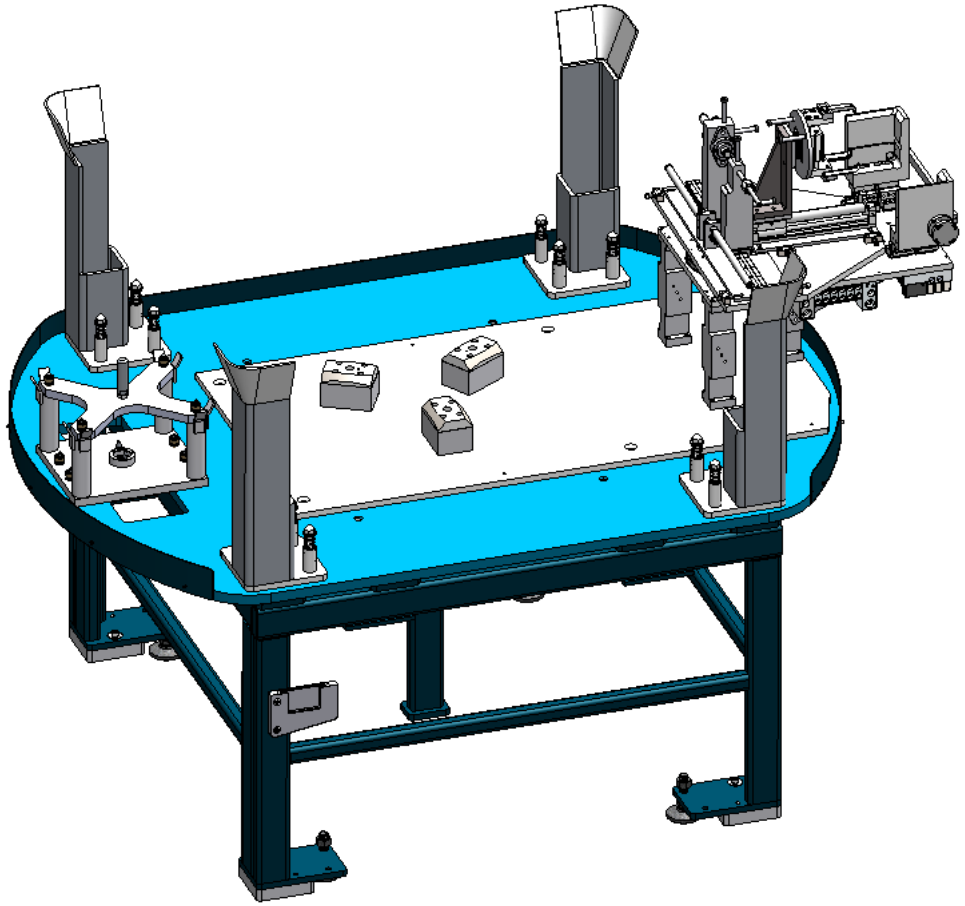
Target Modifications

- Modifications to a single disk target heat exchanger were made
  - Allows remote handling to remove graphite disk assembly only
    - » Cooling fins not required for single disk
    - » Changed downstream cover to hinged door
    - » Updated spindle shaft nut for remote interface
  - Remote operations proved successful
- Multi disk version required for higher power
  - Need to continue to remove just graphite disk
    - » Cooling fins will be required for multi-disk version
    - » Will need to separate heat exchanger remotely to allow for just graphite to be removed
    - » Consider adding workstation to change graphite disk configuration on hub remotely



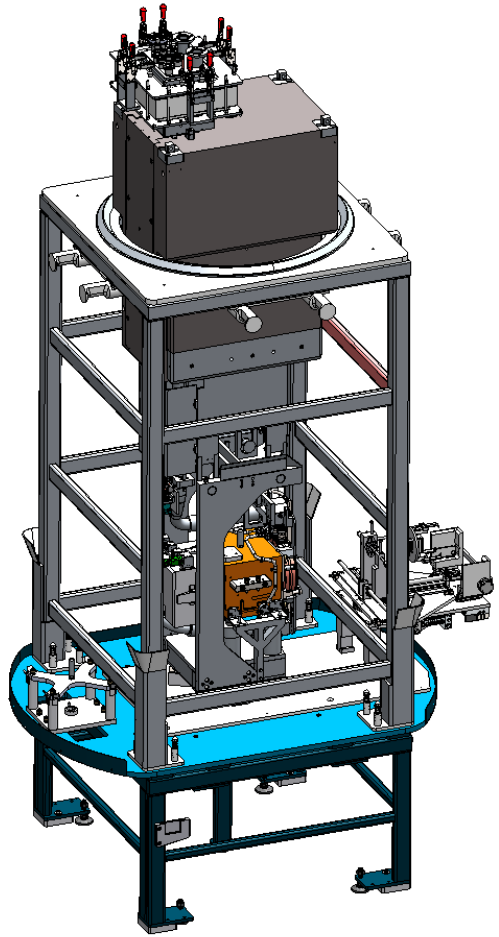
New single disk heat exchanger design

Target Disk Tooling and Process [1]



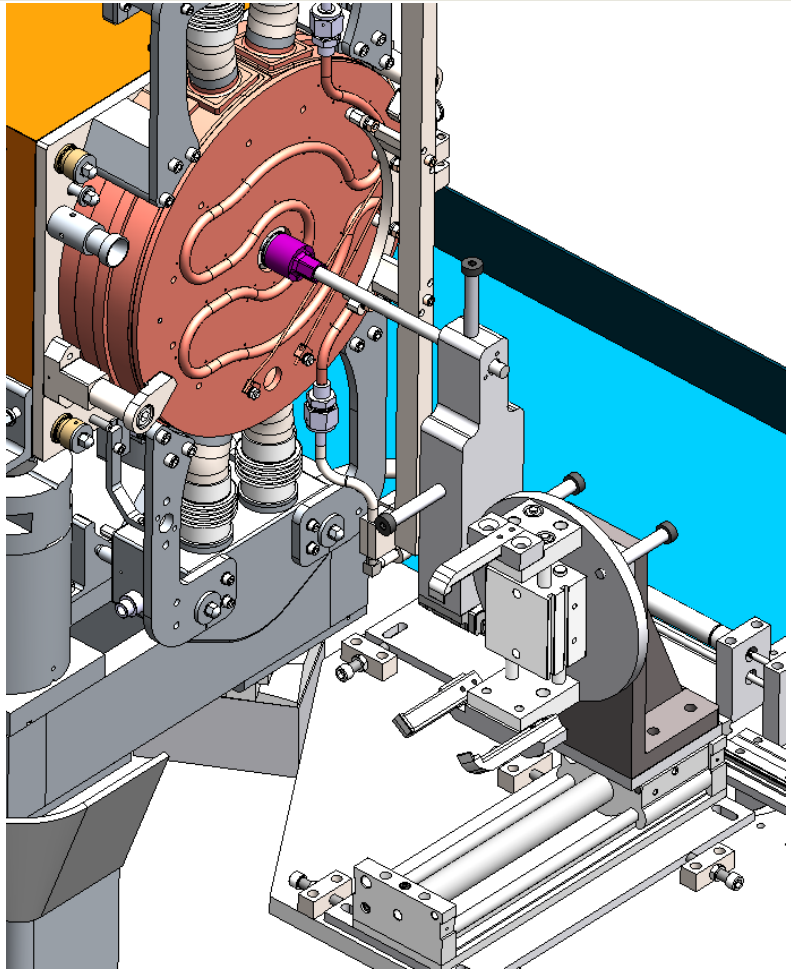
Place target tooling on worktable located on lift

Target graphite disk change fixturing/tooling

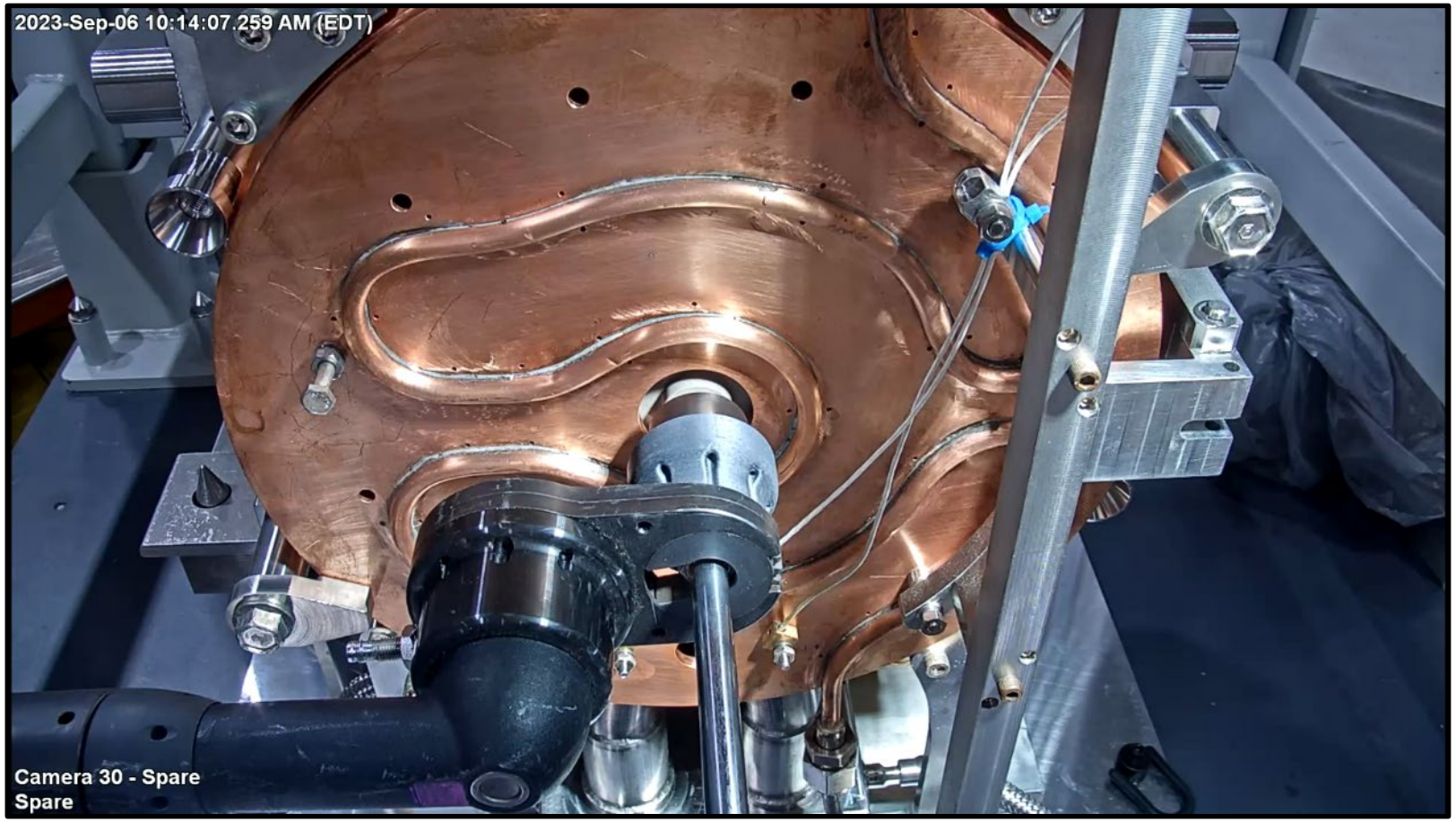


Place target stand and assembly

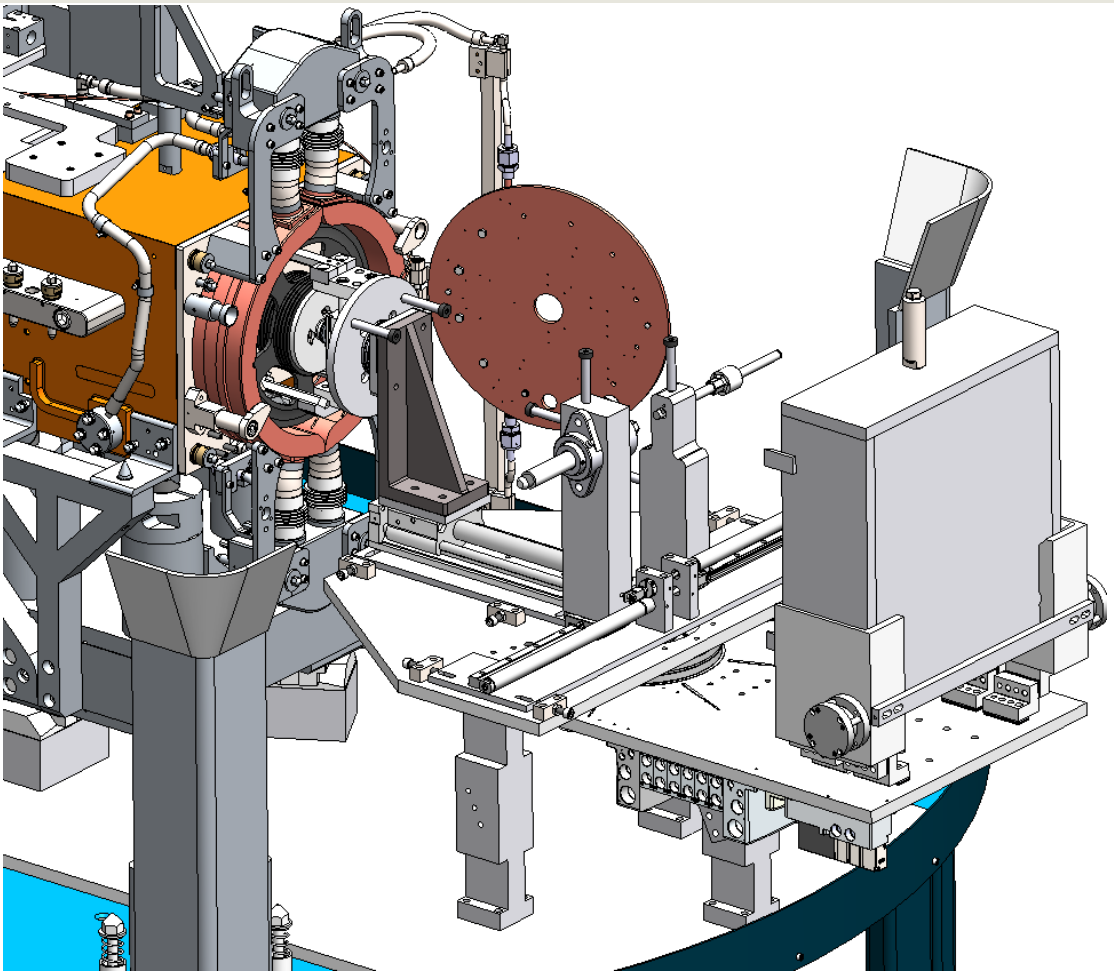
Target Disk Tooling and Process [2]

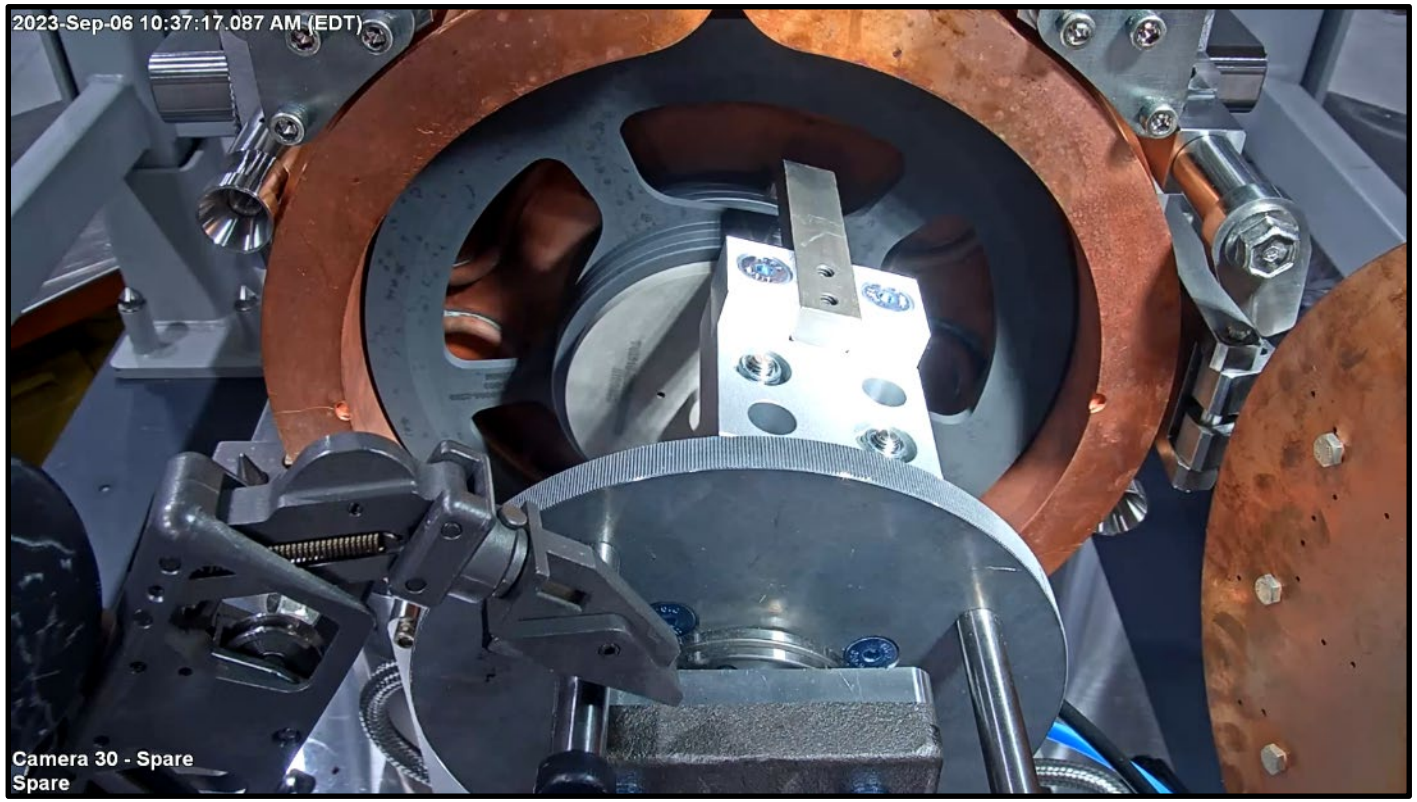


Remove spindle nut



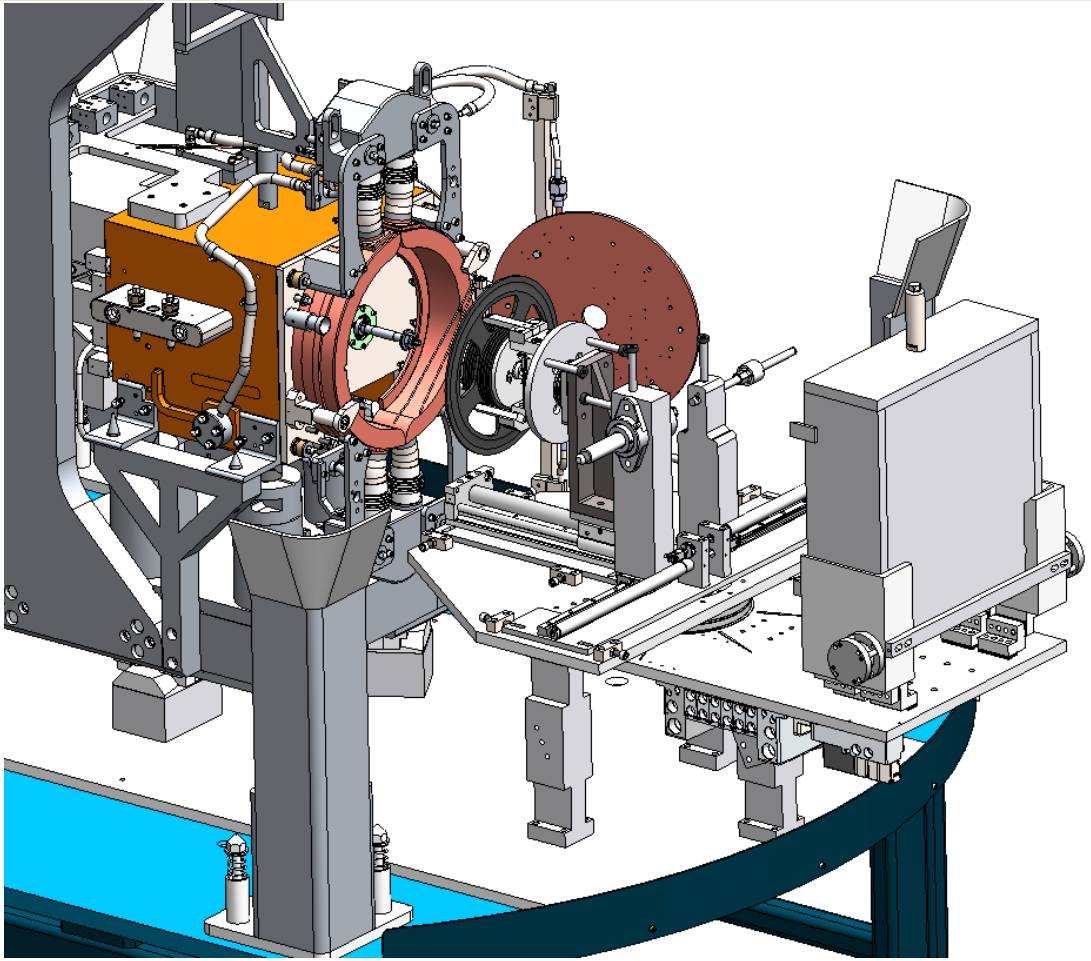
Target Disk Tooling and Process [3]

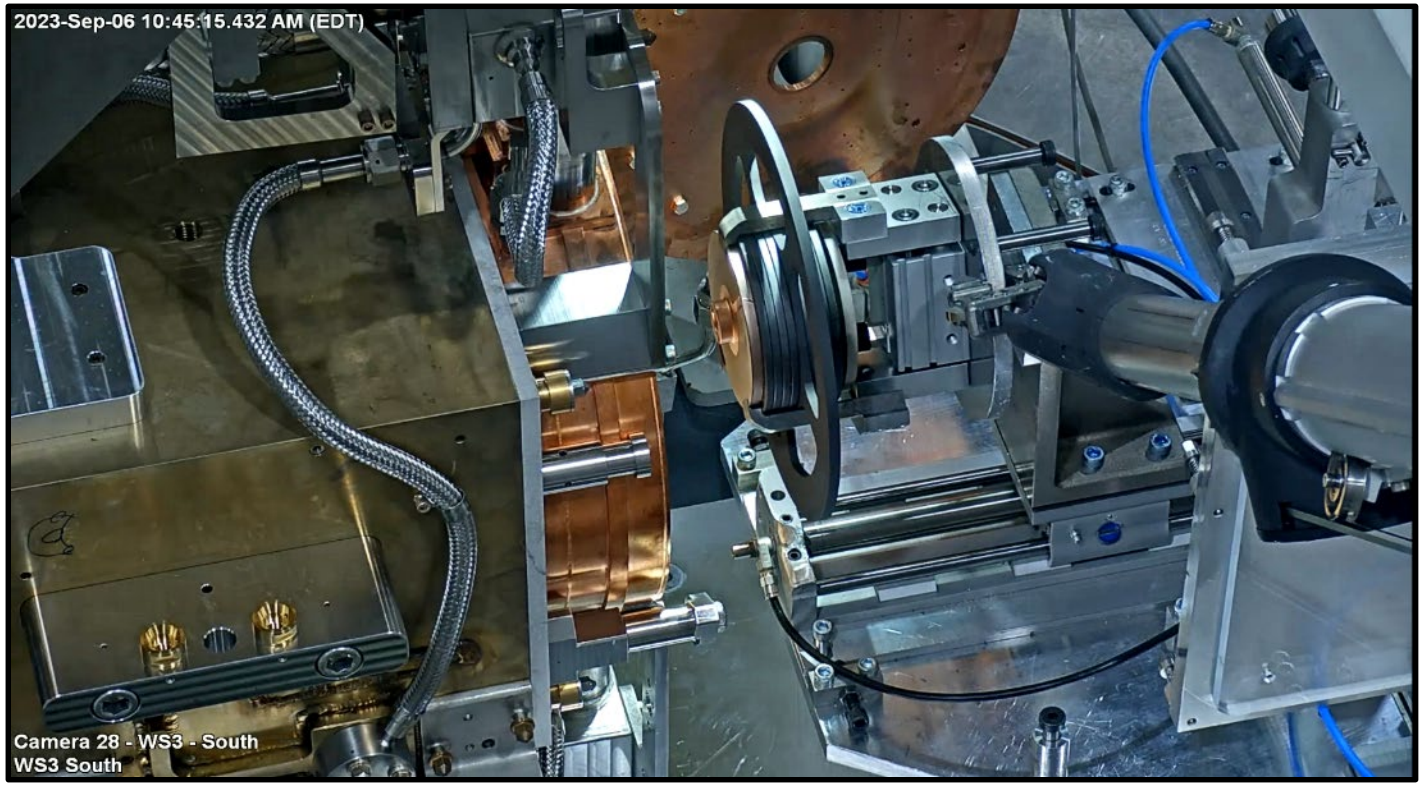




Open heat exchanger door and insert gripper

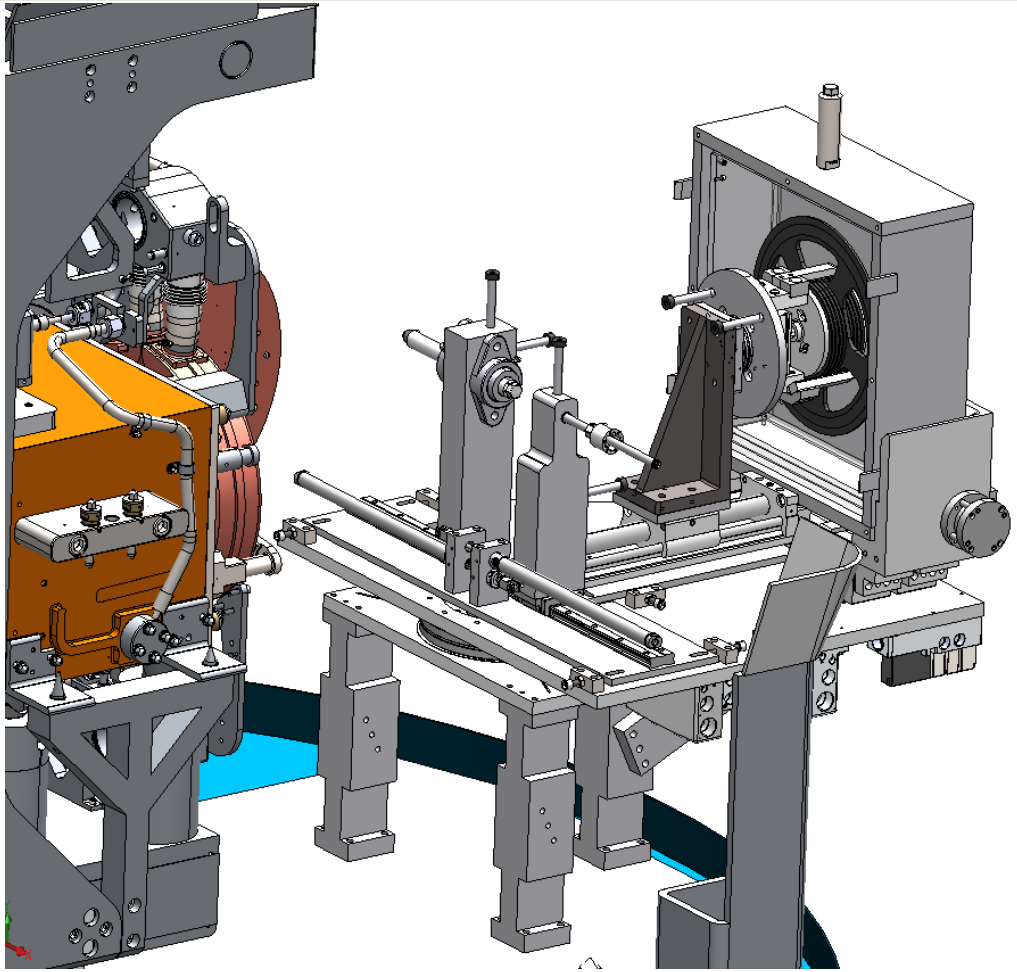
Target Disk Tooling and Process [4]

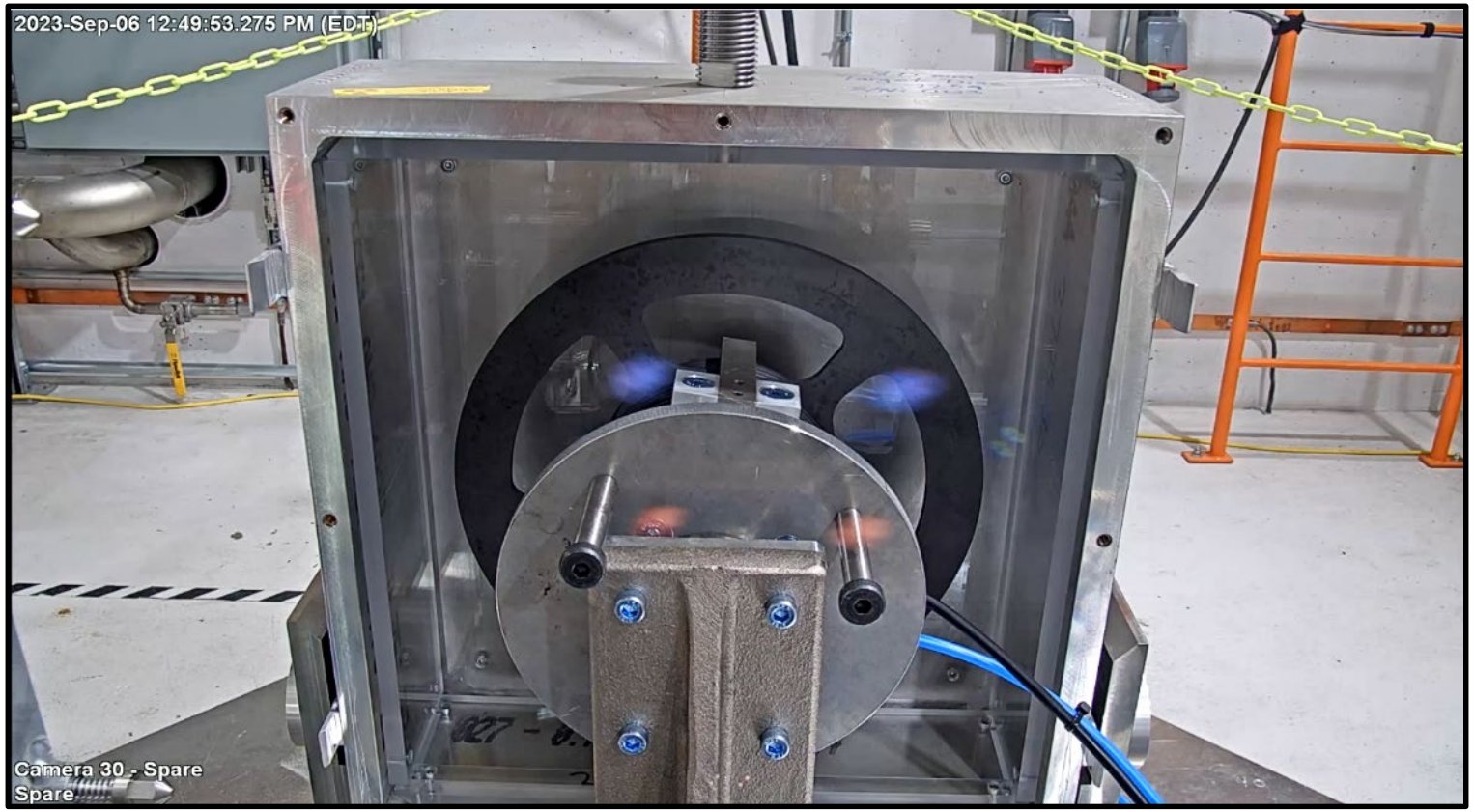




Clamp disk and remove from heat exchanger

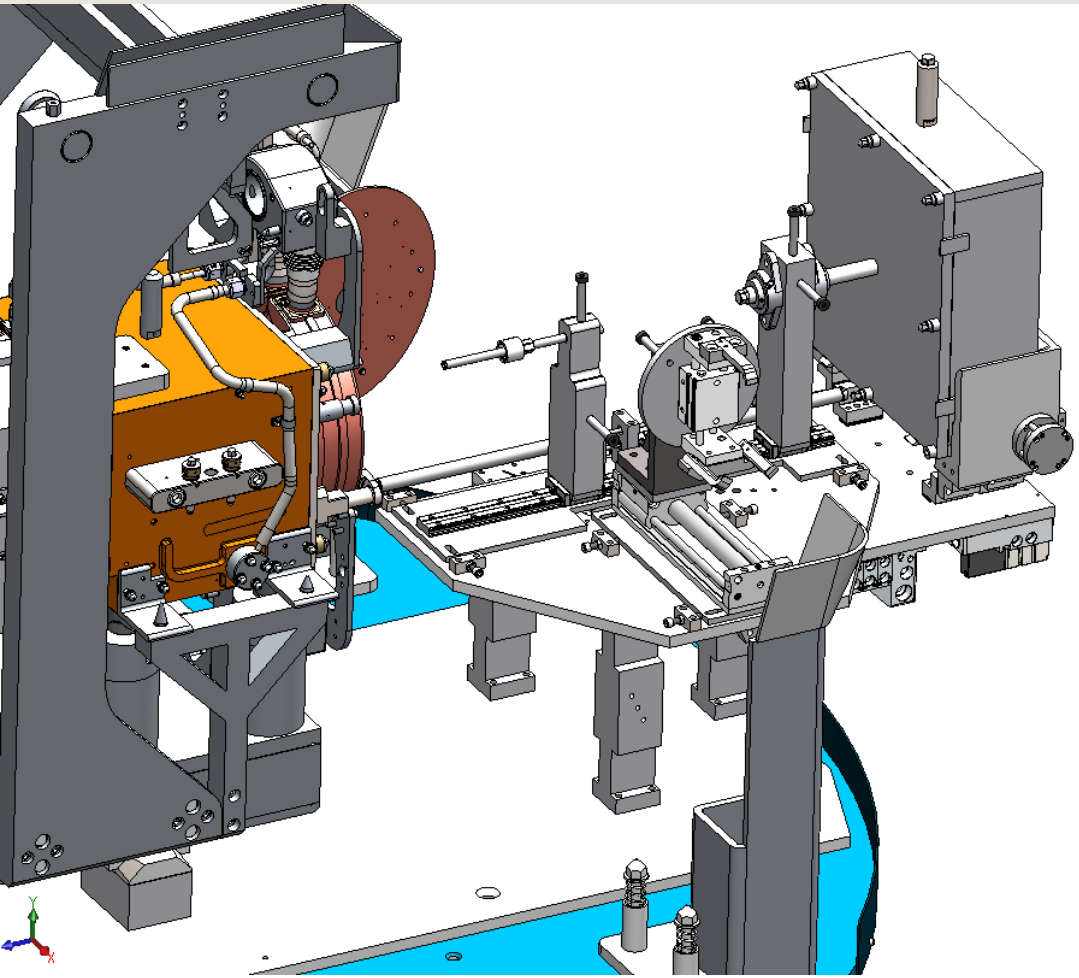
Target Disk Tooling and Process [5]





Rotate fixture 180˚ and insert into waste staging container

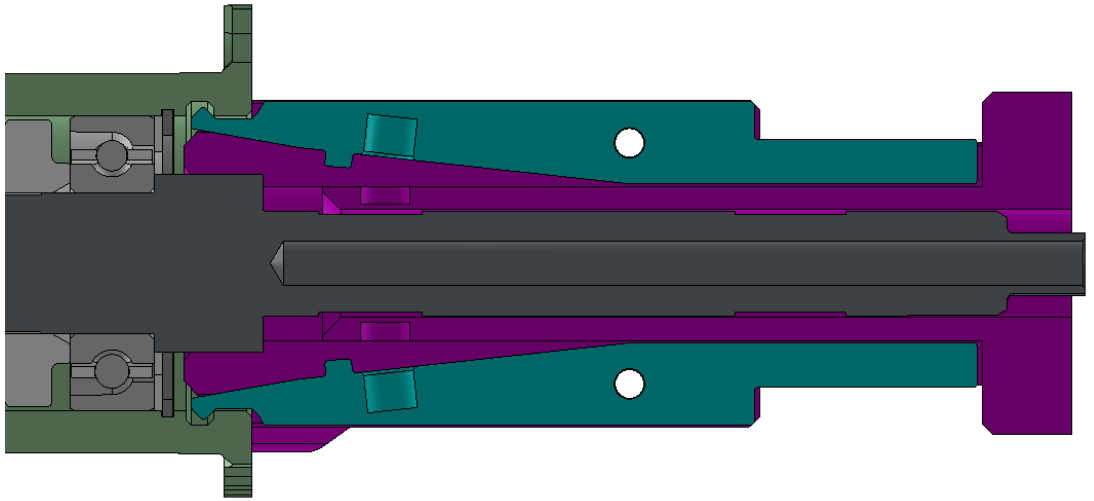
Target Disk Tooling and Process [6]

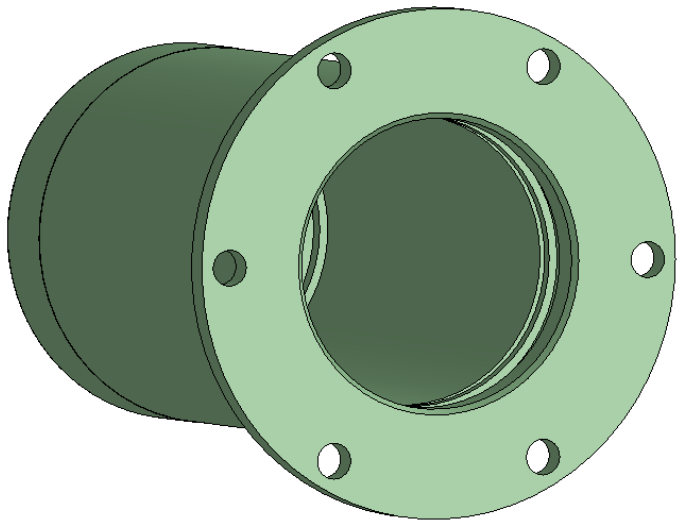


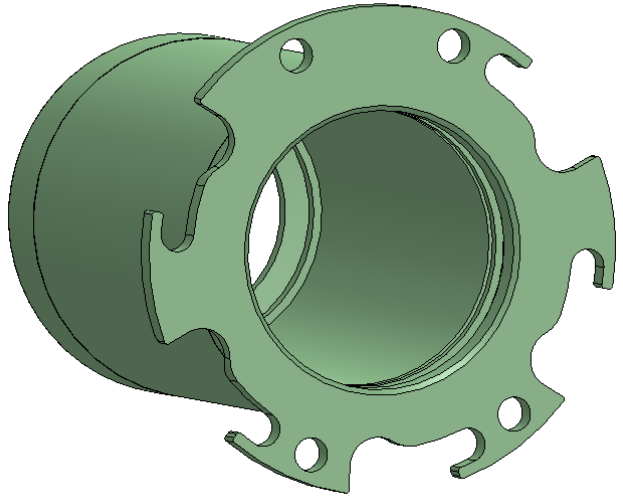
Place and secure lid on staging container, remove, and place new disk on fixturing. Perform process in reverse to install new disk

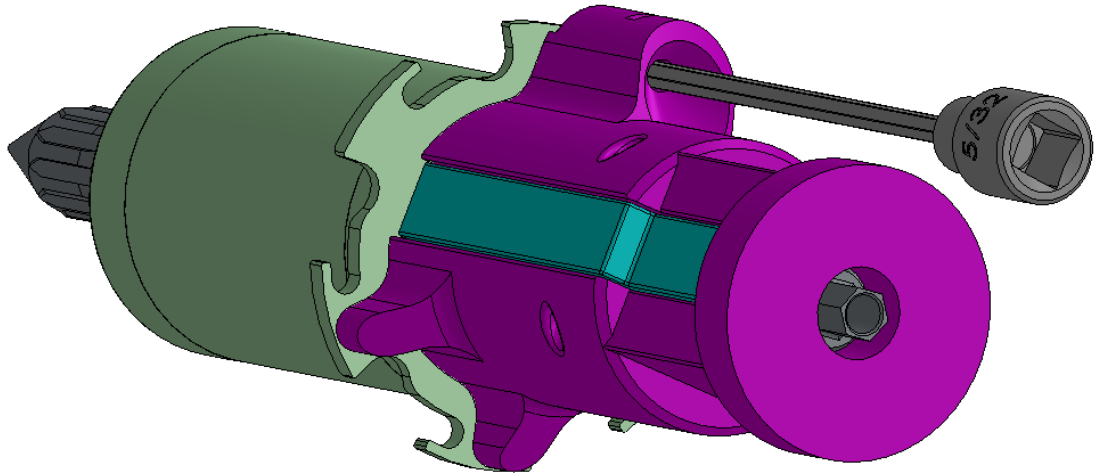
New Scope, Target Bearing Replacement [1]

- Developed capability to change just bearing cartridge
  - During 5kw operation temperature on spindle bearings was found to be higher than expected
  - To change bearings, the entire heat exchanger requires removal and disposal
  - Made minor part revisions to bearing housing and created 3d printed tooling to remotely change bearings

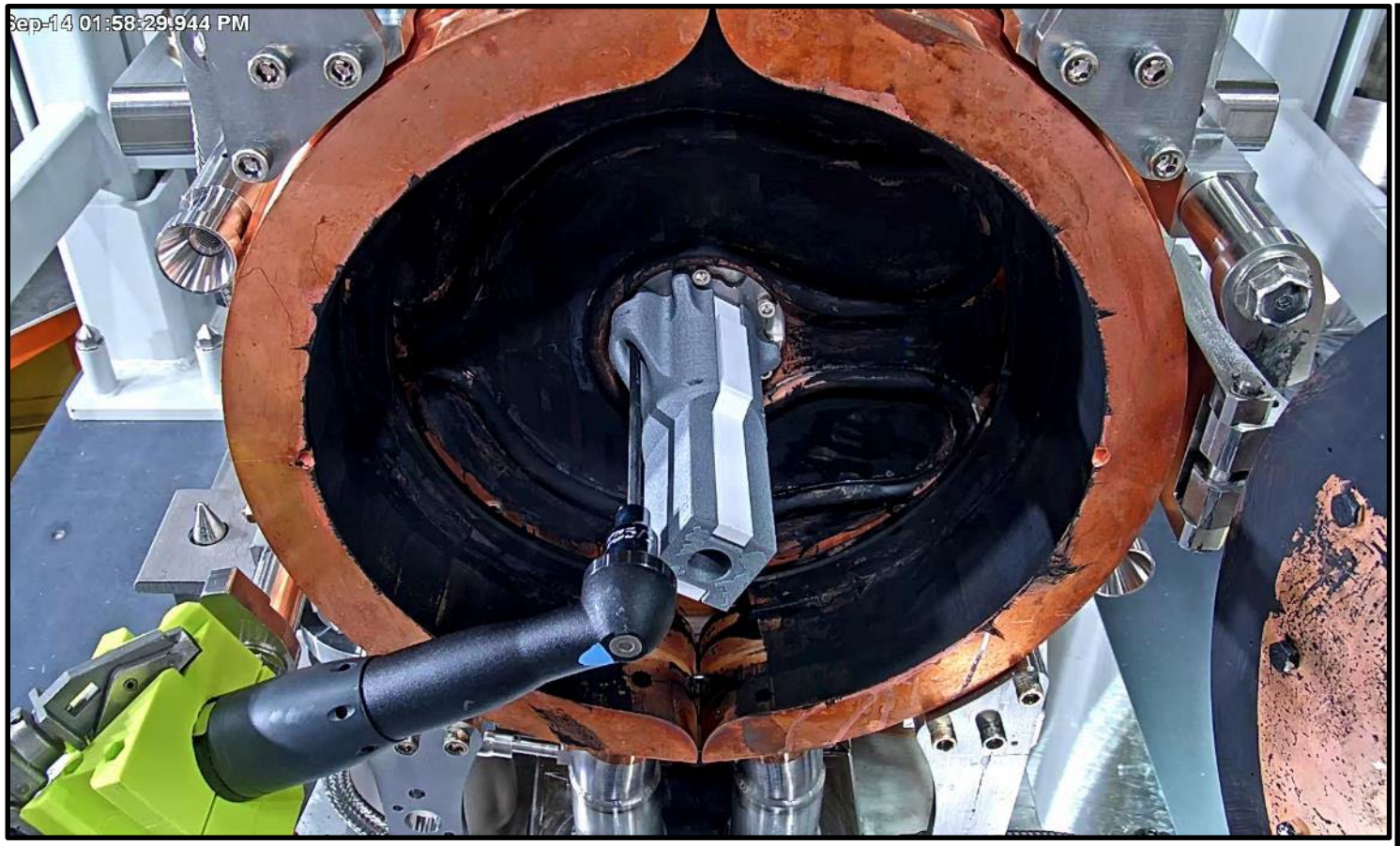




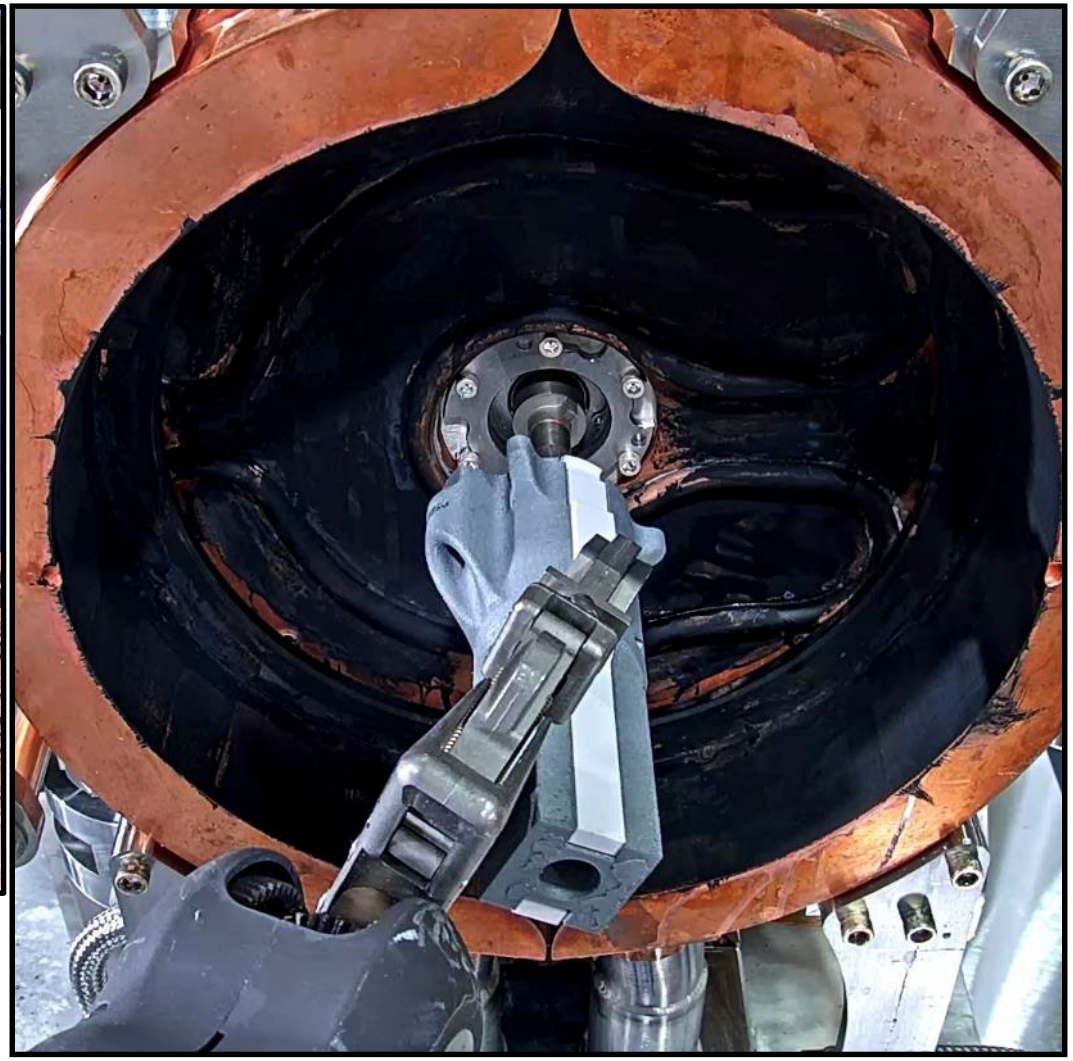




New Scope, Target Bearing Replacement [2]

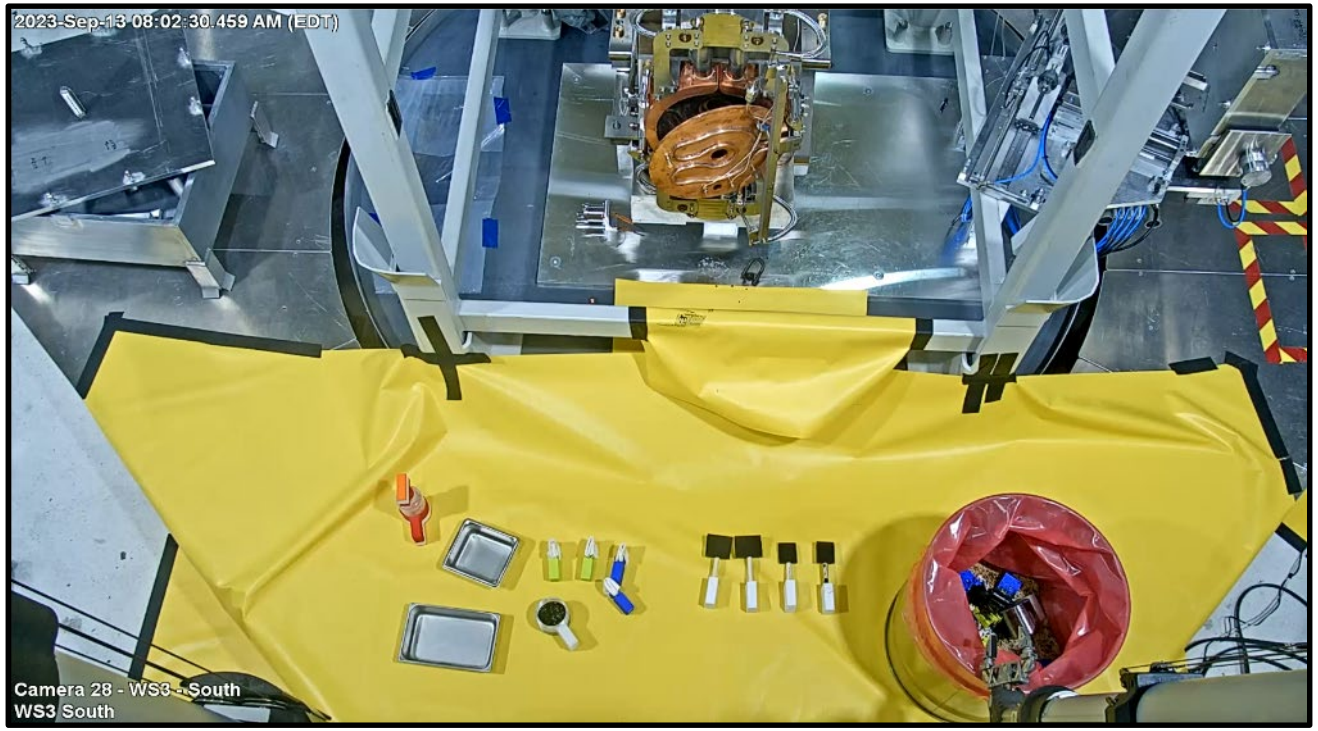


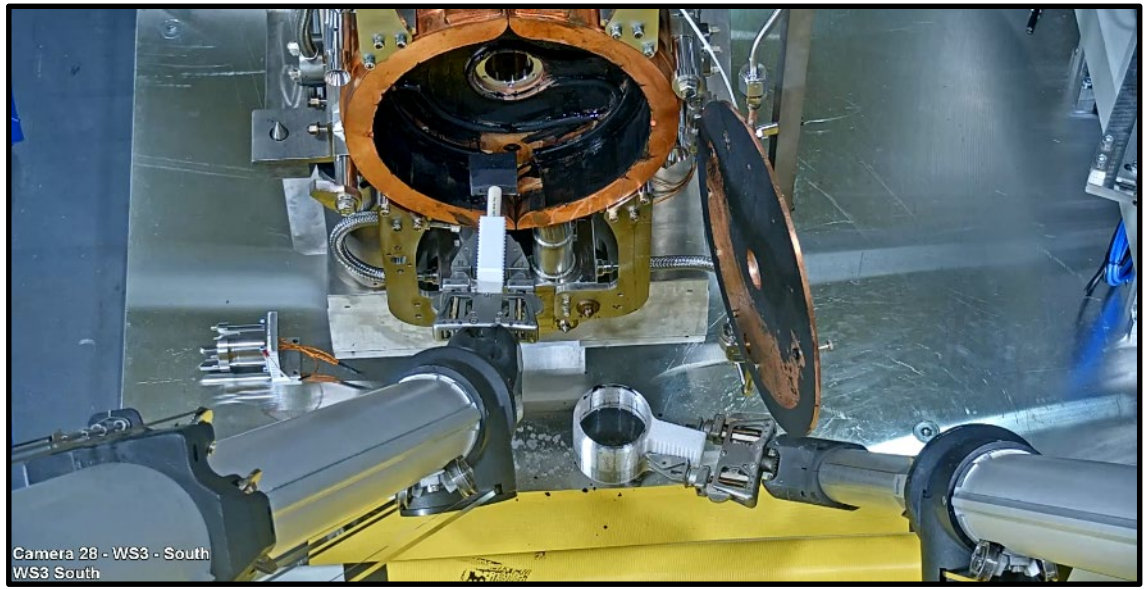
Using torque tool to secure remaining fastener and manipulators to remove tooling



Additional Short Term Tooling [1]

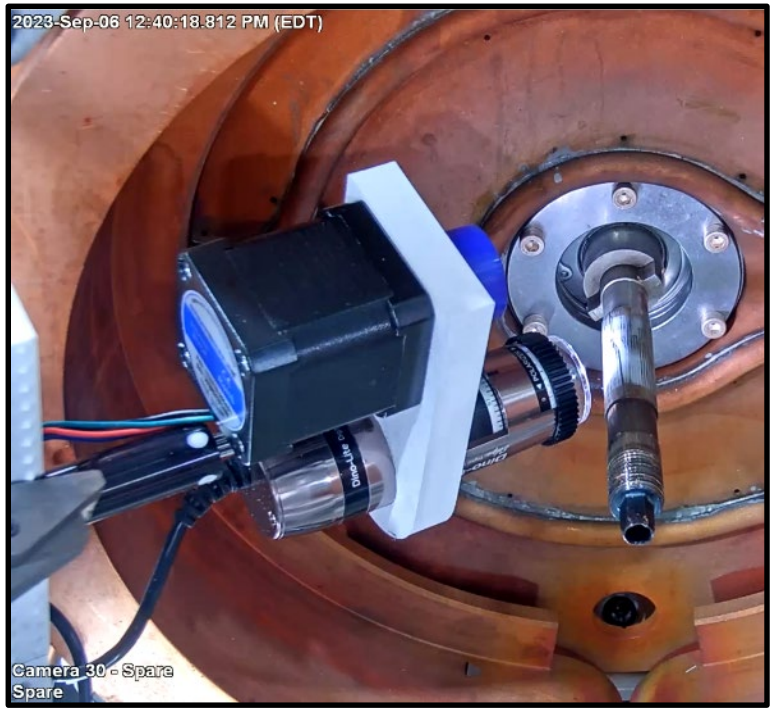
- High emissivity coating
  - Used 3d printed tooling to coat inside of target heat exchanger with high emissivity coating
  - Achieved coating with foam brush, prepped surface by wiping copper with Citric Acid and Acetone

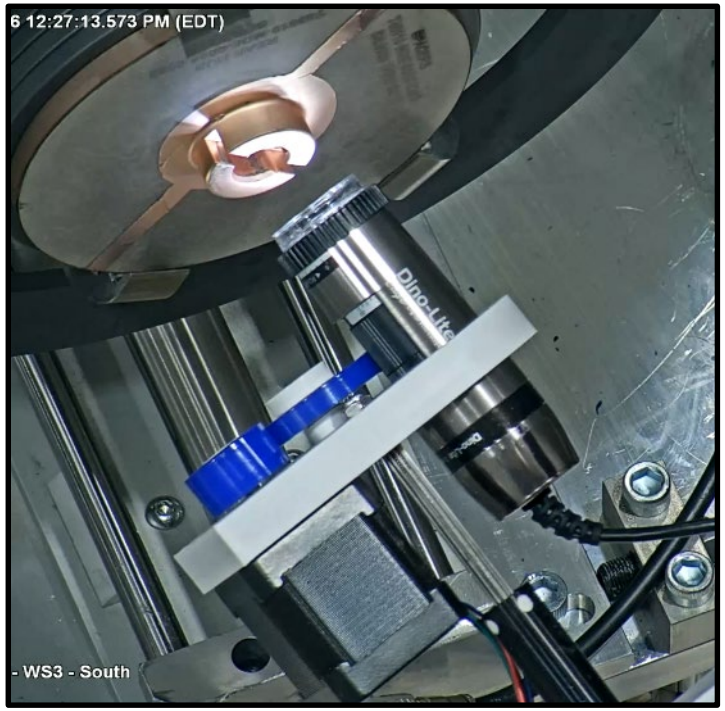


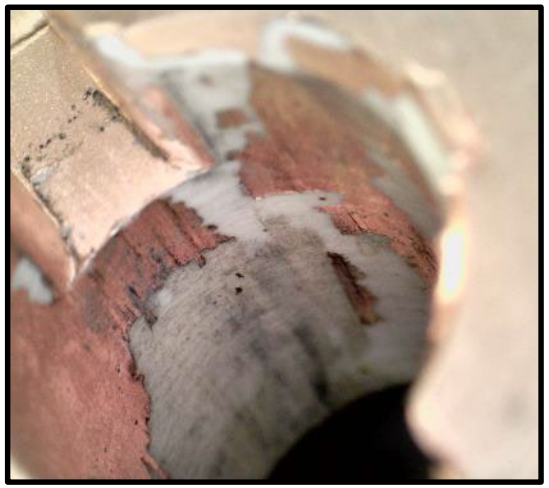


Additional Short Term Tooling [2]

- Inspection camera
  - Utilize a digital microscope camera and adapted with stepper motors for zoom and focus to allow 10x-220x magnification inspection with manipulators remotely

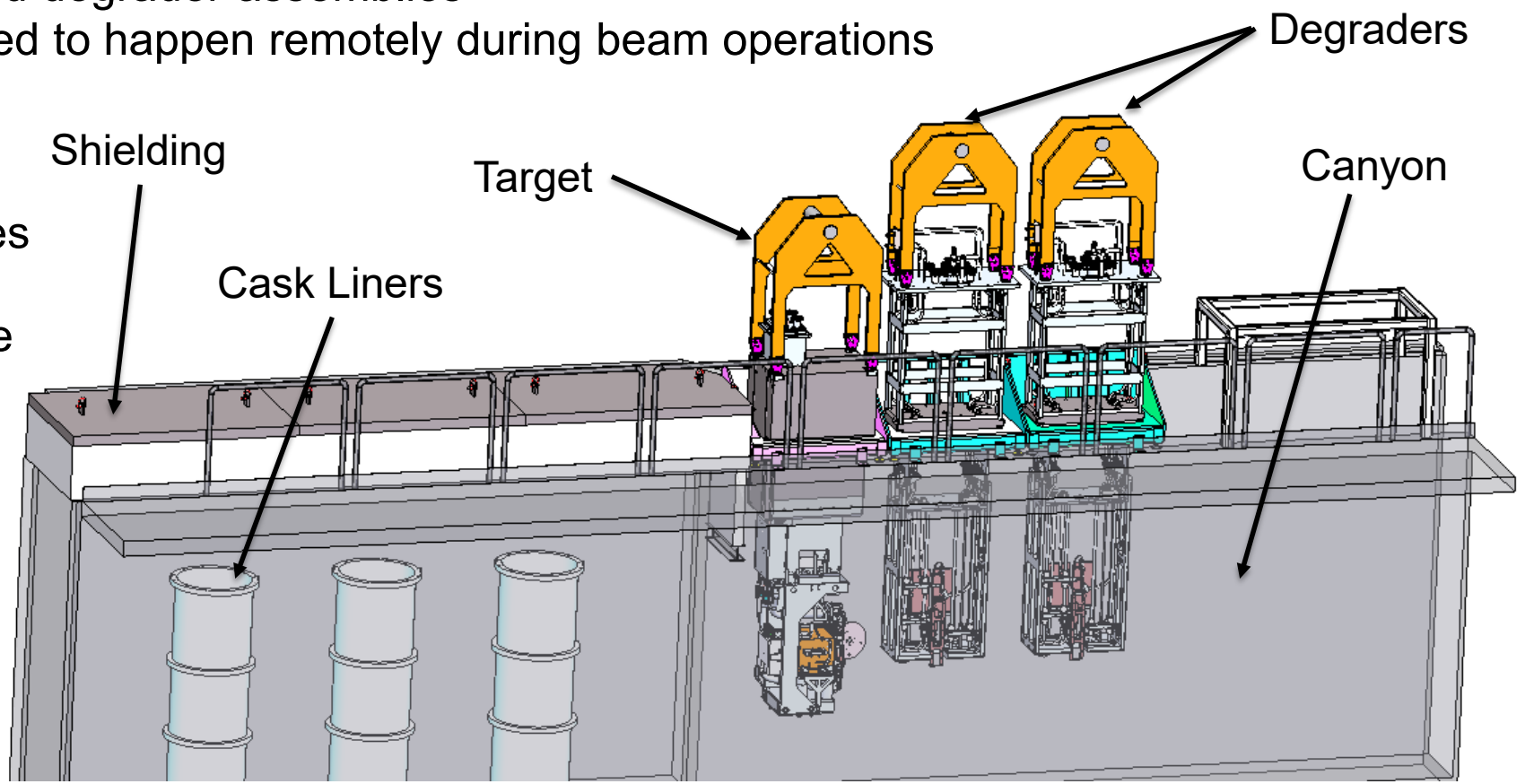






Future Requirements

- 24hr target and degrader reconfiguration
  - Currently can change target disk or degrader ladder in 24hrs, unable to complete both
  - Will require 2nd complete target and degrader assemblies
  - Reconfiguration of devices will need to happen remotely during beam operations
- Proposed 24hr process
  - Turn off beam
  - Enter target hall, disconnect utilities
  - Close target hall and remotely remove target and degrader, place in work stand
  - Install pre-configured 2nd assemblies from canyon
  - Place removed assemblies from vessels into shielded canyon
  - Enter target hall and reconnect utilities
  - Continue Operations



Thank You!