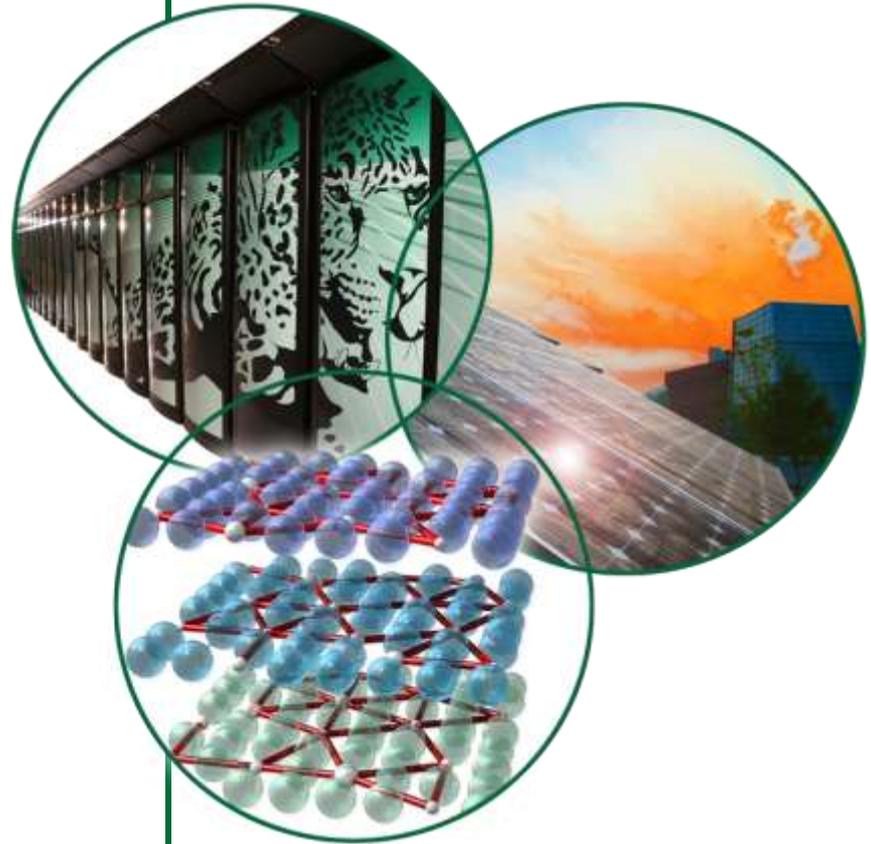


Target Systems Performance and Plans

T. McManamy
NFDD Chief Engineer

AAC Meeting February 2 -4, 2010

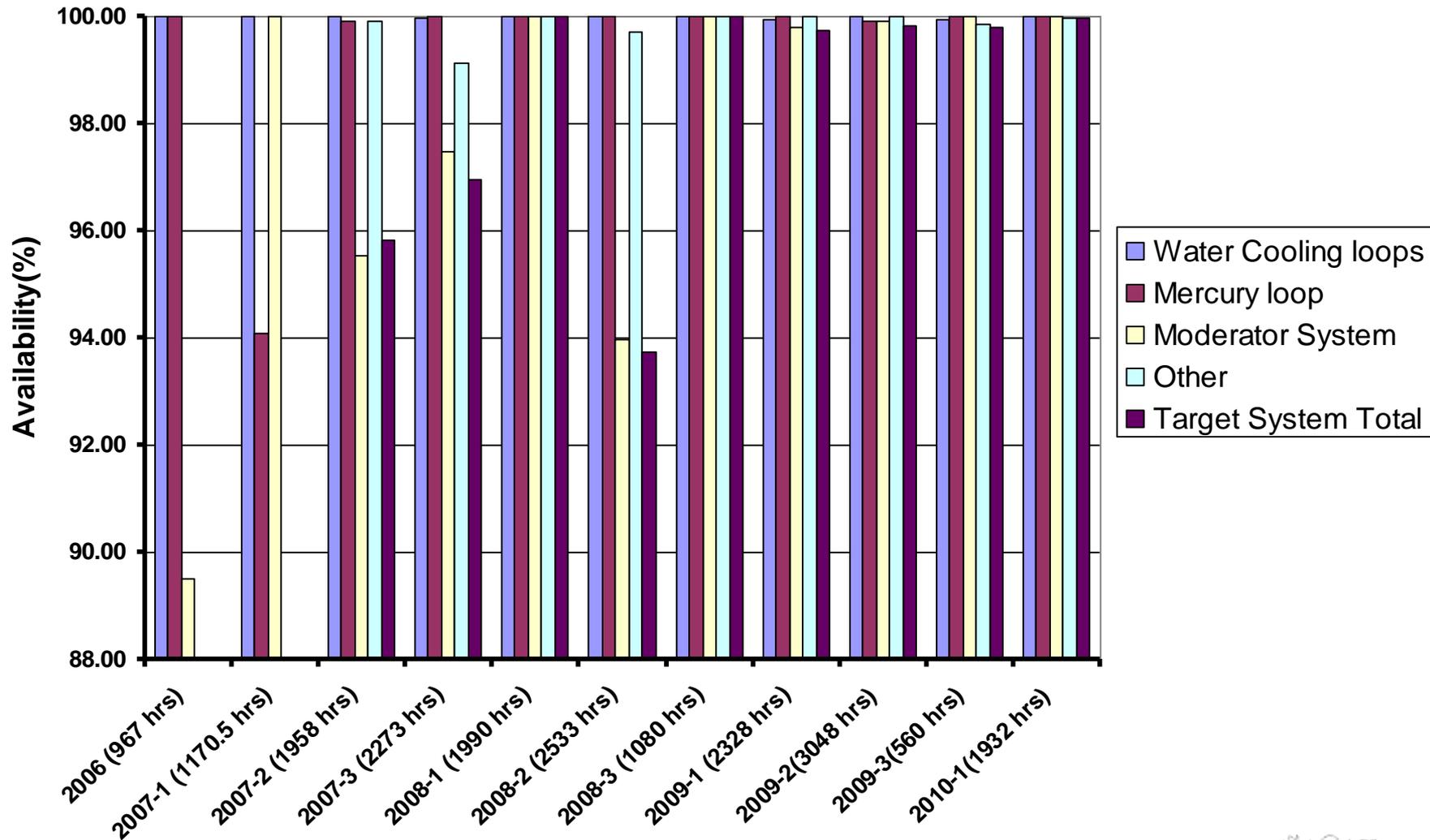


Overview of Topics

- **Overall Target Systems Availability**
- **System Performance and Plans**
 - Target Modules & Mercury loop
 - Moderator System
 - Proton Beam Window
 - Utility Systems
 - Shutter Systems
 - Remote Handling
 - Rotating Target Development

Target System Availability from 2006

Target Systems are meeting the goal of < 1% hours of unscheduled downtime



Availability Consideration

- **Events which had the potential to cause significant down time fortunately did not occur during operating periods**
 - Target replacement took 6 weeks instead of 1 week due to a leaking connection and the time required to locate and recover complicated by problems with high contamination levels within the service bay
 - Moderator refrigerator lost capacity which would have required a regeneration if the accelerator power was not reduced for other reasons
 - An electrical transformer feeding CMS compressor controls failed shortly after the shutdown which would have caused a multi-day outage – a power outage of only 3-6 seconds would cause a 3+ day outage
- **Improvements are being studied or implemented**
 - Target replacement procedures and leak checking process under review
 - CMS refrigerator issue is being addressed
 - Loss of capacity is now thought to be due to inadequate removal of contamination particularly in the adsorber between run cycles and an extensive purge is being conducted this shutdown
 - The spare heat exchanger is being installed in a new vertical cold box to allow replacement if needed

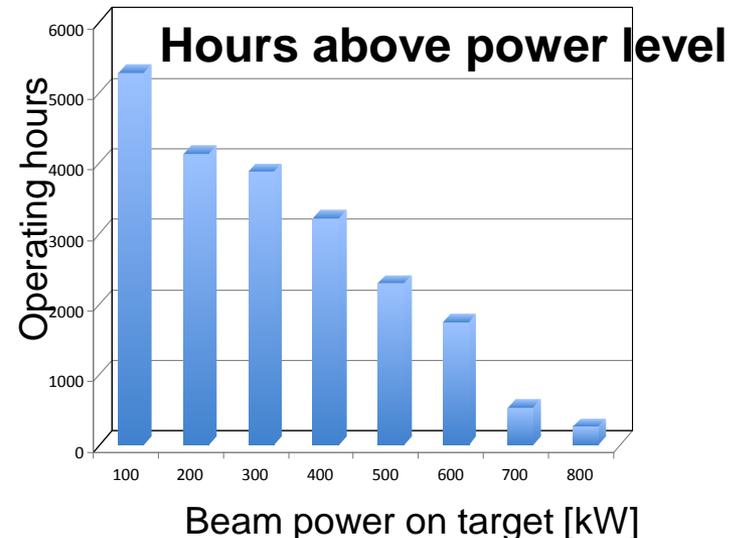
First target replacement



- The first target module reached 7.5 dpa peak on the mercury vessel, a peak fluence of 1×10^{19} protons/mm² with a peak power of 800 kW and an accumulated energy of 3055 MW-h
- Target replaced during shutdown to avoid exceeding 10 dpa on the water shroud prior to the next scheduled shutdown



- No observed external corrosion

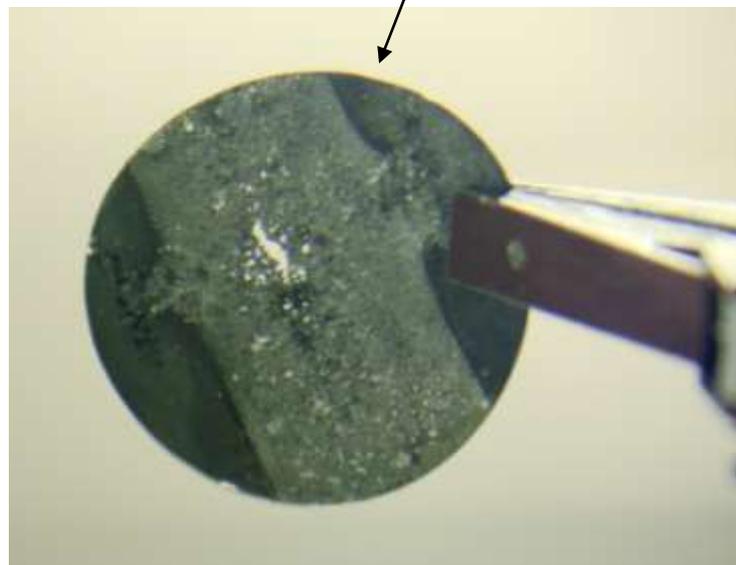
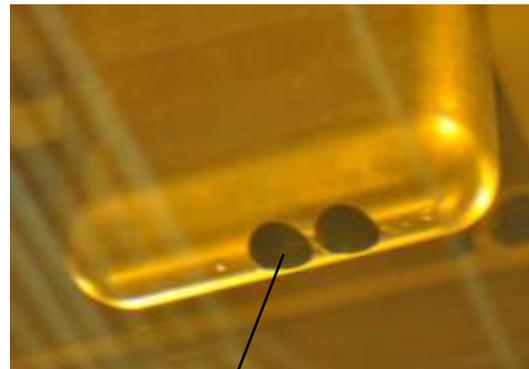
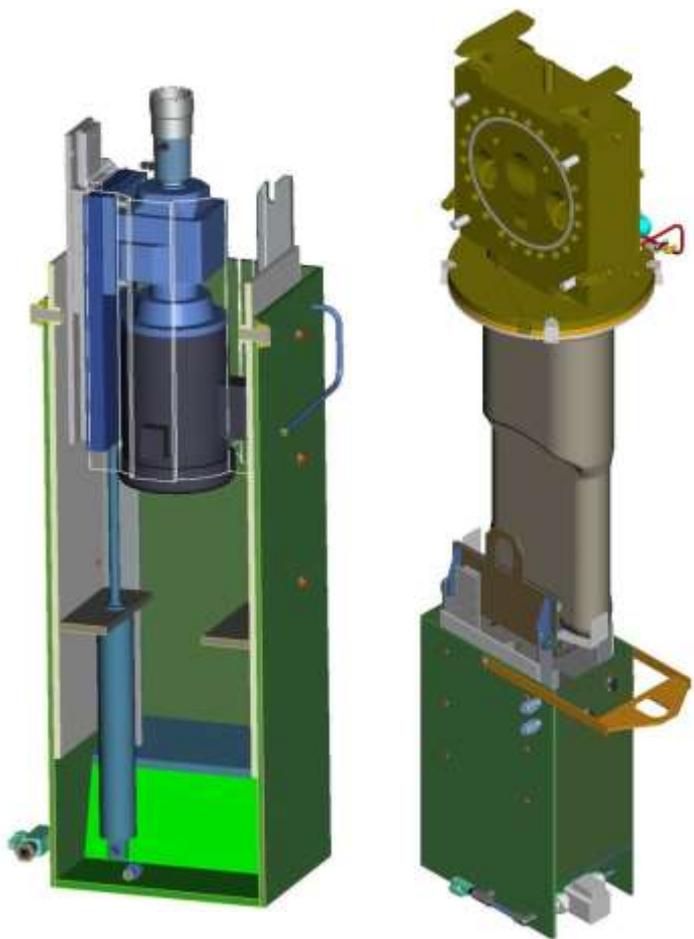


Post Irradiation Examination

- **The first target had circular samples cut from the nose region**
 - **Samples showed severe pitting damage to the inner wall which separates the window flow channel from the bulk flow**
 - **The damage was strongly peaked near the nominal bulk flow stagnation point**
 - **Little or no damage was observed on other samples where there was good mercury flow across the surface**
 - **Samples will be ultrasonically cleaned in the service bay**
 - **Discussions and evaluations are in progress to ship samples to B&W to produce tensile and SEM samples**
- **The method of sampling the second target will be decided after it has reached end of life**
 - **Tooling has been fabricated and tested to allow full sectioning of the target to examine a failed region (WACHS saw)**
 - **This tooling would be remotely installed in the cell**
 - **If only samples of the nose region are desired, the same type of tooling used for the first target can be employed**

Nose Region Sampling

- Sampling Cutter used to remove complete samples from the target nose (two water shroud, two mercury vessel) in two locations.

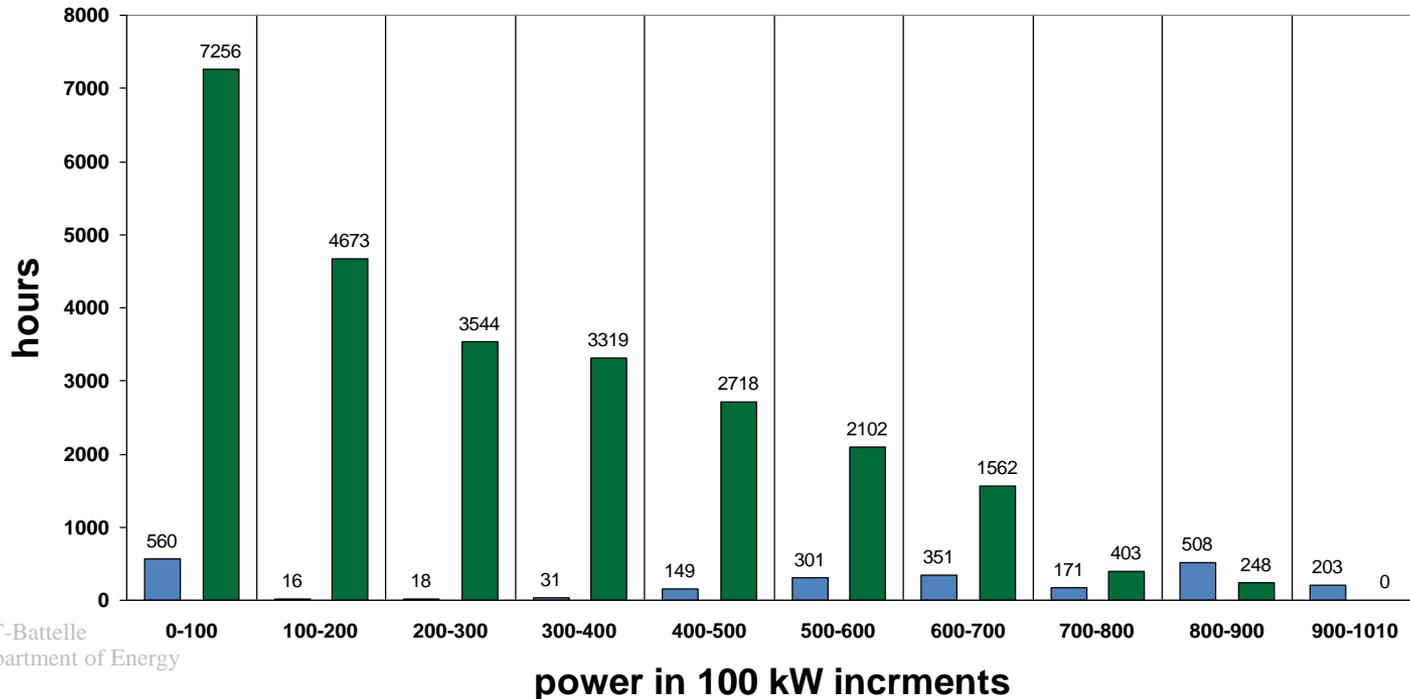


Damaged inner Hg Vessel wall- bulk flow side

Second Target Installation and Operation

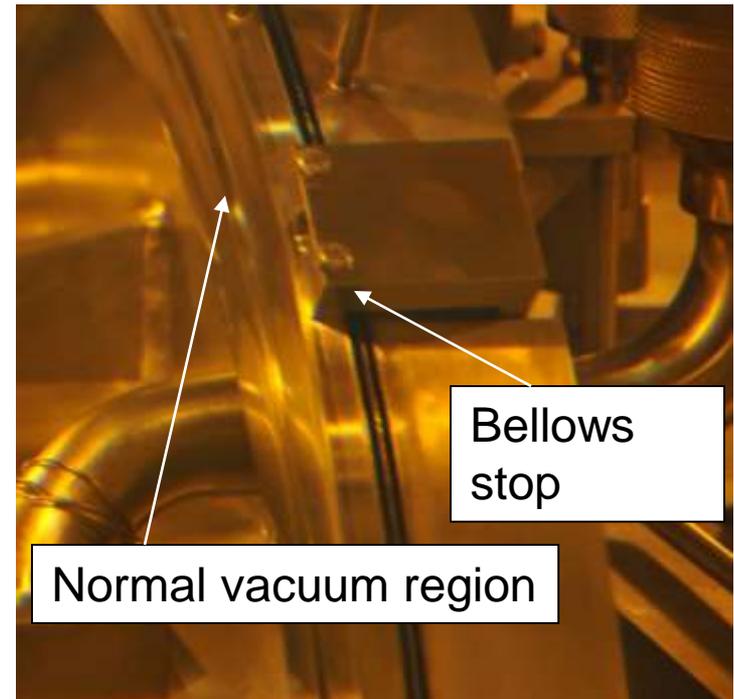
- Initial removal and target replacement took approximately 1 week however the system did not pass a vacuum leak test which required retracting the target to find the problem
- Improvised leak detection methods were needed to find the location of the leak
- After installation target was operated for 1240 MW-hrs and up to 1 MW prior to the Dec. shutdown

Targets 1 & 2 operating hours vs power



Second Target Inflatable Seal Problem

- During operation the interstitial vacuum in the target inflatable seal was lost causing the helium concentration in the core vessel to go below 98%
- The cause appears to be an incorrect setting for the brackets on the seal which limit the stroke of the included bellows
- By feeding a small flow of helium to the middle region instead of pulling vacuum and by operating at close to atmospheric pressure, the core vessel helium concentration has been maintained at > 99.9%
- The target will be run in this mode until the next replacement



Target inflatable seal
and one bellows stroke
limiting bracket

Target Module Status

- **Current Power Operating Limit for the target is 1.2 MW with the nominal beam profile**
 - Limiting case is for the interstitial region filled with mercury without a rapid beam trip
 - Methods to increase the allowable power to 1.4 MW are under evaluation
 - Further analysis with actual material properties and interstitial gap dimensions
 - Additional redundant and diverse leak detection
 - Better beam profile distribution information from Target Imaging System
- **Three spare target modules have been delivered and another three should be completed this year**

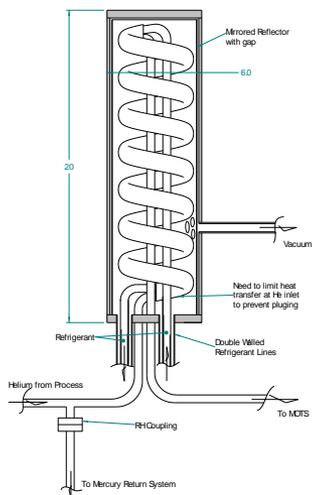
Mercury Loop Performance and Plans- Status of Hg Pump

- The fixes that were applied to the Hg pump in December 06 continue to perform satisfactorily
- A replacement pump of the same type (vertical shaft centrifugal pump) that fits the existing mercury reservoir tank has been procured, tested and is in storage at SNS
- Spare Mercury heat exchanger in fabrication - expected delivery June, 2010

Mercury OFF-Gas Treatment System (MOTS) Operating Experience

- Dose rate issues with the noble gas hold-up in the system from initial operations
- Sorption of noble gases on the gold sorbent was suspected
 - Gold (alumina) not known as a noble gas sorbent
 - Xenon conditioning of gold bed (to flood sorption sites)
 - Relocation/shielding of gold bed and CuO bed
- Dose rate was reduced in subsequent operations
 - 9 mrem/h at 30 kW
 - 30 mrem/h at 130 kW
 - Dose rate increased because of noble gas sorption in the mol sieve beds
 - Shielded mol sieve beds
- Transitory noble gases now only issue, room dose rate is 1-6 mrem/h at 0.3 m at 900 kW

MOTS Changes to Enhance Reliability



Mercury
Condenser



Parallel
CuO
Reactor



Regenerable Molecular
Sieve Beds



Parallel
Refrigerated
Carbon
Adsorber



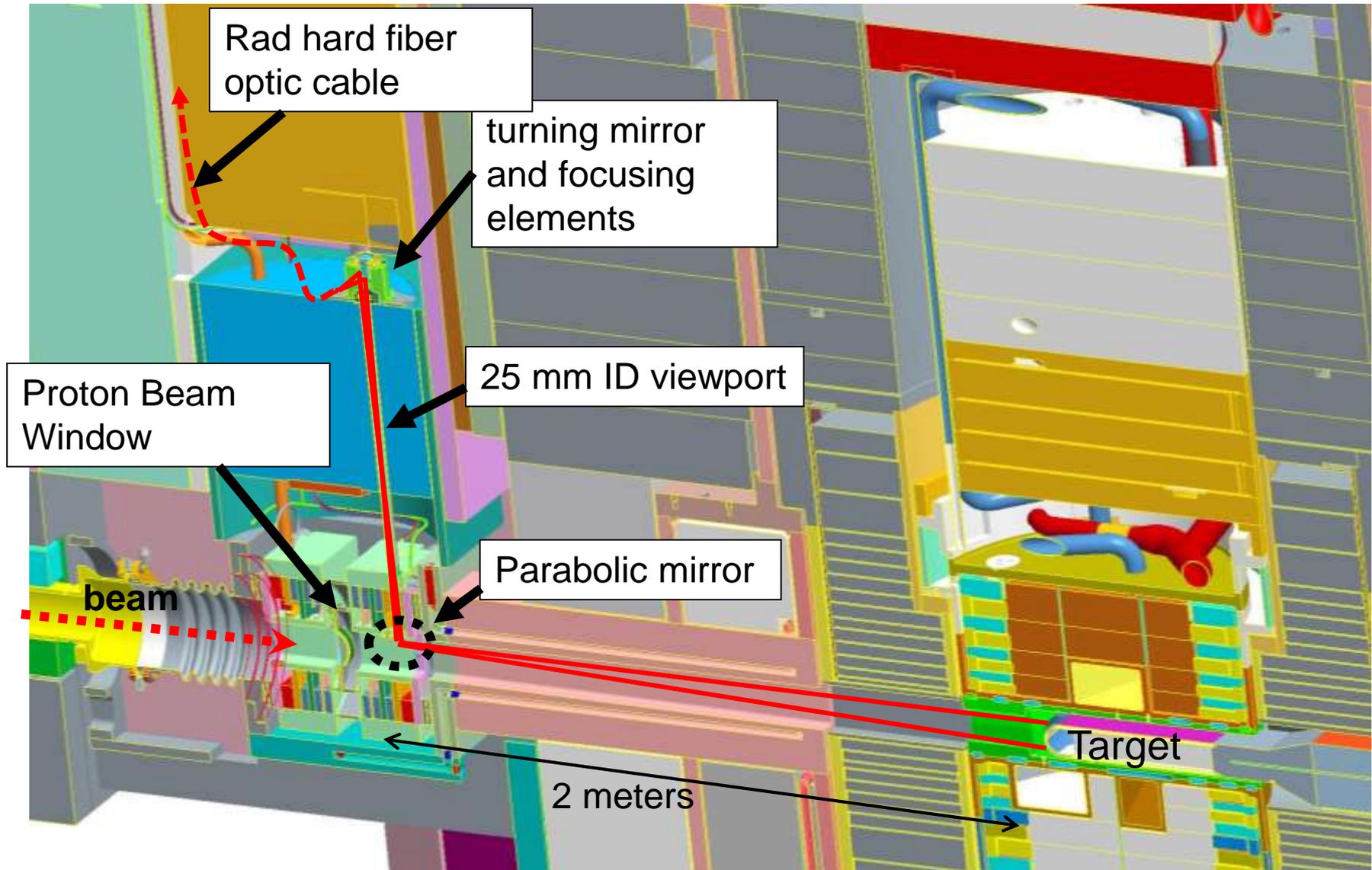
Cryogenic Moderator Systems

- **Repair to the bottom downstream moderator has allowed normal operation to date with no problems**
- **Helium Refrigerator has shown a loss of capacity with time**
 - **Loss believe to be due to contamination buildup in adsorber with inadequate removal of contamination between run cycles**
 - **Extended warmup and gas purge is being conducted this shutdown**
 - **Spare heat exchanger is being installed in a spare vertical cold box to be available if needed**
- **Pressure control mode developed for hydrogen system and used on loop 3**
 - **Avoids dependence on thermocouples which have had problems**
- **Development of a moderator development laboratory at ORNL is being studied**

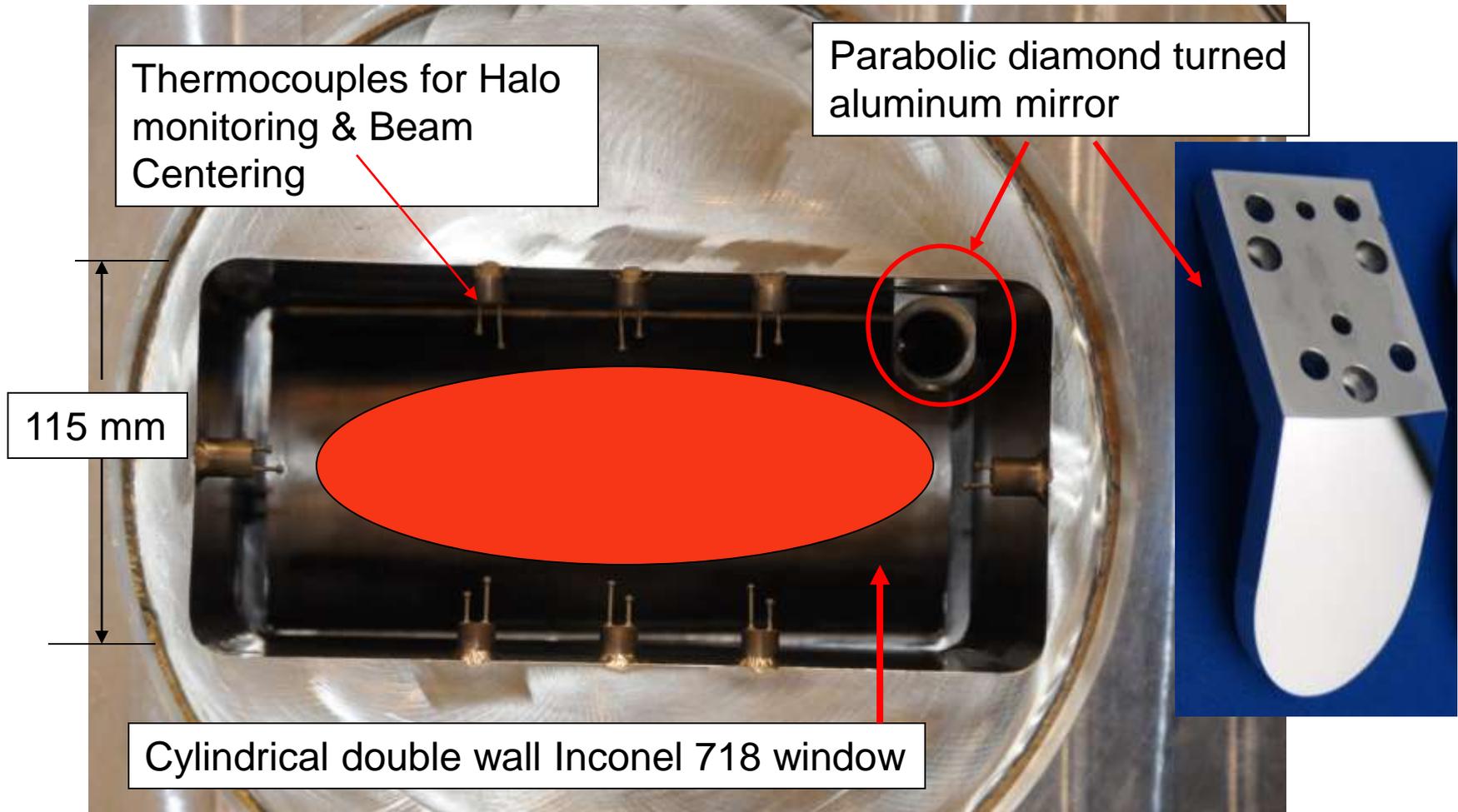
Proton Beam Window (PBW)

- The first proton beam window reached 6.5 dpa and was replaced during the July shutdown
- The second proton beam window included the optical components used in the target imaging system to view a phosphor coating and beam image on the target
- Proton Beam Window Procurement Status
 - Delivery of the 3rd PBW is expected by March, 2010
 - The option for procurement of the 4th PBW modules has been exercised

Target Imaging System Optical Path



PBW view from downstream side



Imaging Fiber routing

Radiation Hard Fiber 38 ft overall length

10,000 fibers, ~1 mm diameter

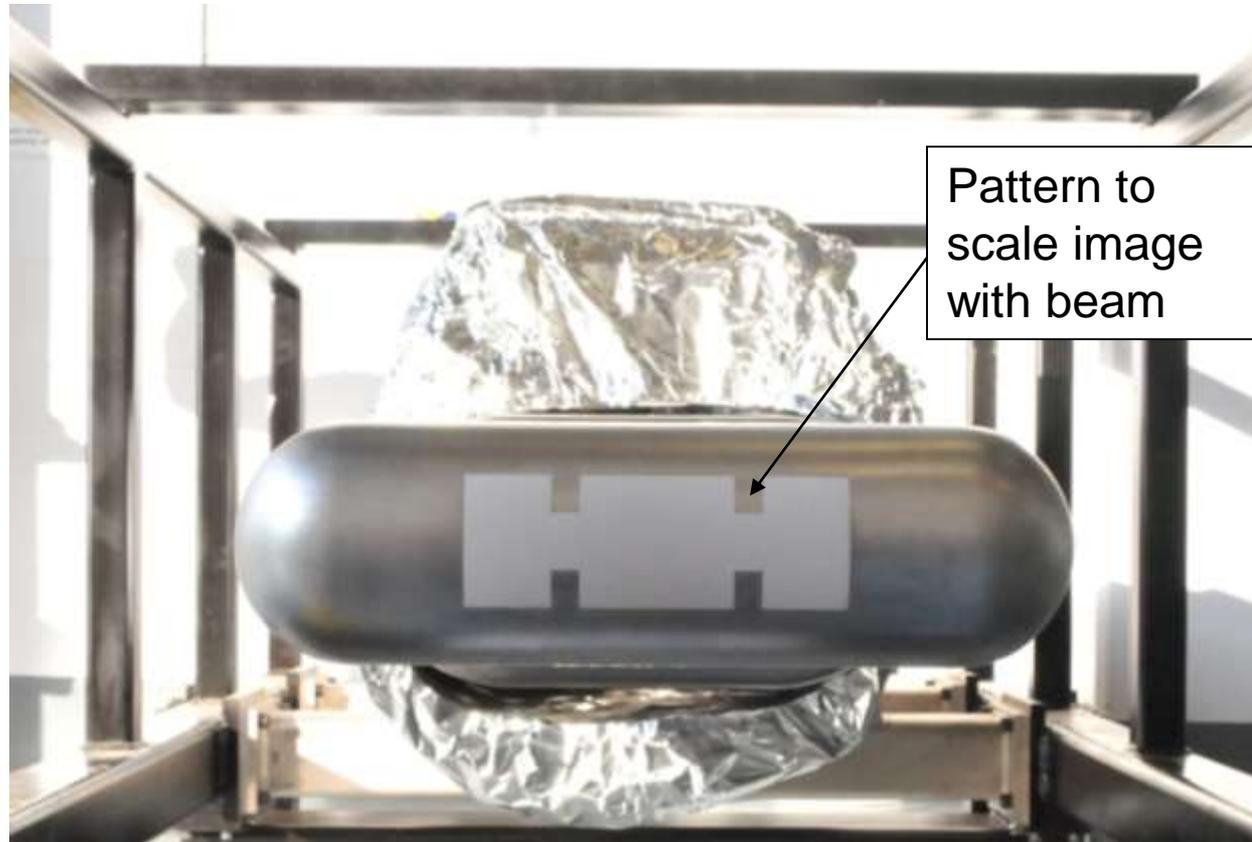
Camera located outside of shutter drive equipment room

Standard camera with GigE interface used



Camera mounted outside shielding

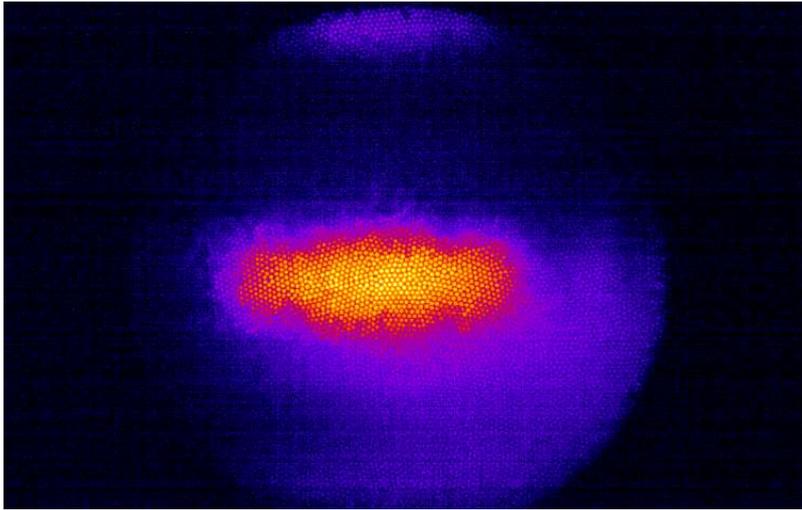
Completed Target Coating



Nominal Thickness 0.25 mm, 200mm x 70 mm pattern

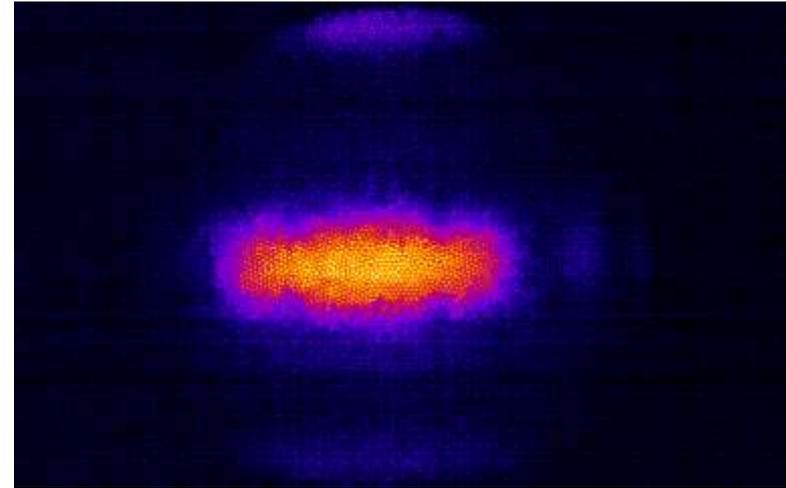
Mockup testing established parameters and showed substrate temperatures were < 120 C with air cooling

Images after initial operation

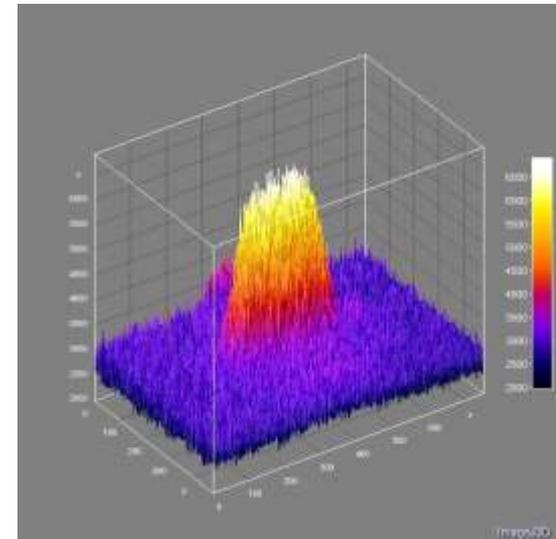


Case 1: image with potential gas scintillation

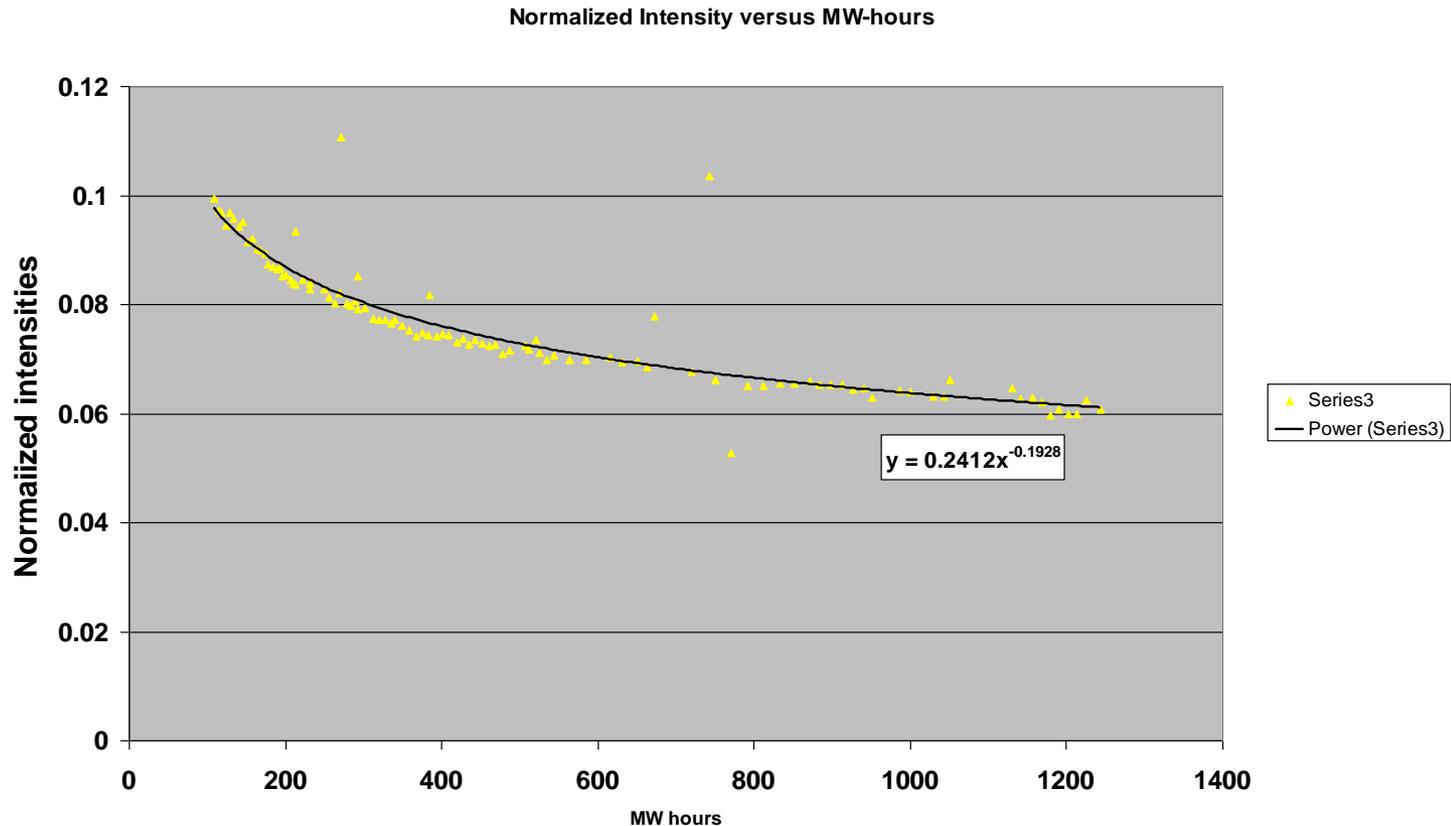
- No beam tilt observed
- Initial comparison of TIS with RTBT Wizard gave peak densities $\sim 10\%$ higher from TIS
- On line TIS fits show lower peak density than projections from harp
- Detailed comparison study of the two methods is needed for single pulse and at power and is planned for the next startup



Case 2: image with shutter delayed by 4 microseconds to gate out suspected gas



Intensity normalized to start on 9/7/09

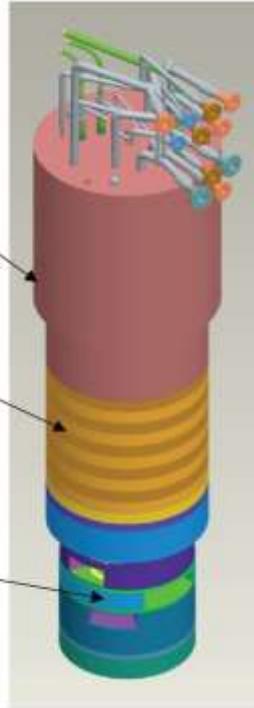


- An initial 90% drop in intensity over the first 100 MW-hours was observed, but it now appears to show a very slow reduction
- Current intensity is acceptable for developing beam profiles and projections to 5000 MW-hrs (10 dpa) also appear acceptable
- Loss is believed due mainly to neutron damage producing “F centers” (Oxygen atom dislocations) which saturate at $\sim .1$ dpa (100 MW-hrs)

Spare IRP Procurement

Spare IRP Assembly

- **Upper IRP**
 - Passively cooled shielding
- **Intermediate IRP**
 - Actively cooled shielding
- **Lower IRP**
 - Actively cooled shielding
 - Integrated moderators
 - Be reflector
 - Moderator beam tubes
 - Target opening



- Spare IRP contract has been awarded to Metalex Manufacturing
- Contract is design / build – Thermal analysis and final design for manufacturability is included in the vendor's scope
- Scheduled delivery is July, 2010
- 1st IRP at ~ 4200 MW-hrs of 30,000 MW-hr life

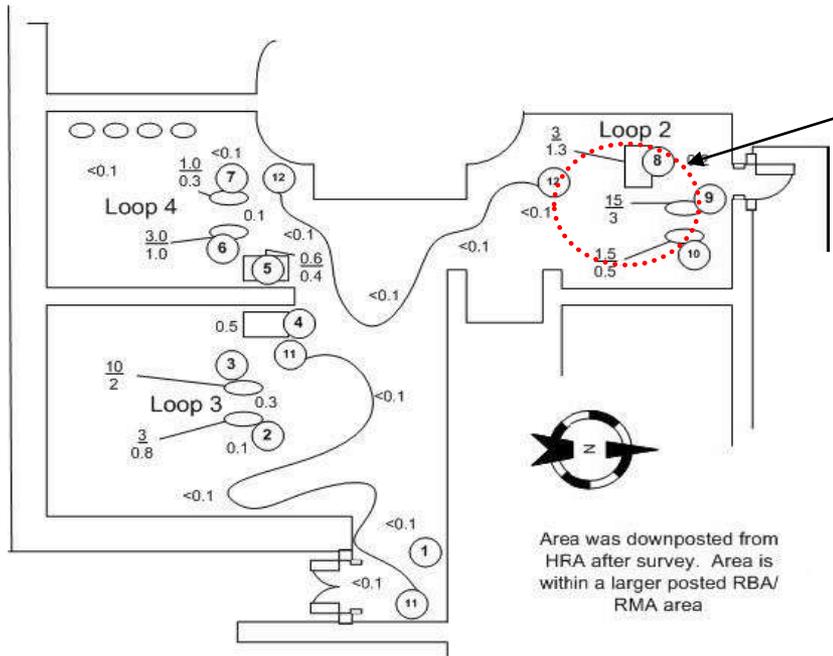
SNS Target Utilities – 2009 Operating Experience & Status

- **Minimal beam down time attributed to Target Utilities.**
- **Drying of Loop 2 prior to Proton Beam Window replacement went well**
- **Background radiological dose levels in piping around the proton beam window were minimal allowing “hands-on” access**

Water Loop Experience- Vaults

- **Utility vault dose rates**

- Beam on: at 800 kW beam, dose in PR4 ~800 mrem/hr (vs 100 R/hr predicted)
- Beam off data (10/27/2009):
 - The maximum dose rate is at the Loop 2 pump (15 mrem/hr on contact and 3 mem/hr at 30 cm)
 - All disc smears <1000 dpm/100 sq cm BG)



15 mrem/hour highest dose on loop 2 primary pump

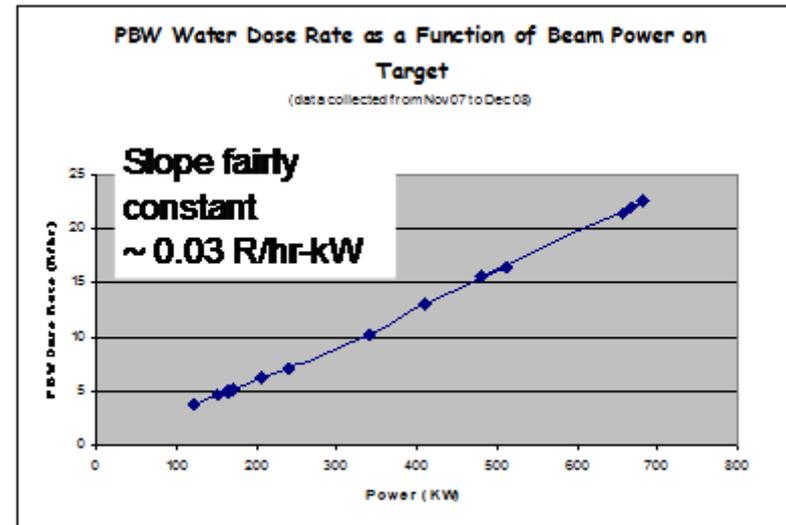
| Symbol | Smear Location | Boundary Designations | |
|--------|------------------------|------------------------------------|-----------------------------------|
| ⊙ | Large Area Smear | RBA - Radiological Buffer Area | |
| ⊕ | Contact Dose Rate | RA - Radiation Area | CA - Contamination Area |
| ⊖ | 30 cm Dose Rate | RA/N - Radiation Area/Neutron | HC - High Contamination Area |
| ⊗ | General Area Dose Rate | HR - High Radiation Area | AR - Airborne Radioactivity Area |
| ⊠ | Stop-off Pad | HR/N - High Radiation Area/Neutron | RM - Radioactive Material(s) Area |
| AS | Air Sample | VR - Very High Radiation Area | |

The default units for dose rates are expressed in dose equivalent as mrem/h. Any units other than mrem/h (e.g., rem/h, μrem/h) shall be noted on the map. Dose rates designated on the survey indicate a summation of all the types of radiation detected, unless the indicated dose rate has a type identifier with it (e.g., βG), with the type identifiers of β - beta, G - Gamma, N - Neutron. Boundary designations are looking from the designations into the shaded area.

BNS-200410 on 10/27/09

Radiation level measured on PBW return line water, Utility vault and tank cavities

- ~ 2 second water transit time from irradiation in PBW to top of shielding
- Measured dose rate are ~ 0.03 R/hr-kW
- Recent measurement at 1 MW was ~ 30 R/hr
- Utility Vault (ceiling pipe chase): 2.5 R/hr (.8 MW)
- Delay Tank Cavity: 22 R/hr (.8 MW)
- Separator Tank Cavity: 7.9 R/hr (.8 MW)



Remote Handling

- **First target replacement successfully completed**
- **First proton beam window replacement successfully completed.**
- **The Core Vessel Mockup in fabrication. Installation in the Target Building mockup test stand is scheduled for FY-10.**
- **The tooling for replacing the Inner Reflector Plug will be procured in parallel with the Spare IRP. The design is nearing completion and the tooling will be procured in FY-10.**
- **Fabrication and testing of the multi-channel Core Vessel Insert tooling has been completed. The first change-out on BL-16 is scheduled for Jan 11.**

Proton Beam Window Replacement

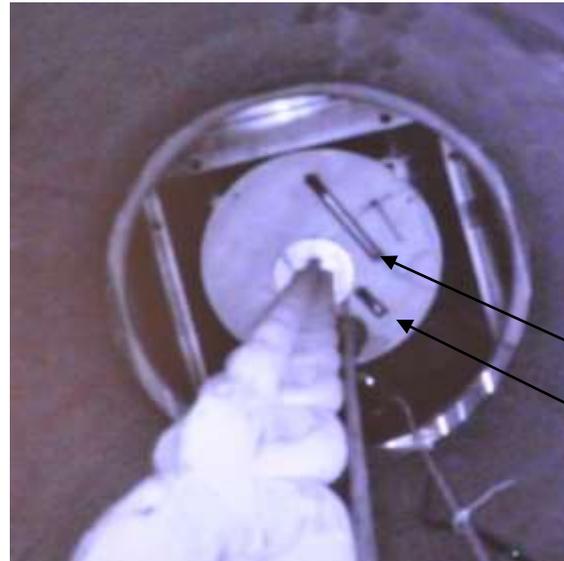


Shielded Cask and Hoist



New PBW with guide can and counterweight being installed

Old PBW during retraction into cask →



Cooling lines cut prior to removal with long handle tools

Rotating Solid Target Concept Development

- **Conceptual design development has started for a 1.5 MW rotating solid target for the second target station (STS)**
- **Neutronic evaluations for a 1.2 m rotating tungsten target with tantalum clad with two large para-hydrogen coupled moderators above and below the target show equal or slightly better performance compared to a mercury target**
- **Mockup testing of a suitable drive module with a 1.2 m diameter inertial target has started**
- **Collaboration with the ESSBi team who are developing a 5 MW rotating target concept is continuing and they are planning to produce a target module based on the STS design for flow testing at Bilbao and later at SNS**
- **A decision between use of a rotating target or a mercury target is expected this fall.**

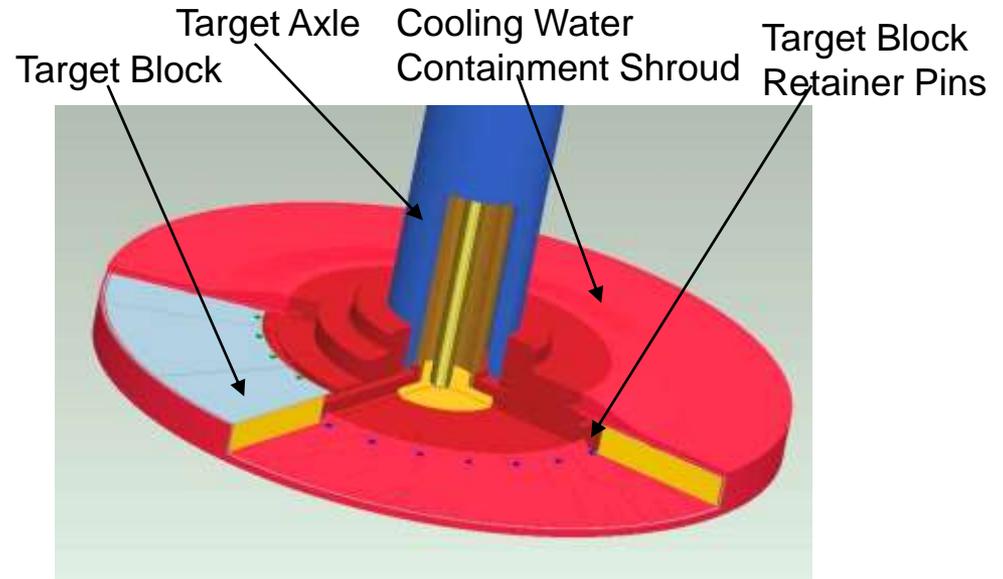
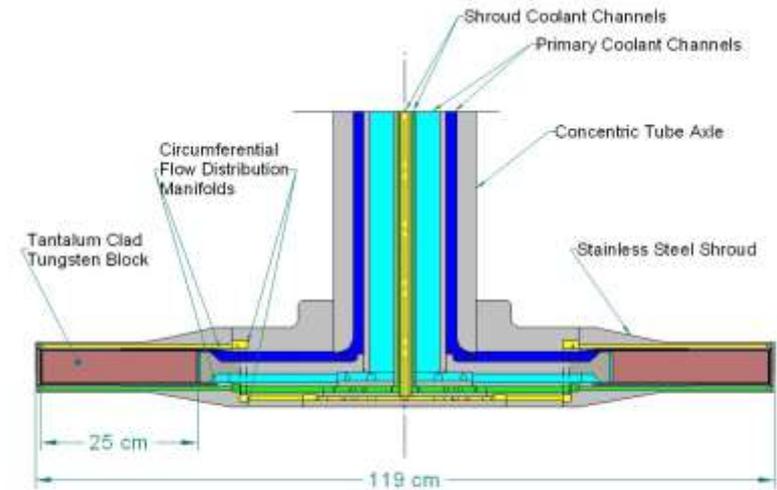
Rotating Target Mockup testing

- **Mockup testing**
 - The drive module was tested for over 1000 hours at 30 rpm with no water seal leakage in FY09
 - The ESS-Bilbao team delivered a 4 m shaft and 1.2 m diameter target and it was assembled with the drive unit Oct – Dec 09
 - Mechanical testing of the assembly has started and it is showing very good alignment with low run-out at the target outside radius (nominal $\sim .2$ mm and maximum $\sim .5$ mm @ 34 Hz)



Design Development

- **Conceptual 1.5 MW design development**
 - Neutronic studies
 - Target structural and thermo-hydraulic design
 - Safety Evaluations
 - Evaluation of loss of cooling
 - Monolith layout integration studies for a rotating target
 - Target & moderator handling and hot cell layout
 - Neutron beam line layout

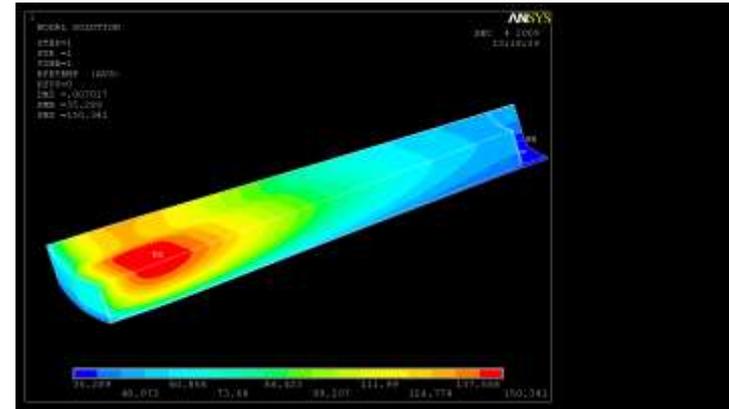


Neutronic Studies

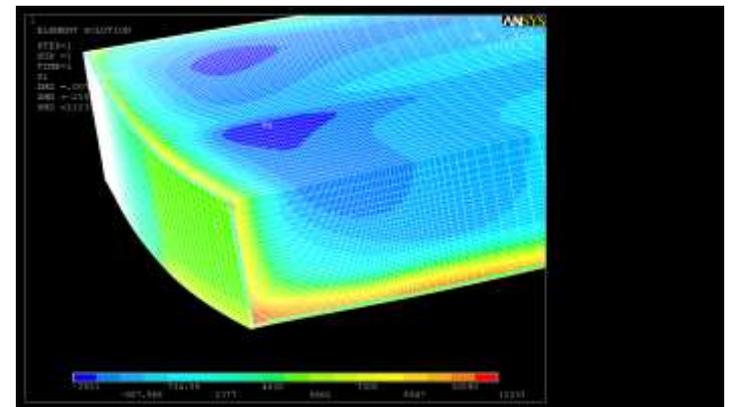
- **Large Para-hydrogen moderator performance is equal or slightly better for the rotating solid target compared to mercury**
- **Target lifetime is approximately 10 years for 10 dpa on the structural shell at 1.5 MW**
- **Decay heat with 1 mm tantalum clad is approximately 18 kW at beam shutdown and long term decay is dominated by the tantalum**
- **Pre-moderator and moderator damage rates and heating are higher for the rotating target (max 20 dpa in 2 years)**
 - Damage strongly peaked on pre-moderator closest to target
 - Sensitivity studies indicate that a broader beam and more separation between the target and moderator can reduce the moderator damage rate with little performance loss

Target Analysis in Progress

- Structural and thermal hydraulic analysis and optimization is in progress
- Wedges are cooled on top, bottom and front surfaces
- CFD flow modeling and analysis is starting
- Sensitivity to reduced tungsten thermal conductivity is being evaluated
- Temperatures and stress levels appear modest



Peak Temperature 155 C



Peak 1st Principal Stress 122 MPa

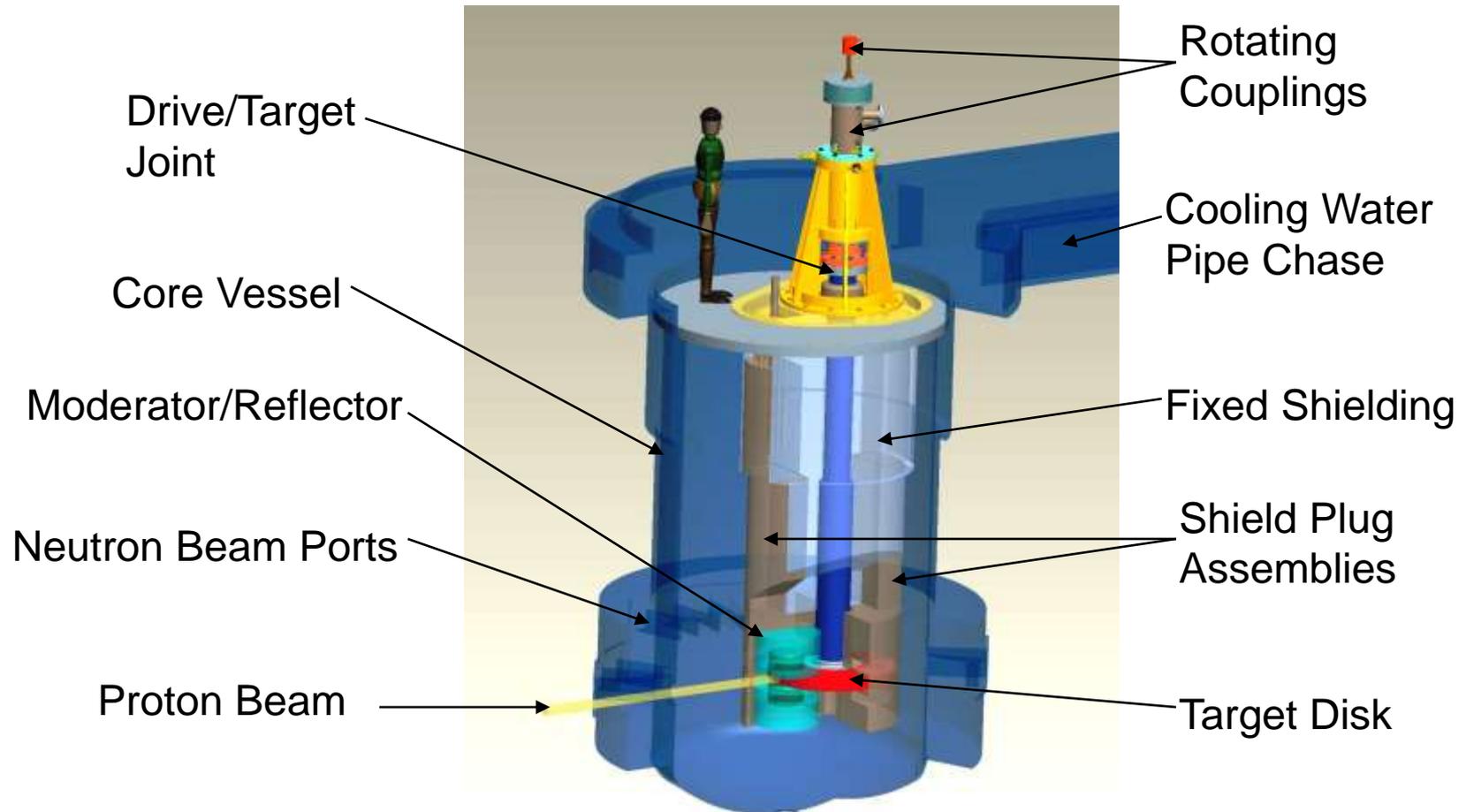
Safety Considerations for Tungsten Targets

- Chemical reactions of tungsten with steam above ~ 800 C form hydrated tungsten-oxide which has a high vapor pressure and is readily convected in flowing atmosphere
- Initial SNS evaluations in ~ 2002 of a 1 MW target assumed the target could be vaporized because there was no seismically qualified water supply and the resulting site boundary dose was not acceptable
- Sources for high temperature
 - Continued beam operation with loss of cooling
 - Decay heat
- Mitigation Schemes
 - Active or passive beam trip for loss of cooling
 - Limit peak temperature to below vaporization threshold
 - Current STS rotating target approach
 - Allow target to vaporize but show that the resulting powder can not be transported by a low pressure release
 - Current Los Alamos Spallation target approach
 - Show that water is not available to drive the reaction after a loss of cooling
 - STS designing to limit water source but is not planning to “credit” these features

Preliminary SNS Safety Approach

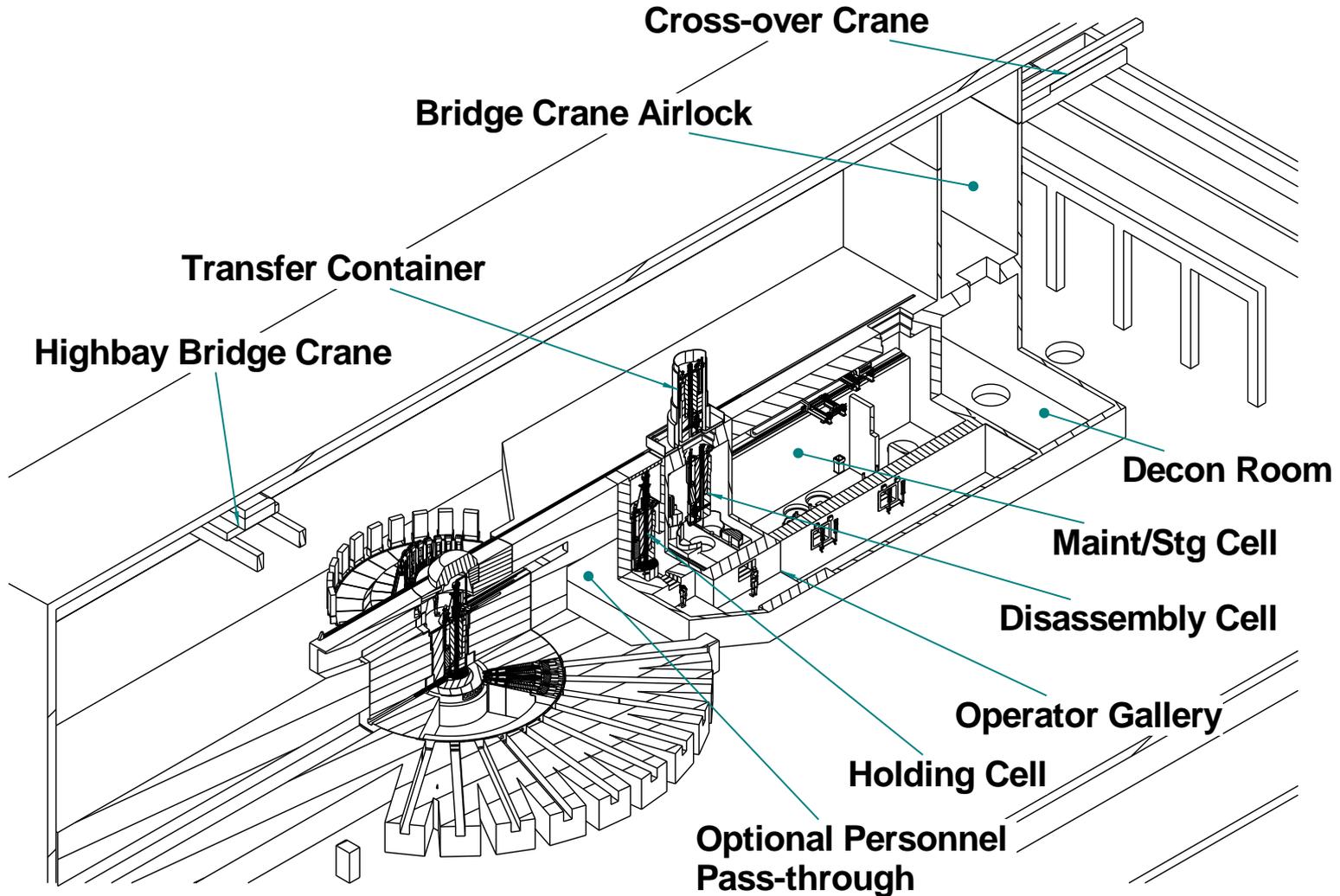
- **Estimate allowable fraction of the total inventory to be released which results in a 1 rem dose at the site boundary – (0.15% for 5 year, 1.5 MW operation)**
- **Estimate the peak temperature allowable based on vaporization rate tests done at BNL – (790 C)**
- **Develop the thermal design for loss of cooling**
 - **Passive systems desired**
 - Preliminary optimistic conduction/thermal radiation case evaluated
 - More realistic design with enhanced natural convection started
 - **Multiple redundant cooling sources (shroud, reflector plug, secondary pumps on primary system)**
 - Possible but not the desired solution because of the difficulty in proving the required reliability for all accident cases

III. Target Assembly Description



Drive designed to be removed “hands-on” independently of the target module

Rotating Target Monolith and Maintenance Cells Concepts under development



Summary

- **Target systems have achieved good availability but are vulnerable to failures that can cause long down times**
 - Potential problem areas and improvements are being studied
- **The bottom downstream moderator was successfully repaired**
- **All target systems appear capable of operation at 1.4 MW with the current configuration**
 - Some further target module analysis/development is needed to go above 1.2 MW
- **The Target Imaging System has been a success and is being turned over to Operations**
- **Rotating solid target concept development is promising and it appears to be a good option for STS although further evaluations including safety and fabrication are needed.**