SNS Hot Cell Design Philosophy

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OAK RIDGE National Laboratory | SPALLATION NEUTRON SOURCE

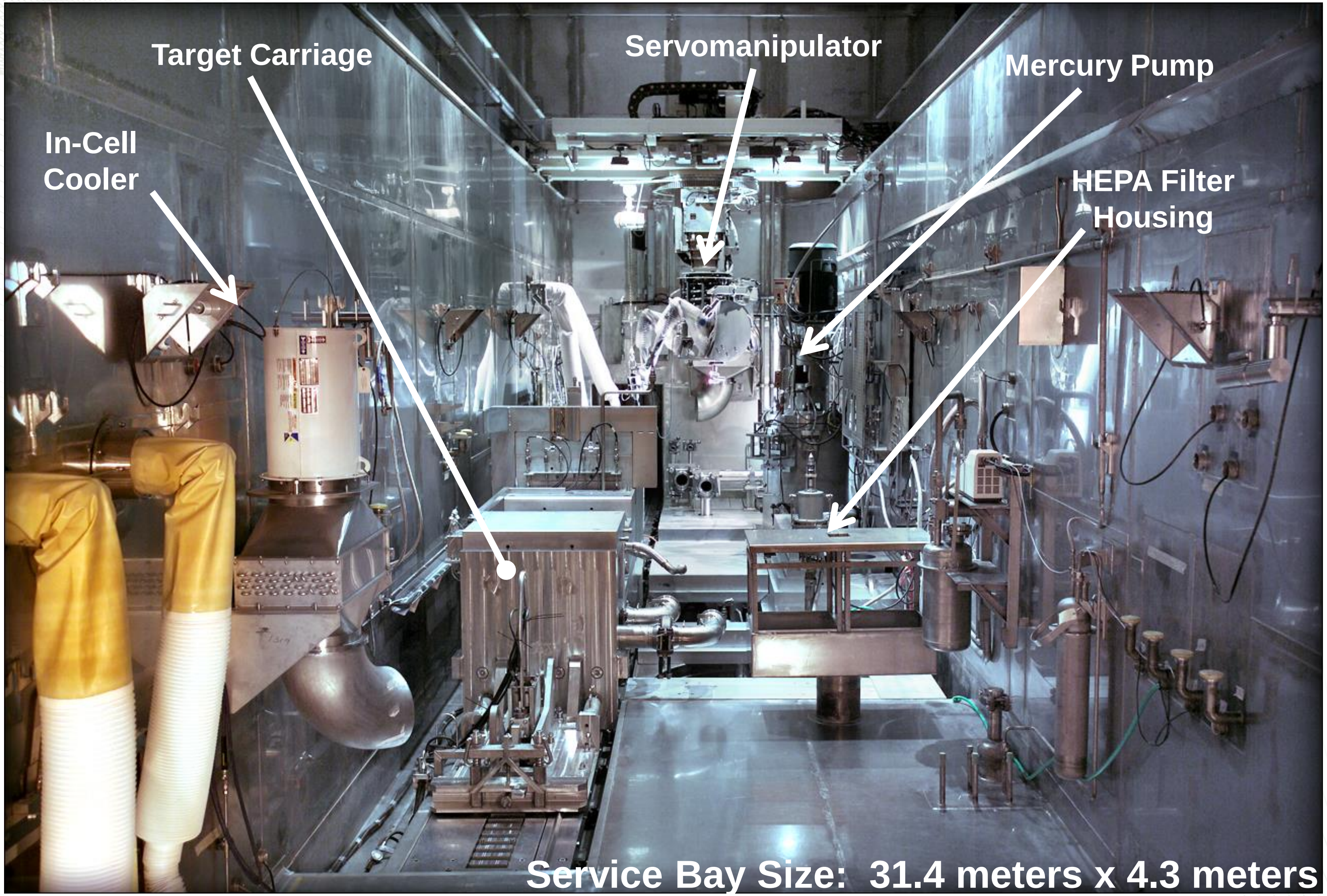
Introduction

- ORNL's Spallation Neutron Source utilizes liquid mercury as its spallation target material
- The requisite infrastructure to support the operations and maintenance of the mercury process system must be reliable and robust to support neutron production, yet versatile and flexible to react to contingencies and adapt to changing operational requirements
- Due to the unique hazards associated with activated liquid mercury, the entire process system is housed within a heavily-shielded hot cell
- The following details the philosophy of the SNS hot cell design which is predicated on fully remote operations with no hands-on human involvement

Outline

- Basic Hot Cell Details
- Bridge Systems
- Window Workstations
- Servomanipulator
- Credited Safety Functions
- Radiological Conditions
- Nominal Cell Operations
- Evolution of Operational Philosophy
- Lessons Learned

Basic Hot Cell Details



Cameras:

IST/Mirion R981 Series
- Wall-mounted (5)
- Bridge-mounted (4)
- Servo-mounted (3)

Lighting:

400W High Pressure Sodium

Penetrations:

~188 individual penetrations

Wall Hangers:

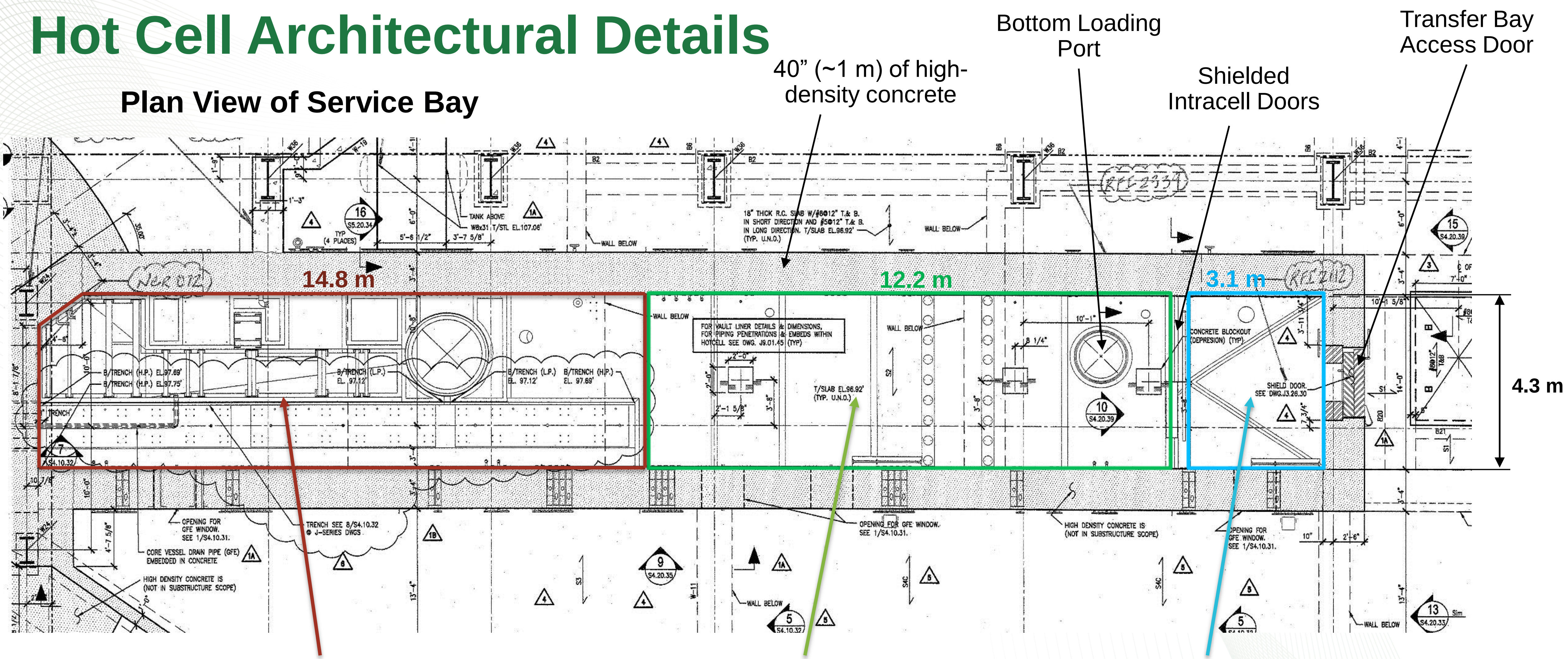
~106 individual hangers

Confinement Exhaust:

~1900 cfm (54 m^3/min)

Hot Cell Architectural Details

Plan View of Service Bay



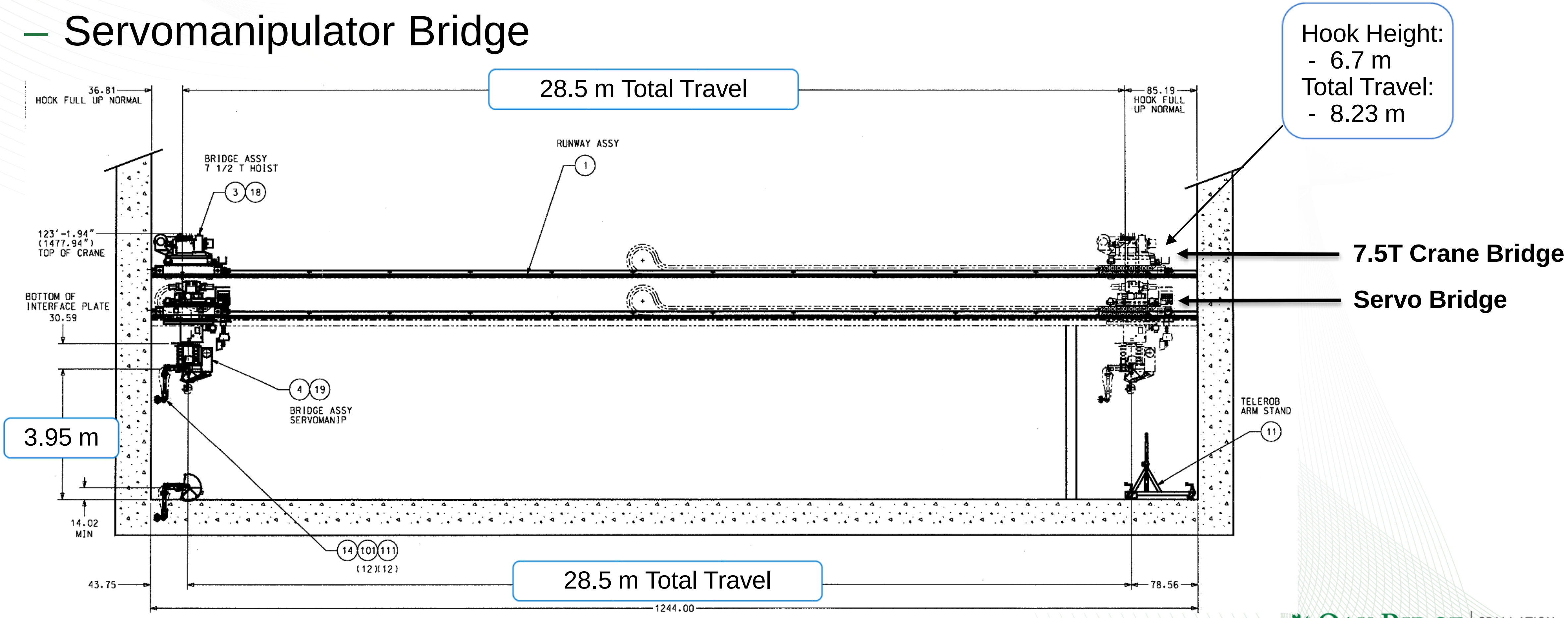
Process Bay
- Mercury Process Equipment (pump, HX, drain tank, etc.)
- Target Carriage
- Target replacement activities

Maintenance Bay
- PIE activities
- Shielding storage during target replacement
- Spent target storage
- Waste disposal activities

Transfer Bay
- Personnel access
- Equipment maintenance
- Access point for large items

Bridge Systems

- The hot cell is served by two independent bridge systems
  - A 7.5T Overhead Bridge Crane
  - Servomanipulator Bridge



Four Window Workstations

(1 Process Bay, 2 Maintenance Bay, 1 Transfer Bay)

Each Workstation Contains:

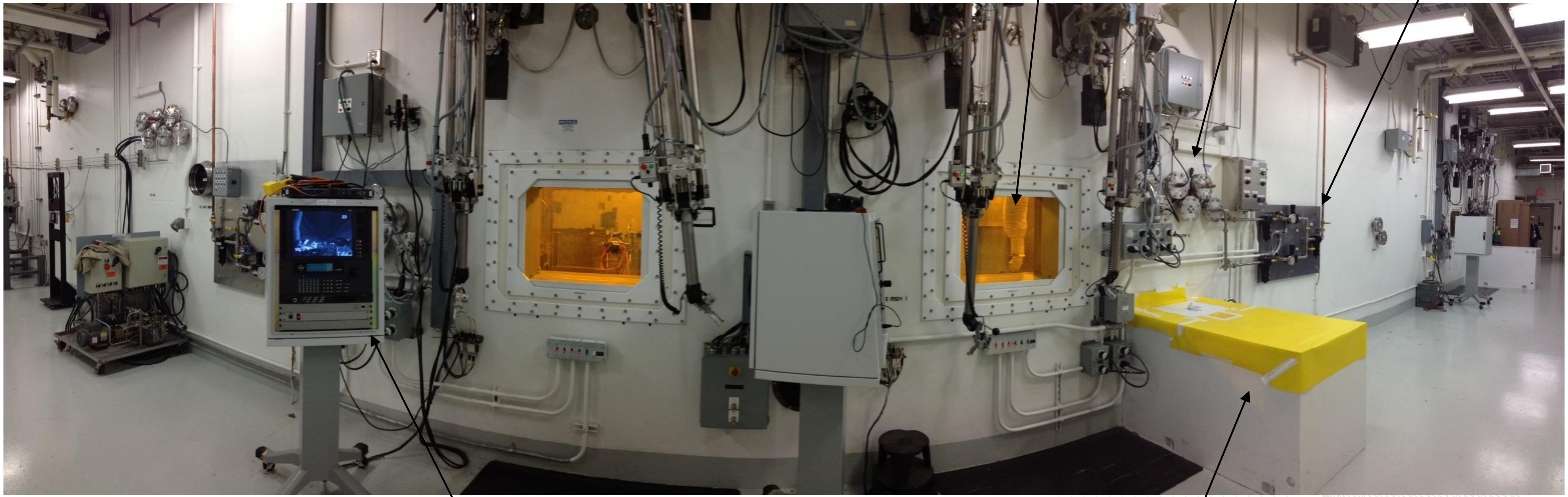
- Two CRL Model F Master-Slave Manipulators
- One video monitor
- In-cell utility connections
  - Two regulated air supplies (pneumatic tools, etc.)
  - Two electrical supplies (120VAC)

Shielded Windows

- British Shielded Windows
- 6 layers
  - 5 shielded layers (lead; 2.5 – 5.2 g/cc)
  - 1 anti-glare layer

Penetrations

Pneumatic Supply Controls

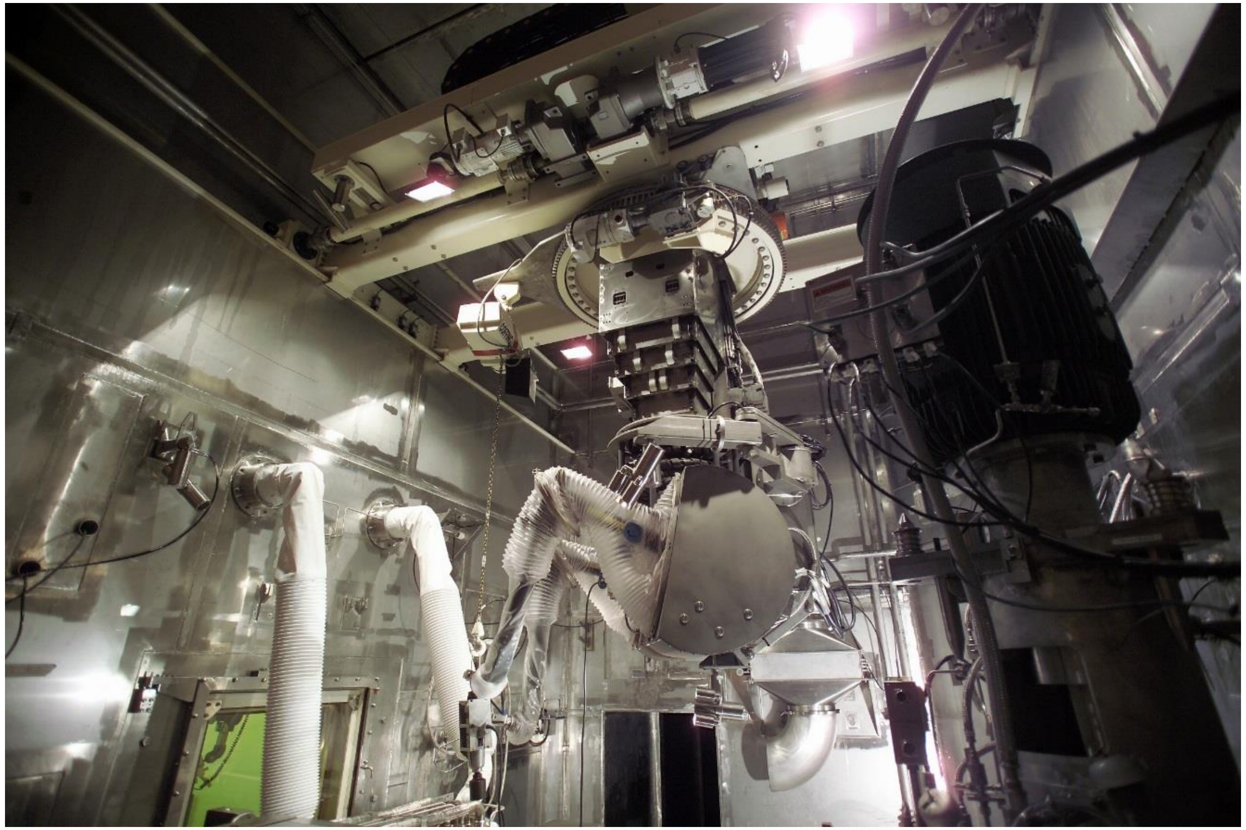


Video Monitor

Shielded Transfer Enclosure for placing small items into cell

Servomanipulator

- The servo is critical for everything from routine maintenance to critical component replacements
  - Target replacement
  - Cell Maintenance:
    - Camera maintenance/replacement
    - Light maintenance/replacement
    - HEPA filter replacement
  - Waste disposal support
  - PIE
- Continued SNS operation relies on a functional servomanipulator



Telerob EMSM-2B Servomanipulator

- Dual-arm, high performance servo-manipulator (SM) provides full cell coverage
- Mounted on a 4-degree-of-freedom bridge and mast system
- Master arm position control with force feedback
- 25 kg continuous/45 kg peak capacity per arm
- Three servo-mounted cameras
- 500 lbs (225 kg) auxiliary hoist

Credited Safety Functions

- The hot cell plays an integral role in the primary safety function of preventing the release of mercury vapor
- Of the 16 Credited Engineering Controls identified in the SNS Safety Assessment Document, 7 involve the hot cell design or features within the cell:
  - Service Bay Fire Barrier
  - Fire Suppression System inside the Service Bay
  - Service Bay Confinement of Mercury
  - Mercury Heat Exchanger
  - Service Bay Differential Pressure Monitoring System
  - Mercury Pump Tank Exhaust Line Loop Seal
  - Transfer Bay Access Control System

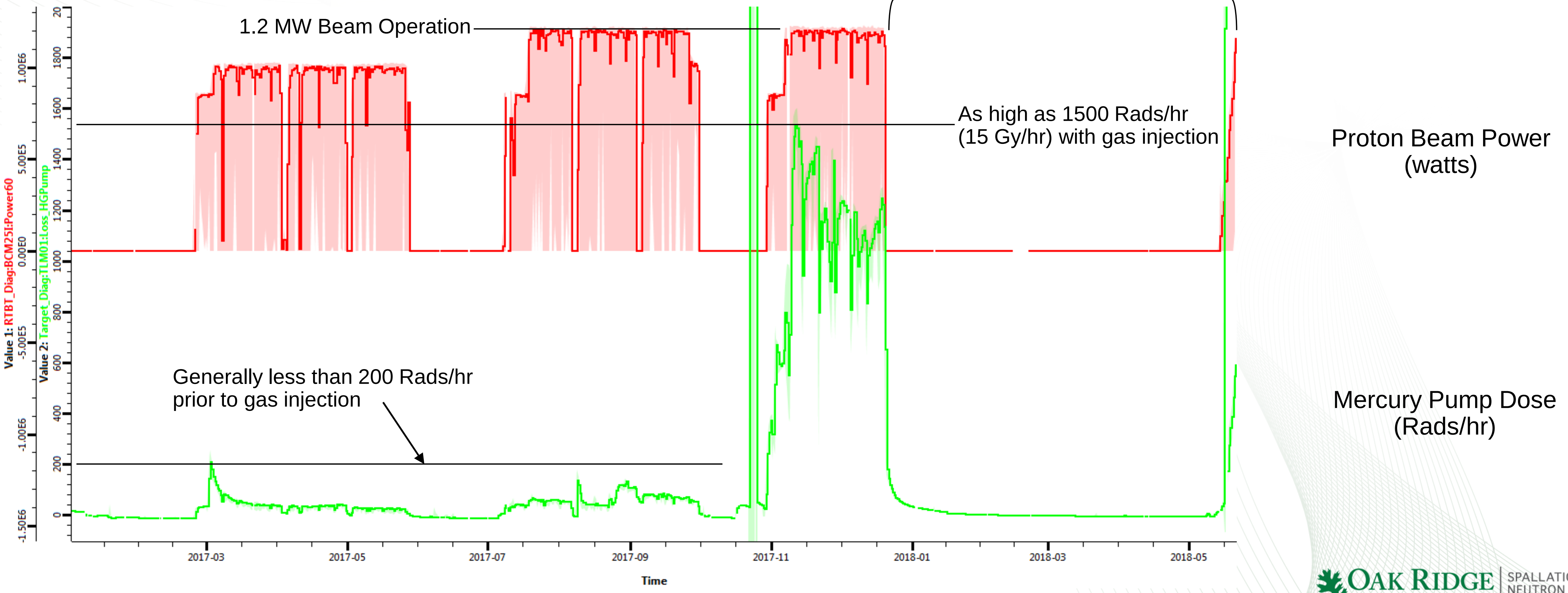
Radiological Conditions

- The SNS cell has three primary hazards:
  - Radiation dose
    - General area dose is typically less than 1 Gy/hr
    - Dose rates during target replacements exceed 350 Gy/hr
  - Radioactive contamination
    - Spallation product isotopic contamination is extensive
    - No formal survey regimen is conducted, but surveys on the servo during maintenance have revealed individual smears >7.5 mSv/hr
  - Mercury vapor
    - Vapor levels in the cell average less than 10 micro g/m^3 but can exceed 125 micro g/m^3 during target replacement or PIE operations

Radiation Control Technician surveying servo grips during Transfer Bay entry

Radiological Conditions

- Helium gas injection has greatly increased the dose rates in the cell
  - An ion chamber on the mercury pump measures dose rates in the Process Bay portion of the cell:



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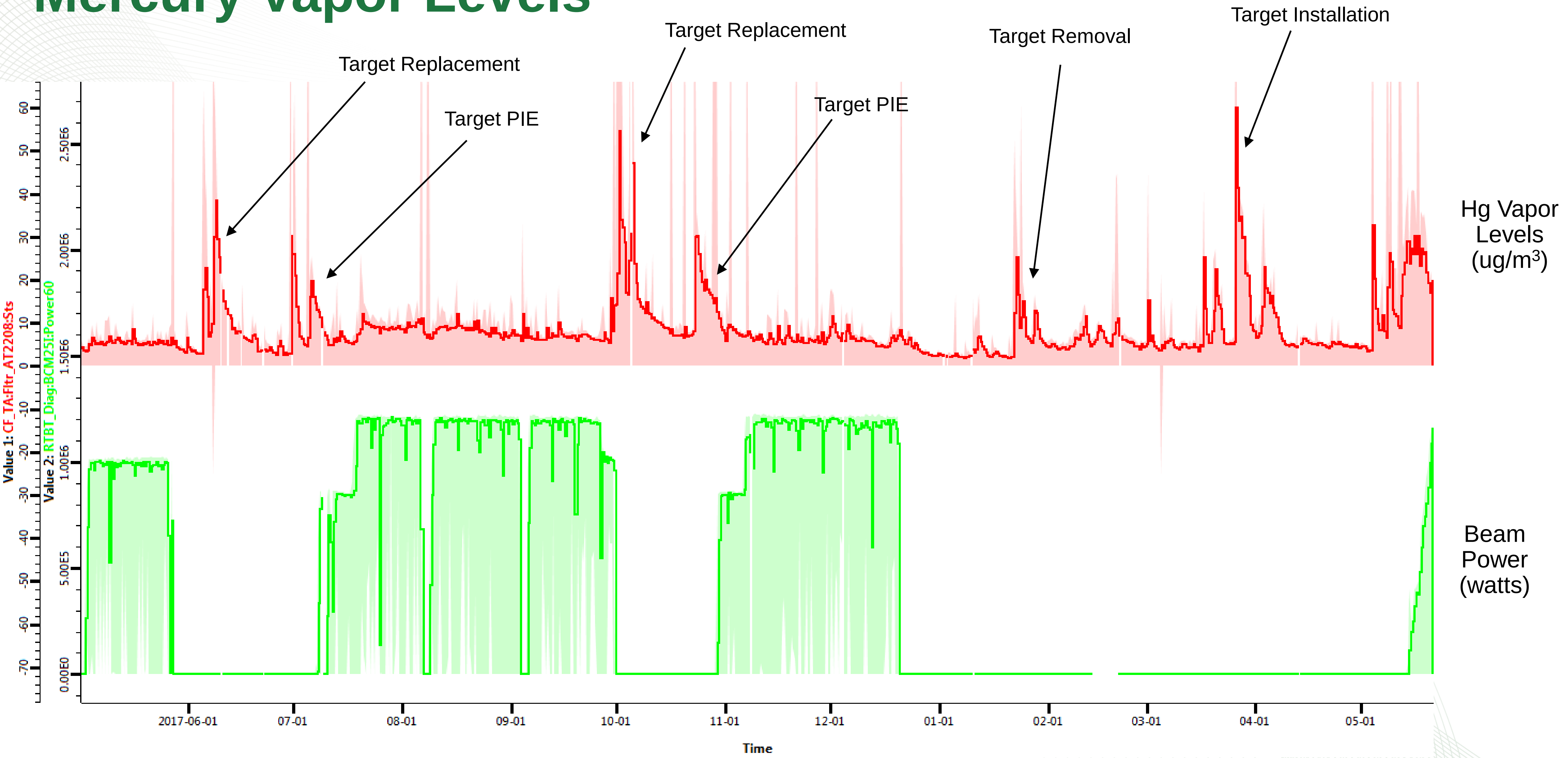
Mercury Vapor Levels

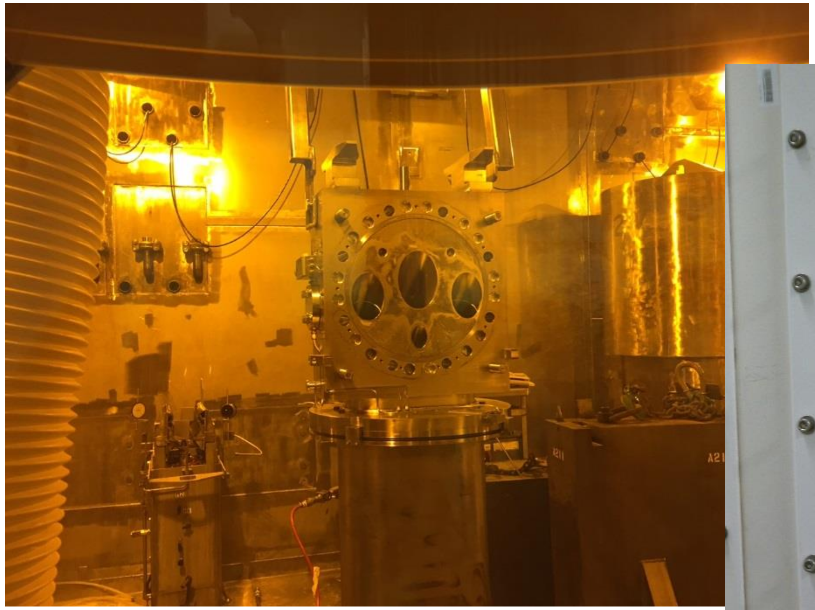


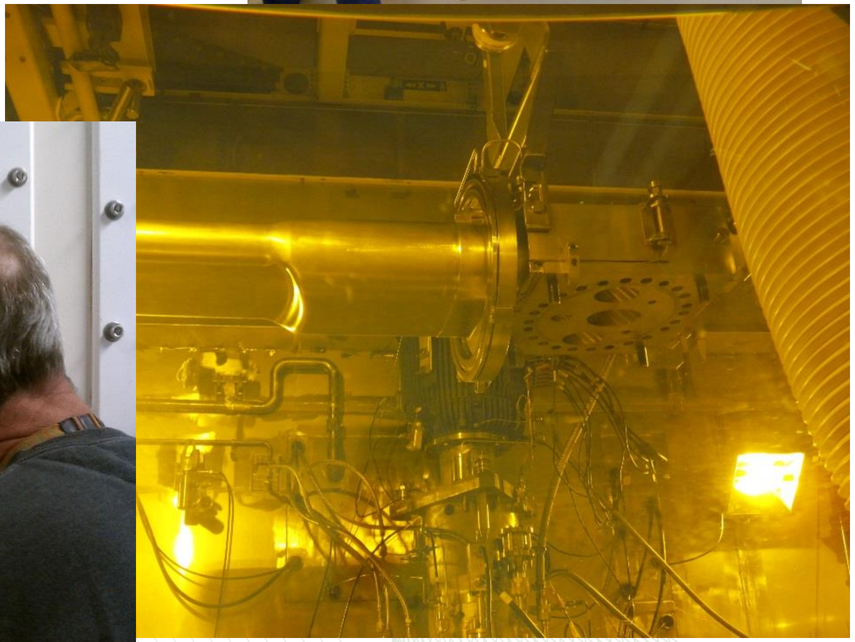
Nominal Hot Cell Operations

- Target Replacement
- PIE
- Waste Disposal
- Hot Cell Maintenance

Target Replacement

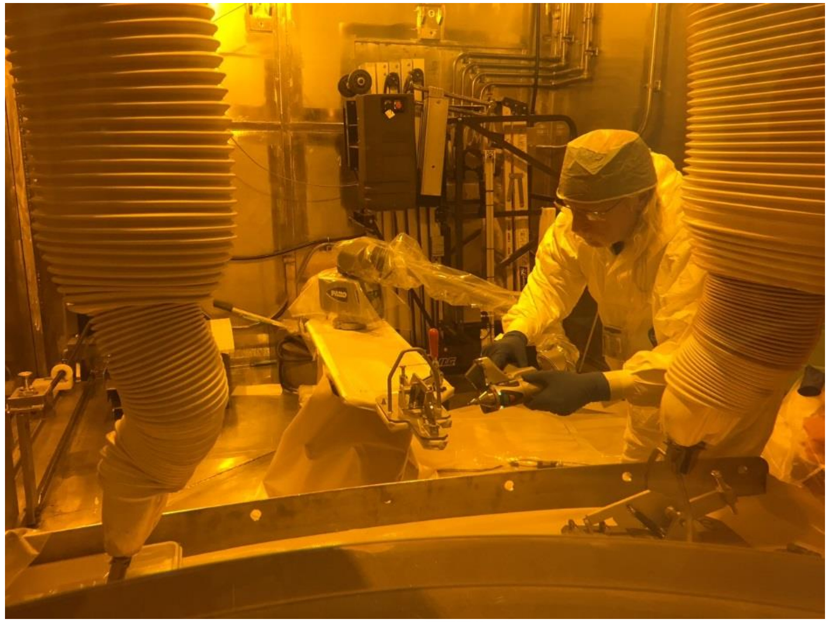
- SNS has completed 18 remote target replacements
  - Each replacement requires approximately 8-10 days of in-cell work
    - Process requires approximately 100 individual tasks
  - All elements of the replacement are fully remote

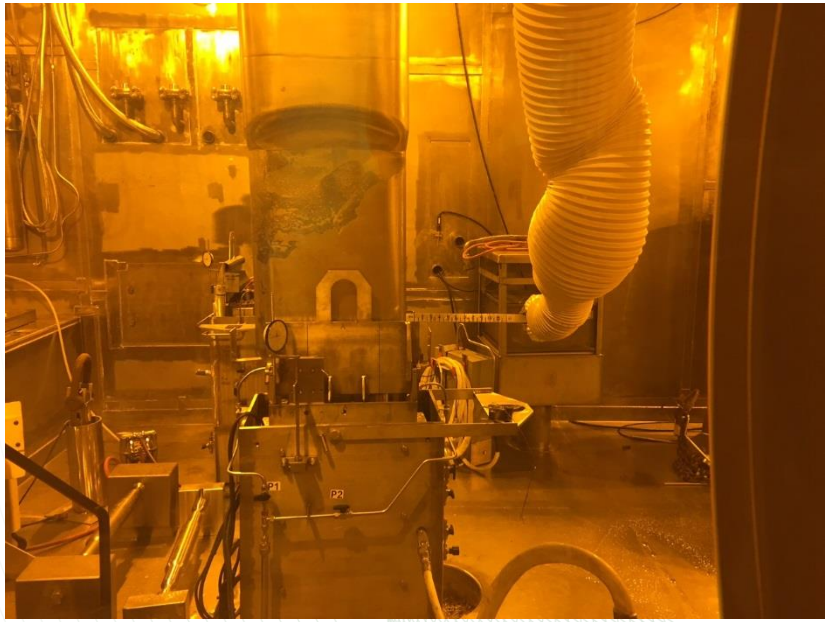




Post-Irradiation Examination

- A significant amount of PIE is performed on each target module:
  - Pressure decay testing (interstitial region and water-cooled shroud)
  - Video probe inspection of target internals
  - Nose sampling
  - External photography
  - Water Shroud removal and mercury vessel inspection
  - Laser scanning of nose samples





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Waste Disposal

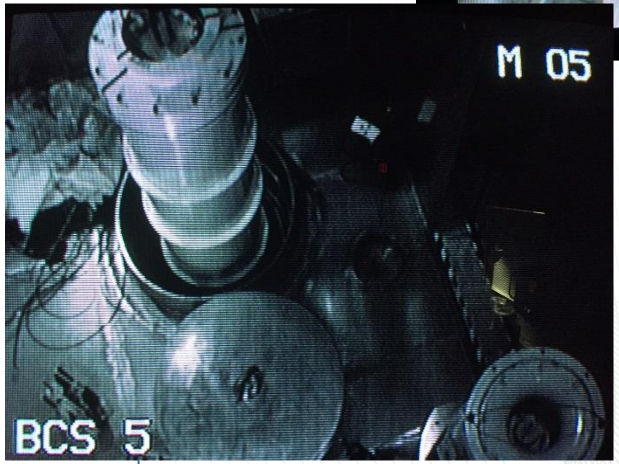
- Waste disposal shipments utilize much of the hot cell infrastructure
  - ① – Cask Liners are loaded into the cell via the Top Loading Port
  - ② – The liner is loaded remotely in the cell using the 7.5T crane/Servo
  - ③ – The Liner is loaded into the cask via the Bottom Loading Port

①

Loading a Liner into cell via Top Loading Port

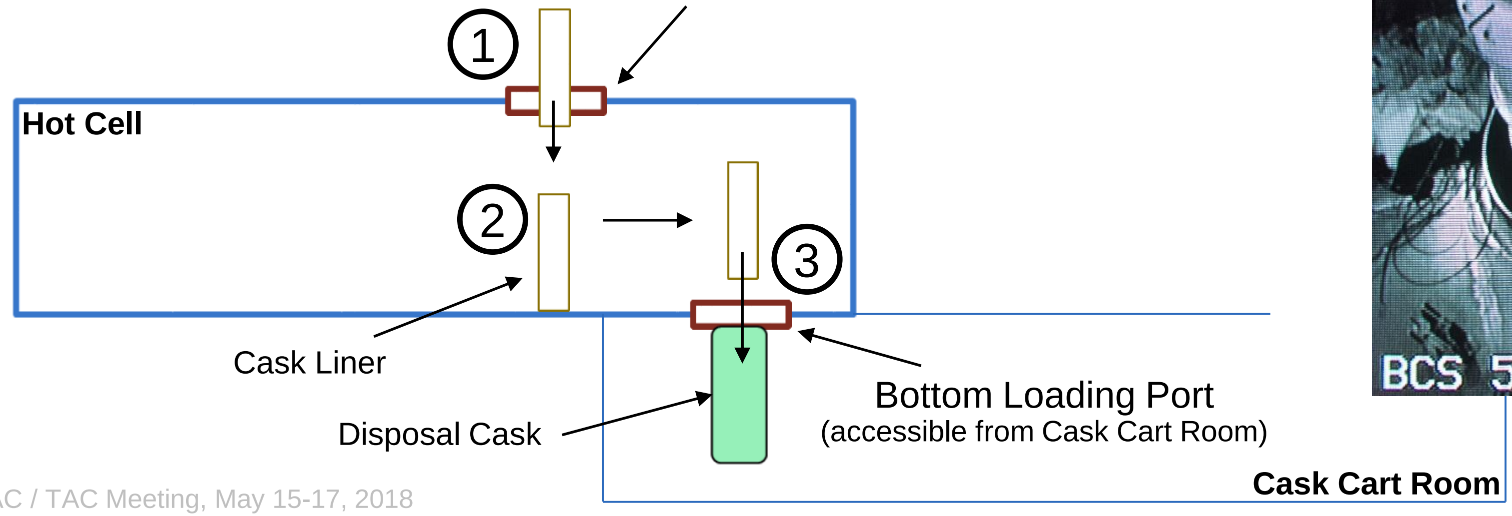
Loading a spent target module into a Liner using 7.5T crane

②



Lowering a loaded Liner down thru Bottom Loading Port and into TN-RAM cask

③



Hot Cell Maintenance

- The servomanipulator is required to support all in-cell maintenance and support
  - Planned infrastructure maintenance and operations:
    - Light replacement
    - Camera maintenance
    - Valve actuation
    - Electrical connections (Amphenol, etc.)
    - Moving items from Transfer Bay to Service Bay
    - Cleaning
  - Unplanned contingencies
    - Repairing failed components
    - Retrieving dropped objects
  - Increased scope of operations and testing as the facility evolves

Evolution of Operational Philosophy

- Initial planned SNS hot cell operations centered around target module replacements and maintenance of the mercury process equipment
- Operational experience has shown that time is spent:
  - Target replacements (3/year): ~6 weeks/year
  - Target PIE: ~6 weeks/year
  - Target waste disposal shipments (3/year): ~6 weeks/year
  - Infrastructure maintenance: ~3 weeks/year
  - Unplanned/out of scope work: ~4 weeks/year
- Initially, the goal was simply "get the job done successfully", but the learning curve was steep

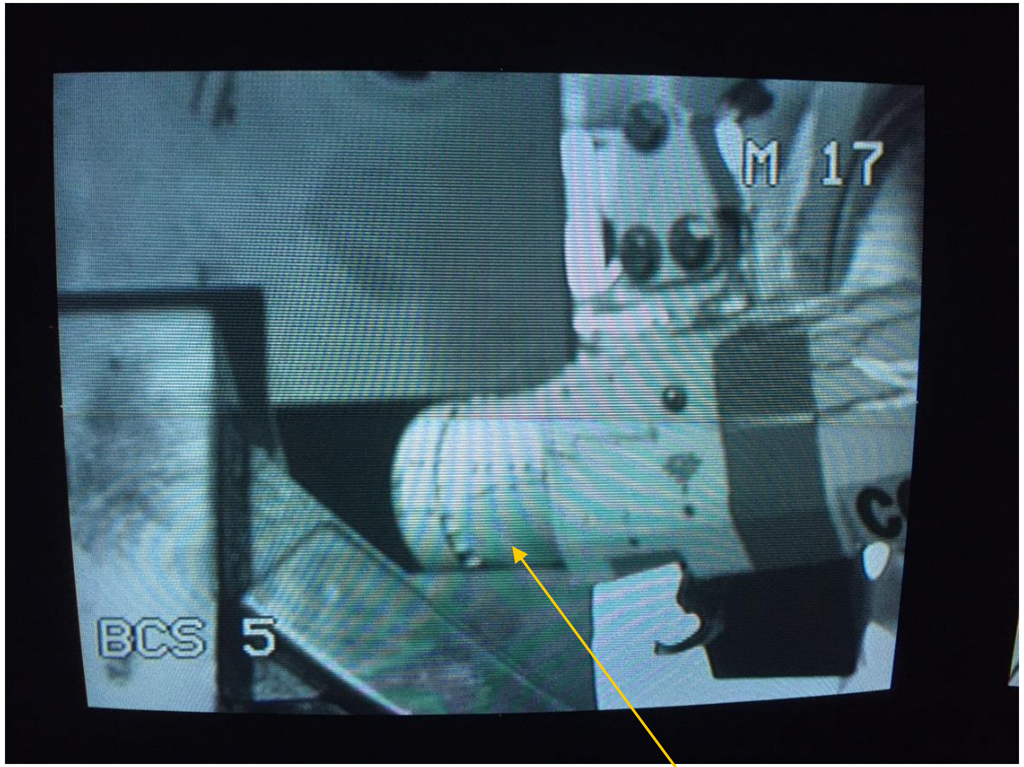
Evolution of Operational Philosophy

- It soon became apparent that success required:
  - Relentless planning
    - Definition of the scope of the operation (fully understand the task)
    - Clear, reviewed procedures and work instructions for all tasks
  - Continuous improvement
    - Each step of each process is studied for improvements that increase efficiency and reduce risk – lessons learned meetings capture process and tooling improvements
    - Tools and processes are continuously modified and improved
  - Personnel engagement
    - Every person involved in hot cell operations is empowered to make improvements, mitigate risk and is invested in the successful outcome
- When it comes to hot cell work, though, "never say never"
  - *Whatever can happen, will…*

Lessons Learned/Observations

During routine closing of our Lower Intracell Shield Door, we found that the door would not close fully. Further investigation found that we had inadvertently pinched our servomanipulator aux hoist motor in the door…

Door would not fully close

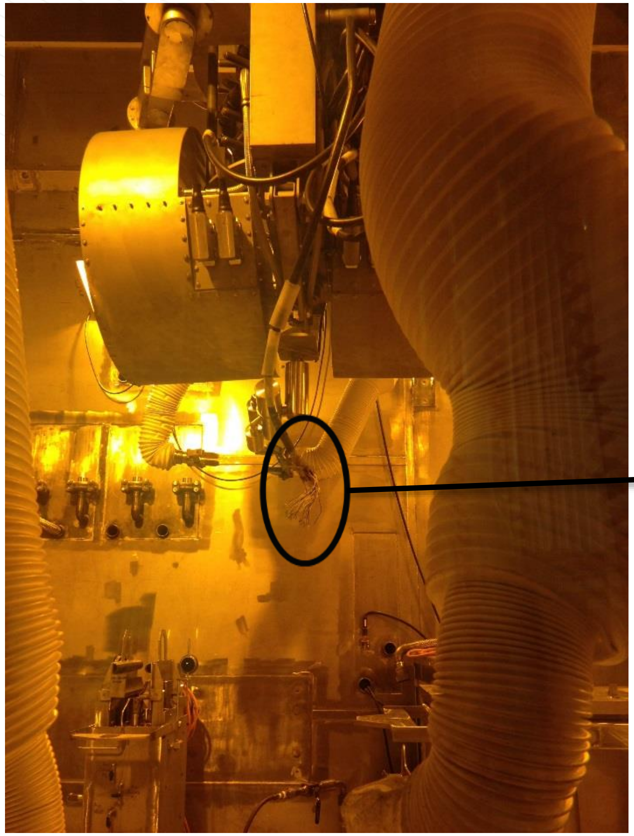


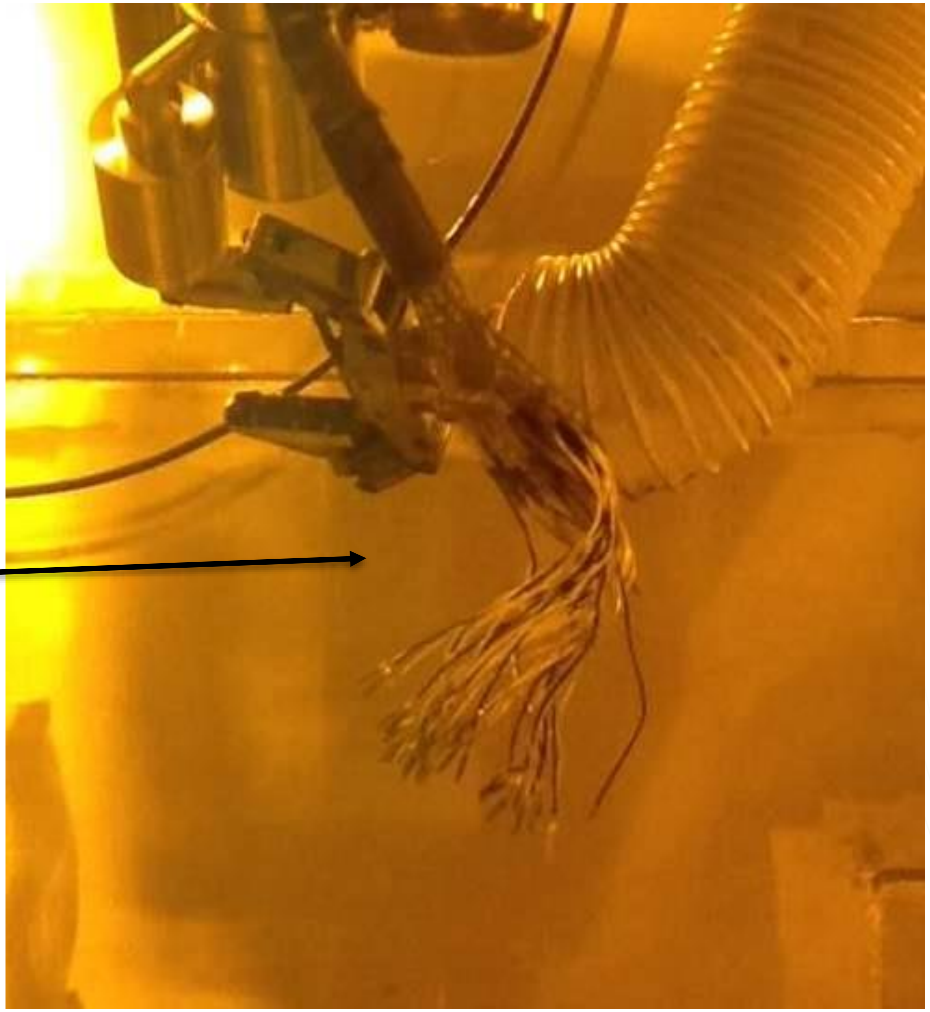
Motor caught in door opening

Technicians replacing damaged door actuation mechanism

Lessons Learned/Observations

A moment of inattention during a target replacement resulted in catching a control cable for the servomanipulator on a fitting mounted on the cell wall as the servo was being lowered. The cable was pulled completely out of the connector and destroyed. A spare cable was installed losing only one day of operation.



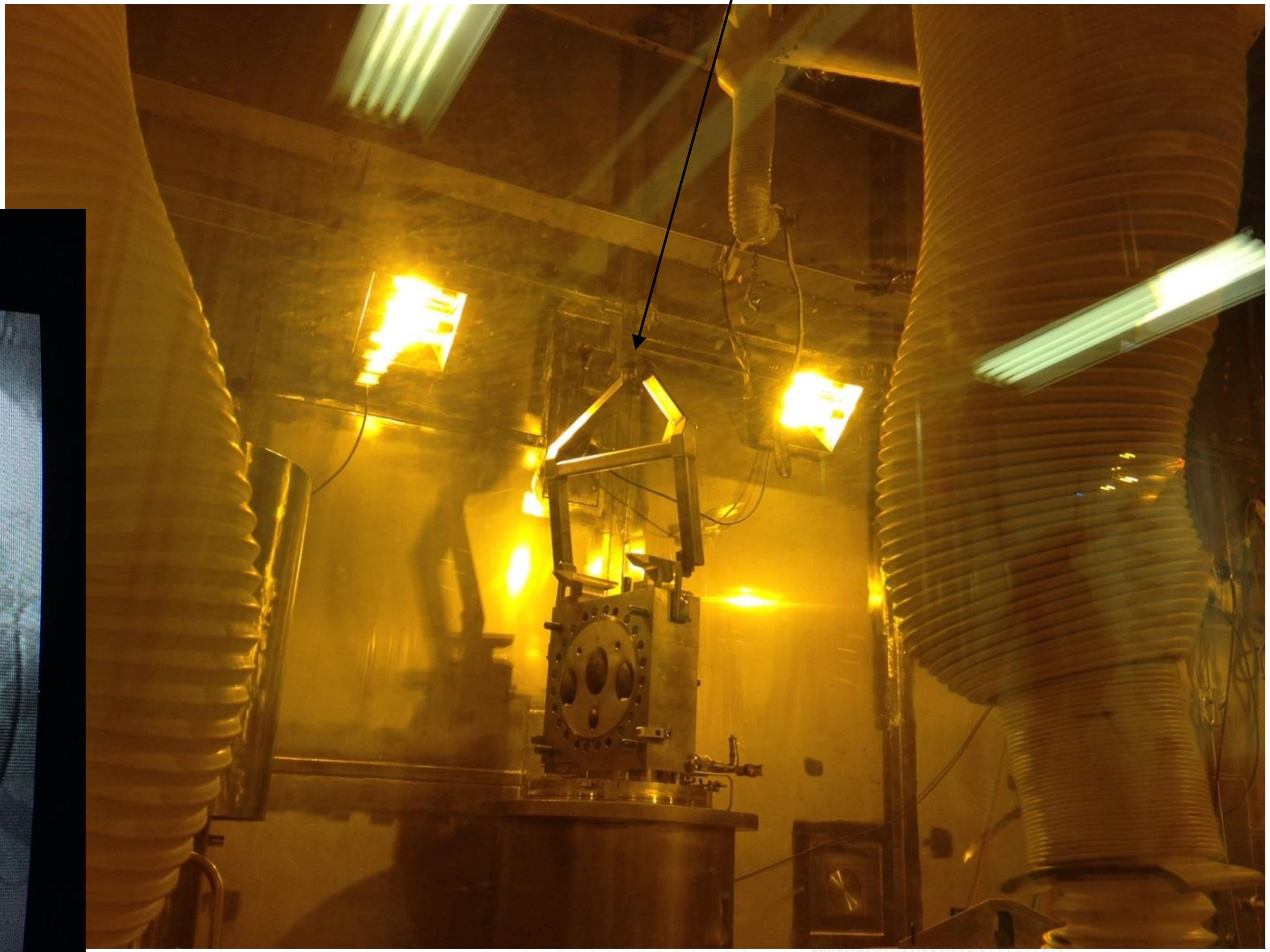


Myself and a technician replacing the damaged cable in the Transfer Bay

Lessons Learned/Observations

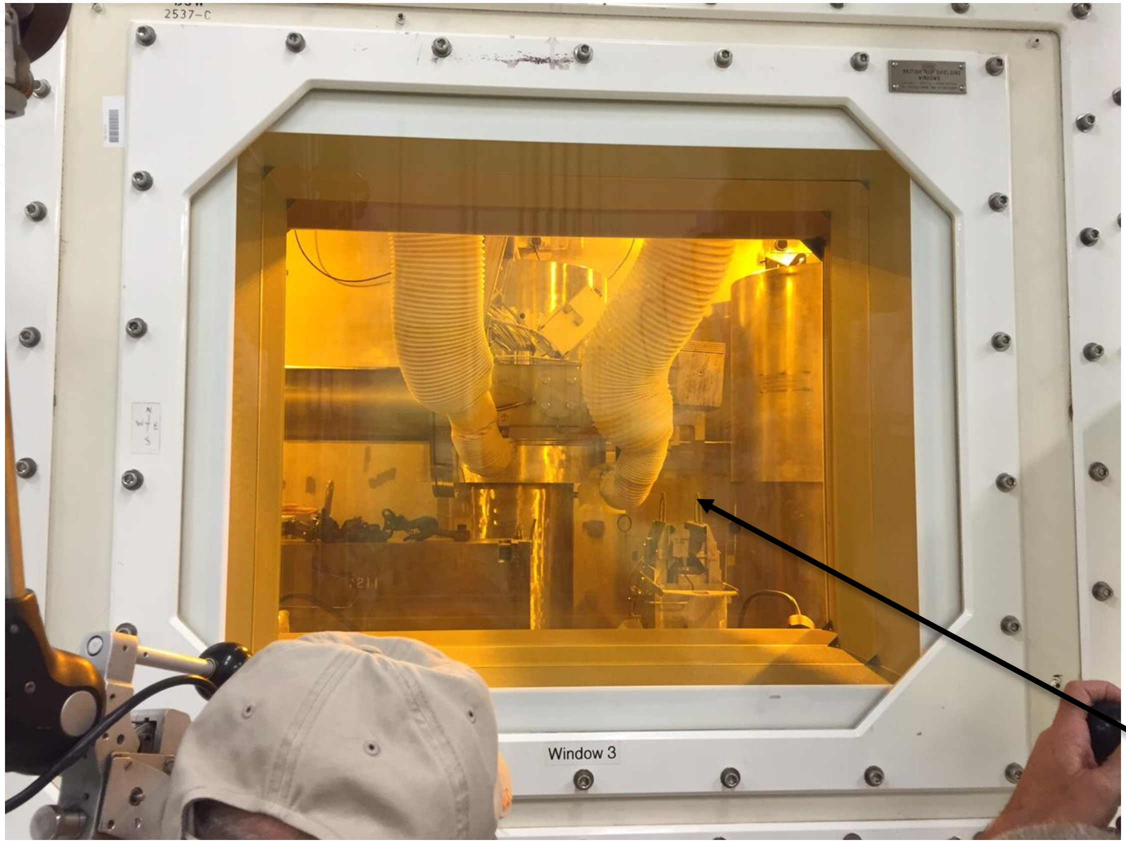
Lift Fixture stuck on spent
target module (note no crane hook)

The Lift Fixture used to hoist the target became stuck on the target module…removal was very difficult.

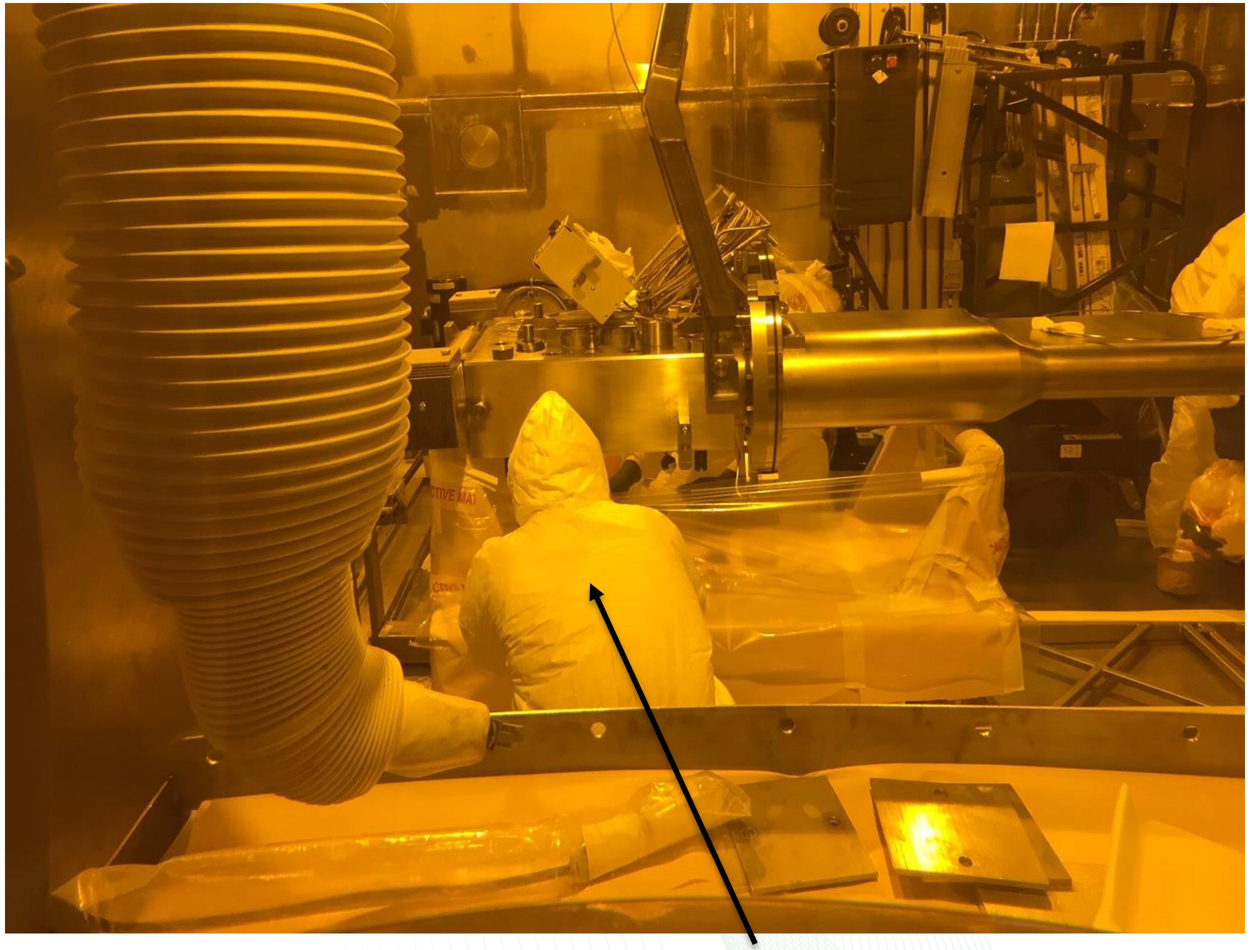


Lessons Learned/Observations

Following an unsuccessful seal test during a target module installation, we had to remove the target and take it back into the Transfer Bay for hands-on installation of a new iron seal…we've actually done this three times.



Attempting to wipe highly-activated mercury off the bottom of the target with MSM at WWS#2

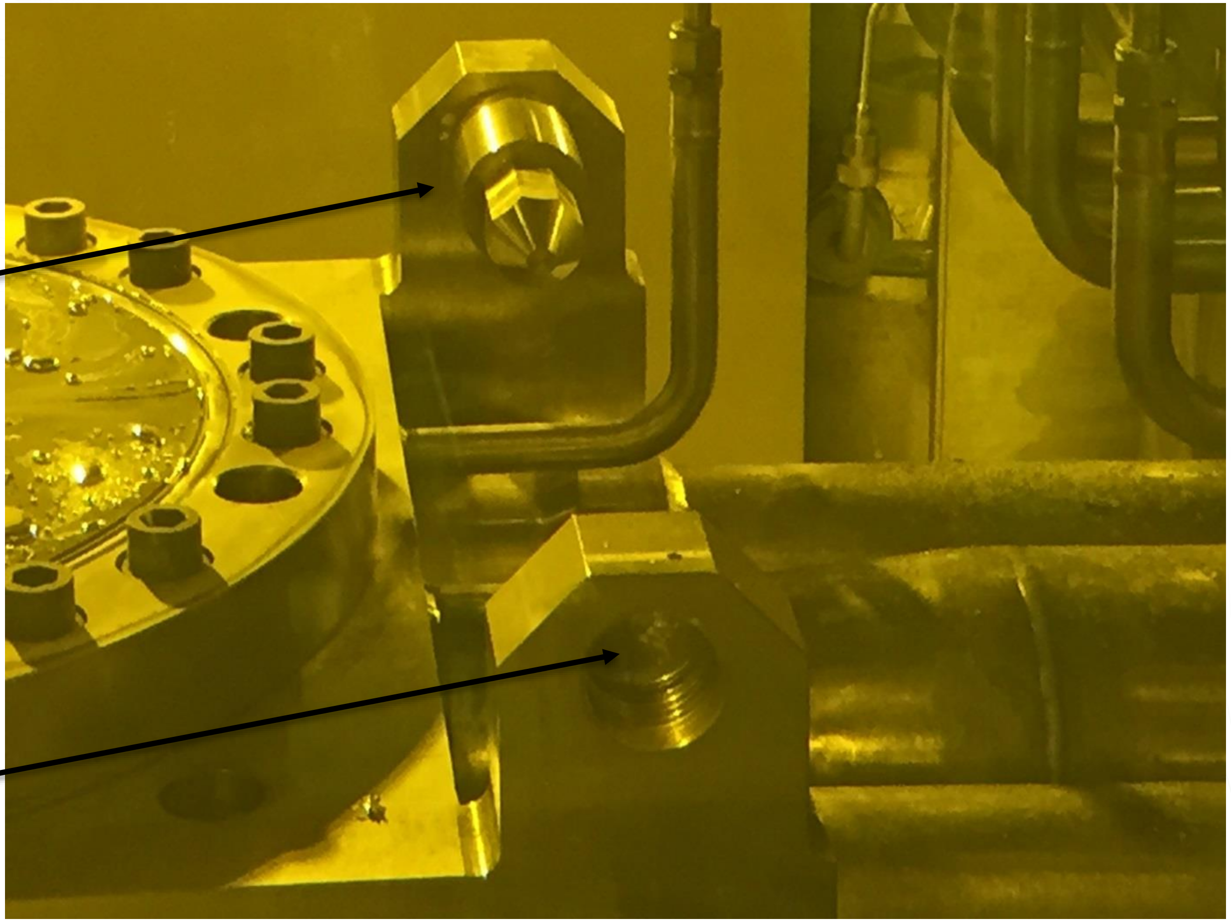


Technician in PPE (and respirator) installing new soft iron seal in Transfer Bay

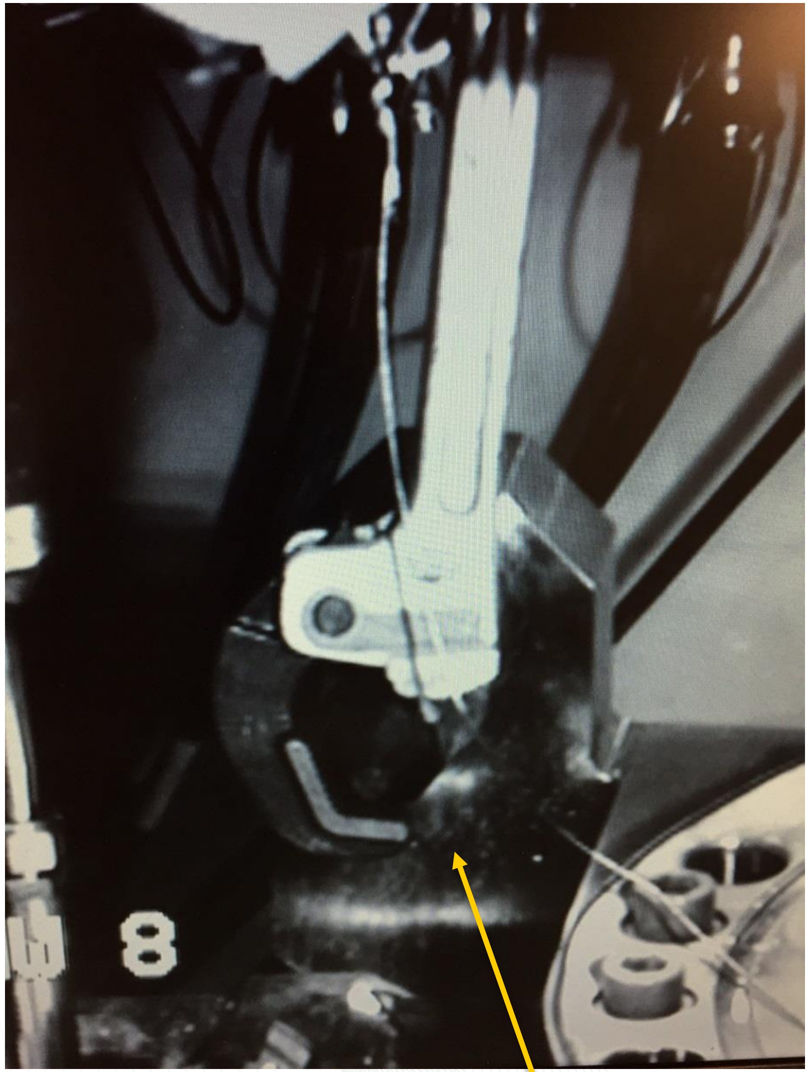
Lessons Learned/Observations

Upon retracting the Target Carriage, we found that a large pin had un-threaded and fallen out. We were able to find and retrieve the pin and re-install it, but had no wrench that fit this pin, so a pipe wrench was employed to tighten the pin…

Pin was supposed to be threaded like this one



Pin Missing



Using a pipe wrench to "torque" the pin in position

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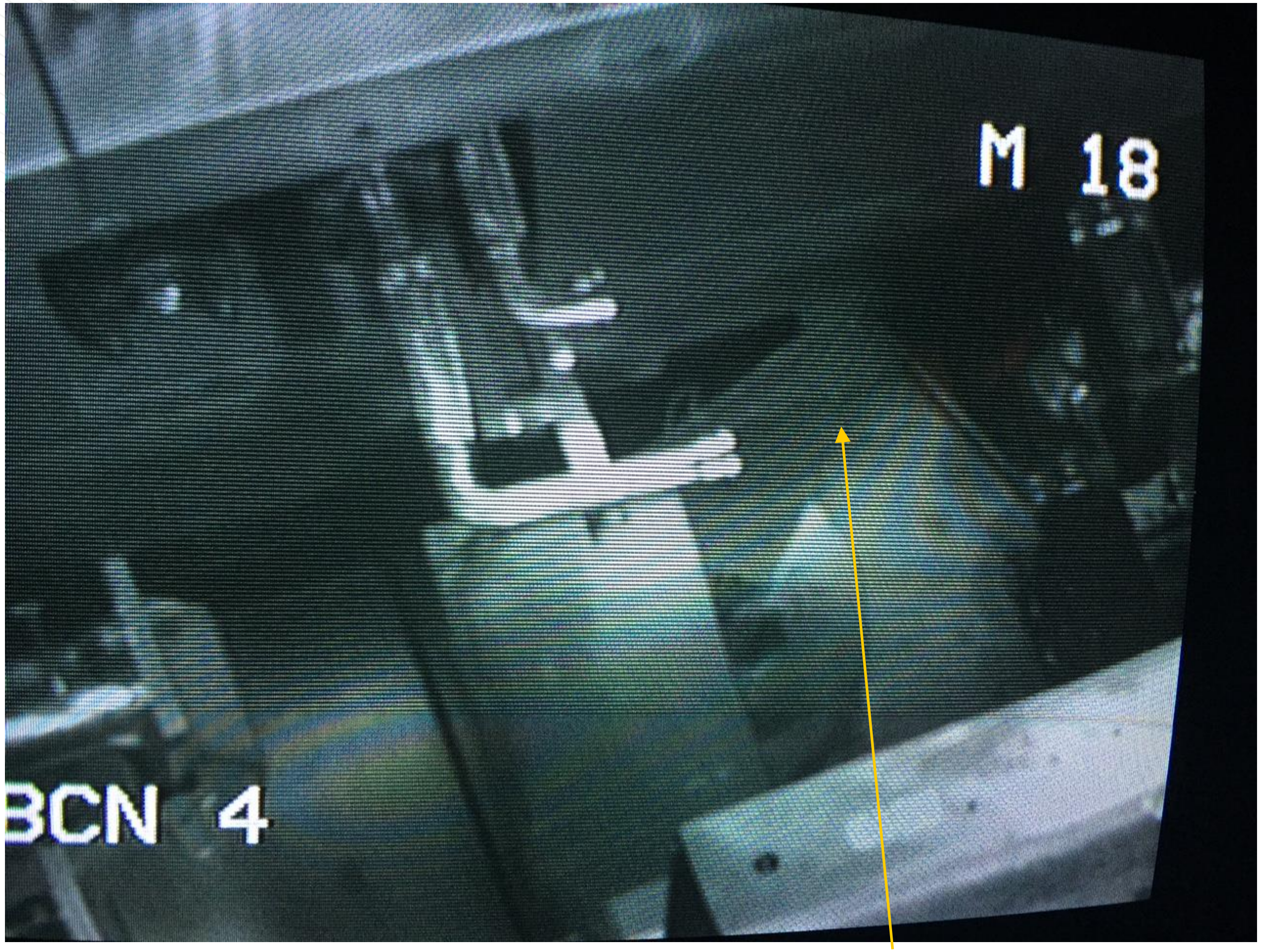
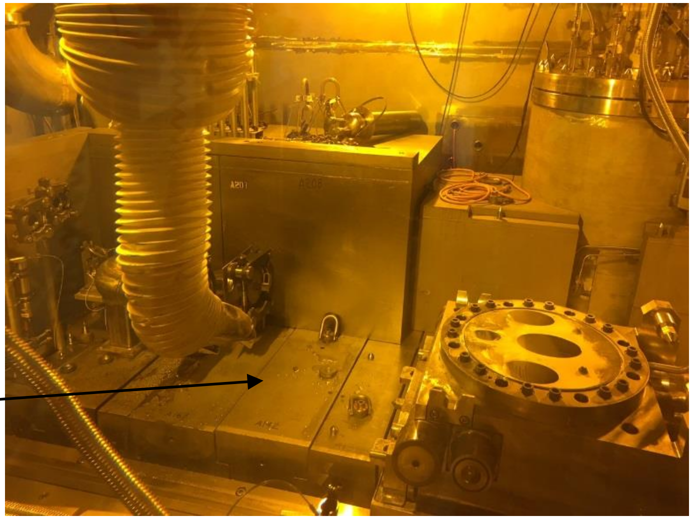
Lessons Learned/Observations

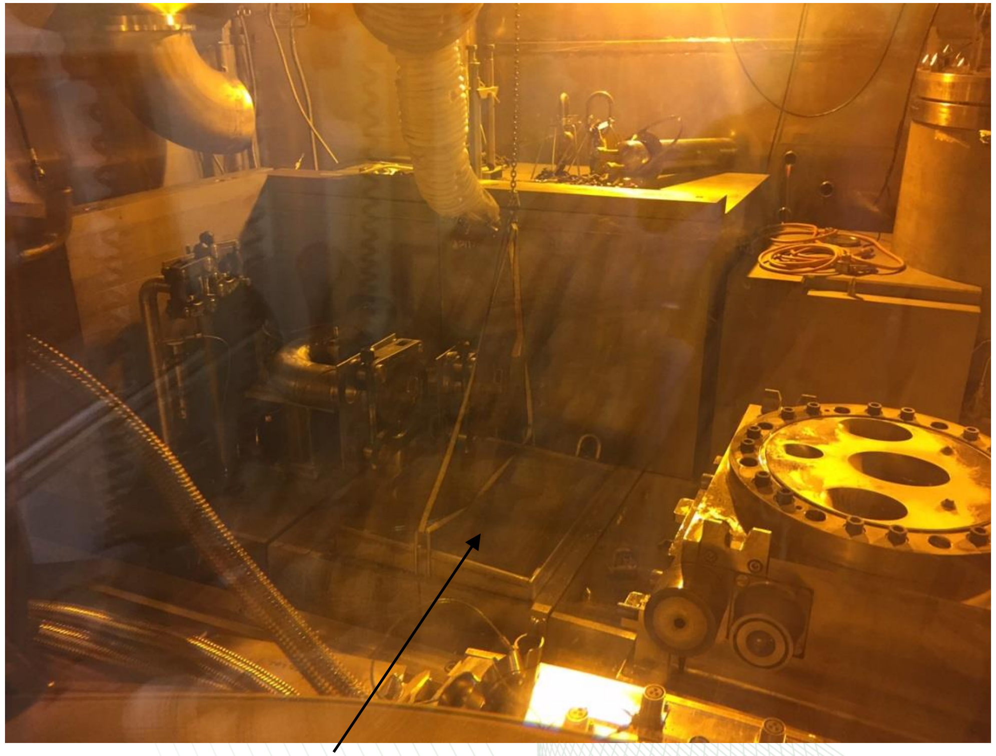
During Target Carriage retraction, the Carriage contacted a pan designed to catch spilled mercury. The pan stopped the Carriage travel damaging the pan. A new pan was required. The pan was redesigned to mitigate the chances of future problems.



Pan caught/Carriage jammed



Damaged pan removed



New pan installation

Lessons Learned/Observations

- Visibility is key to success
  - Cameras, windows, etc., are critical in successful operations and developing solutions when things go wrong…*and things will go wrong*.
- Always have a recovery plan
  - Never proceed without an understanding of the consequences of every action
- Preserve critical components/infrastructure
  - The servo was initially used for most tasks – now we use the servo mostly for moving things around the cell and use easily-repaired MSMs for the hard work
  - Design tools and processes to preserve/protect equipment and mitigate risk
  - Don't push too hard – both people and equipment. Know when to stop or take a break

Summary

- The initial design philosophy of the SNS hot cell was heavily influenced by the hazards associated with liquid mercury
- Over ten years of hot cell operations have validated this philosophy with many successful operations completed
- The flexibility afforded by the complex servomanipulator has enabled successful completion of many operations never envisioned during initial design
- Continuous improvement coupled with a healthy respect for what can wrong continues to guide the operational philosophy

Thank You!