Target Systems Engineering

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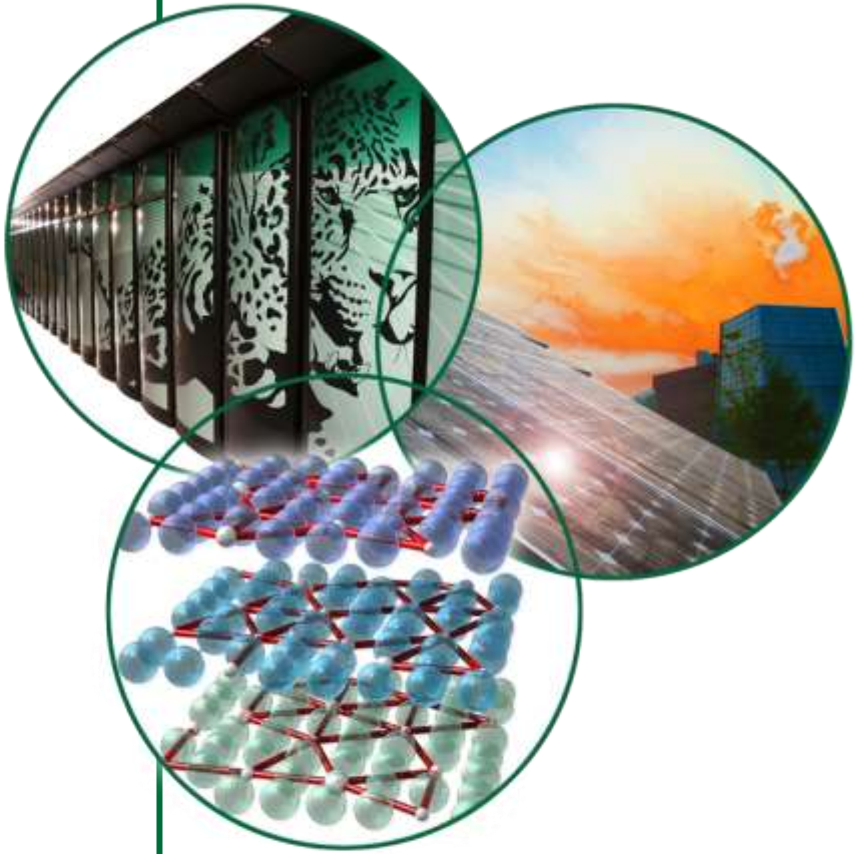
Target Engineer

AAC Meeting, January 10-11, 2012



U.S. DEPARTMENT OF ENERGY

OAK RIDGE NATIONAL LABORATORY
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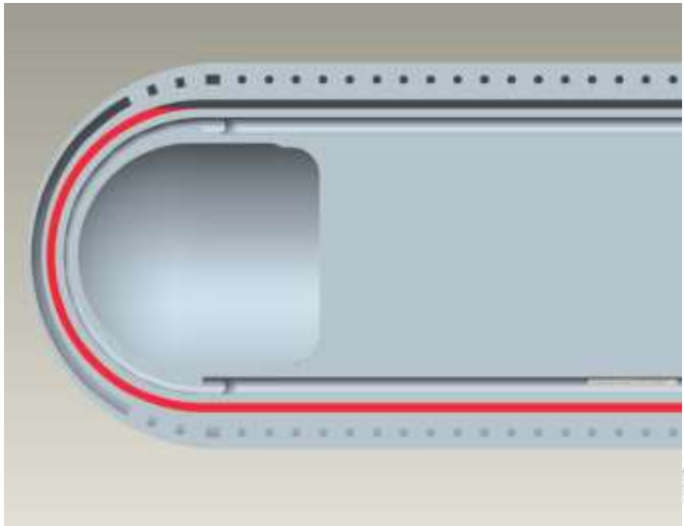
Topics

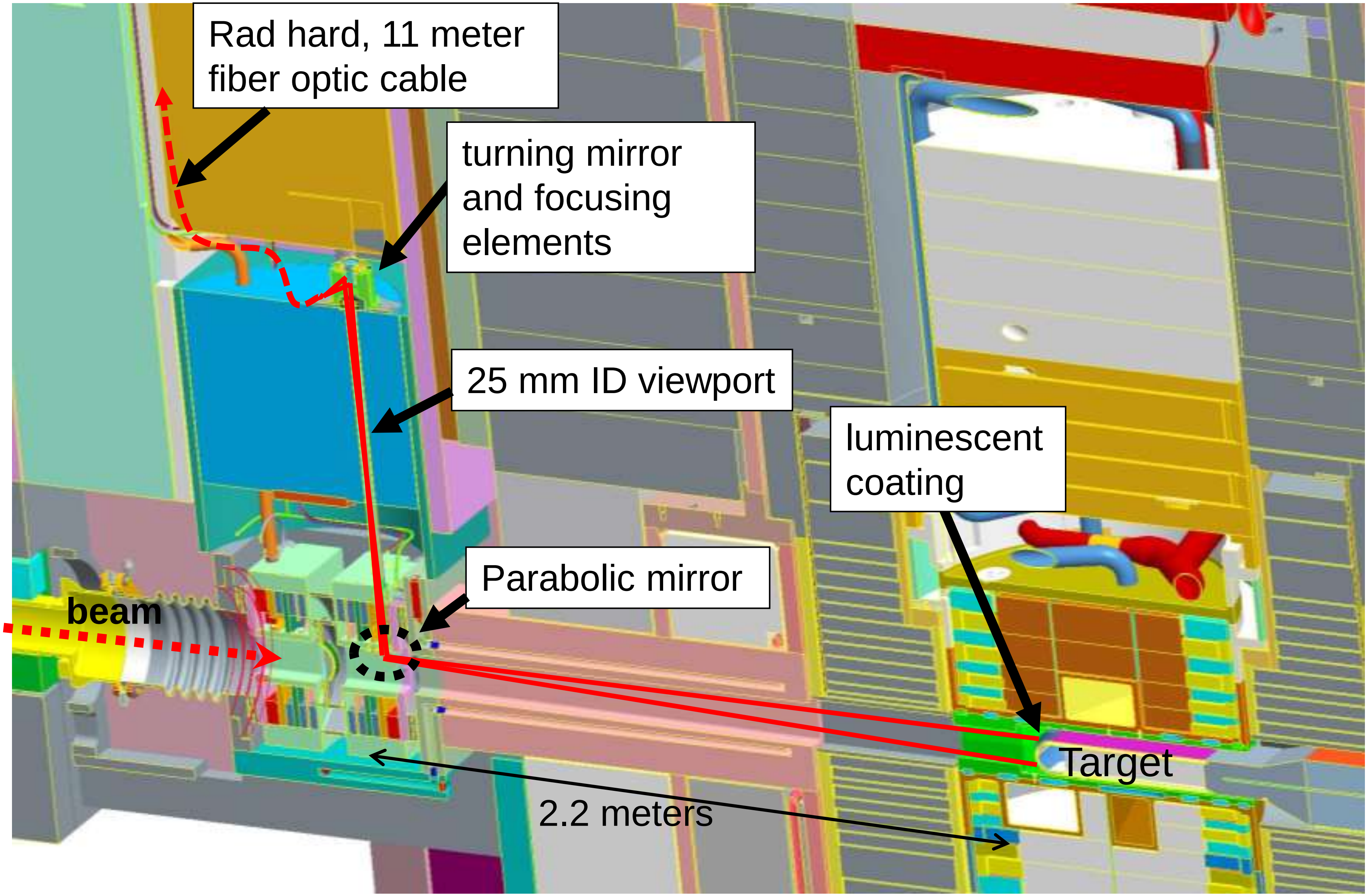
- Target Module Power Handling Update
- Target Imaging System (TIS) and Beam Profile
- Target Module Fabrication and Usage
- Next Generation Target
- Leak Detection
- Bolt on water shroud
- CMS System Update
- Aluminum Proton Beam Window (PBW)
- Mercury loop spares and plans
- Fusion Materials Irradiation Test Station (FMITS)
- Challenges

Target Module Power Handling and Beam Profile

- Nominal Hg Vessel design can take 1.54+ MW of beam power with nominal beam profile (peaking factor = 1, 1.25e-4 p/mm^2/p)
- Nominal Water Shroud design can take 1.4 MW of beam power with nominal profile and interstitial filled with Hg (leak at steady state)
- Nominal Water Shroud design can take 2 MW if filled interstitial is not considered



Target Imaging System (TIS) Update



Rad hard, 11 meter fiber optic cable

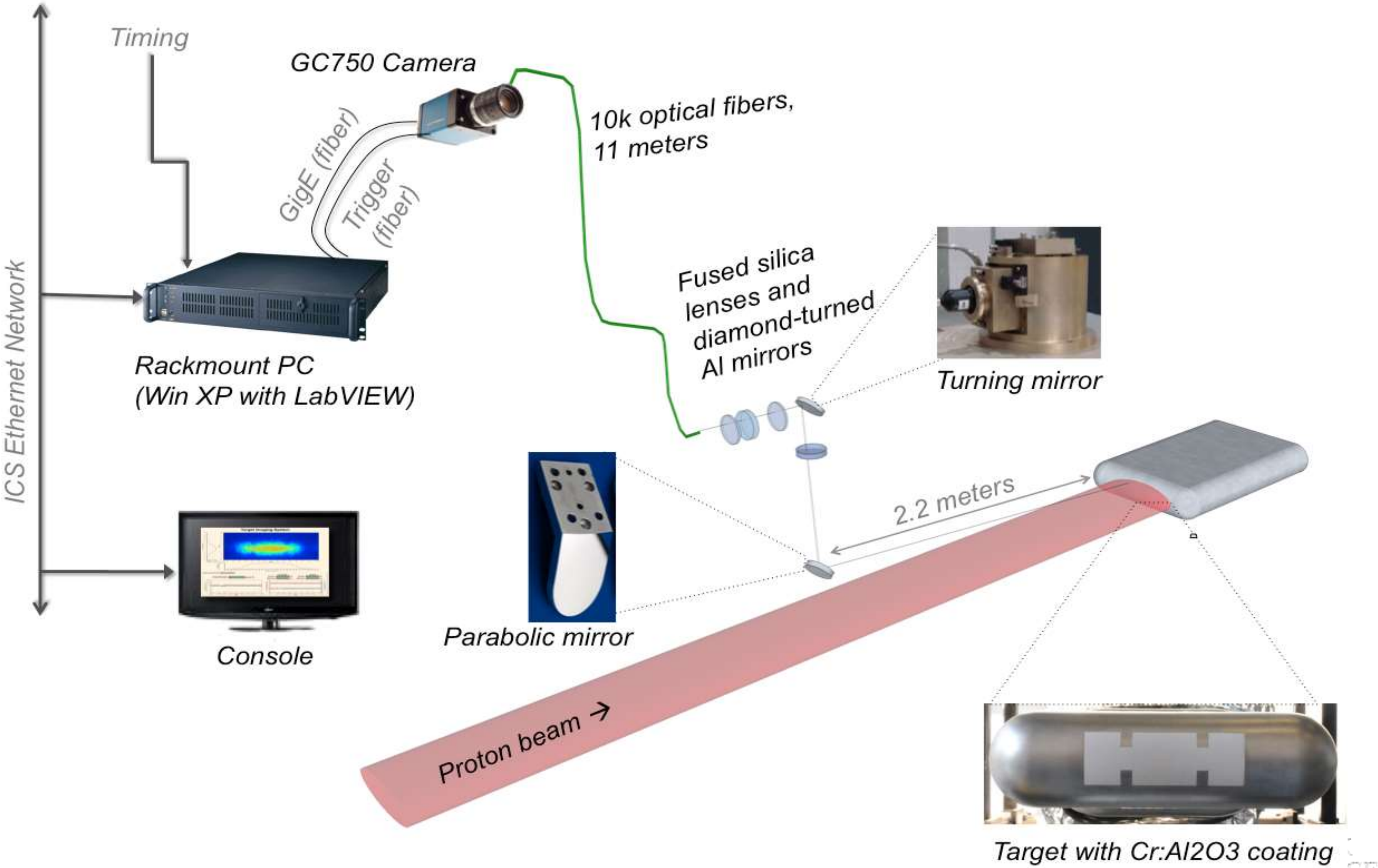
turning mirror and focusing elements

25 mm ID viewport

luminescent coating

Parabolic mirror

Target Imaging System (TIS) Update

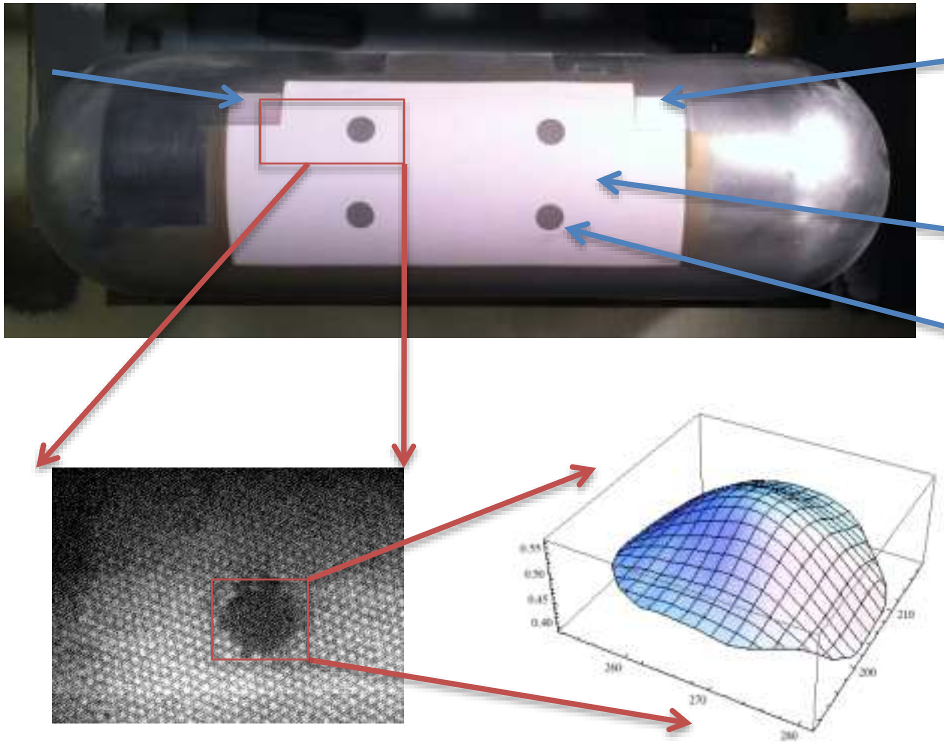


Coating Pattern

Target 1: no coating
Targets 2-4: coating survived for lives of targets

Target 2

Targets 3 and 4



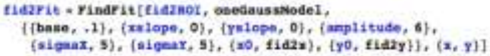
Pre-reacted Ruby

Alumina

Alumina/Chromia blend

Final location of fiducials determined by survey

Finds Shroud center to +/- 1mm



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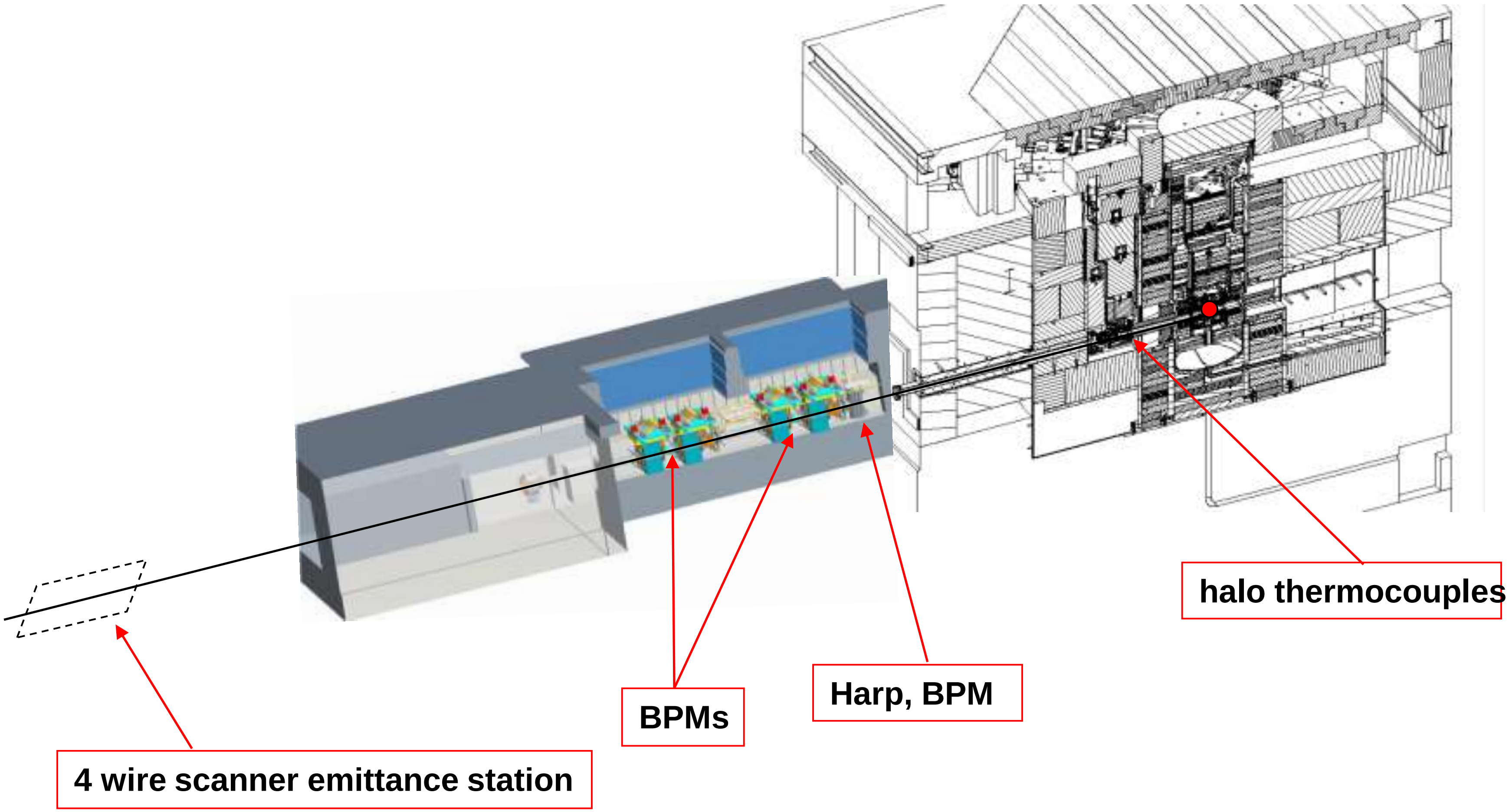
```

Predicting Beam-on-Target Parameters with “RTBT Wizard” application



halo thermocouples

Harp, BPM

BPMs

4 wire scanner emittance station

- **Fitting normally only done at the start of a neutron production run of several weeks**
- **Harp: only projections monitored during production run**

M. Plum, S. Cousineau

Upgrades, Applications, Related R&D

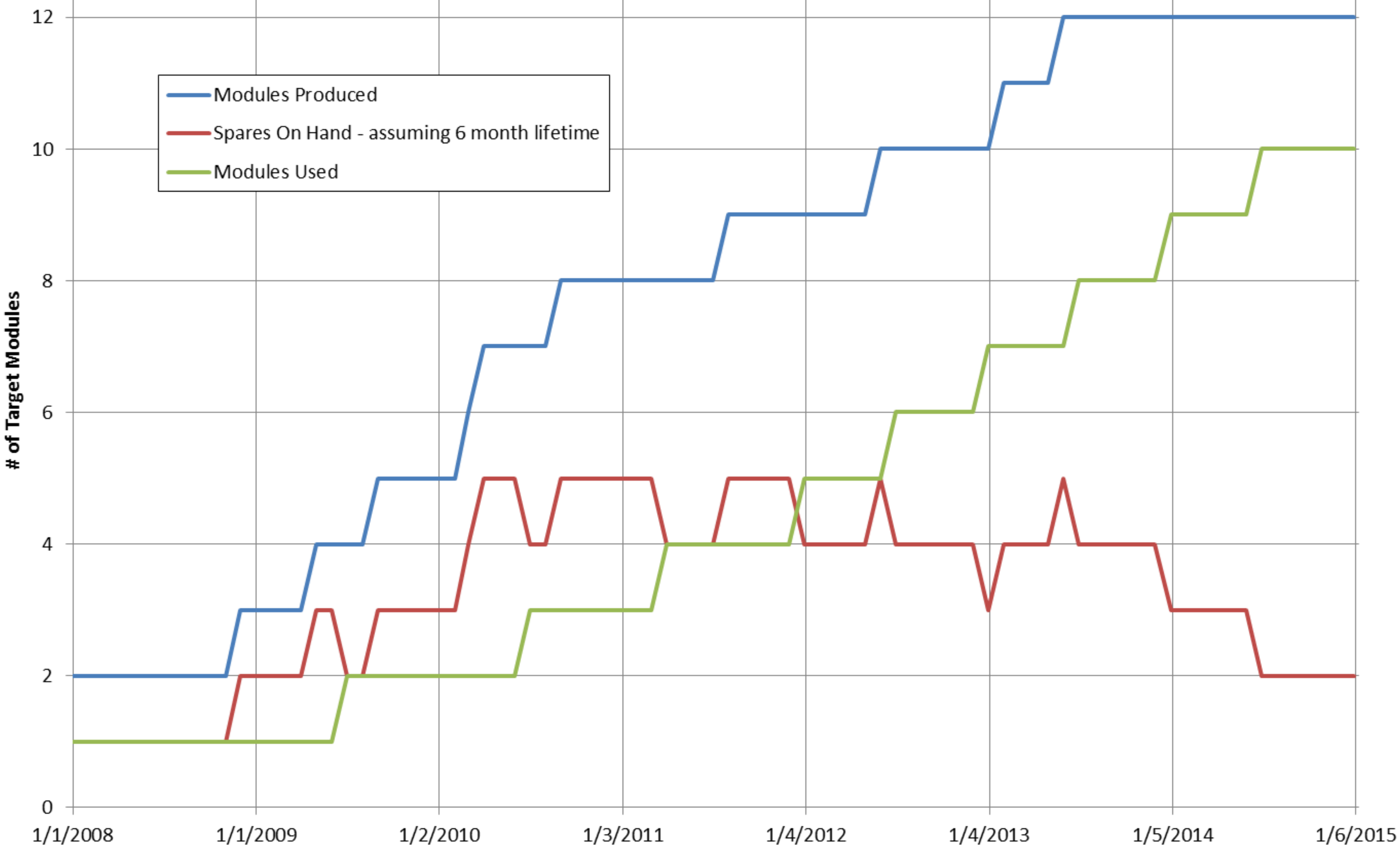
- Planned
  - Accelerator physics studies to further assess TIS accuracy
  - Testing and possible use of more sensitive CMOS camera
  - Proposal for injection dump imaging system
- Deferred pending development funding:
  - Low noise camera and 60 Hz acquisition
  - Instrumenting of Window 4 with dual optical paths
  - Alternate luminescent coatings
  - Irradiation testing of coating samples
  - Beam tests at SNS, LANL and/or other facility
  - Image plate analysis from target nose or test plate to calibrate fluence measurement
  - Optical modeling and bench measurements
  - Online measurement of core vessel emission spectrum
  - Development of proton beam window imaging concept

Beam Profile Experience

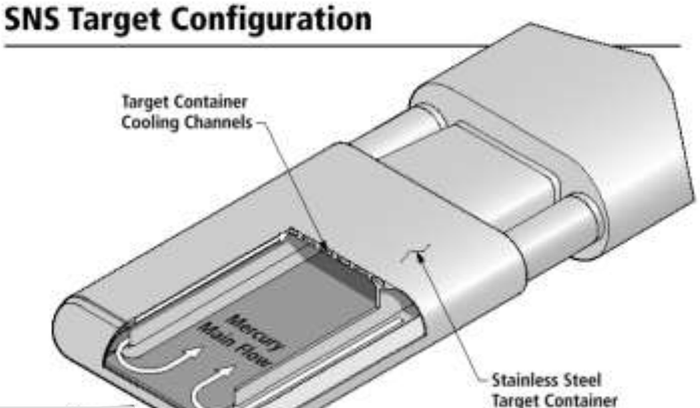
- RTBT wizard calculation of peaking factor is generally 10% higher than TIS measurement
- RTBT wizard peaking factors have ranged from ~.8 to 1.2 for operations around 1 MW recently, which is significantly lower than earlier operations. actual numbers?
- Target lifetime by DPA limit scales directly with peaking factor
- Future Plans
  - Accelerator Physics reduce peaking factor by increasing the vertical beam size on target from 80 mm to ~94 mm
  - This could lower the peaking factor by 25%
  - Other components require evaluation (PBW, ORP, IRP, Core Vessel)
  - Taller/wider beam may also complement the change to an aluminum PBW, which will scatter the beam less than Inconel.

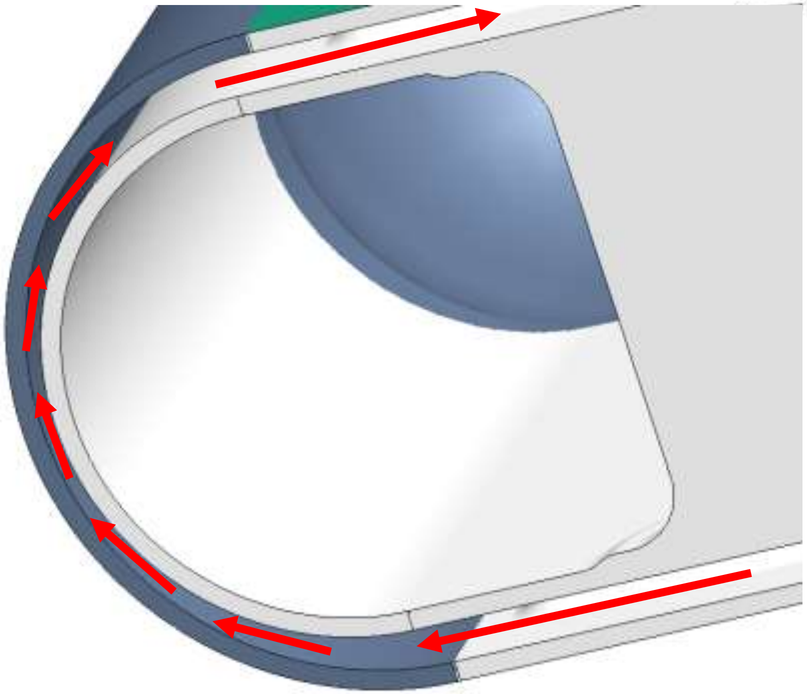
Target Module Fabrication and Usage

- We have established at least two capable manufacturers
- Chart assumes no new procurements

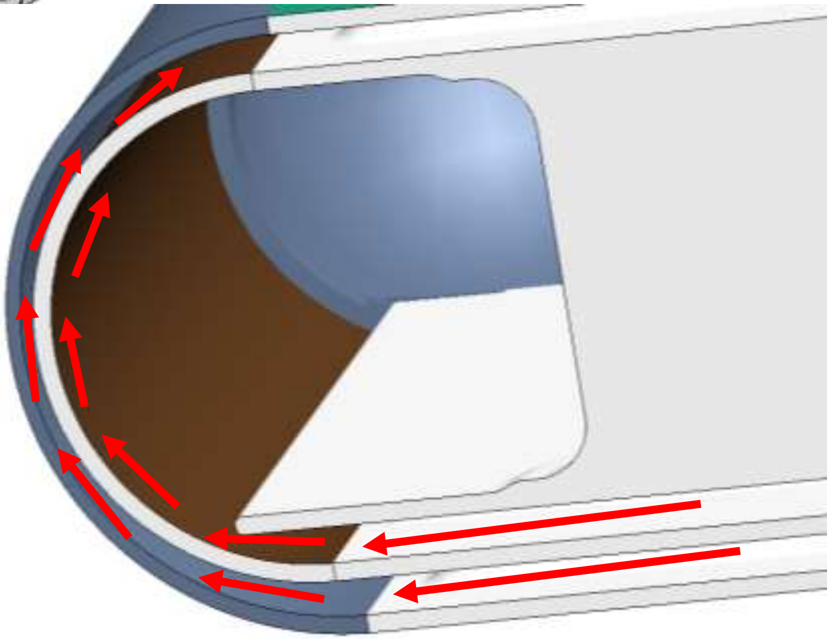


Next Generation Mercury Vessel– Jet Flow





Existing Configuration

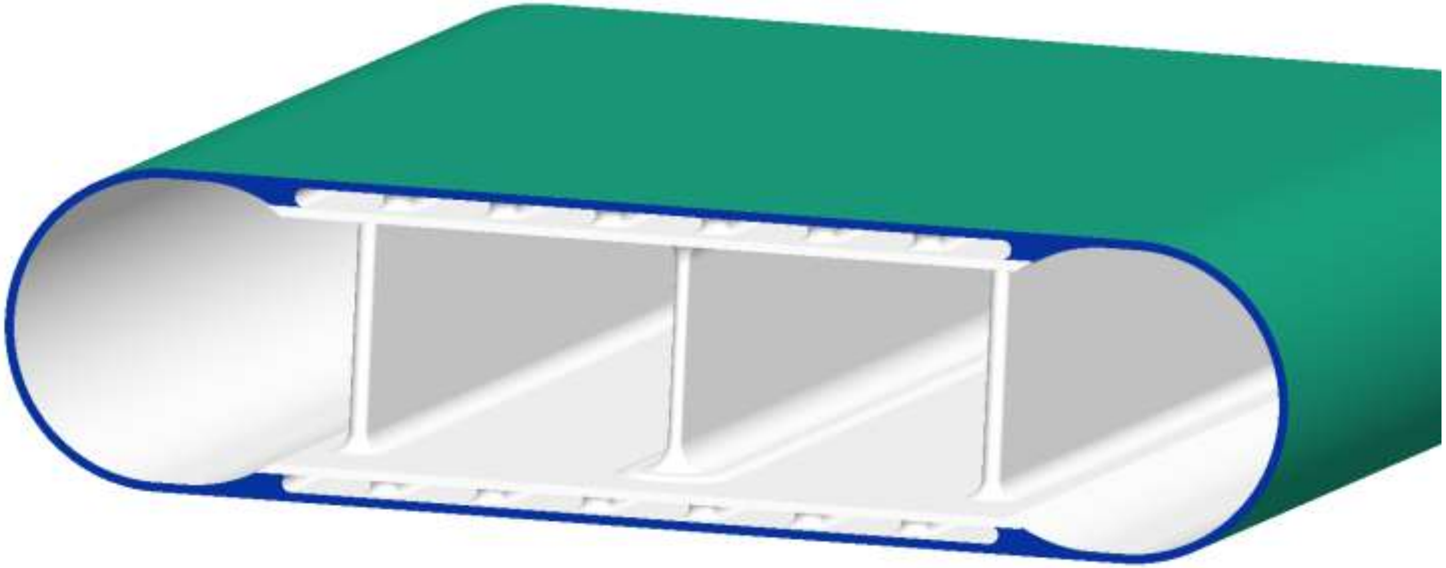


Proposed Configuration

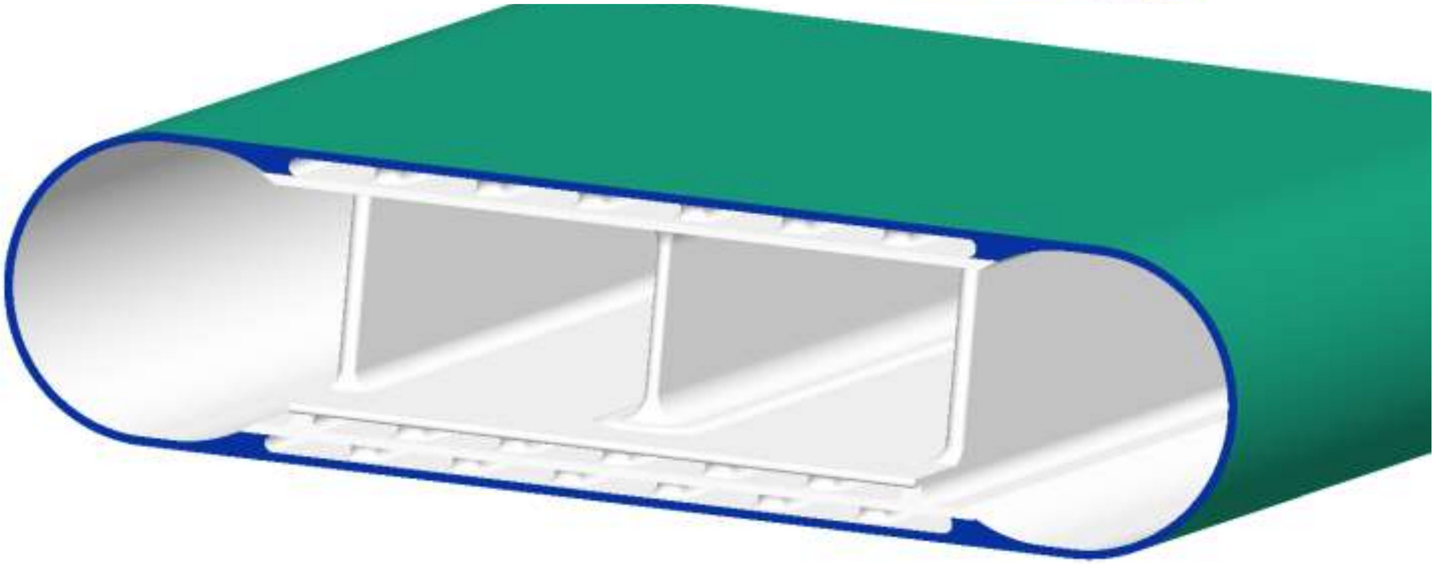
Next Generation Mercury Vessel– Jet Flow

- Power Assumption:
  - Power handling is limited to 1.4 MW, although higher power would not drive the design
- Goal:
  - Reduce cavitation damage on Hg vessel inner wall based on mitigation via flown observed in R&D and PIE data
- Schedule
  - Conceptual Design: Complete
  - Thermal / Structural Analysis, feedback: ~4/1/2012
  - Detailed Design / Specification: ~7/1/2012
  - Begin Procurement <u>or</u> begin prototype build for TTF this FY

Mitigate Damage Via Flowing Hg

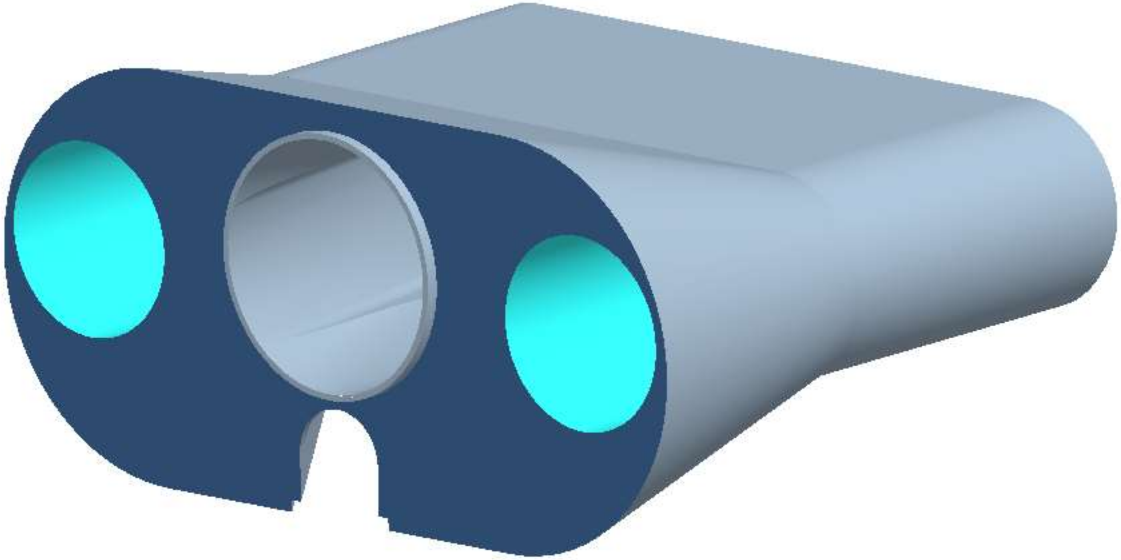


Existing Configuration



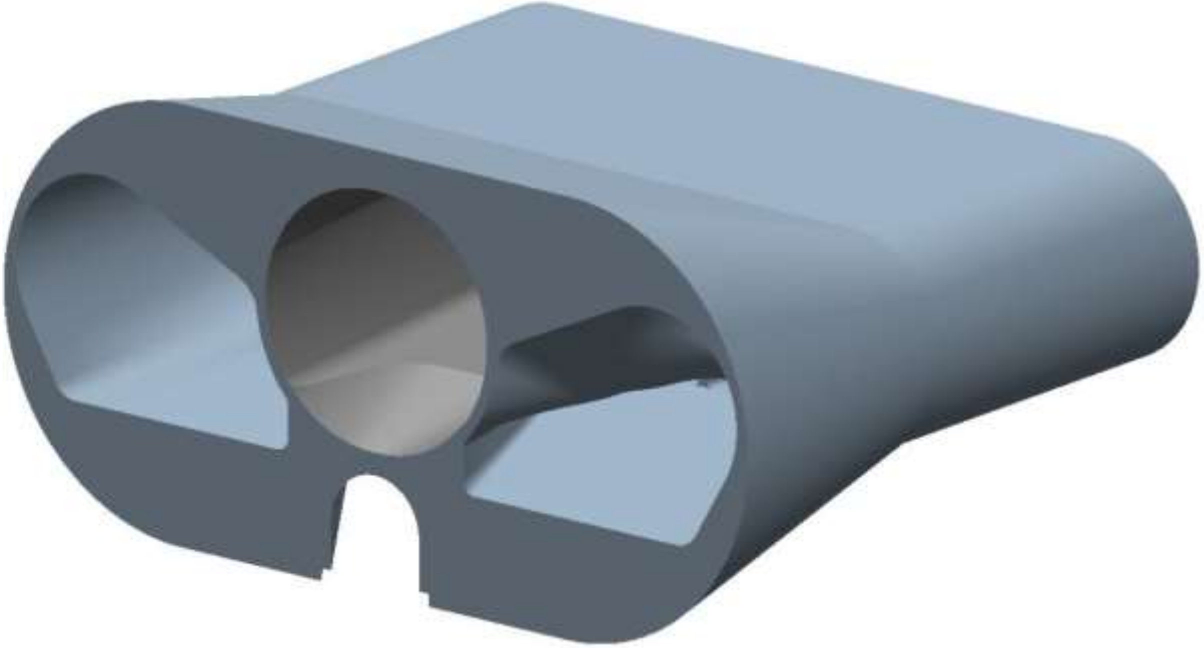
Jet Flow Design

Mitigate Damage Via Flowing Hg

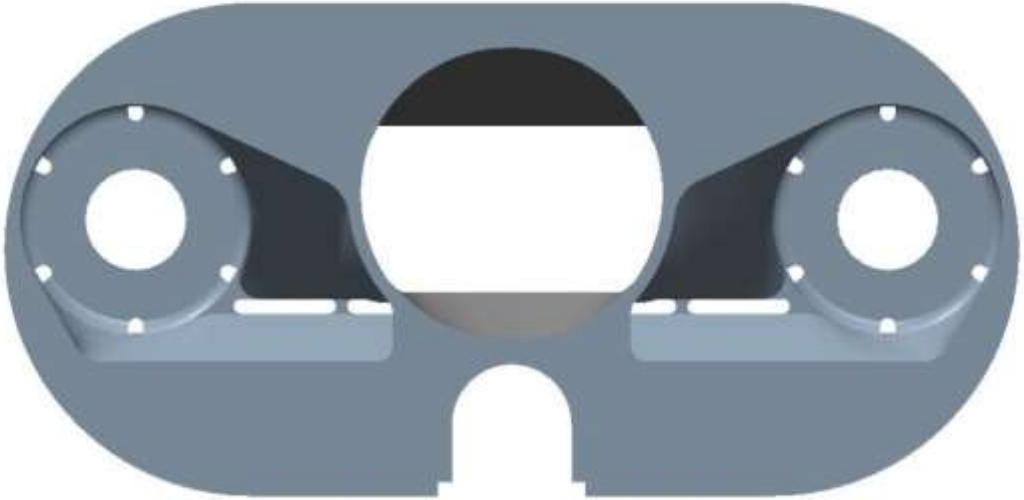


Existing Configuration

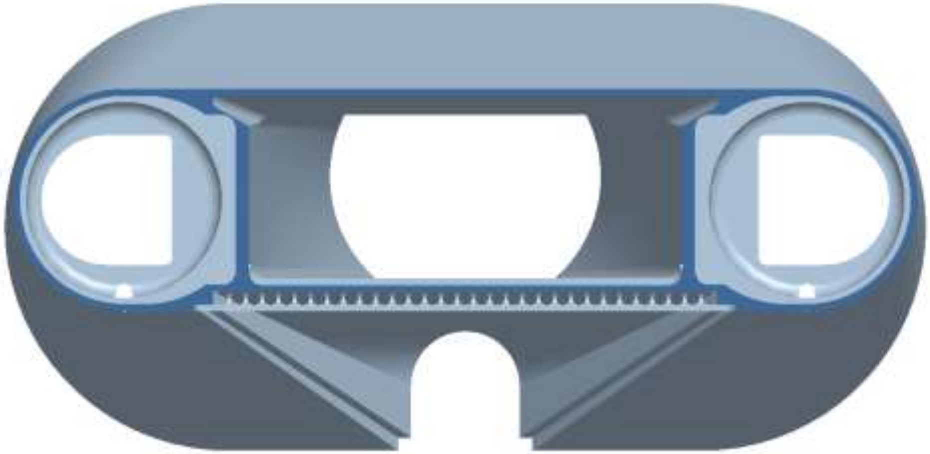
Jet Flow Design



Mitigate Damage Via Flowing Hg



Jet Flow Design



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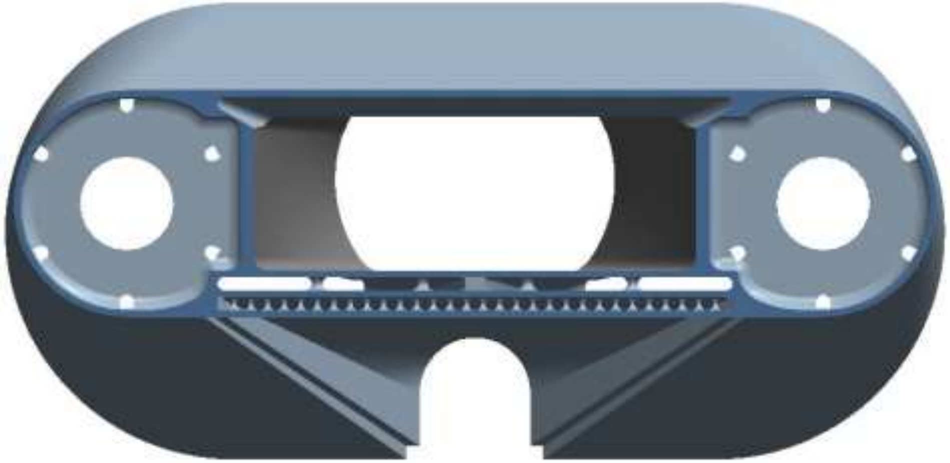
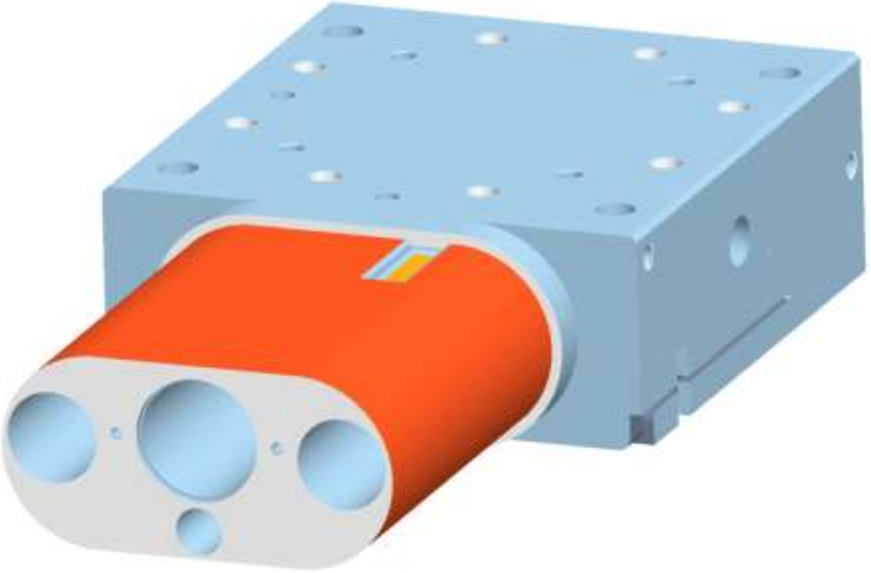
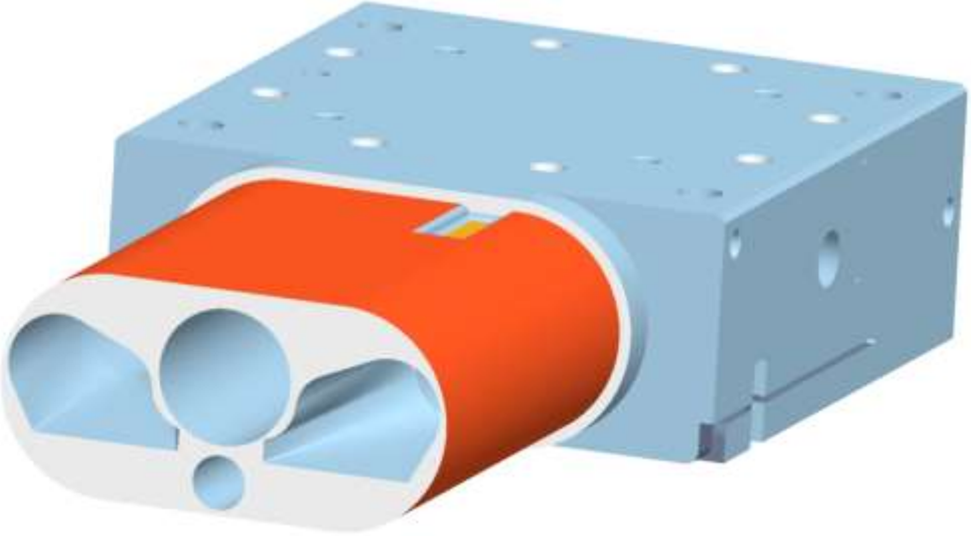


Jet Flow Design

Mitigate Damage Via Flowing Hg



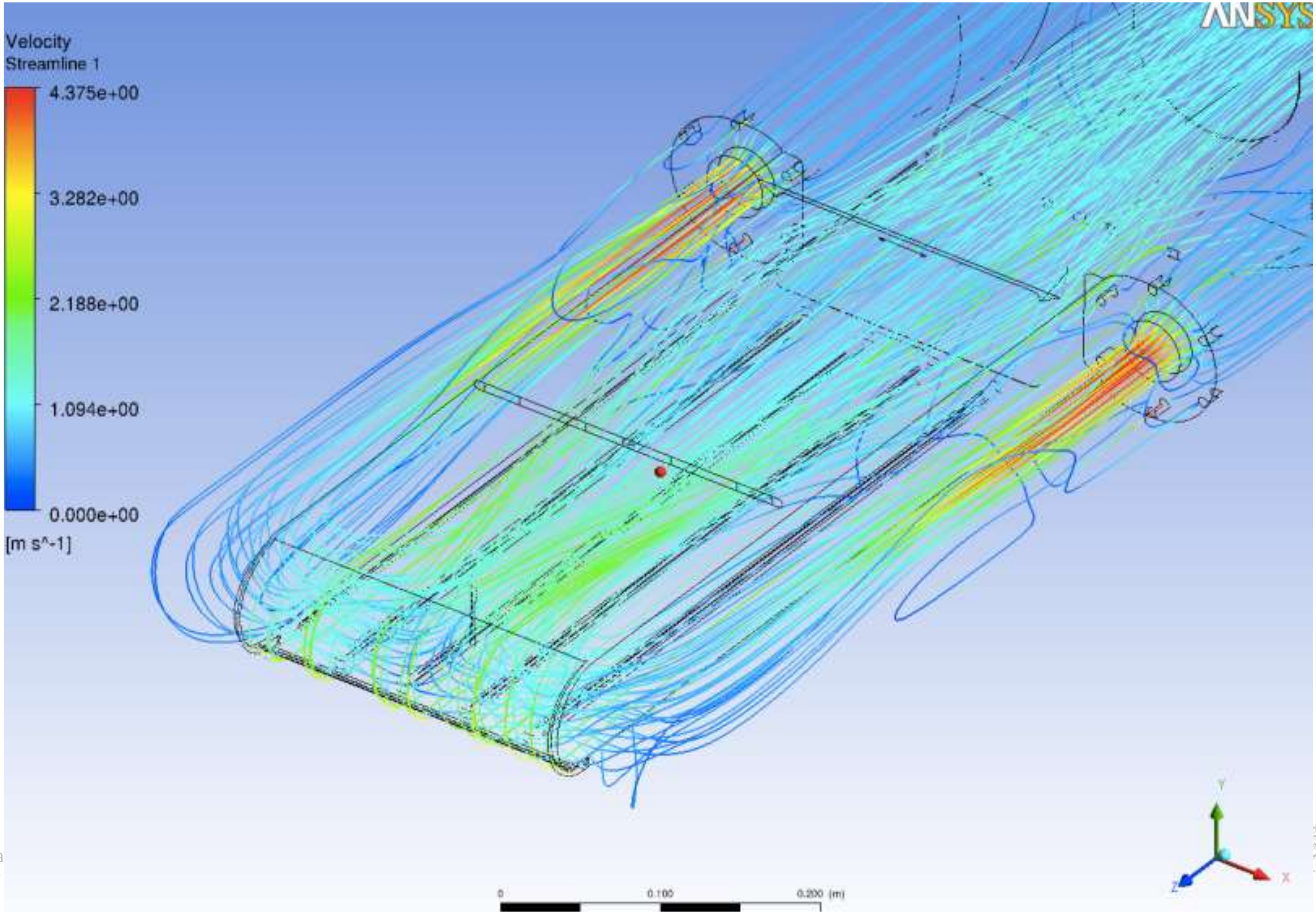
Existing Configuration



Jet Flow Design

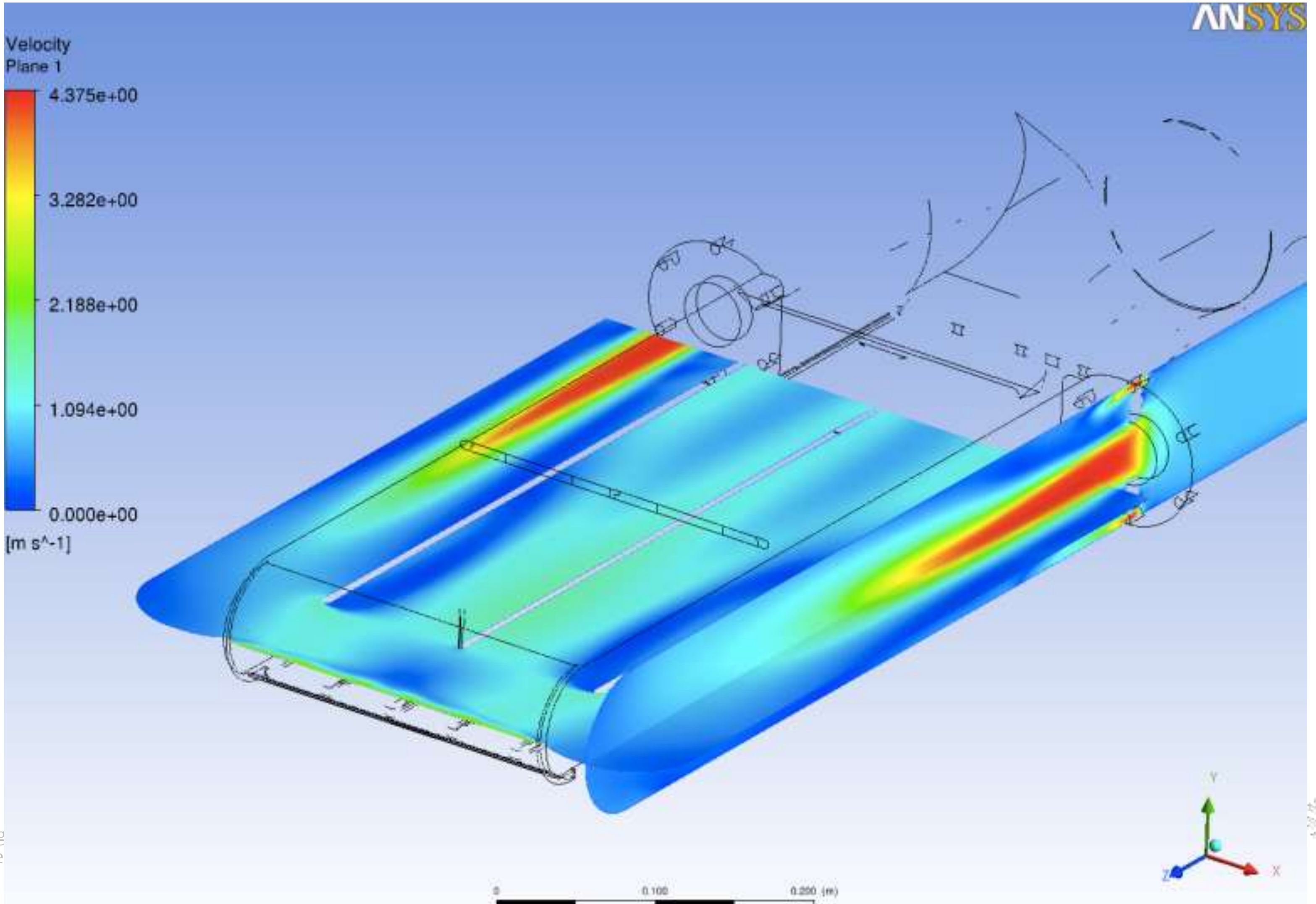
Jet Flow CFD

- **2 - 2.5 m/s velocity along length of Hg vessel inner wall**



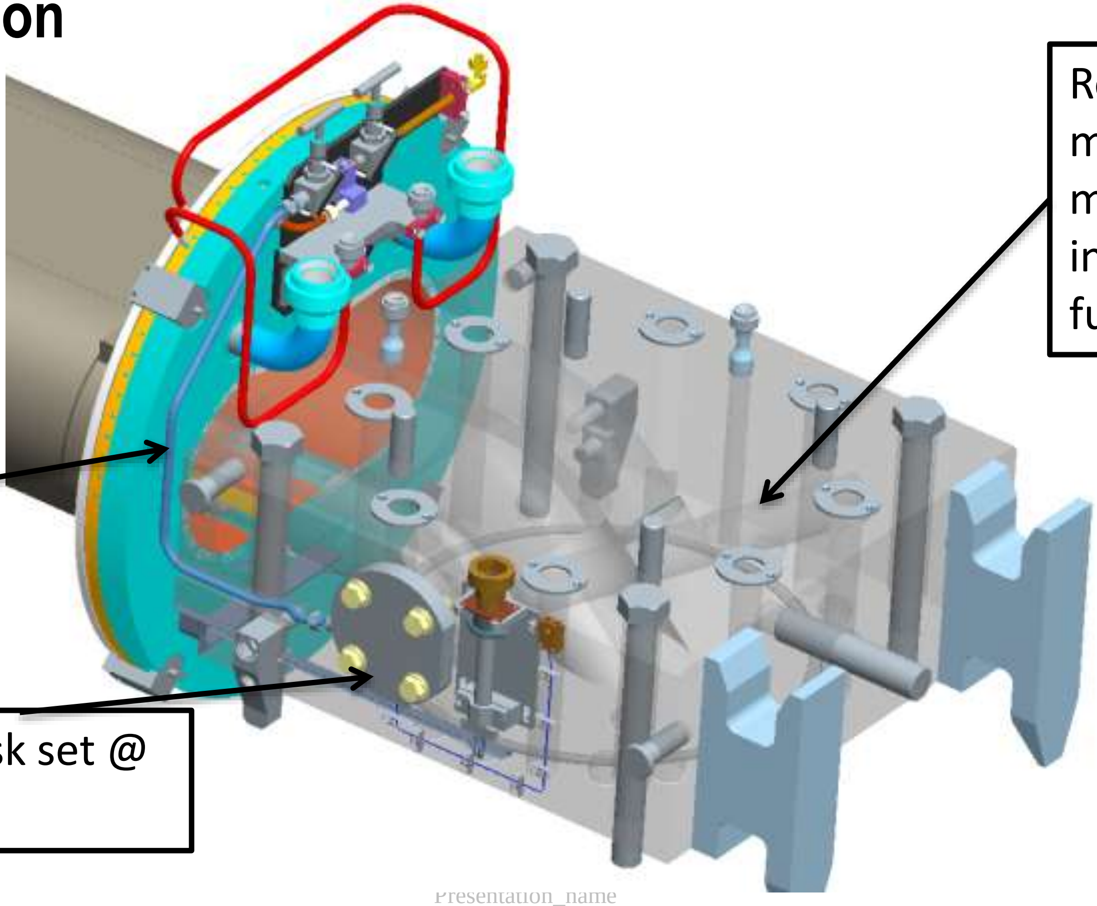
Jet Flow CFD

- “Swiss Cheese” orifice design produces most stable bulk supply flow



Additional Leak Detection via burst disk

- **Burst disk leak detection method has been mocked up and tested successfully**
- **Employs off-the-shelf burst disk with custom holder and indicator**
- **Detailed design is complete, ready to obtain vendor quotes for implementation**



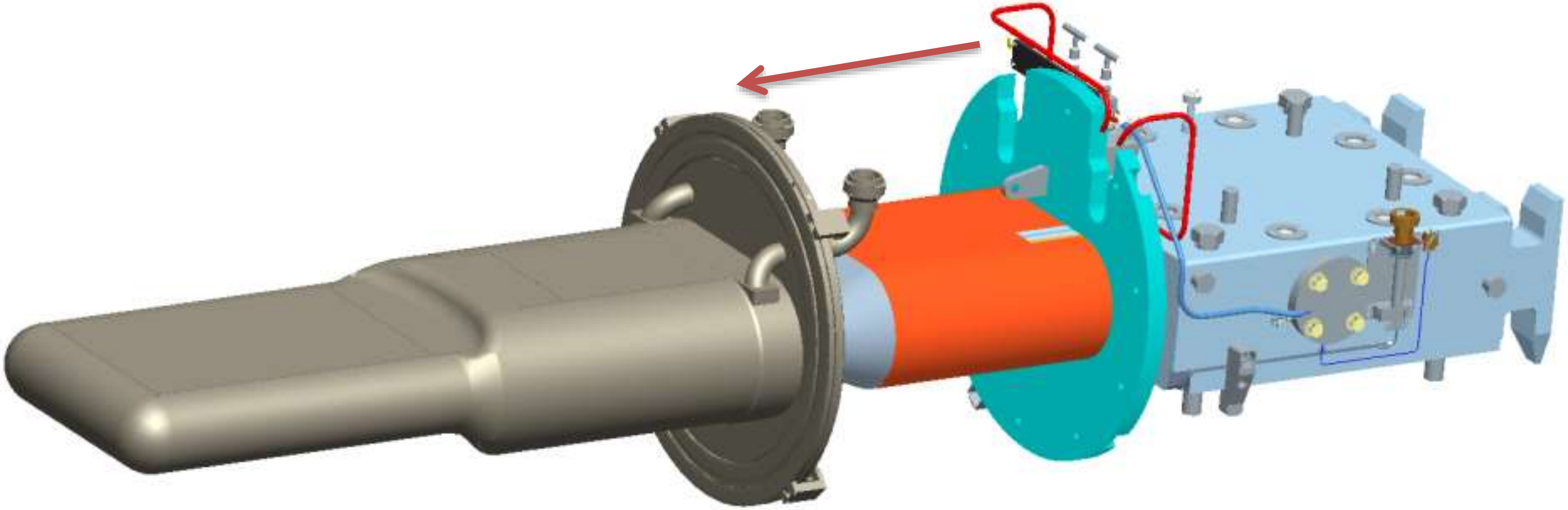
Reservoir machined into manifold allows indicator to function

New Tubing Provides access to interstitial

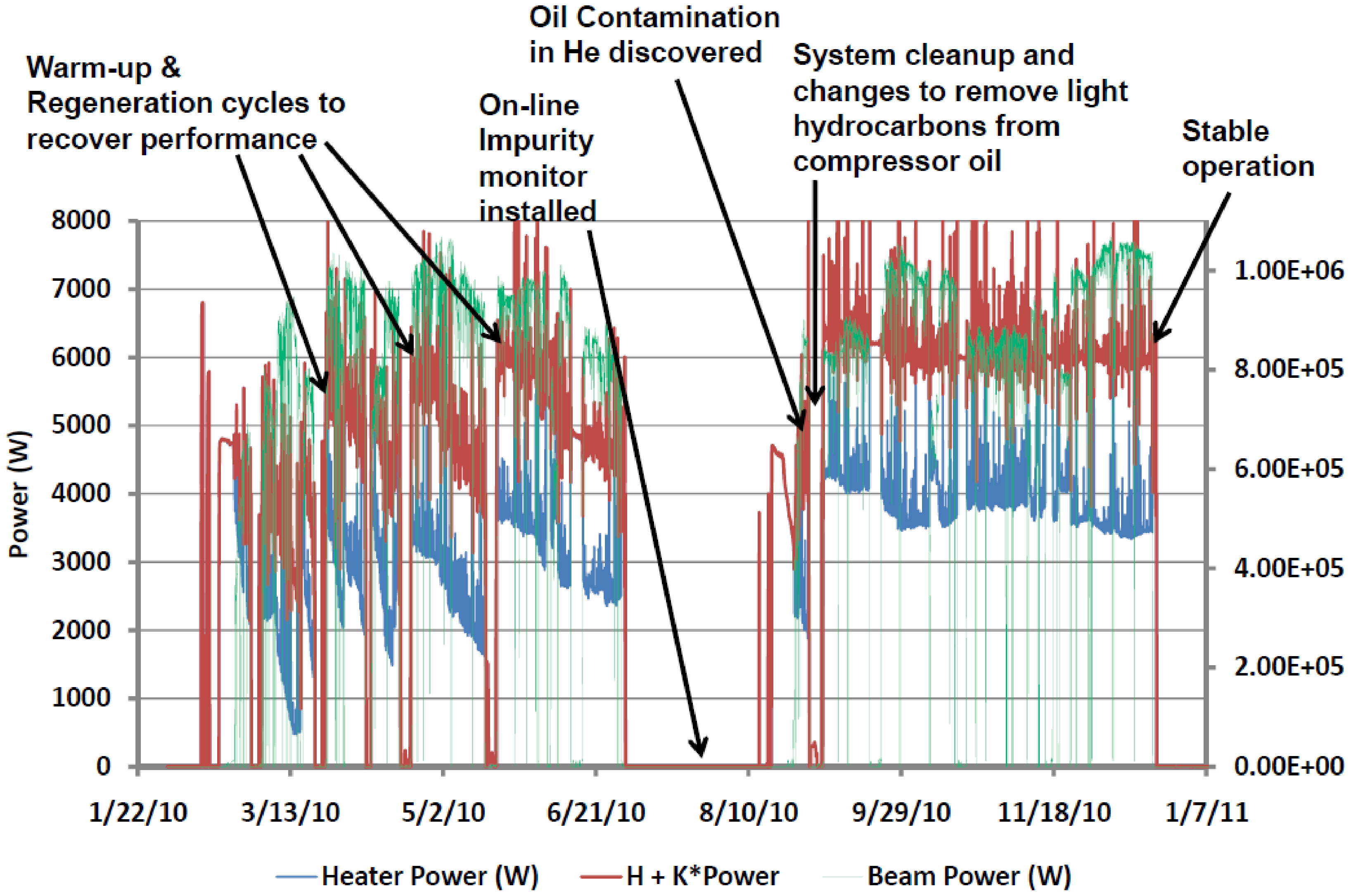
2” (50mm) burst disk set @ 8 psi (.54 atm)

Bolt on water shroud

- PIE options do not currently allow cutting away of water shroud to facilitate visual inspection of the Hg vessel outer surface
- Bolted joint would replace so called “closure weld” to seal the interstitial space between Hg vessel and water cooled shroud
- Sealing method is TBD…metal seal will be tested



Cryogenic Moderator System Refrigerator Performance



Warm-up & Regeneration cycles to recover performance

On-line Impurity monitor installed

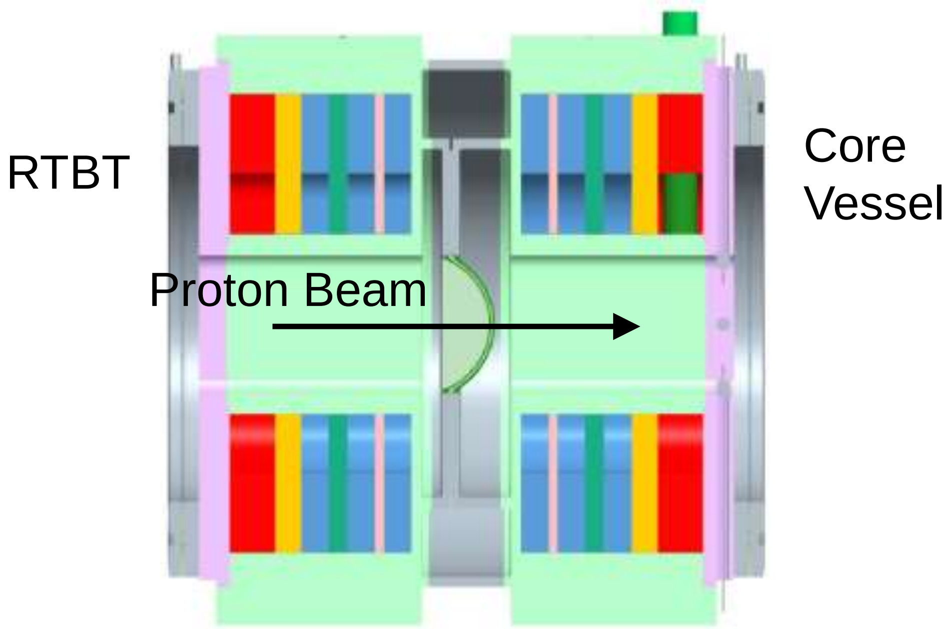
Oil Contamination in He discovered

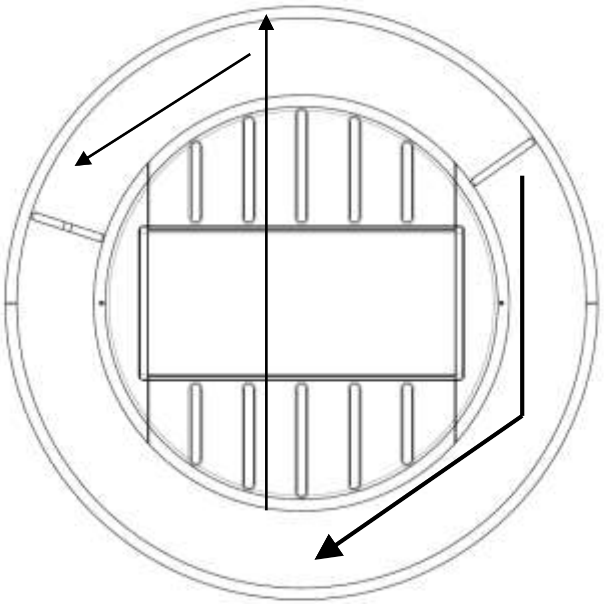
System cleanup and changes to remove light hydrocarbons from compressor oil

Stable operation

Current SNS PBW Design

- Inconel 718 window between 316 SS shield blocks
- 330mm ID inflatable seals interface to RTBT and Core Vessel
- 118 C max. shielding temp., 193 C max. window temp.
- Worst case stress 2.76 times below ASME BPVC allowable
- Approximate lifetime of 7500 MW-hours – 10 DPA

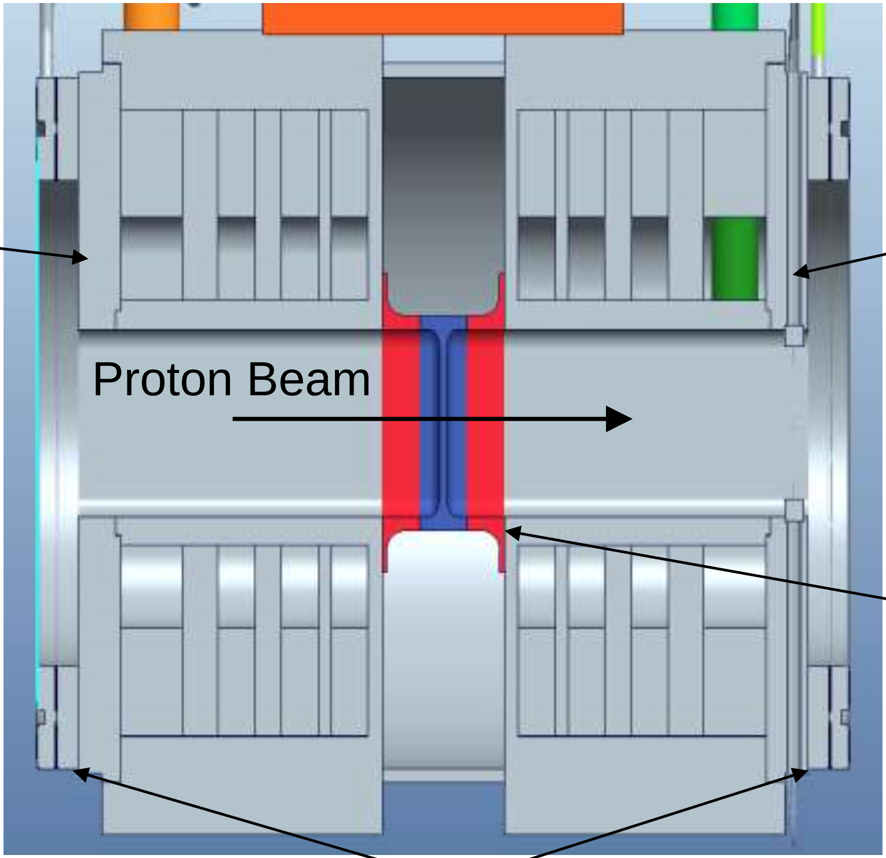




J. Janney, ORNL

Aluminum PBW Design

- **Internal design of shield blocks remains unchanged**
- **Minor changes to shield blocks for aluminum to steel interface**



Upstream Shield Block

Downstream Shield Block

Proton Beam

RTBT

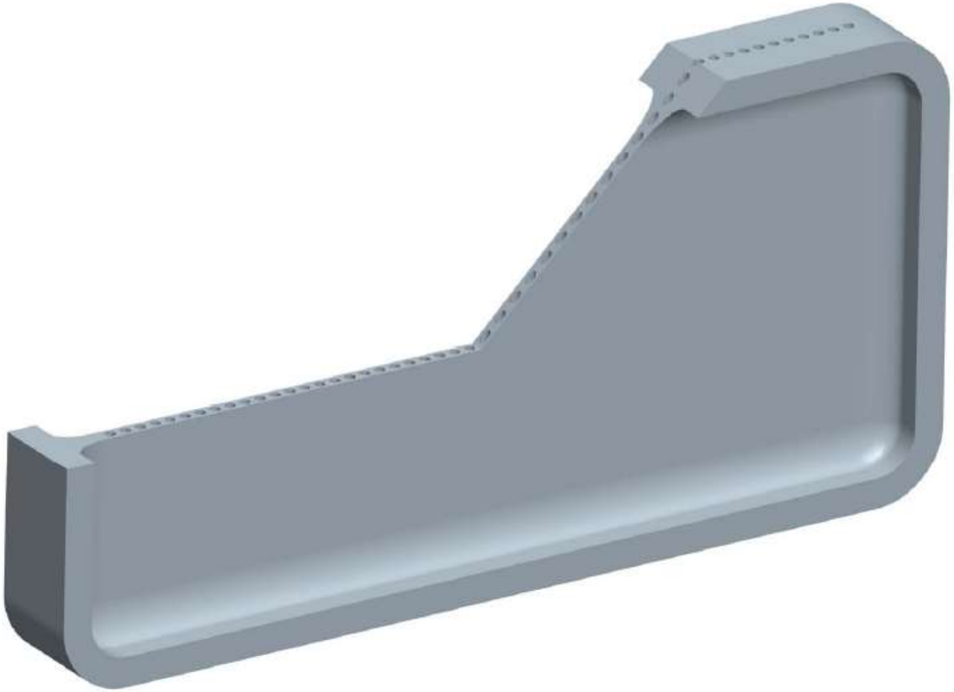
Core Vessel

Aluminum Bosses (red) and Aluminum Window (blue)

Inflatable Seals

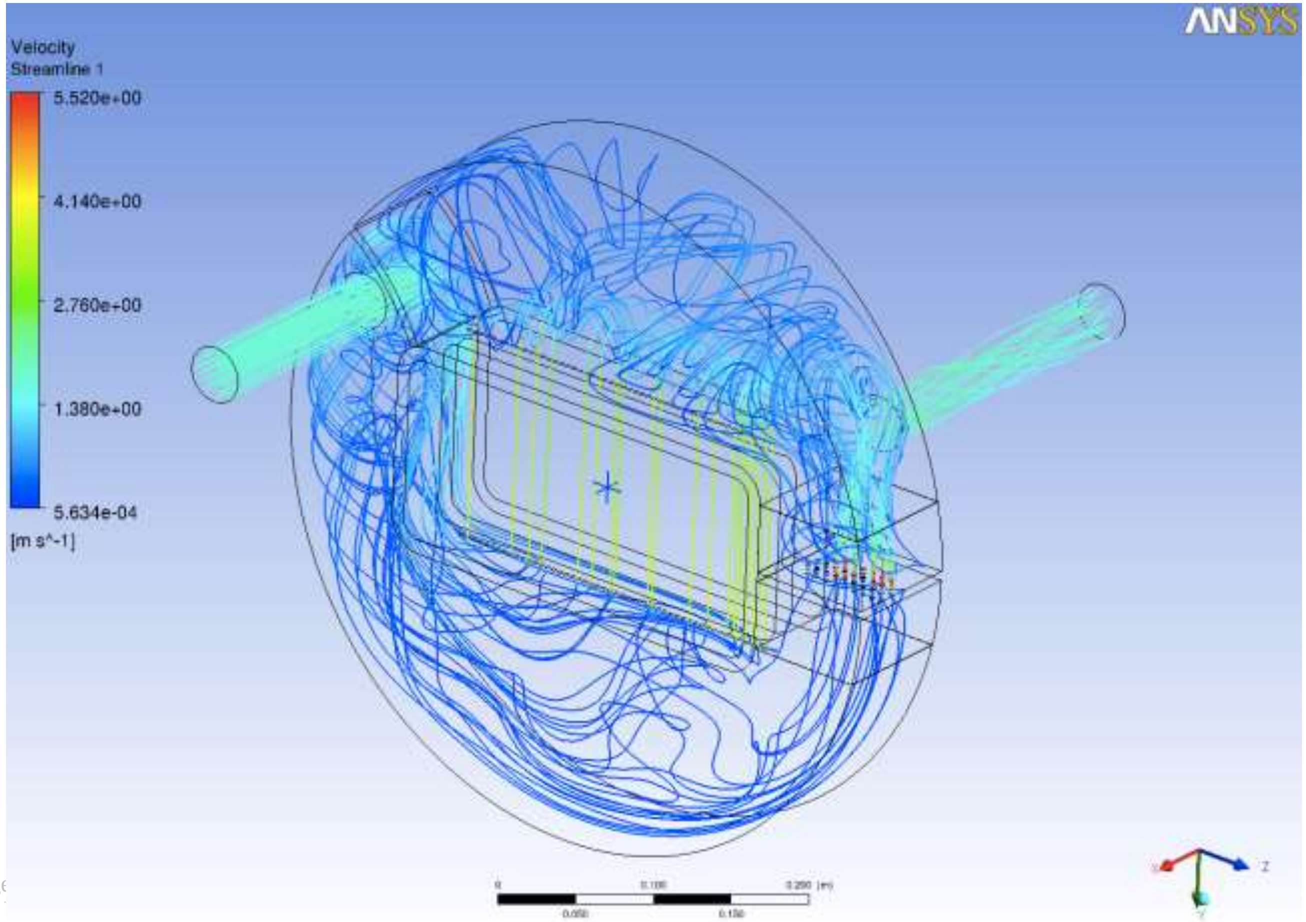
Design Description

- Flat plate with closely spaced parallel holes from single piece of aluminum
- 0.200” thick plate with 50 vertical .125” diameter holes spaced uniformly 0.200” apart center to center
- 1.25” welding boss all around exterior



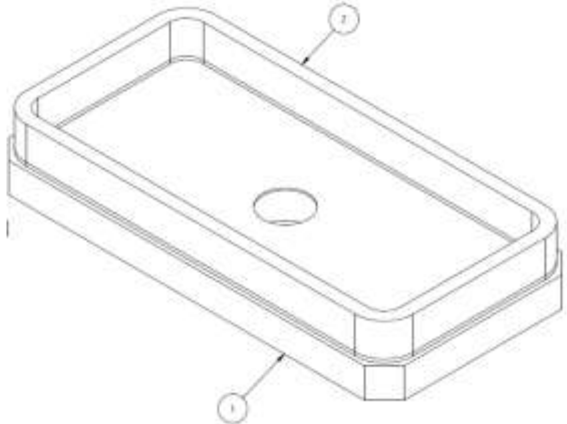
Window Flow Arrangement

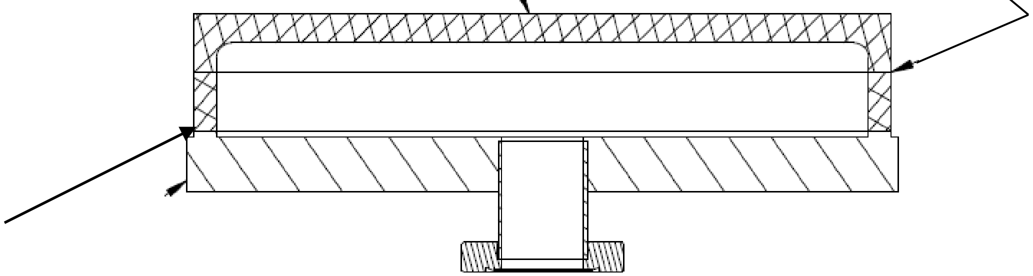
- Basic window flow pattern unchanged from original design
- Bypass flow increased to limit flow velocity through window
- Window Hole Avg. Velocity – 2.95 m/s



Explosion Bond Test Program

- Evaluate explosion bond metallographically
- Evaluate reliability of explosion bond joints for vacuum applications with repeated thermal cycling of joint
- Evaluate effect of welding close to explosion bond joint and post weld heat treatment on explosion bond joint
- No radiation studies due to relatively low dose at interface location





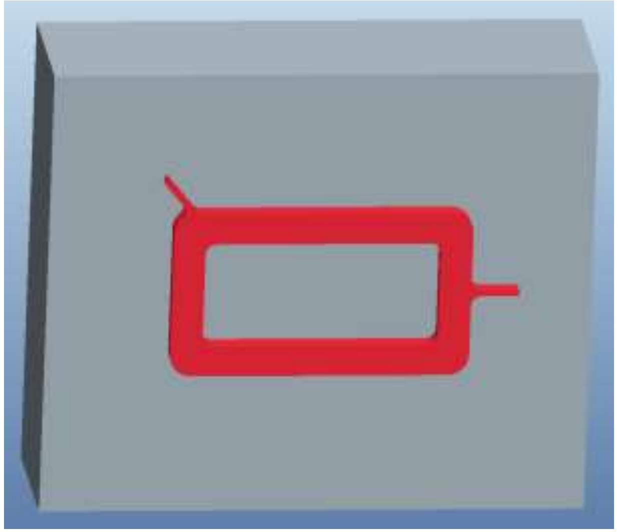
EB weld

Explosion Bond

Manufacturing – Explosion Bonding

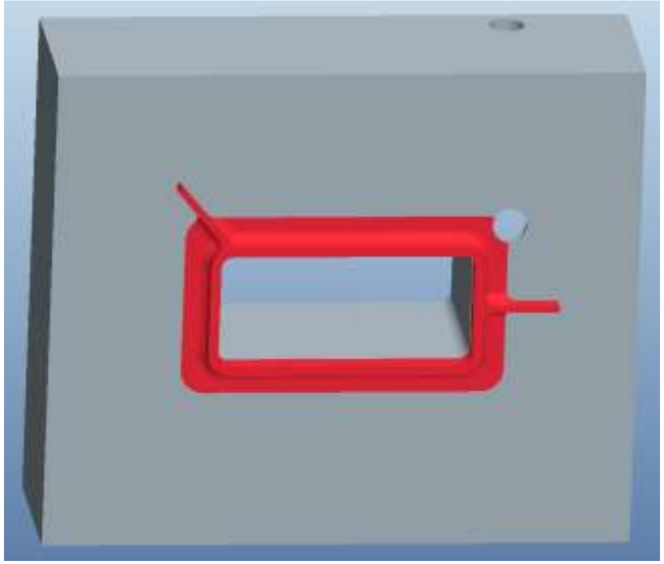
Explosion Bond Al to SS

Ultrasonic Inspection



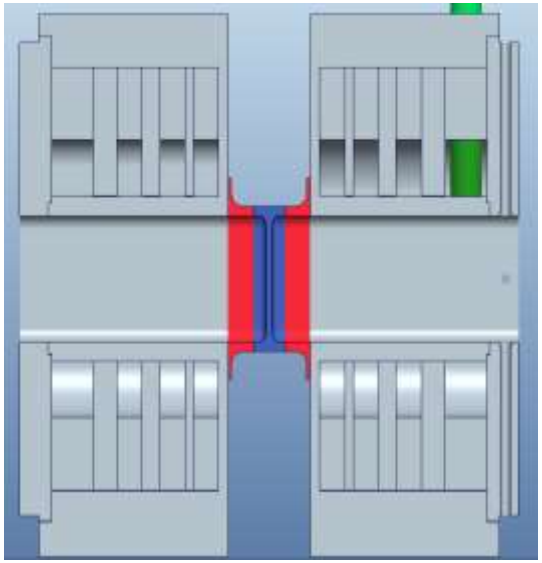
Machine to Final Interface

Helium Leak
Test Bond



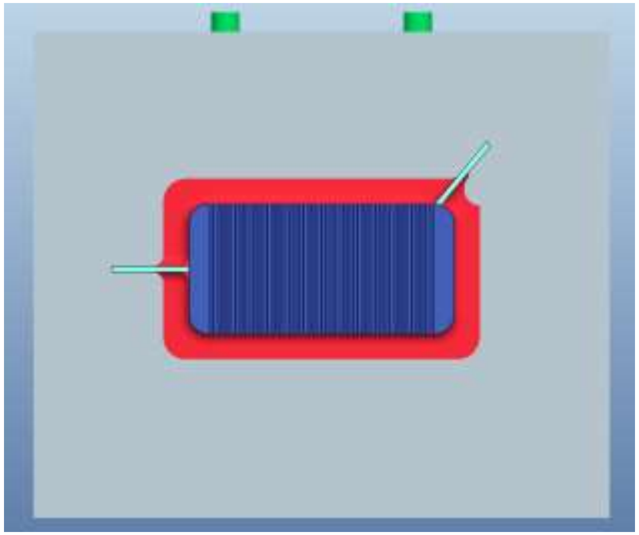
Final Machine Weld Boss

Manufacturing – EB Welding



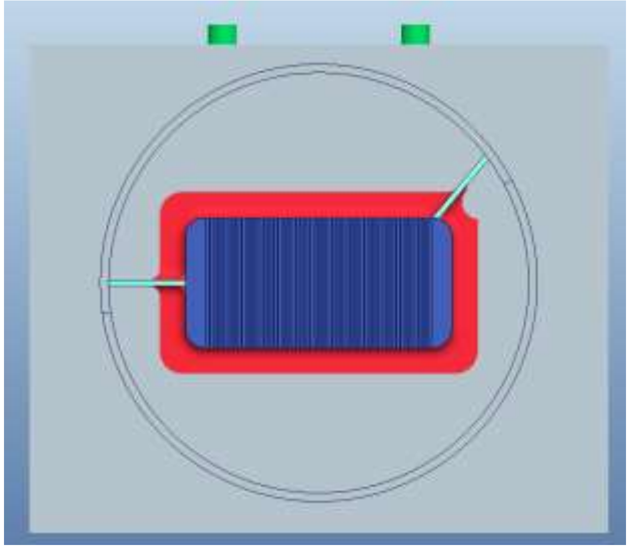
EB Welding

Remove Weld Crown
and Helium Leak Test



Weld Baffles

Heat Treat
to T6



Weld Outer Ring

Aluminum PBW Summary

- 6061 – T6 aluminum exceeds requirements for mercury containment
- Optimized coolant flow through holes with CFD
- Well below ASME stress allowables and fatigue design curves for Al 6061 – T6
- Slightly improved neutron performance, but higher peaking on target for nominal beam profile
- Lifetime estimated to be 15500 hrs @ 1 MW – double current Inconel 718 window
- Even though niobium explosion bond failed in extreme testing, explosion bonds determined to be more than robust enough for expected conditions
- The design has been evaluated against the safety basis and a formal USID will accompany the change at instalation

Proton Beam Window Manufacturing

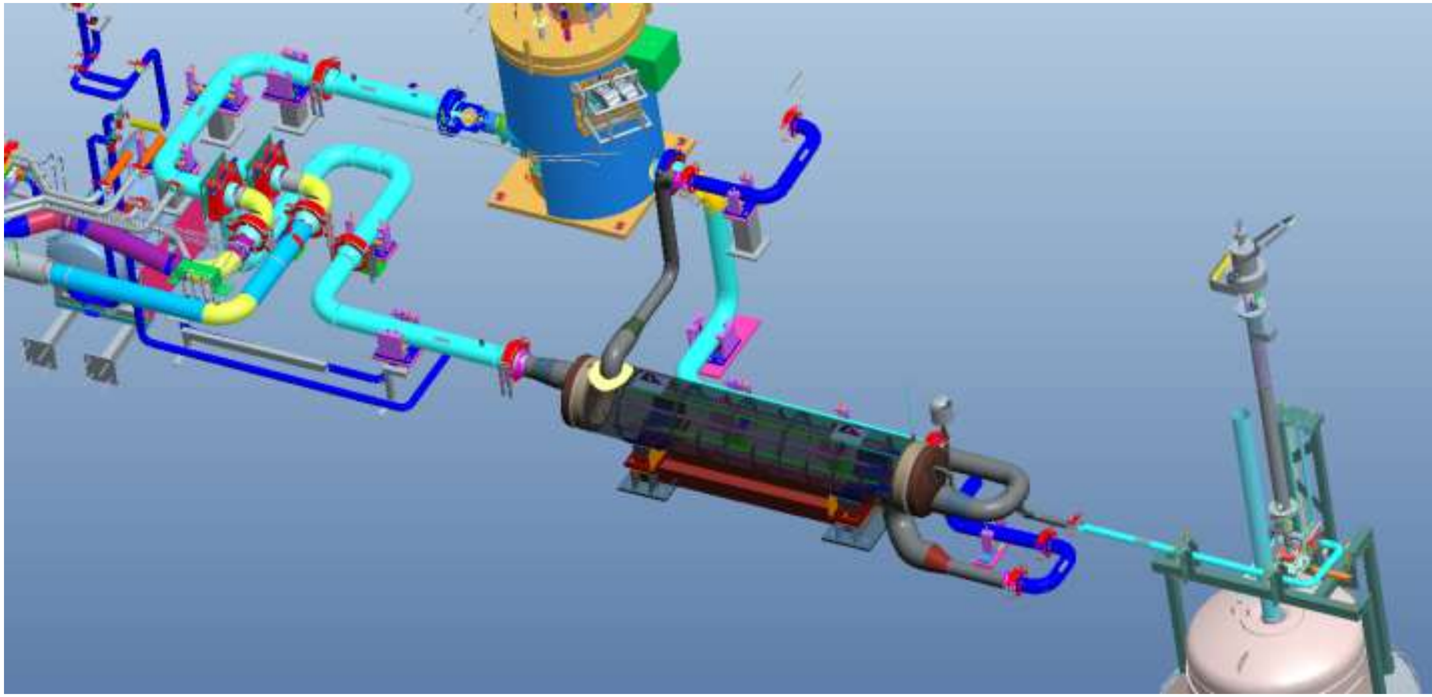
- PBW #3 is currently installed
- PBW #4 is onsite and will be installed in July, 2012
- PBW #5 (Inconel) is in fabrication and will be delivered this year
- PBW #6 (Aluminum) is under contract at early stages of fabrication
- Tentative plan is to install PBW #6 (Aluminum) in July, 2012 so that we have an Inconel window on hand as a spare

Mercury Loop Spare Parts

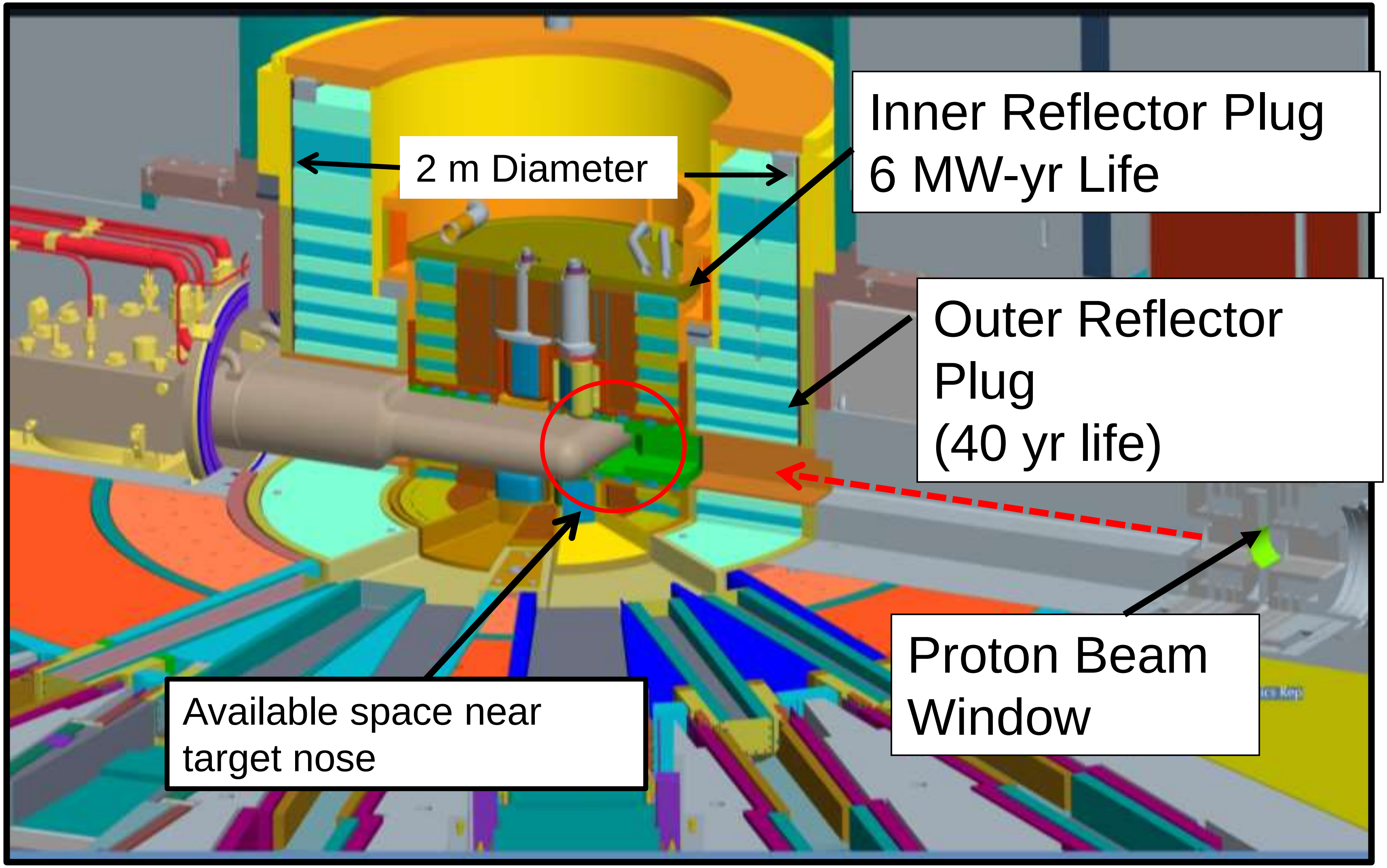
- **Spare Hg pump on hand – delivered 2008**
- **Spare Hg-water heat exchanger on hand – delivered 2010**
- **Spare Hg transfer valve on order – expected summer 2012**
- **Spare parts focus now shifts to piping sections (jumpers) that could be damaged during component change-out**
- **Several jumpers are identified as “difficult” to replace**

Development Plan:

1. Mock-up joints
2. Practice replacement with remote handling equipment
3. Redesign as necessary
4. Procure spare jumpers



Fusion Material Irradiation Test Station Design Study



2 m Diameter

Inner Reflector Plug
6 MW-yr Life

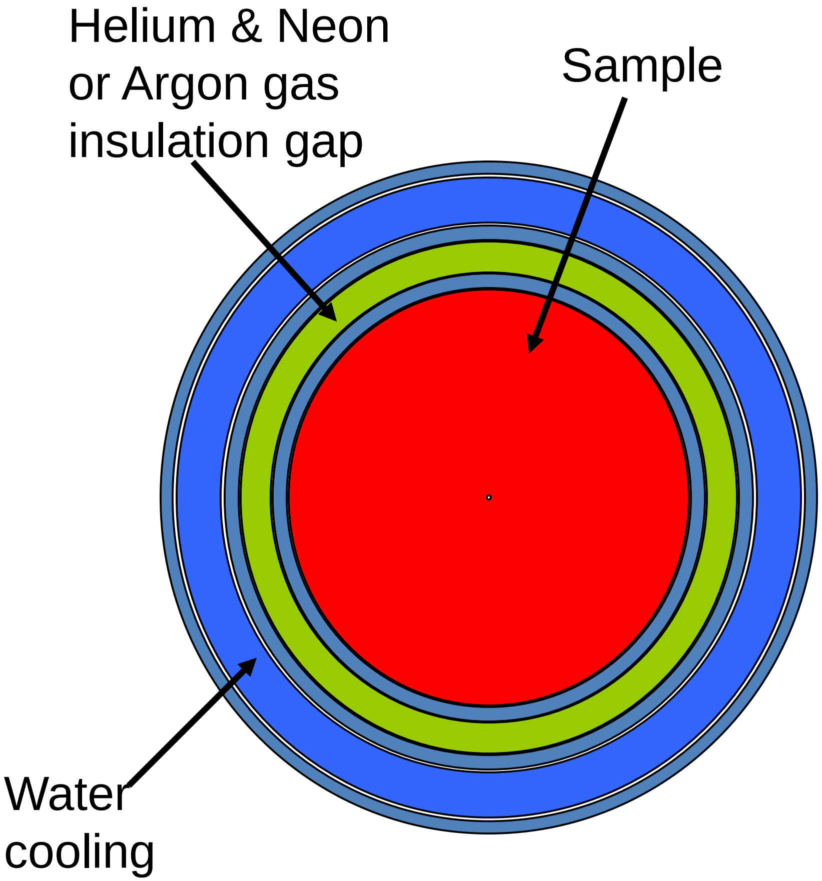
Outer Reflector Plug
(40 yr life)

Proton Beam Window

Available space near target nose

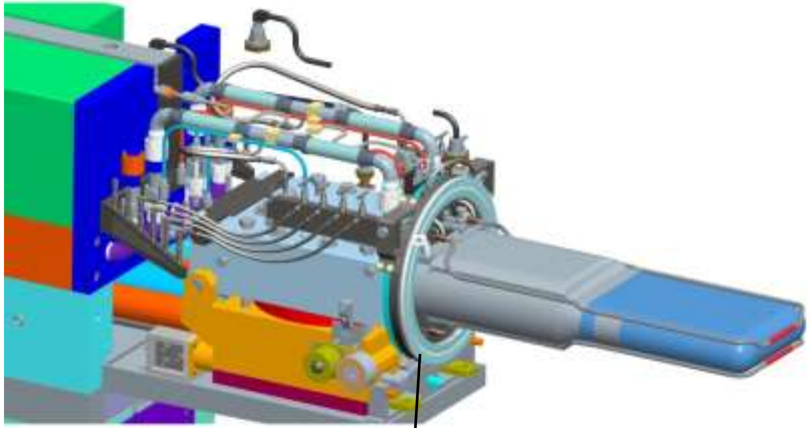
Design Concept

- **Irradiation capsules would be water cooled on the outside with a gas insulating gap between the cooling and the sample for temperature control**
- **Temperature is controlled during operation by changing the gas conductivity with different gas mixtures**
- **Irradiation capsules up to approximately 19 mm OD and 175 mm long can be located near the nose of the target, above and below the proton beam centerline**
- **A new mercury target design has been developed with modifications to fit the cooling lines in the rear target region through the outer reflector plug opening**
- **The target carriage vent line shielding assembly would have to be replaced with a new assembly containing the gas lines and instrumentation**

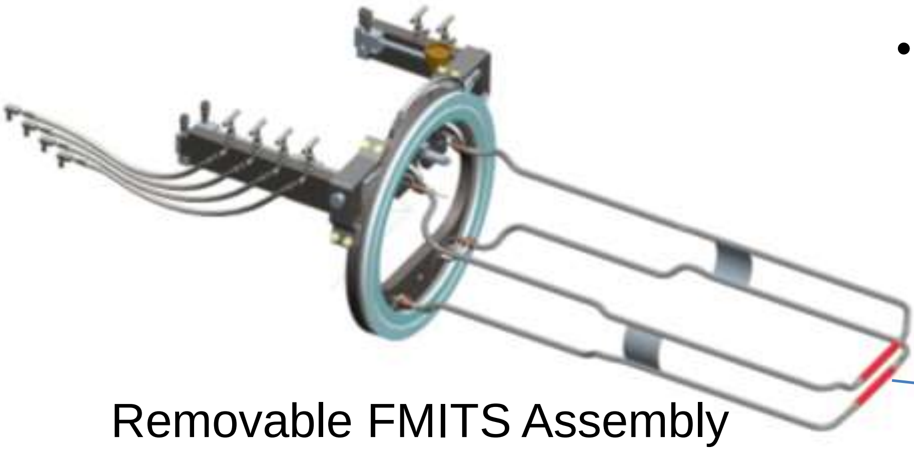


Irradiation Capsule schematic

Revised Target with FMITS

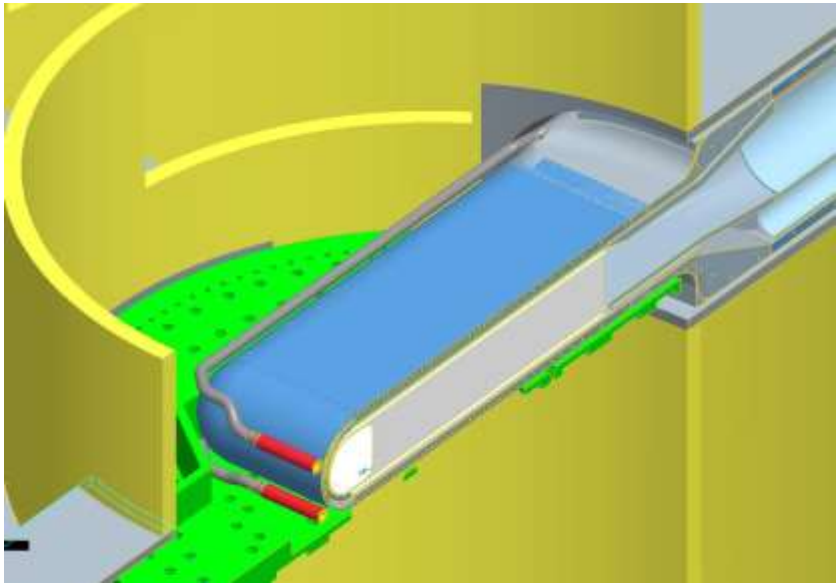


- New target water shroud design with grooves for FMITS in rear
- FMITS assembly with inflatable seal flange bolted to target flange to allow irradiation for multiple target cycles
- Irradiation capsule assembly - all welded within core vessel
- Both capsules instrumented for temperature and flow
- No change to target mercury boundary

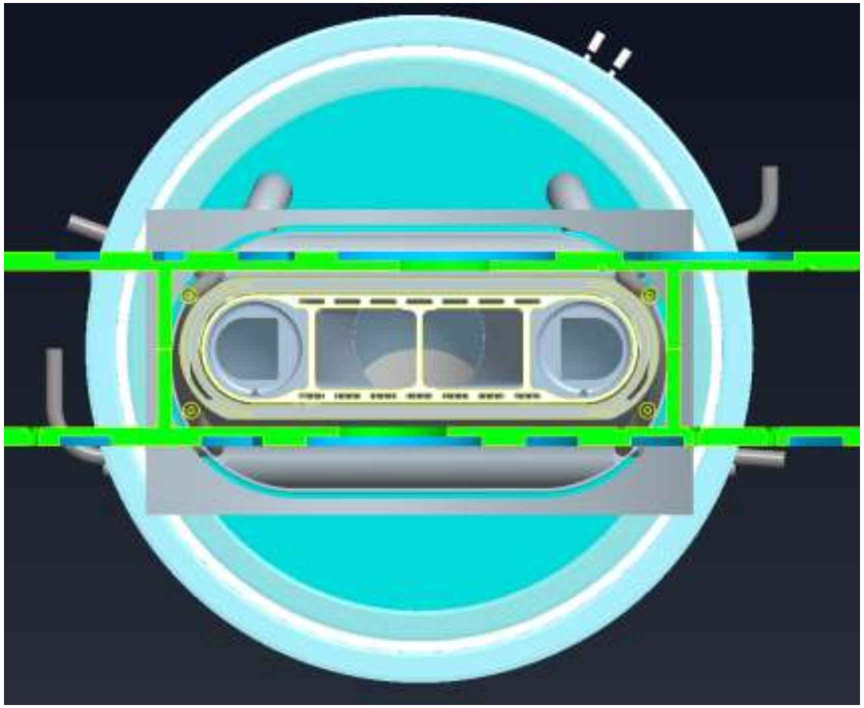


Removable FMITS Assembly

Target and FMITS in Reflector Plugs

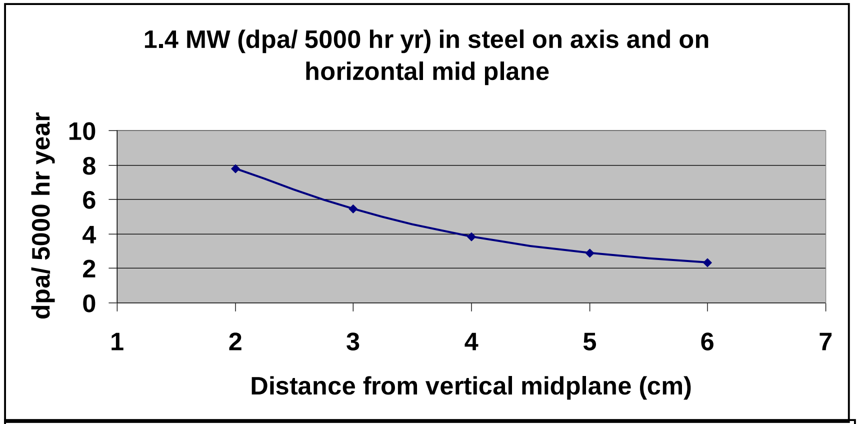


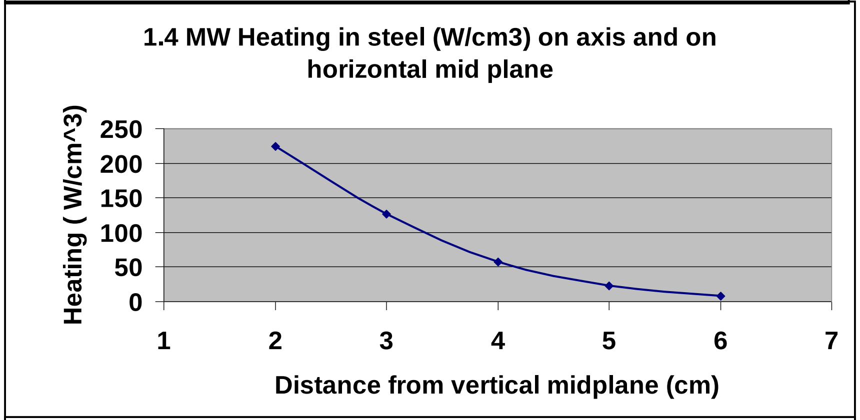
Target in position showing close fit by nose and rear body near racetrack opening in outer reflector plug

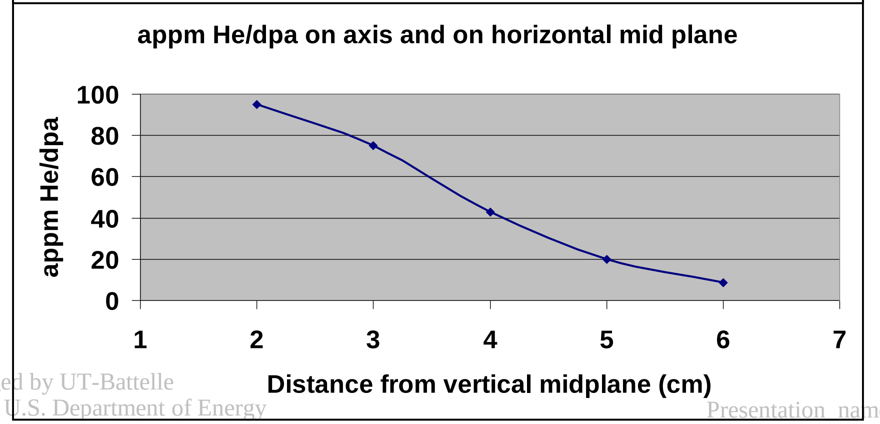


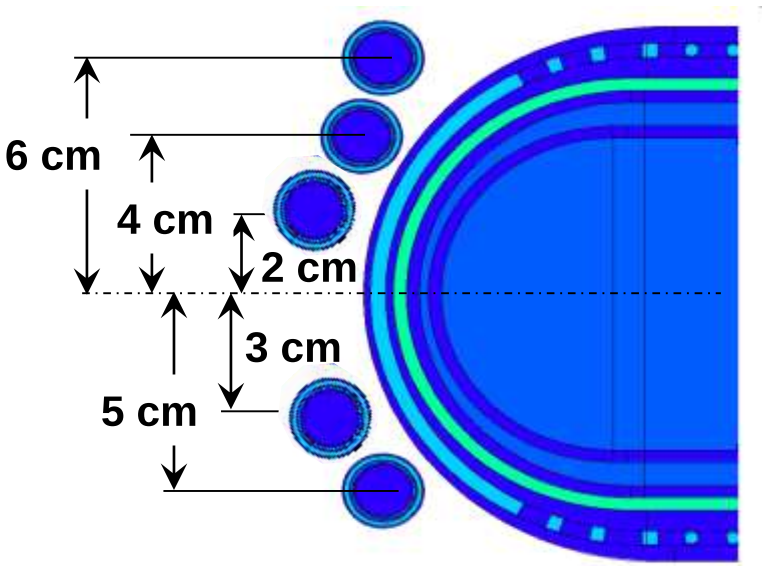
Front body cross section showing FMITS lines in corner regions of inner reflector plug

1.4 MW Irradiation summary


1.4 MW (dpa/ 5000 hr yr) in steel on axis and on horizontal mid plane


1.4 MW Heating in steel (W/cm3) on axis and on horizontal mid plane


appm He/dpa on axis and on horizontal mid plane



Possible sample capsule locations - 6 cm to 2 cm from beam center line

Study based on 3cm and 5 cm locations

90% of beam in 7 x 20 cm^2 area

~ 1.7 cm sigma vertical Gaussian

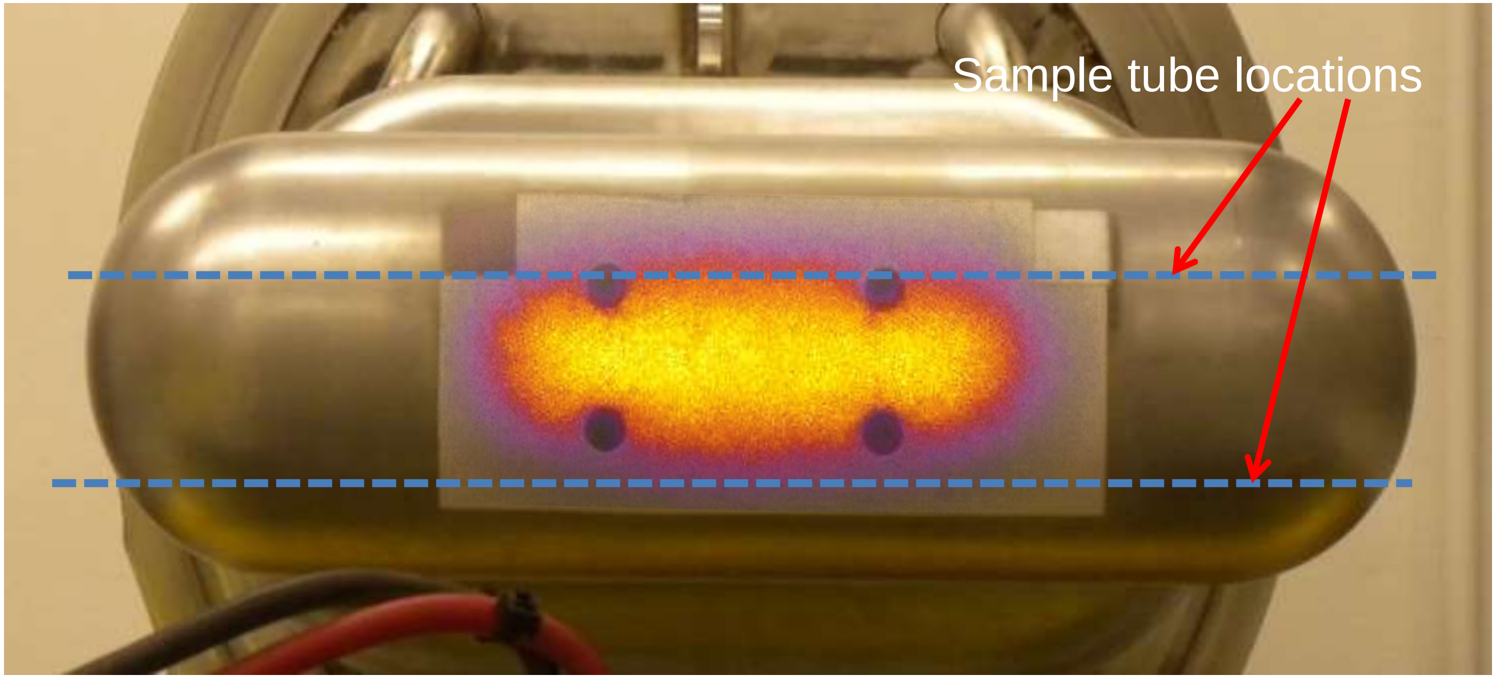
1.4 MW Summary for Steel Samples

Distance (cm)	Displacement (dpa/yr)*	Helium (appm/yr)	appm He/dpa	Hydrogen (appm/yr)	appm H/dpa	E dept. (W/cm³)
2	7.8	741	95.0	2985	384	224.0
3	**5.5**	**413**	**75.0**	**1685**	**309**	**126.0**
4	3.9	168	43.0	748	194	57.5
5	**2.9**	**58**	**20.0**	**290**	**101**	**22.9**
6	2.3	20	8.7	132	56	8.1

* 1 year = 5,000 hours beam time

- Moderator Neutronic performance is nearly unchanged with FMITS tubes at 3 cm and 5 cm offset locations

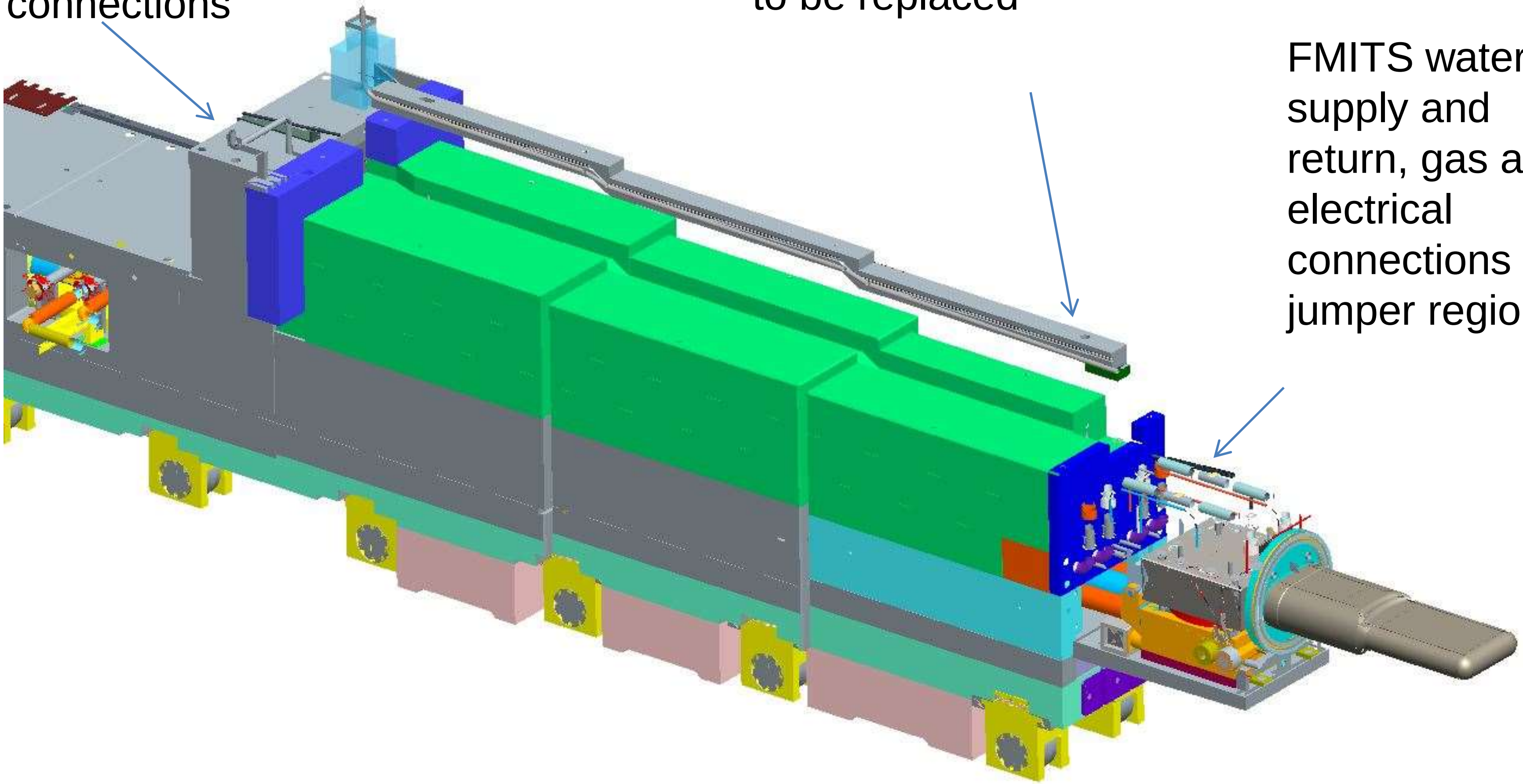
Target Imaging System will give a view of the beam profile on the sample tubes



Target Imaging System

- •0.25 mm thick phosphor coating on target (Alumina with 1.5% Chromia)
  Sample tubes would also be coated
- •Image observed from optical system on proton beam window
- •Individual pulse profiles at 1 Hz measured
- •Beam position can be resolved and controlled to within 1 to 2 mm

Carriage modifications

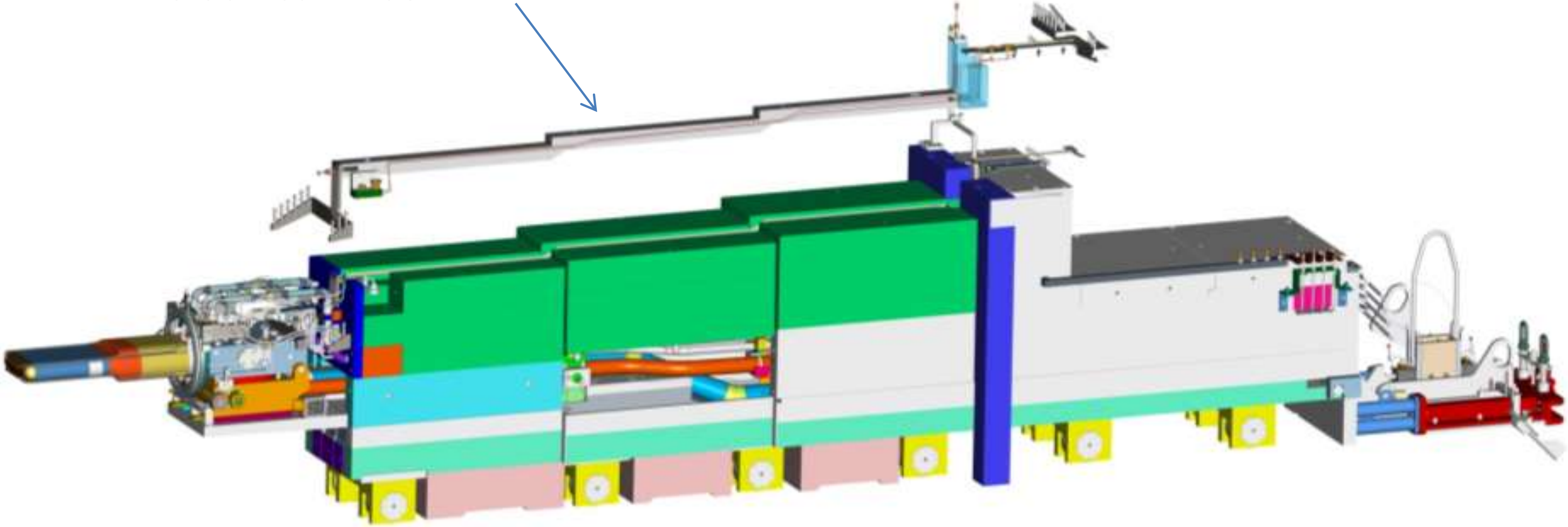


Jumpers added near rear for gas and electrical connections

Existing shielding unit with vent line, to be replaced

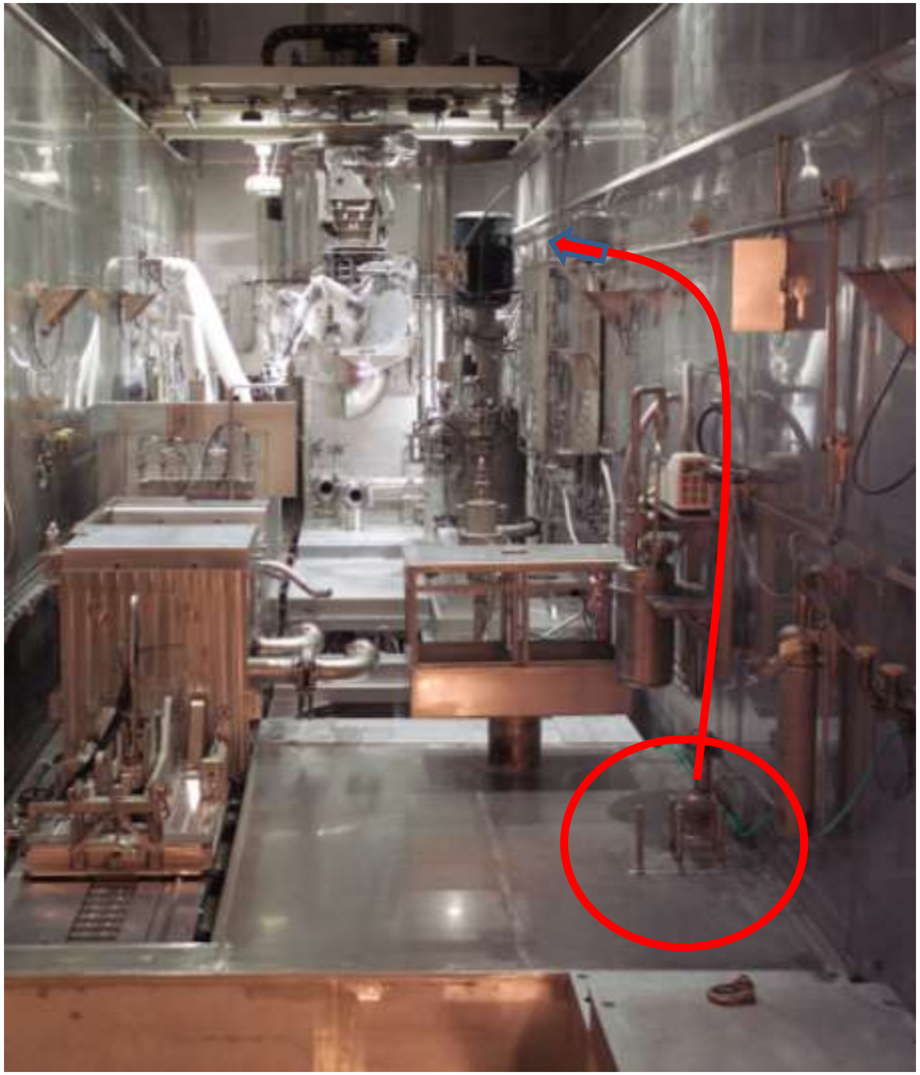
FMITS water supply and return, gas and electrical connections in jumper region

New Vent line shielding assembly



New shielding unit with vent line, target leak detection cables and FMITS gas and electrical lines

Penetrations to Gold Amalgamation Room exist and can be used for gas lines



Gas supply, valves and control system will be located in Gold Amalgamation Room (basement)

FMITS Summary

- Design Study completed 12/31/2011
- Scope included all tasks and systems needed for installation and operation
- Potential impacts to safety and reliability evaluated
- Designs developed by engineers responsible for current target design and with experience of 3 fully remote SNS target replacements
- Design review was well received by committee
- Ultimate decision path is based on balance of mission need of DOE Fusion Energy Sciences and risk to scattering mission of DOE Basic Energy Sciences

Summary of goals / challenges for 2012

- Develop more accurate DPA counting method for target lifetime
- Make best use of TIS within budget constraints?
- Complete Jet Flow Target detail design
- Implement burst disk leak detection
- Develop bolt on shroud scheme and implement ASAP
- Complete preliminary design review of 2nd generation IRP
- Successful fabrication of aluminum PBW
- Prioritize maintenance risks to Hg loop, redesign components as necessary, and procure spare parts
- If funded, develop FMITS design to reduce risk to scattering mission and impacts to target station design