Remote Handling Operations at SNS

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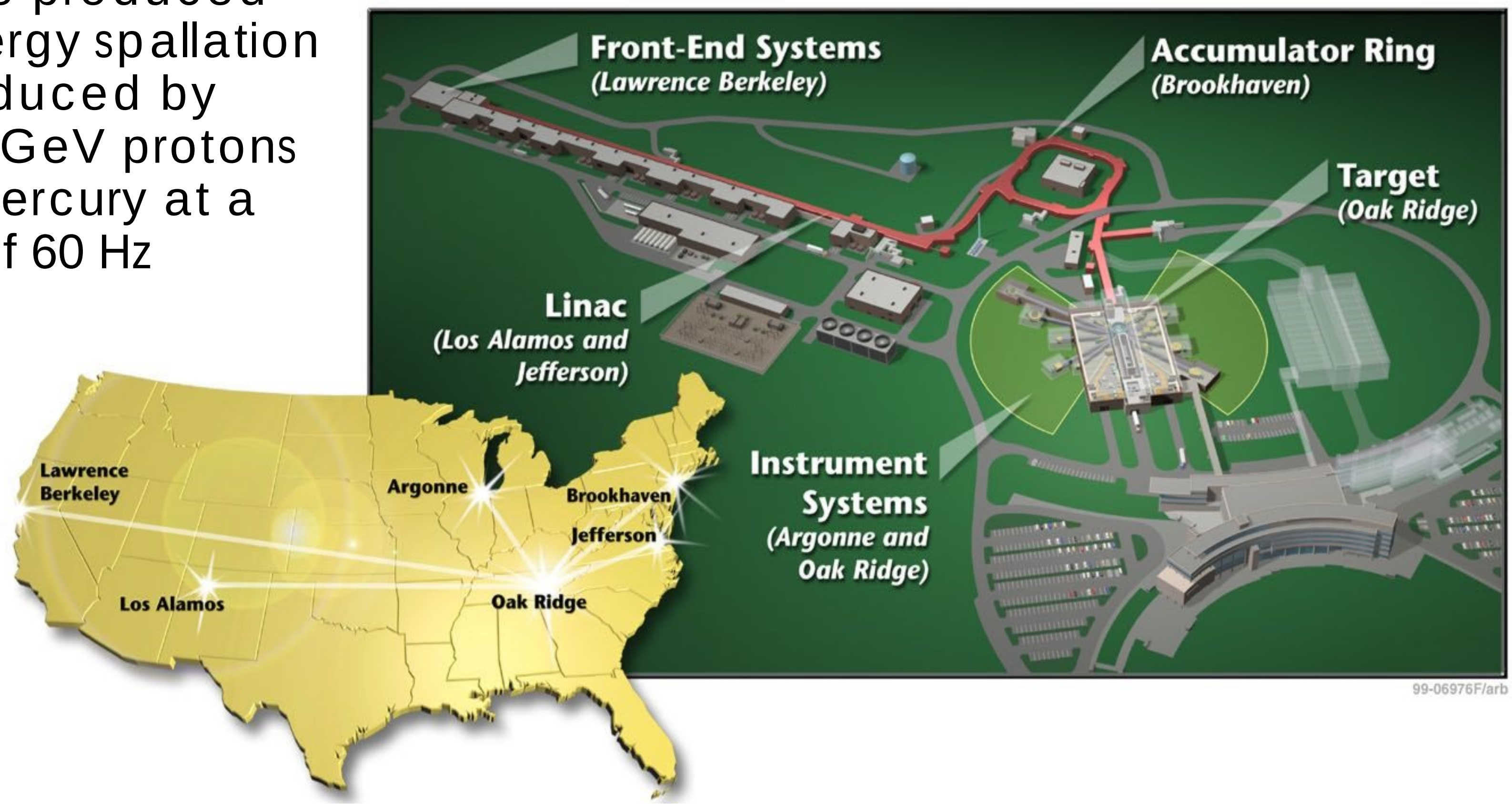
Outline

- Spallation Neutron Source overview
- Hot cell design details and operations
- High Bay remote handling operations
- Remote handling philosophy

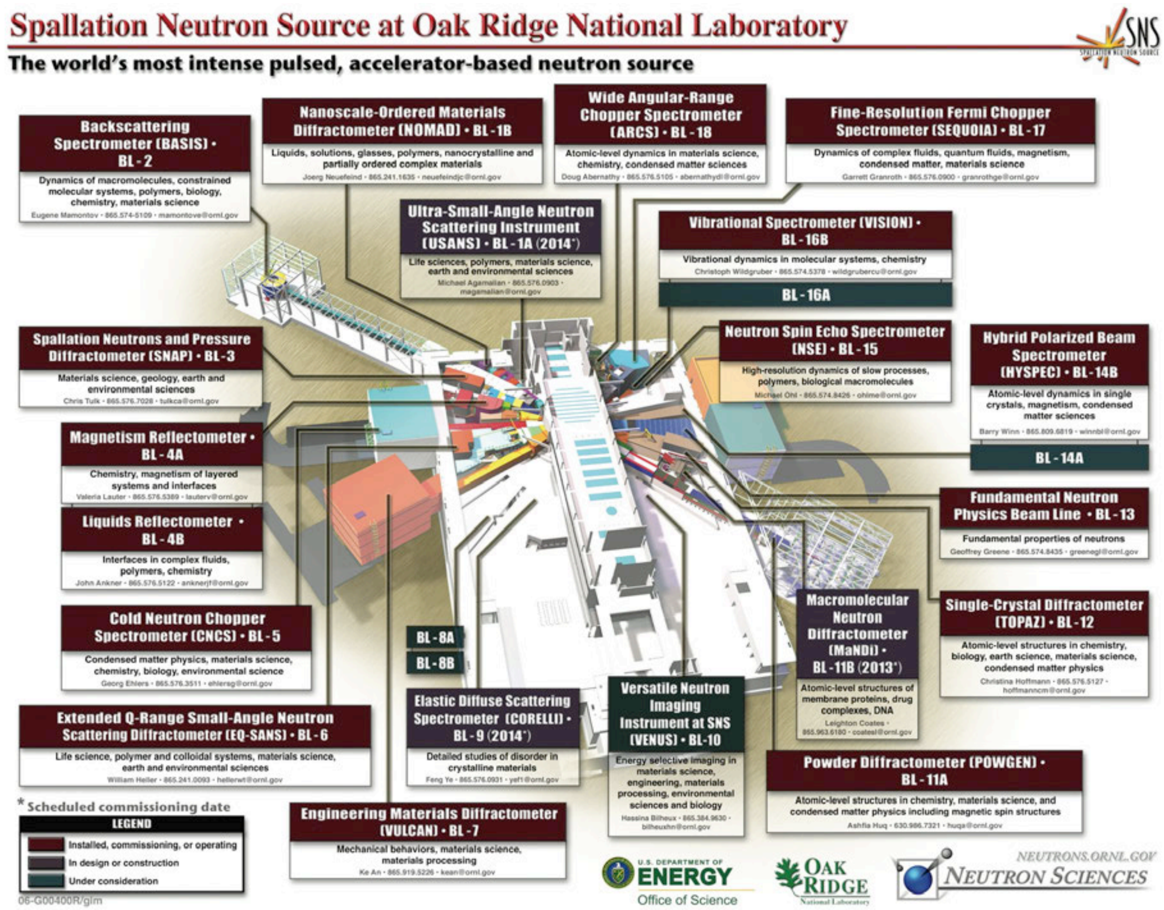
SNS is a megawatt-class, accelerator-based pulsed neutron source

- Neutrons are produced via high-energy spallation reactions induced by injecting ~1 GeV protons into liquid mercury at a frequency of 60 Hz

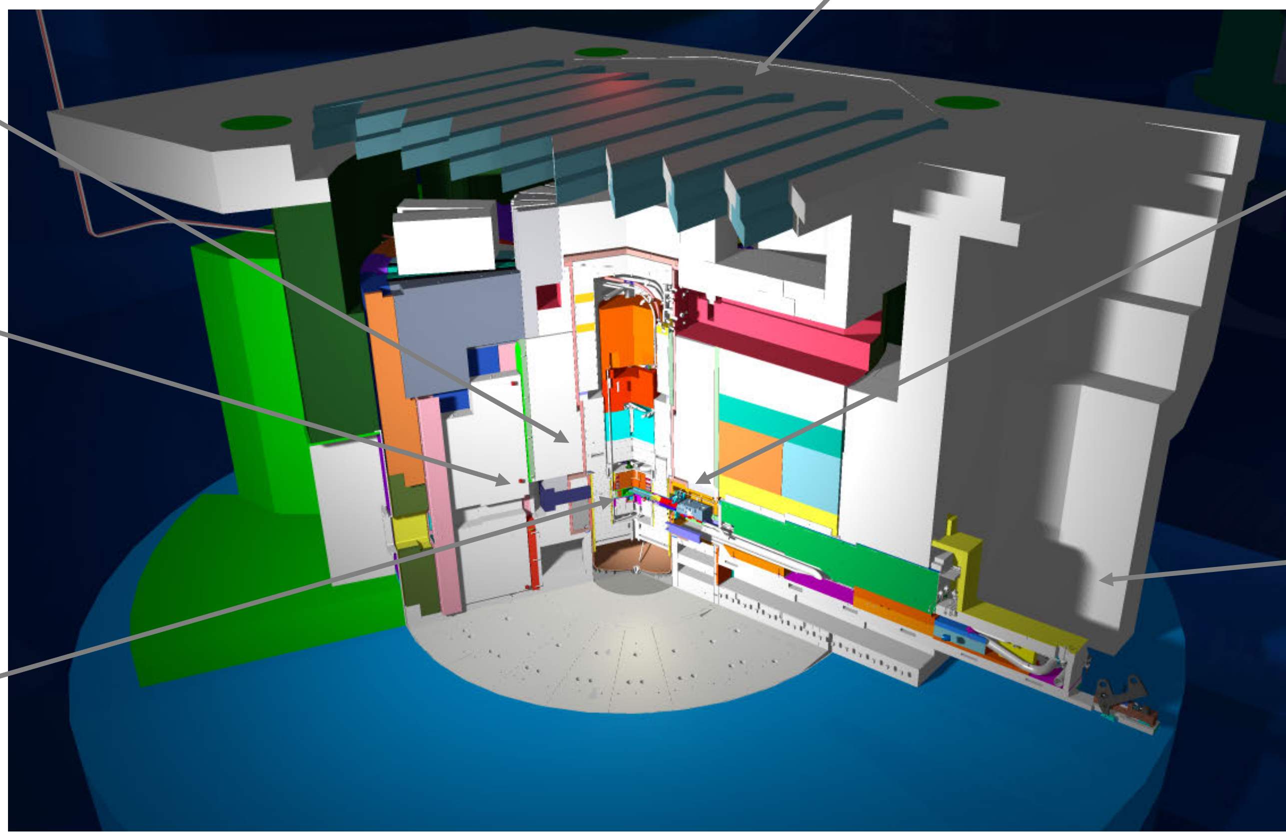


Instruments utilize the pulsed neutrons for material science investigations

- Currently SNS has 18 operational instruments to employ a wide array of neutron scattering techniques in a variety of different sample environments



Several components requiring replacement become highly-activated due to proton and neutron interactions



Proton Beam Window (separates accelerator high vacuum from Core Vessel helium atmosphere)

High Bay Environment

Shutters and Core Vessel Inserts (instrument components requiring replacement)

Mercury Target Module (stainless vessel that contains The flowing mercury)

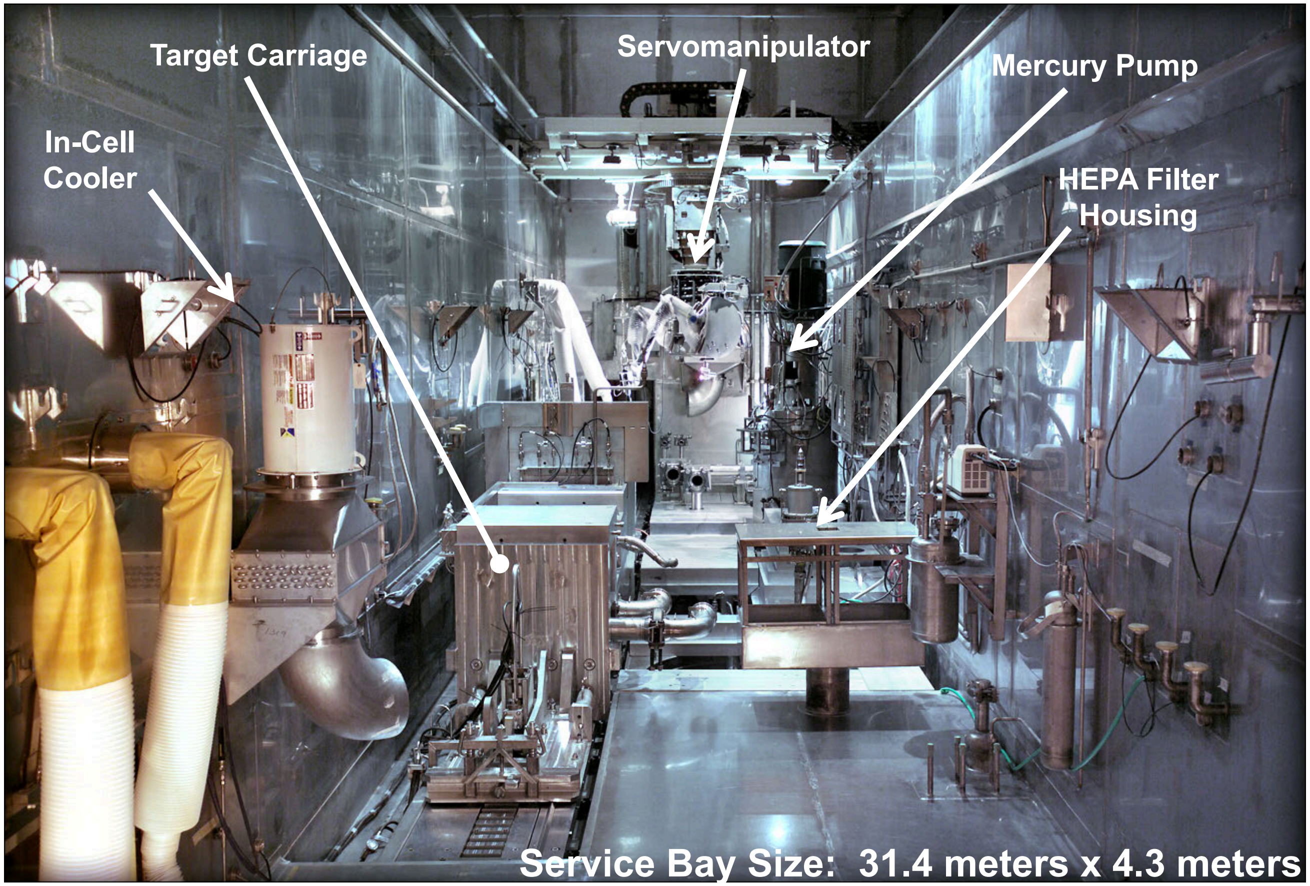
Hot Cell Environment

Inner Reflector Plug (contains hydrogen moderators and beryllium reflectors)

Remote Handling at SNS

- 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 with no hands-on access for maintenance or replacement
- Additional highly-activated components in the monolith require remote replacement from a High Bay environment located above the hot cell
  - Replacement of these components is performed "hands-on" utilizing shielded casks and long-handled tools

Hot Cell (Service Bay) Parameters



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)

Service Bay Details

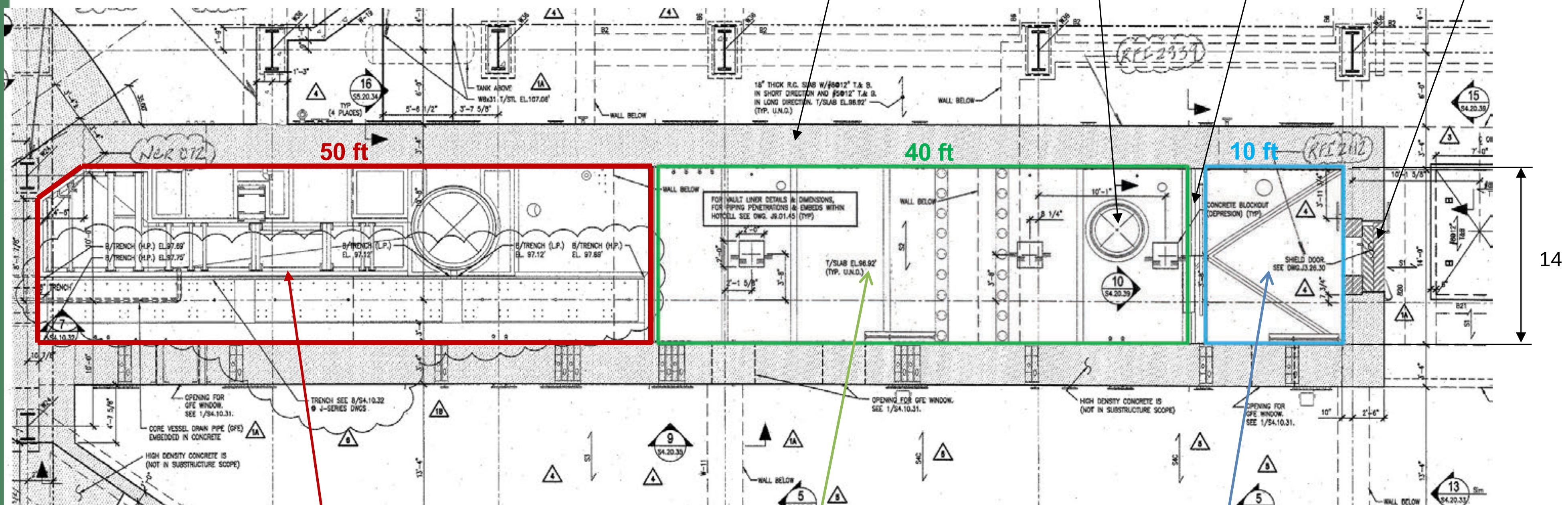
Plan View of Service Bay

40” (~1 m) of high-density concrete

Bottom Loading Port

Shielded Intracell Doors

Transfer Bay Access Door



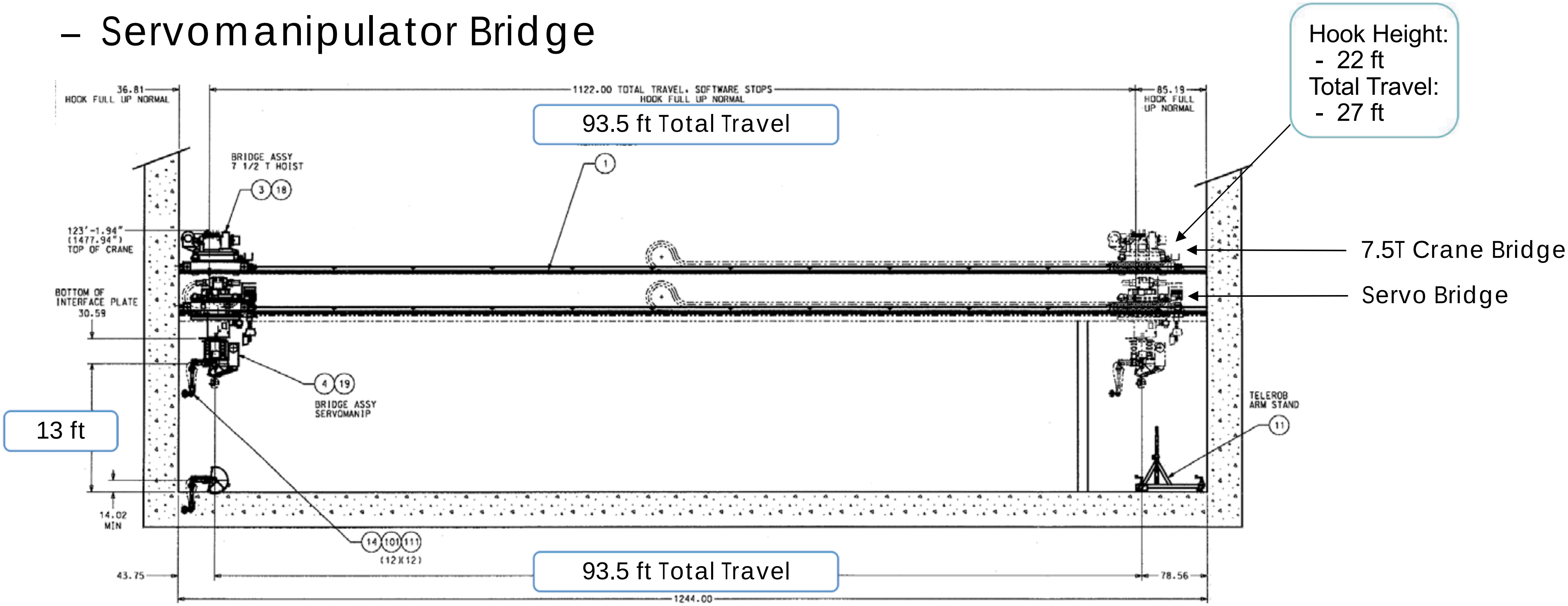
Process Bay
- Mercury Process Equipment (pump, HX, drain tank, etc.)
- Target Carriage
- Target replacement activities

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

Service Bay Bridge Systems

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



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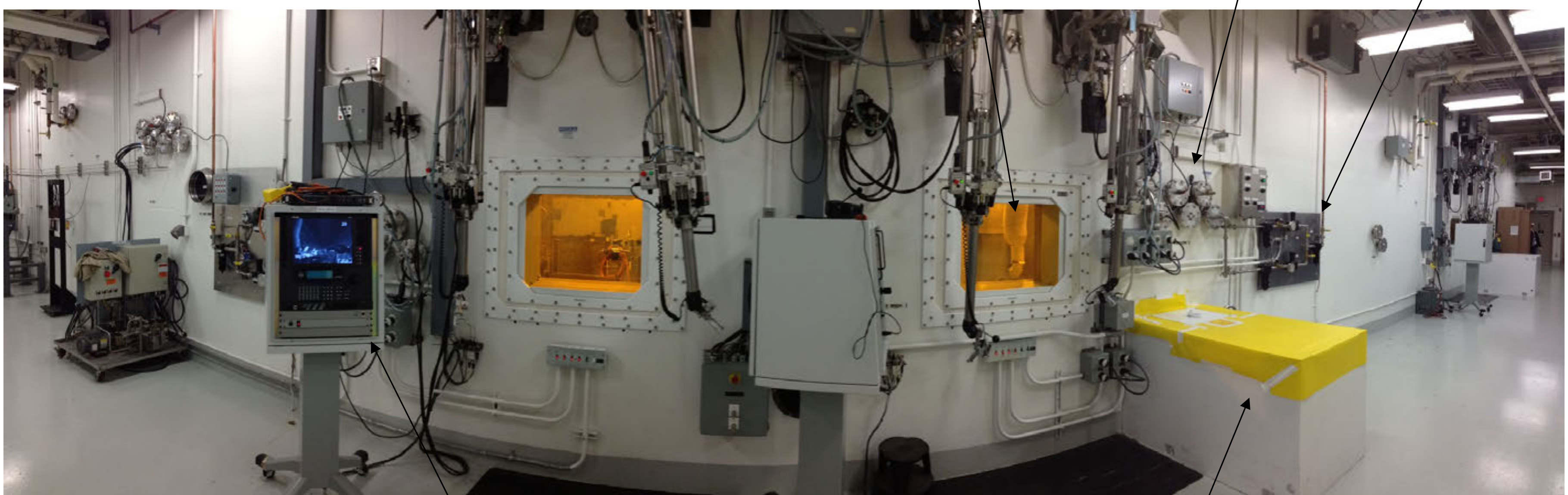
Window Workstations

Process Bay: *1*
Maintenance Bay: *2*
Transfer Bay: *1*

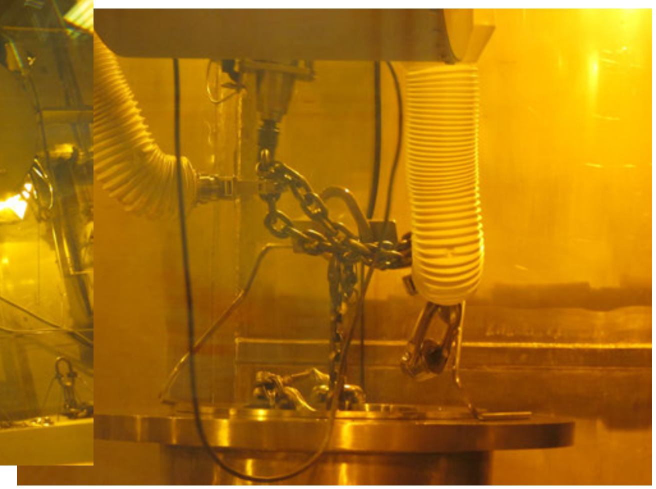
Each Workstation Contains:
- Two CRL Model F Master-Slave Manipulators
- One video monitor
- In-cell utility connections
  - Two regulated air supplies (pneumatic tools, etc.)
  - Two electrical supplies (120VAC)

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



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

Radiological Conditions

- The SNS cell has three primary hazards:
  - Radiation dose
    - General area dose is typically less than 100 R/hr
    - Dose rates during target replacements exceed 35000 R/hr
  - Radioactive contamination
    - Spallation product isotopic contamination is extensive and widespread
    - No formal survey regimen is conducted, but surveys on the servo during maintenance have revealed individual smears >1 R/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

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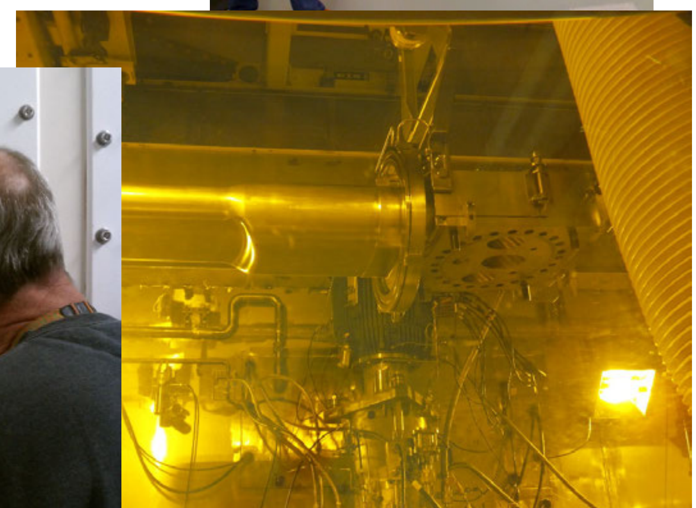
Typical Service Bay Remote Operations

- Target Module Replacement
  - Replacement required due to proton/neutron induced material degradation (DPA) and mercury cavitation erosion
- Post-Irradiation Examination
  - Performed on spent target modules to study and quantify material degradation and inform improved target designs
- Waste Disposal
  - Target module and Proton Beam Window disposal operations
- Hot Cell Maintenance

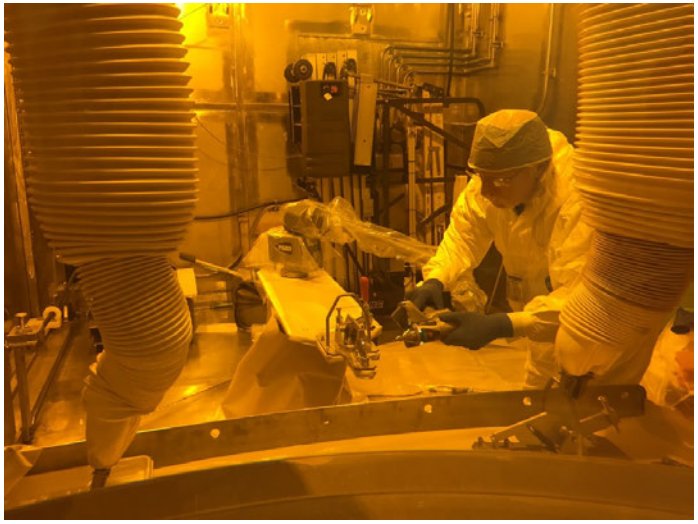
Target Module Replacements

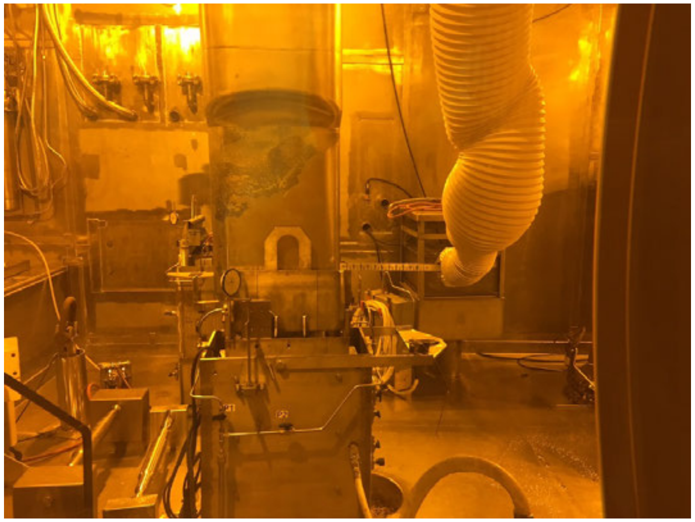
- SNS has completed 19 remote target replacements
  - Each replacement requires approximately 8-10 days of in-cell work
    - Process requires approximately 100 individual tasks
  - All elements of the replacement are fully remote



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 to remove material specimens
  - External photography
  - Water Shroud removal and mercury vessel inspection
  - Laser scanning of removed nose samples





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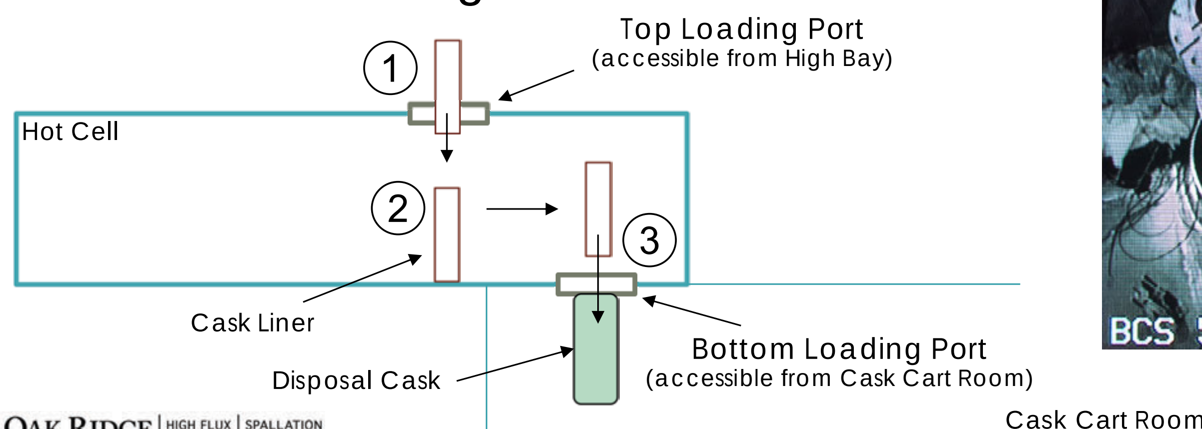
Waste Disposal Operations

- 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

Service Bay Maintenance

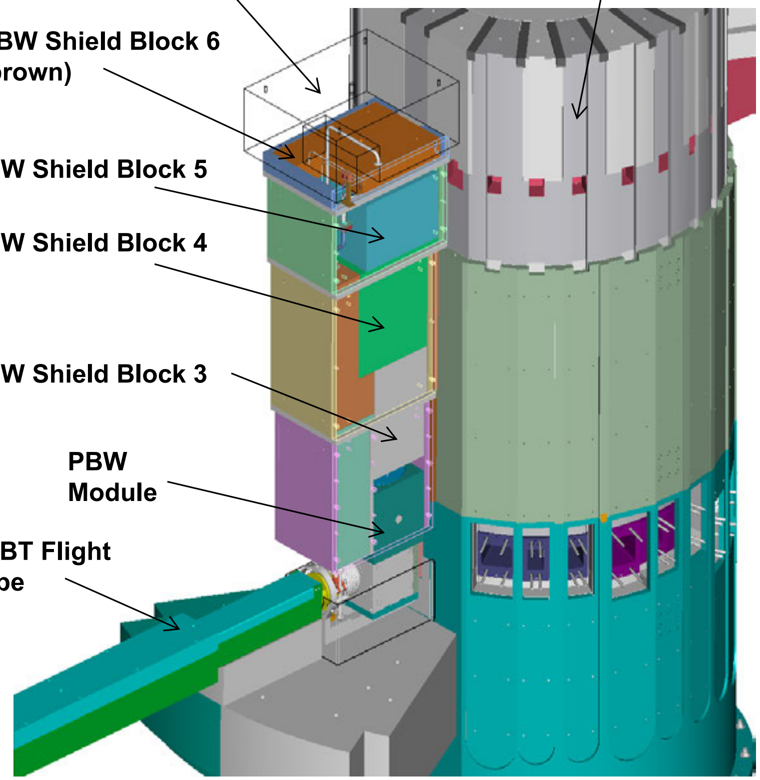
- The servomanipulator is required to support all in-cell maintenance and support
  - Planned infrastructure maintenance and operations:
    - Light replacement
    - Camera maintenance
    - Valve actuation
    - Electrical connections (Amphenol, etc.)
    - Moving items from Transfer Bay to Service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

Typical High Bay Remote Operations

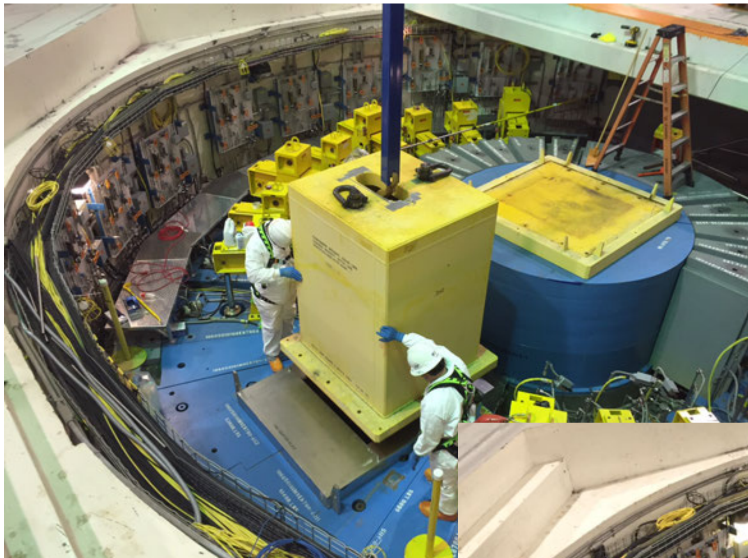
- Proton Beam Window Replacement (5 replaced)
  - Replacement required due to proton/neutron induced material degradation (DPA)
- Inner Reflector Plug Replacement (1 replaced)
  - Typically life-limited by the burnable neutron poison inventory in the liquid hydrogen moderators
- Shutter/CVI Replacement (5 shutters/2 CVIs replaced)
  - Required as a part of new instrument installation

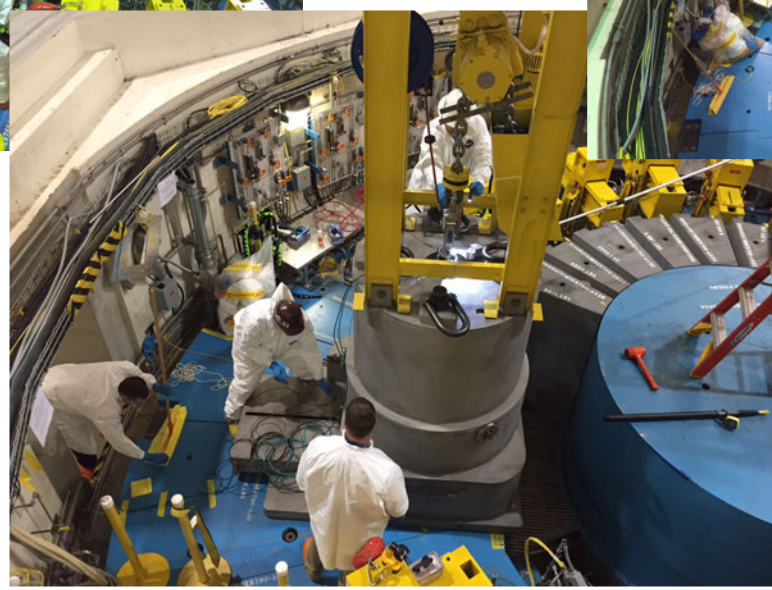
Proton Beam Window Replacement

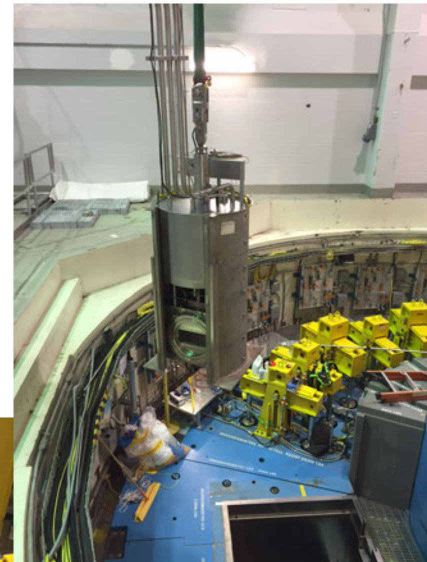
- Replacement of a PBW module involves the following basic operations:
  - Removal of five shield blocks (45 tons of shielding)
  - Drying (water removal) of PBW module
  - Cutting and removal of activated utility piping
  - Withdrawal of PBW module from cavity
  - Installation of new PBW module
  - Connection of utility piping
  - Leak testing of inflatable seals and piping connections
  - Re-installation of shielding



Proton Beam Window Replacement





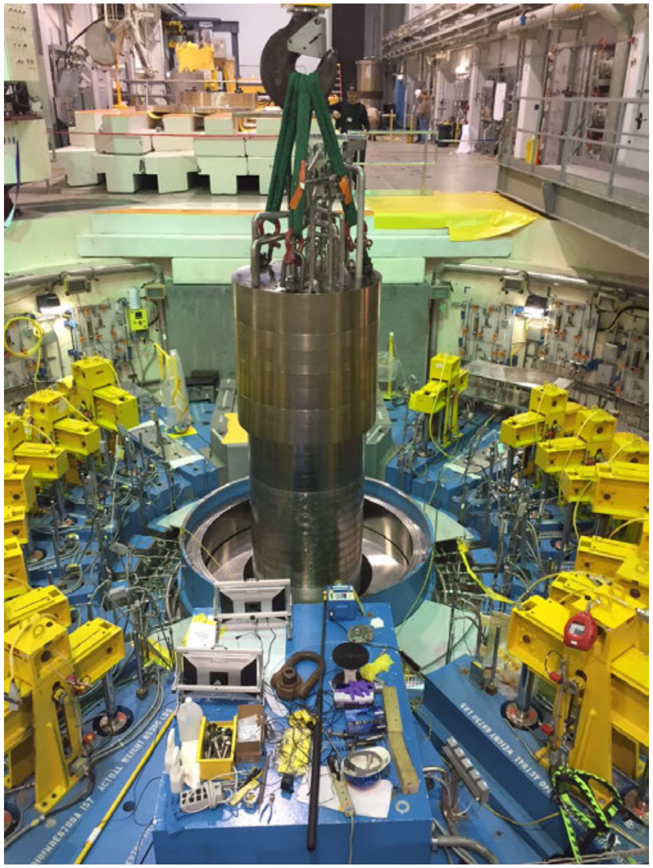


Installation of new
Proton Beam Window

Tooling installation
to remove and install
Proton Beam
Window

Inner Reflector Plug Replacement

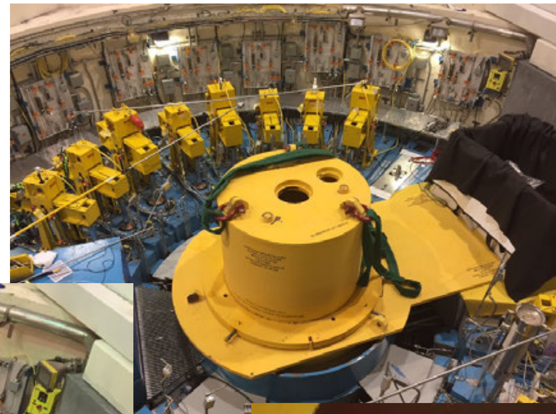
- The initial replacement of an Inner Reflector Plug represented a critical operation demanding significant planning
- Due to the size of the IRP (roughly 16 ft tall and 34 tons), it is removed in three segments
  - Utility pipe cutting and loosening of structural ties is required for each segment removal
  - Shielded casks are required to provide technician protection during removal
  - Long-handled tools are employed to perform the pipe cutting and tie-rod loosening



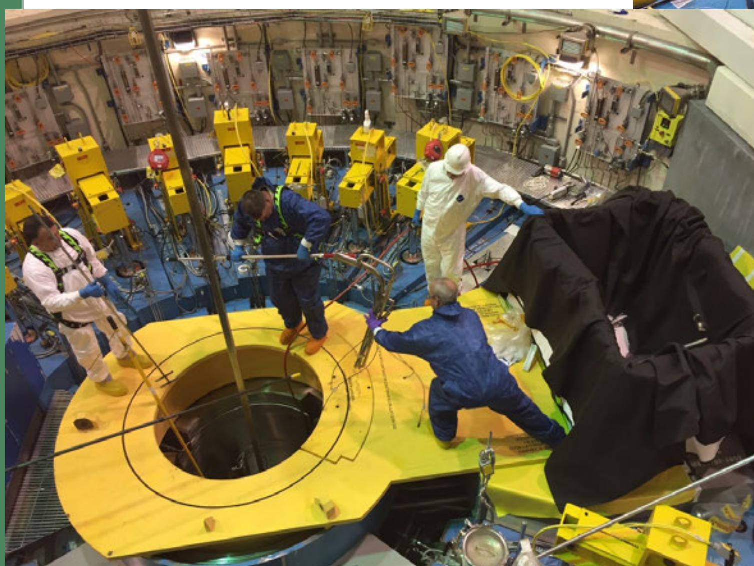
IRP-2 Being Lowered into Core Vessel

IRP Segment Removal

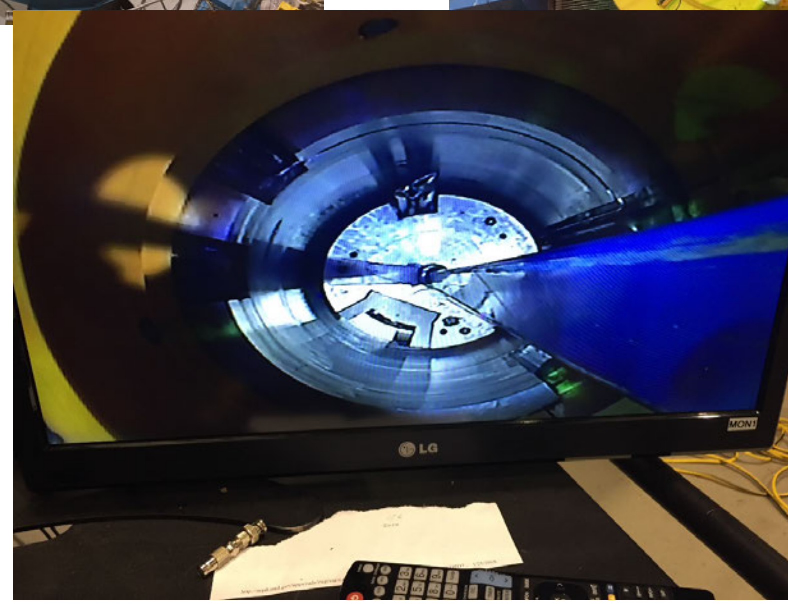
Shielded Cask in
Position over
Core Vessel



Pulling Segment
up into Cask

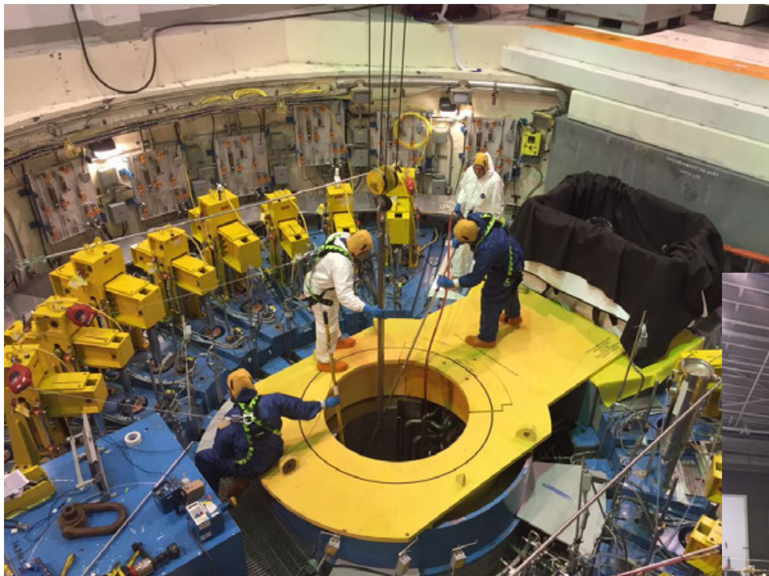


Segment Pipe
Cutting and Removal



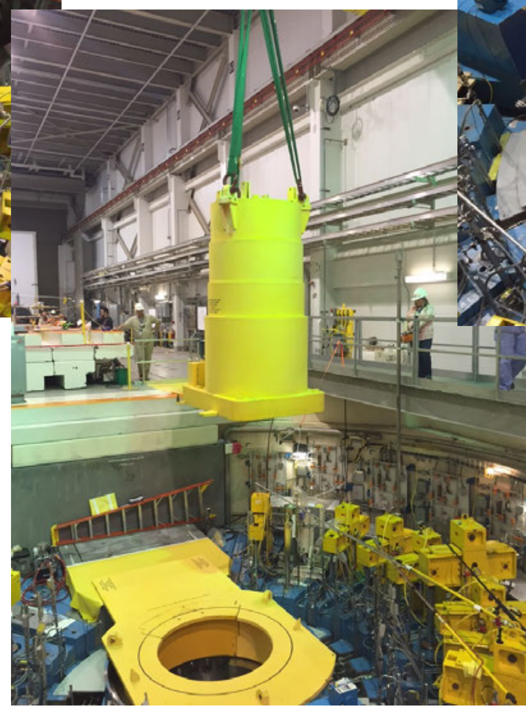
Remote Camera
View of Extraction

IRP Segment Removal



Lower Segment Pipe
Cutting and Removal

Lower segment pipe cutting and removal involved the highest radiological hazards



Installation of Lower Segment
Cask over the Core Vessel

Installation and Testing
of Shielded Door Assembly

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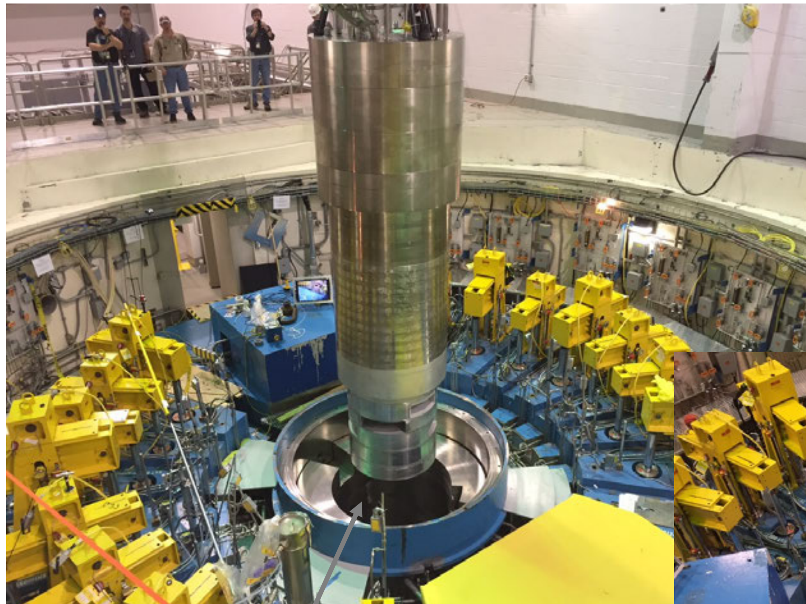
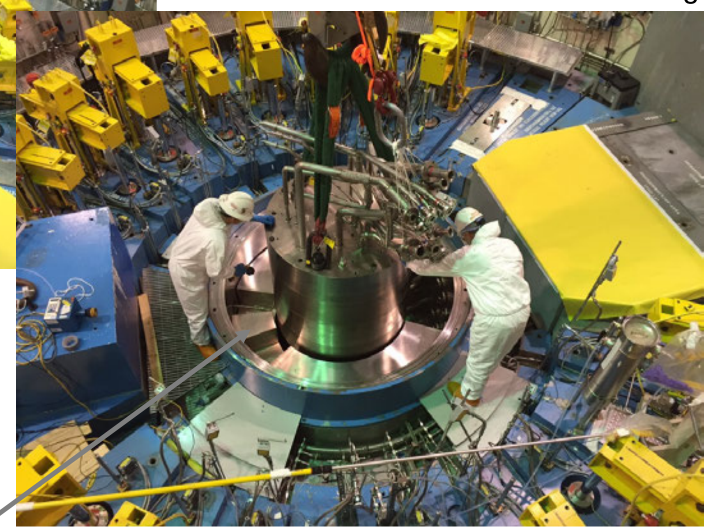
New IRP Installation

Moving IRP-2 Through Airlock



Positioning IRP-2 over Core Vessel

Dose rates in this area were ~ 50 R/hr

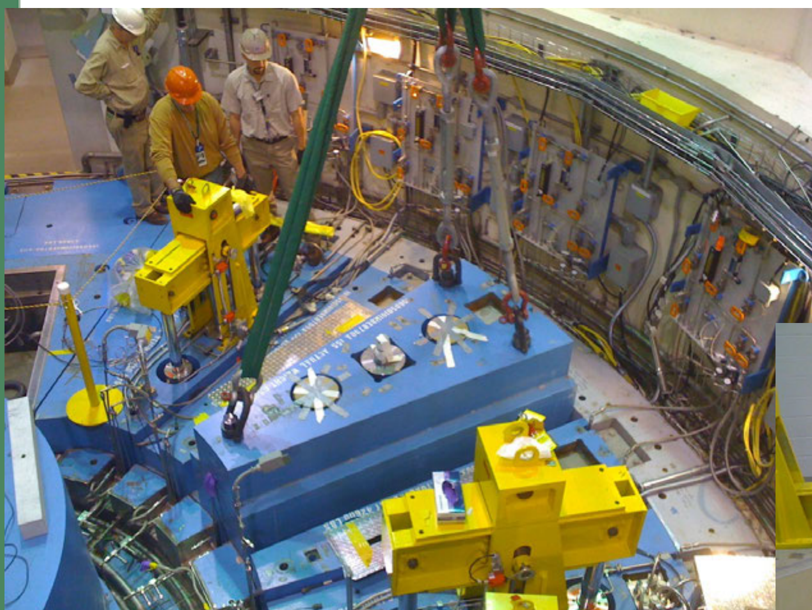


Final Positioning

Self-shielding by the IRP itself allowed technician access for final positioning

Shutter and CVI Replacement

- Initial Shutter Removal



Top Block Removal

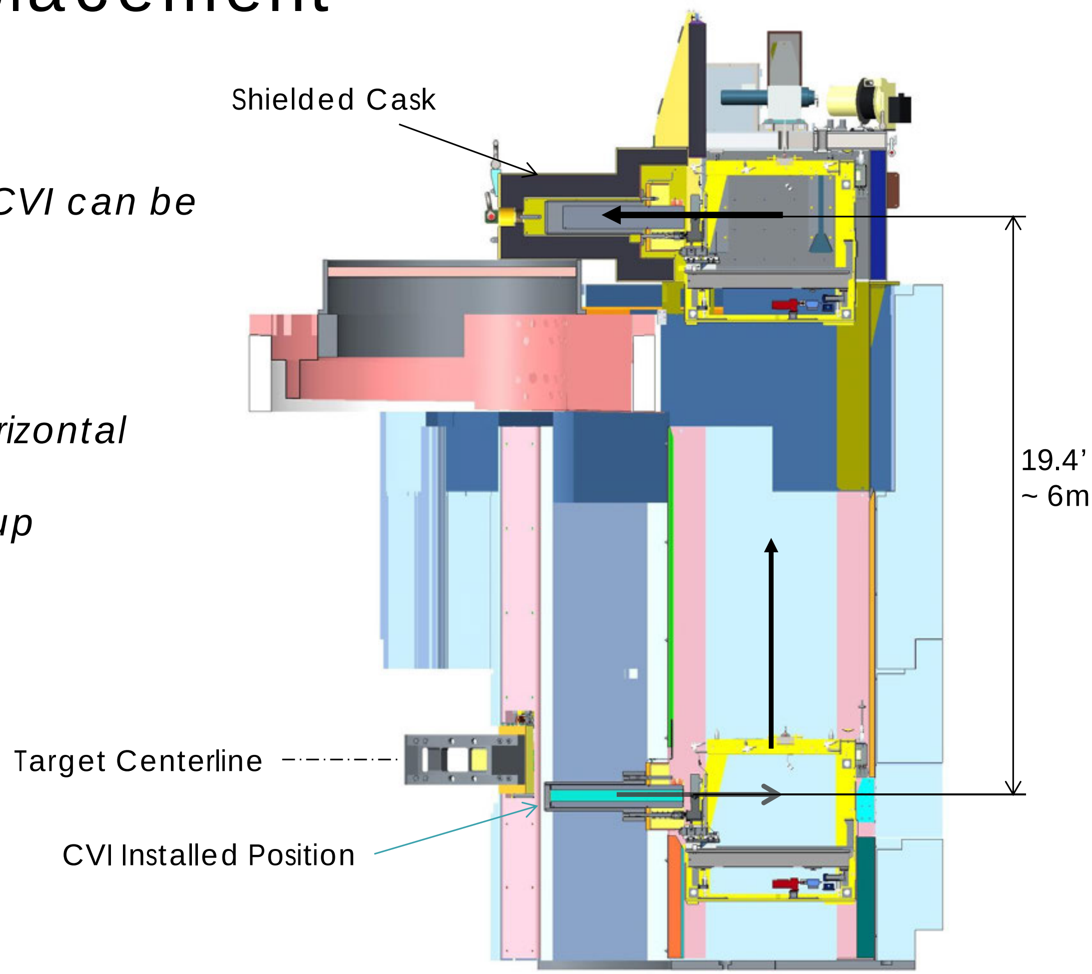
Installation of Shielded Cask for Lower Shutter Plug Removal

Removal of Upper Shutter Plug

Shutter and CVI Replacement

Following Shutter Plug removal, the CVI can be accessed and removed...

Removal the CVI requires horizontal extraction from the Monolith, vertical movement through up through the Shutter cavity and then horizontal insertion into the Shielded Cask



Cross-Section of BL 9 Shutter Cavity

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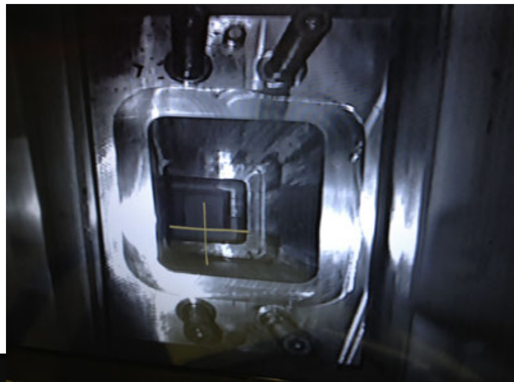
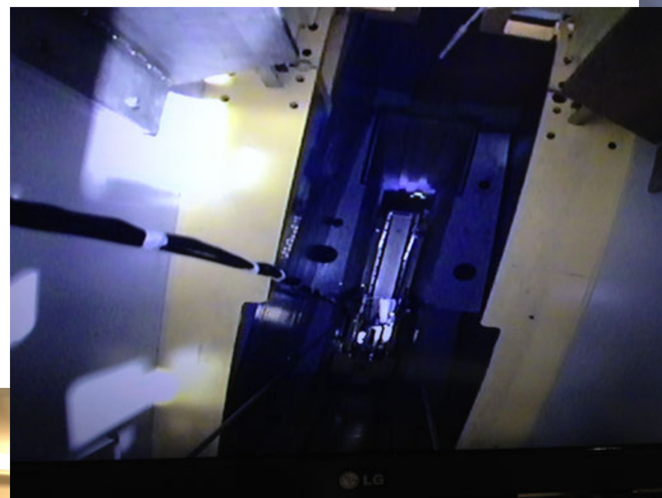
CVI replacement requires extensive use of remote cameras

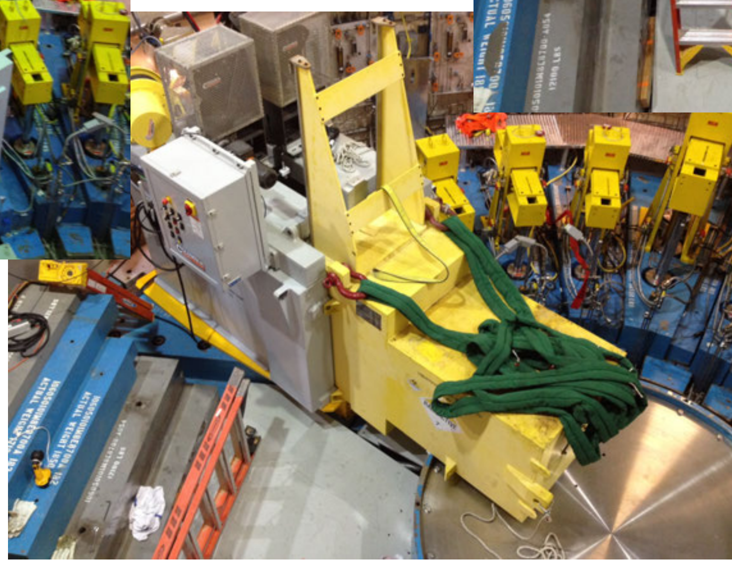


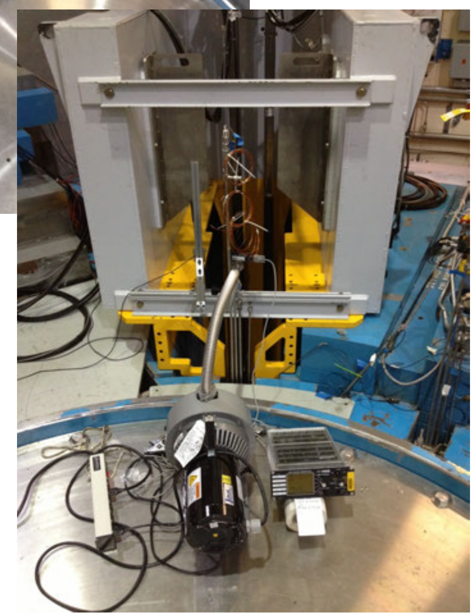


Cameras are used during all phases of the operation to gain the visibility needed remove/install fasteners, align equipment, inspection, etc.

CVI Replacement

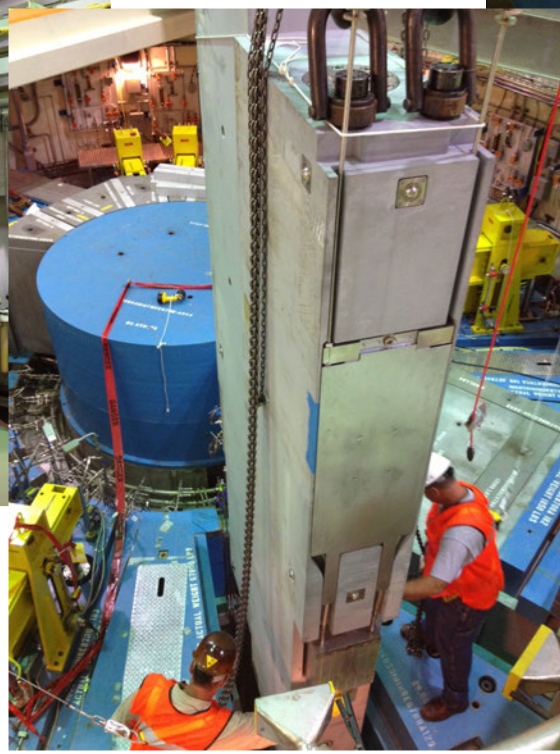
Tooling installation To remove and install CVI

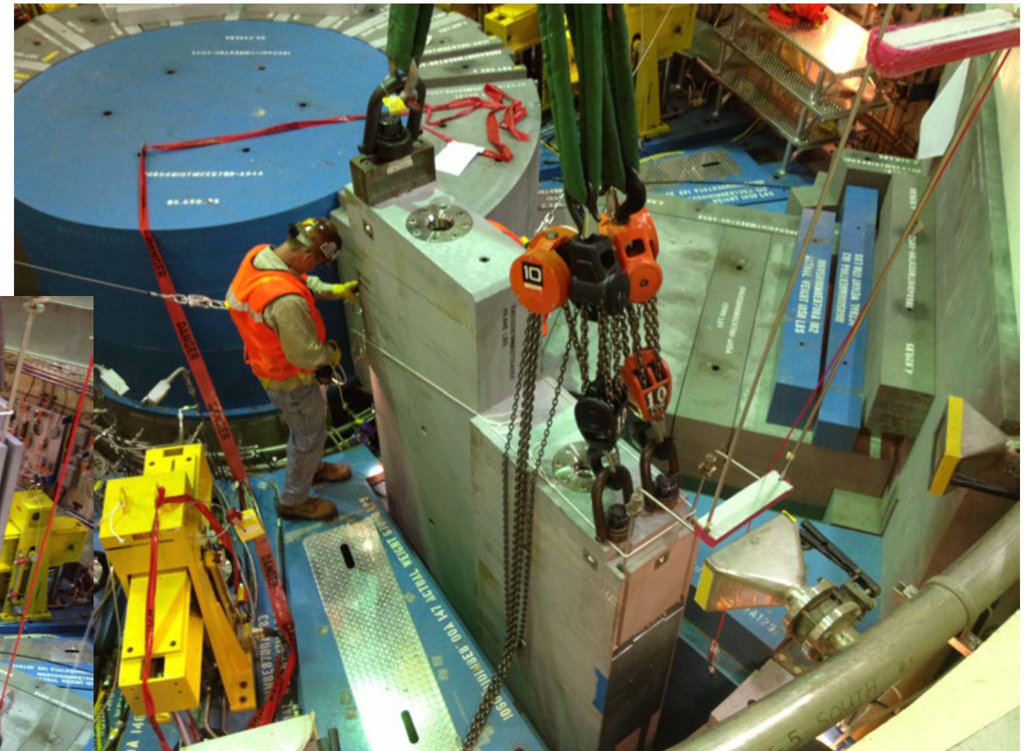




Testing of CVI seal post-installation

New Shutter Installation





Installation of the 30-ton shutter into the cavity

Evolution of Remote Handling 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 remote handling operations is empowered to make improvements, mitigate risk and is invested in the successful outcome
- When it comes to remote handling, though, "never say never"

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. Be very mindful of equipment capacities and operational constraints. Remote handling is very tedious and mentally-challenging work. 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
  - The flexibility afforded by the complex servomanipulator has enabled successful completion of many operations never envisioned during initial design
- Significant planning and tooling design has been required to support the varied High Bay replacement operations
- Over nine years of remote handling operations have resulted in the successful replacement of 32 major components
  - Continuous improvement coupled with a healthy respect for what can wrong continues to guide the operational philosophy

Thank you!!