SNS Core Vessel Water Leak Saga

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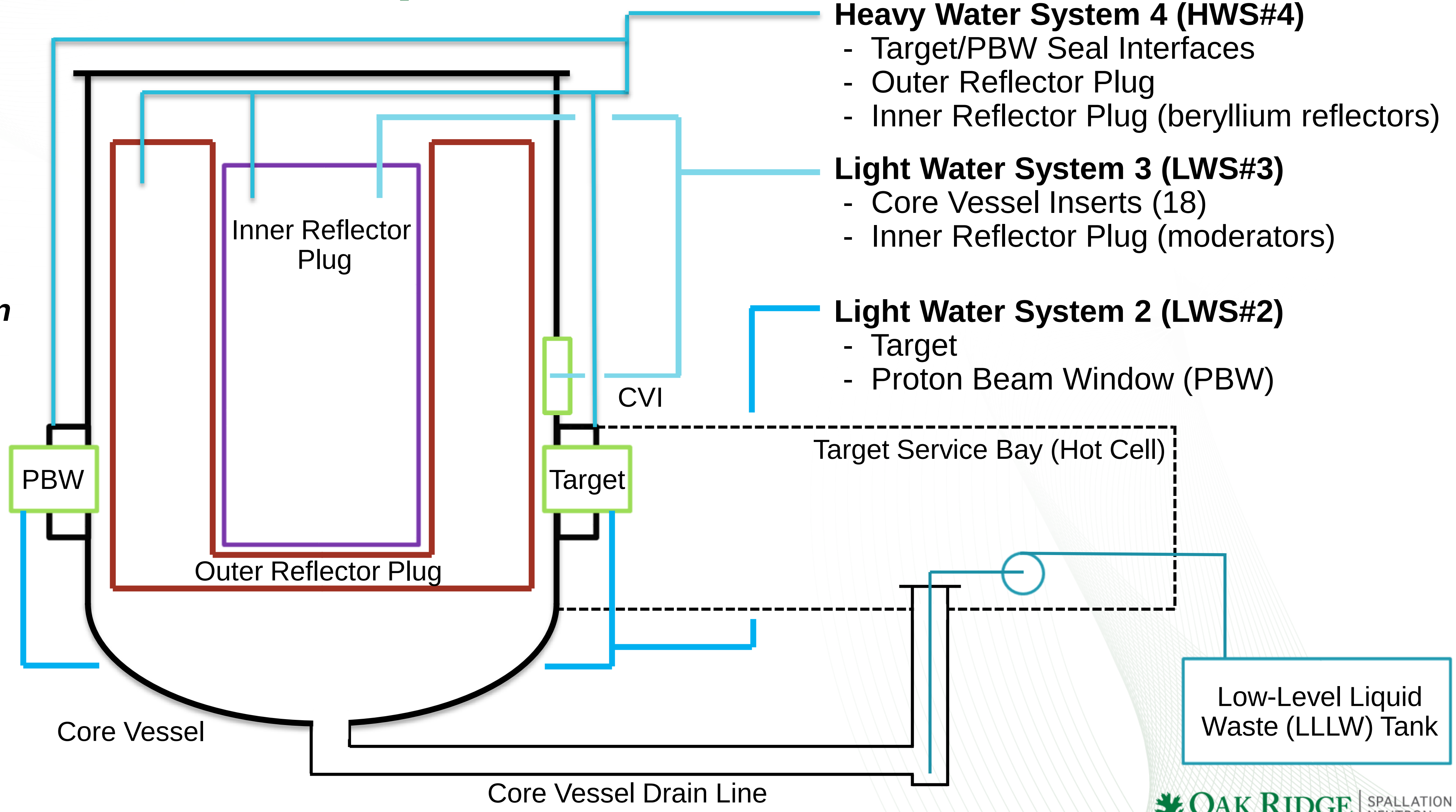
Introduction

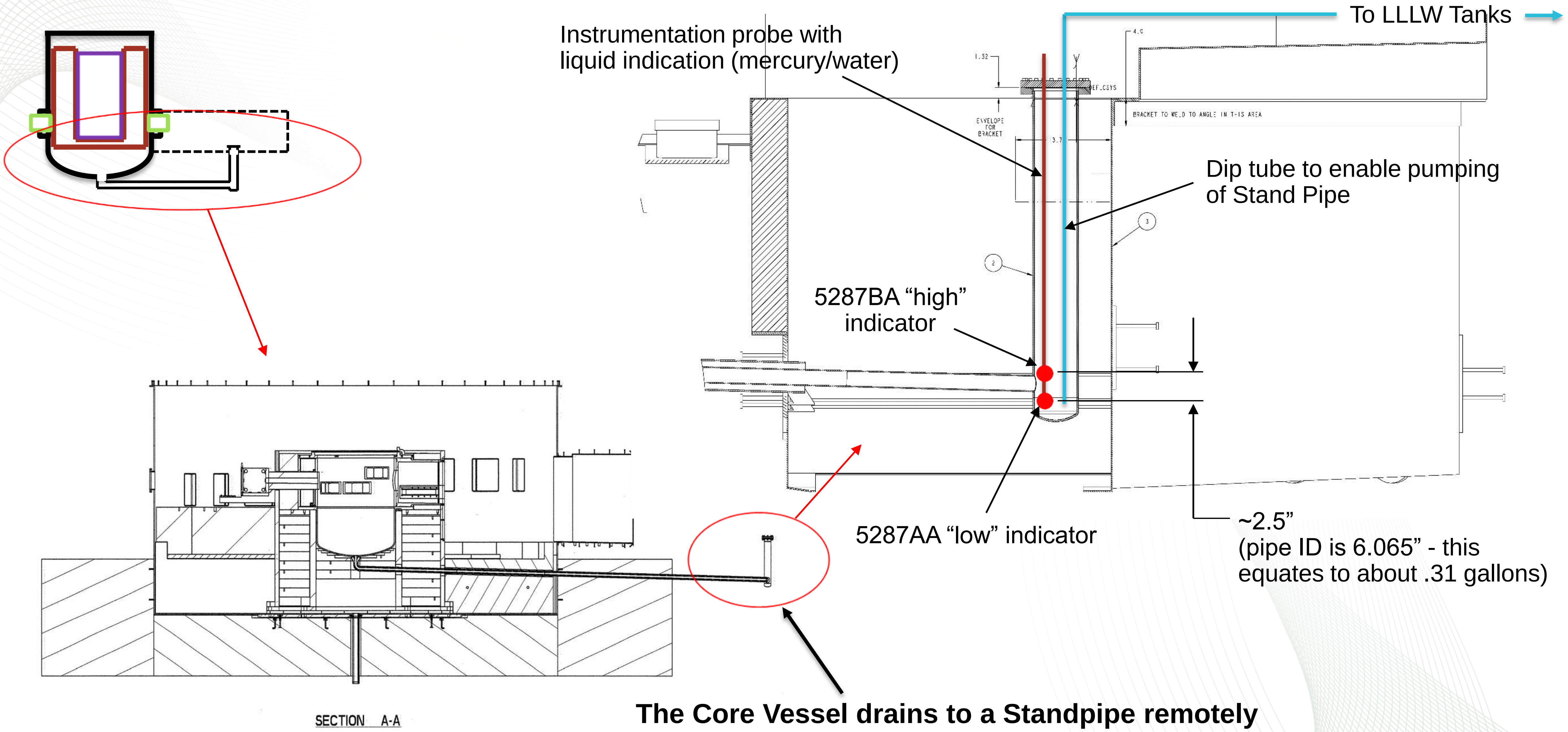
- At approximately 6:06 am on 9/19/2016 a Core Vessel leak indicator went into alarm indicating the presence of liquid water in the vessel
  - Core Vessel RGA confirmed the presence of water vapor
  - Operating with water in the vessel poses a primary concern of corrosion due to beam interaction with water vapor
- After over ten years of beam operations, one of the most dreaded operational occurrences thrust SNS engineering and operations personnel into an epic saga of investigation and remediation to correct this problem
- The following slides detail the story of how a simple water leak can present such a complex problem having far-reaching operational and technical impacts

Core Vessel Components are Cooled by Three Independent Water Loops

Many opportunities for water leaks within the Core Vessel…

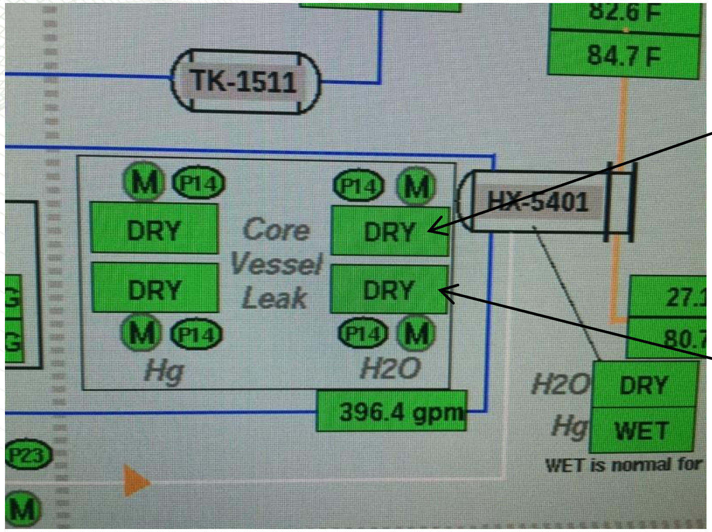


Leaks into the Core Vessel are detected in the Standpipe



The Core Vessel drains to a Standpipe remotely accessible in the target Service Bay

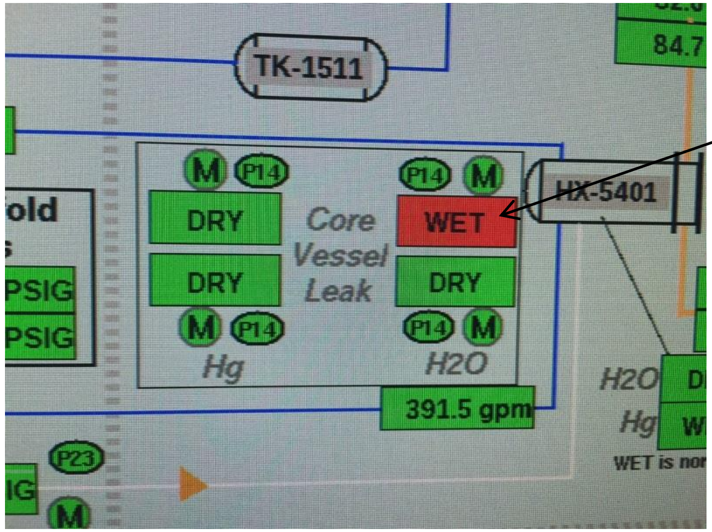
Rate of Initial Leakage Determined



5287AA “low”

5287BA “high”

~8:50 Tuesday
After Initial Pumping



5287AA “low” comes into alarm

~10:00 am Tuesday

Timeline:

- Initial AA alarm comes in at 0600 Monday
- Core Vessel is evacuated and AA alarm clears (1300 Monday)
- AA alarm returns at 1600 Monday
- Initial BA alarm comes in at 0513 Tuesday (MPS trip)
- Core Vessel pumped at 0840 Tuesday
- AA alarm comes in at ~1000 Tuesday
- BA alarm comes in at 2229 Tuesday
- Core Vessel pumped and both AA and BA clear
- AA alarm comes in at 0042 Wednesday

The two initial data points we had indicated a leak rate of approximately .31 gallons/12 hours or .026 gallons per hour

- .026 gallons/hr is 98.4 ml/hr (1.6 ml/min)
- There are approximately 20 “drops” of water/ml
- Leak rate is approximately 1968 drops/hr or 33 drops/min
- This works out to a drop every 2 seconds or so

We knew how much water was leaking, but we had no idea where it was coming from…

Initial Operational Questions

- Once the initial shock wore off, we were faced with several questions:
  - Which loop/component was the source of the water?
    - Can we tell? What are our diagnostic tools?
  - What was the appropriate action to remove the water?
    - Pump to LLLW? How much capacity do we have?
    - Is this appropriate given the nature/chemistry of cooling loop water?
  - Was there risk to SNS to continue operations?
    - Corrosion? Safety Basis impacts?
    - Do we bypass Machine Protection System (MPS) trips to allow continued operation?
  - What "unintended consequences" could arise from water leaking into the Core Vessel?
- The decision was made to bypass MPS trips and begin a regimen of pumping the Standpipe…

Determining the Source of the Water

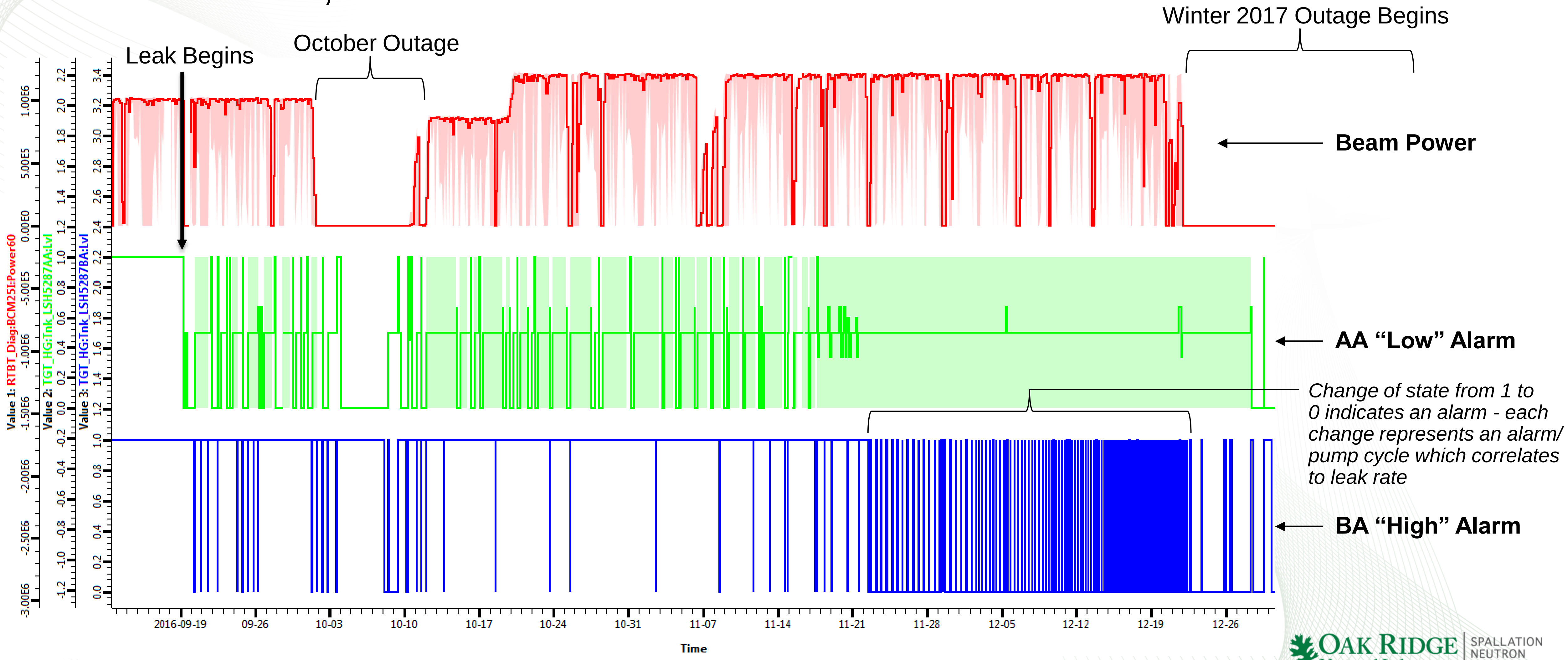
- While we were easily able to detect water and establish a leak rate, we could not determine the source
  - There was no direct method to determine which loop was losing water
    - Quantifying the amount of water in each loop is performed via crude measurements of water level in each loop's Gas Liquid Separator (GLS) tanks. This crude method was only intended for use in filling the system (hundreds of gallons) – not for looking for small leaks (.5 gallons/day).
    - Each GLS utilizes a nitrogen cover gas to maintain H2/O2 levels below flammability limits. The evaporation induced by these cover gas flows exceeded the leak rate.
  - "Secondary" instrumentation was investigated to see evidence of the leak
    - Loop flow rates, component temperatures, etc. were studied to find a correlation but none was found
  - Introducing tracers, dyes, etc. into each loop was not pursued due to potential adverse water chemistry concerns
- An October 2016 maintenance outage to replace a target module provided the first opportunity to pinpoint the source

Target Replacement Implicates LWS#2

- Target module replacement requires draining LWS#2
- During the October 2016 replacement outage, the leak rate decreased, but did not completely stop
- Once LWS#2 was filled, the leak rate returned to pre-outage levels
- It must be the Proton Beam Window!
  - Conveniently, the PBW was scheduled to be replaced in January 2017
  - Plans were developed to enable testing of the PBW cooling water boundary:
    - Prior to removal to validate the existence of the leak
    - Following removal to find the location of the leak (and hopefully the reason for the leak)
- Routine pumping of the Standpipe continued as cautious optimism envisioned resolution of the leak with PBW replacement

The Leak Rate Increases

- After about 9 weeks of a ~.03 gallon/hour leak, the rate began increasing on November 23, 2016

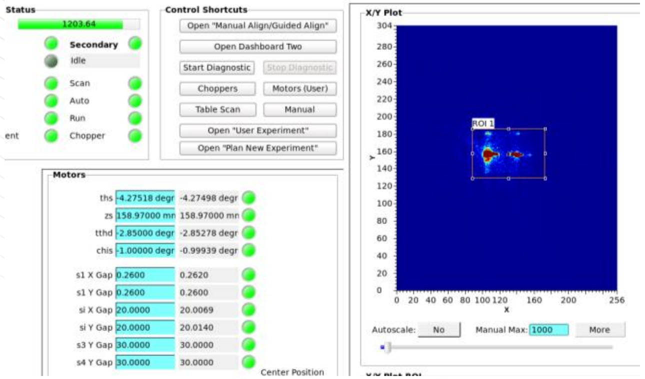


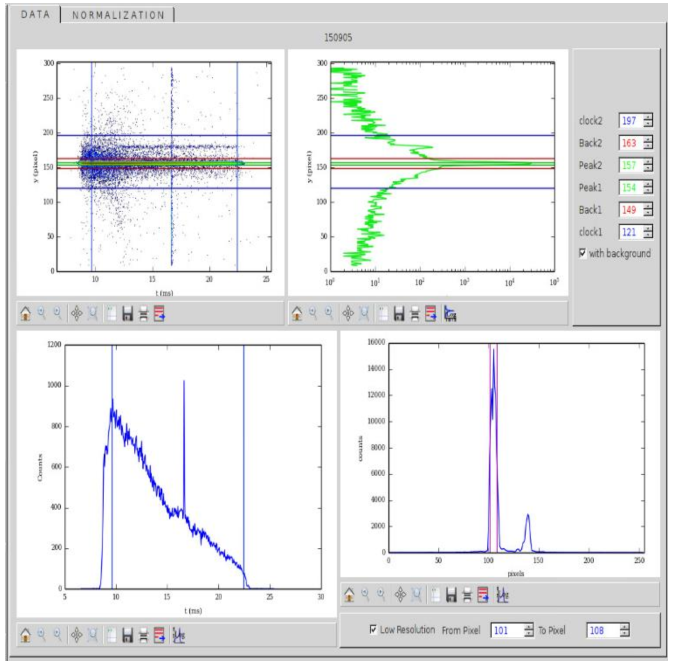
Real-time Concern was Building

- Why was the leak rate in the Proton Beam Window increasing? What was the leak mechanism? Was failure imminent?
  - Catastrophic failure of the PBW would require immediate shutdown for replacement and also risk water entering the high vacuum of the accelerator
- Closer scrutiny revealed that LWS#3 was now leaking
  - GLS level trending revealed a consistent drop in loop 3 levels
  - It seemed highly unlikely that two independent water loops could begin leaking within weeks after 10 years of leak-free operation
- The leak rate was monitored, but the assumption remained that it must be the Proton Beam Window

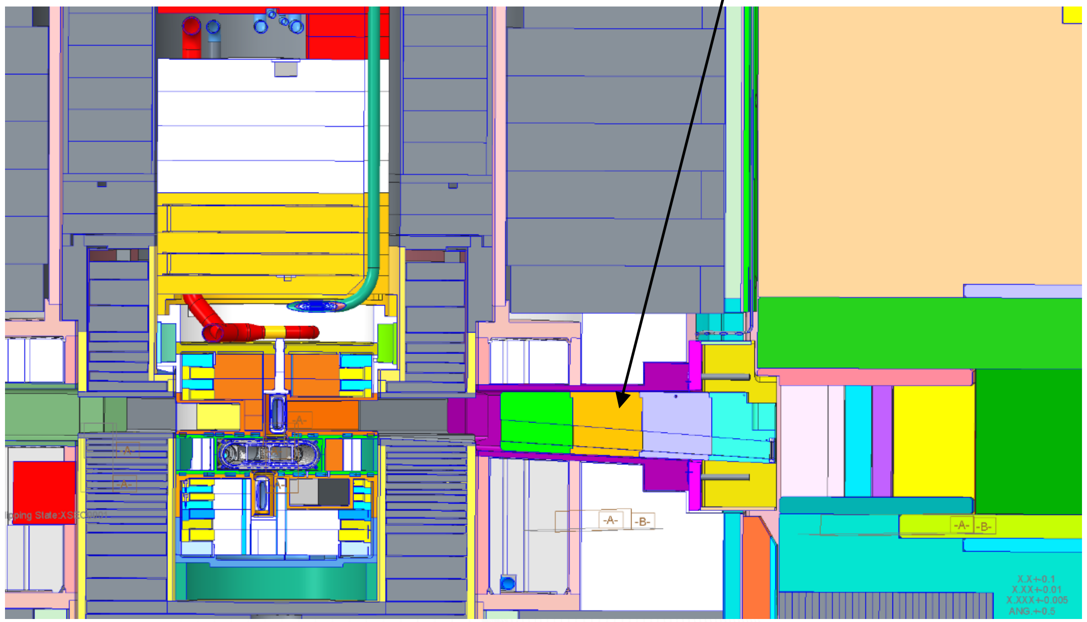
BL-4B Begins Losing Neutrons

- BL-4B scientist began noticing reduced neutron flux:





BL-4B CVI



<u>Double pinhole beam image</u>

- Collected at θ_i = -2.85° - two-bounce zone
- Image height
  h_I = 3 pixel × 0.7 mm/pixel
  = 2.1 mm
- Source height
  $h_S = h_I \times (d_{source\text{-}slit} / d_{slit\text{-}det})$
  = 2.1 mm × 972 cm / 289 cm
  = 7.1 mm
- Source width: 16.4 mm

Consistent with **7.3 cm** of 8.0 cm window blocked at CVI exit

BL-4B Core Vessel Insert beam guide is the only guide at SNS that has a downward slope. Neutronics studies indicated that the flux was decreasing in a manner consistent with the guide slowly filling with water.

BL-4B eventually ceased operation prior to the January 2017 outage.

There was no plausible mechanism for a PBW leak to impact BL-4B…there must be another leak…

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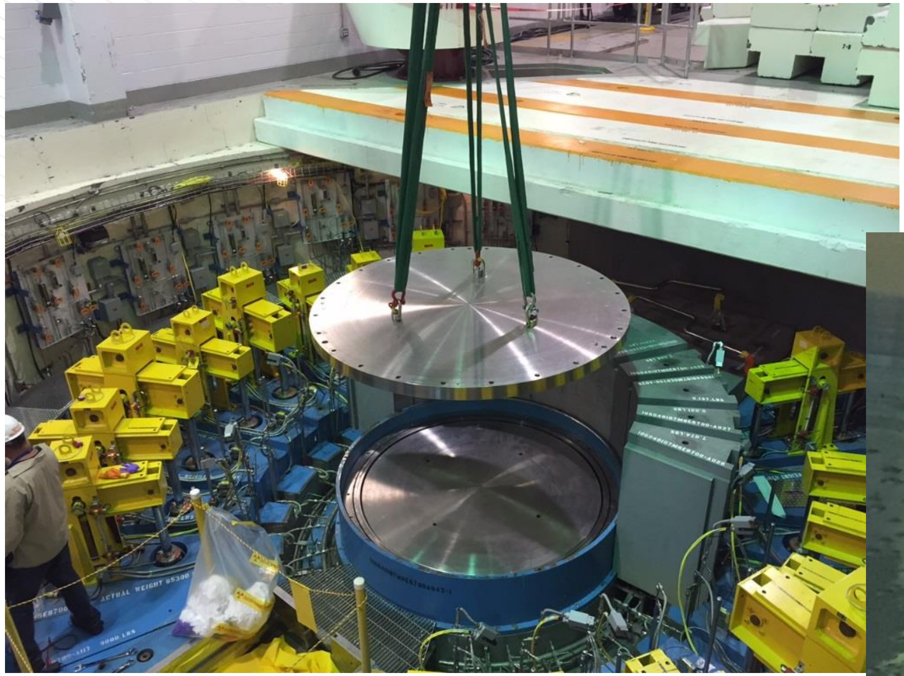
Winter Outage Permits Core Vessel Inspection

- Following replacement of the PBW in January 2017, the Core Vessel lid was removed for the first time since SNS operations began:



Significant condensation was found on lower surface of Lid
- Sampling indicated water was highly tritiated

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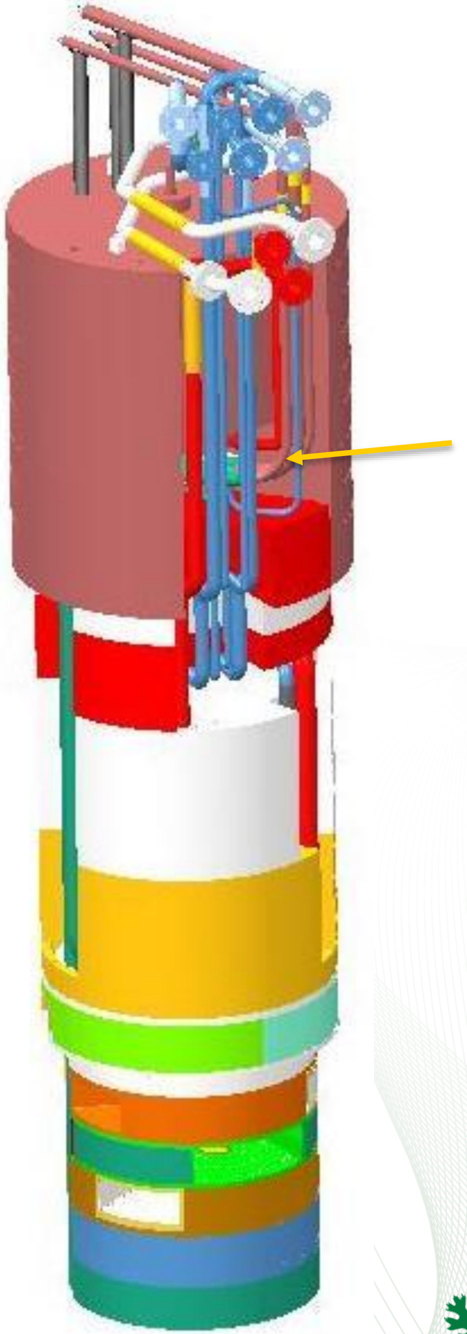
Core Vessel Inspections Locate LWS#3 Leak

- Once access was possible, a bore scope was used to look for evidence of a leak:

Water was observed leaking from the helium jacket tubing around the Top Downstream Moderator LWS#3 hydrogen transfer line

Solutions Were Elusive

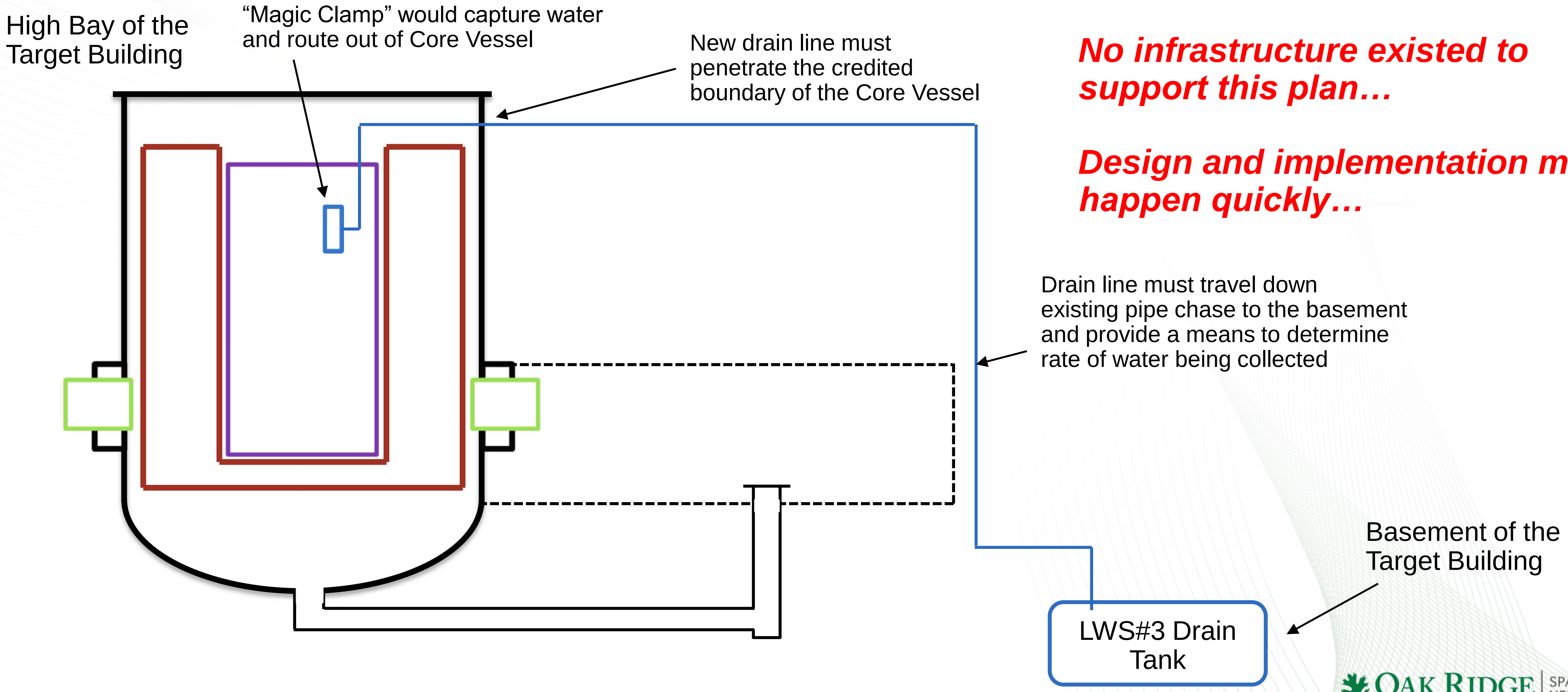
- "Stopping" this leak was not possible
  - The observed leak was not the leak location – only where the water was exiting the helium jacket
    - The leak itself was likely much deeper in the IRP and inaccessible
  - This line was a hydrogen transfer line for the cryogenic moderator – the presence of water in this location involved safety basis implications
  - Capping this line was not possible due to potential unacceptable pressure increases on moderator piping
- Decision was made to attempt to capture water and route out of Core Vessel



Water was found exiting the helium jacket approximately 1 meter below the top surface of the IRP
- Access was very limited

Outage was extended to install mitigation hardware

- The basic plan was to capture the leaking water and route it out of the Core Vessel and back to the LWS#3 Drain Tank

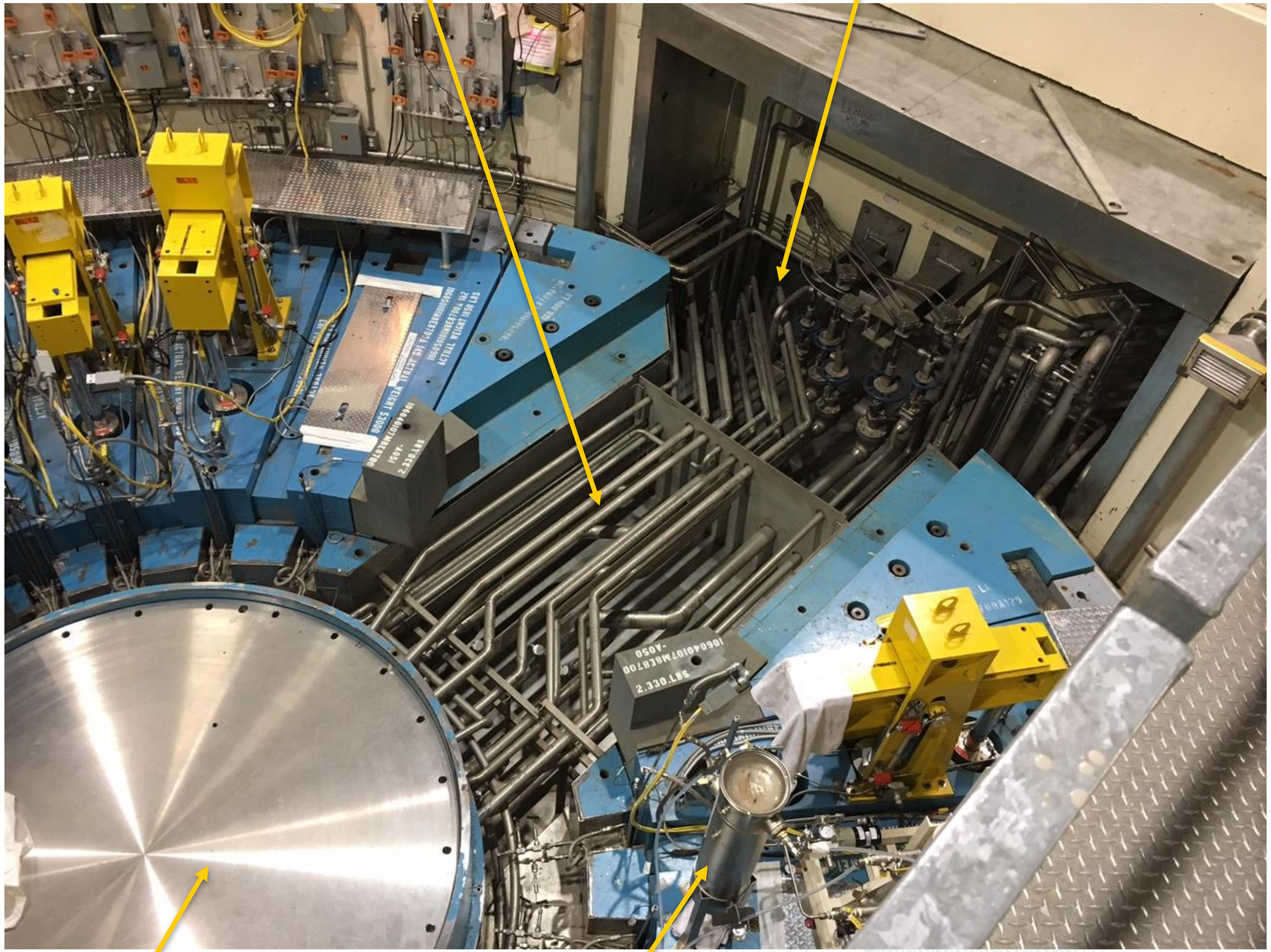


No infrastructure existed to support this plan…

Design and implementation must happen quickly…

Preparation Activities

- Significant shielding was unstacked
- Plan was devised and implemented to dry BL-4B
- Competing designs for magic clamp were produced and tested
- Piping, control and leak rate monitoring equipment was designed and installed



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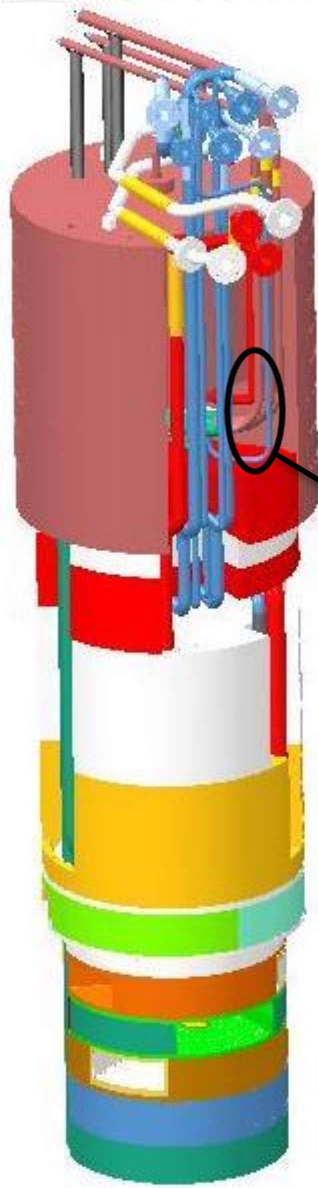
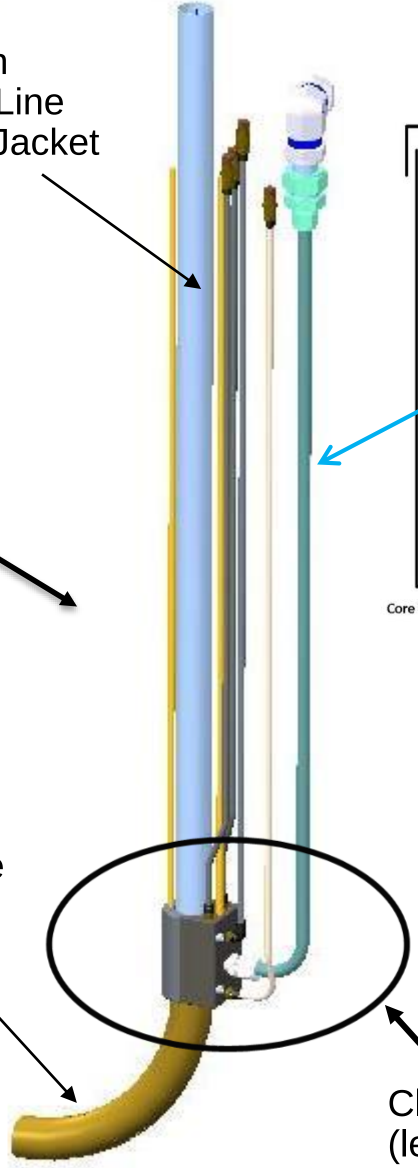
“Leak Monitoring and Control System” Design

IRP

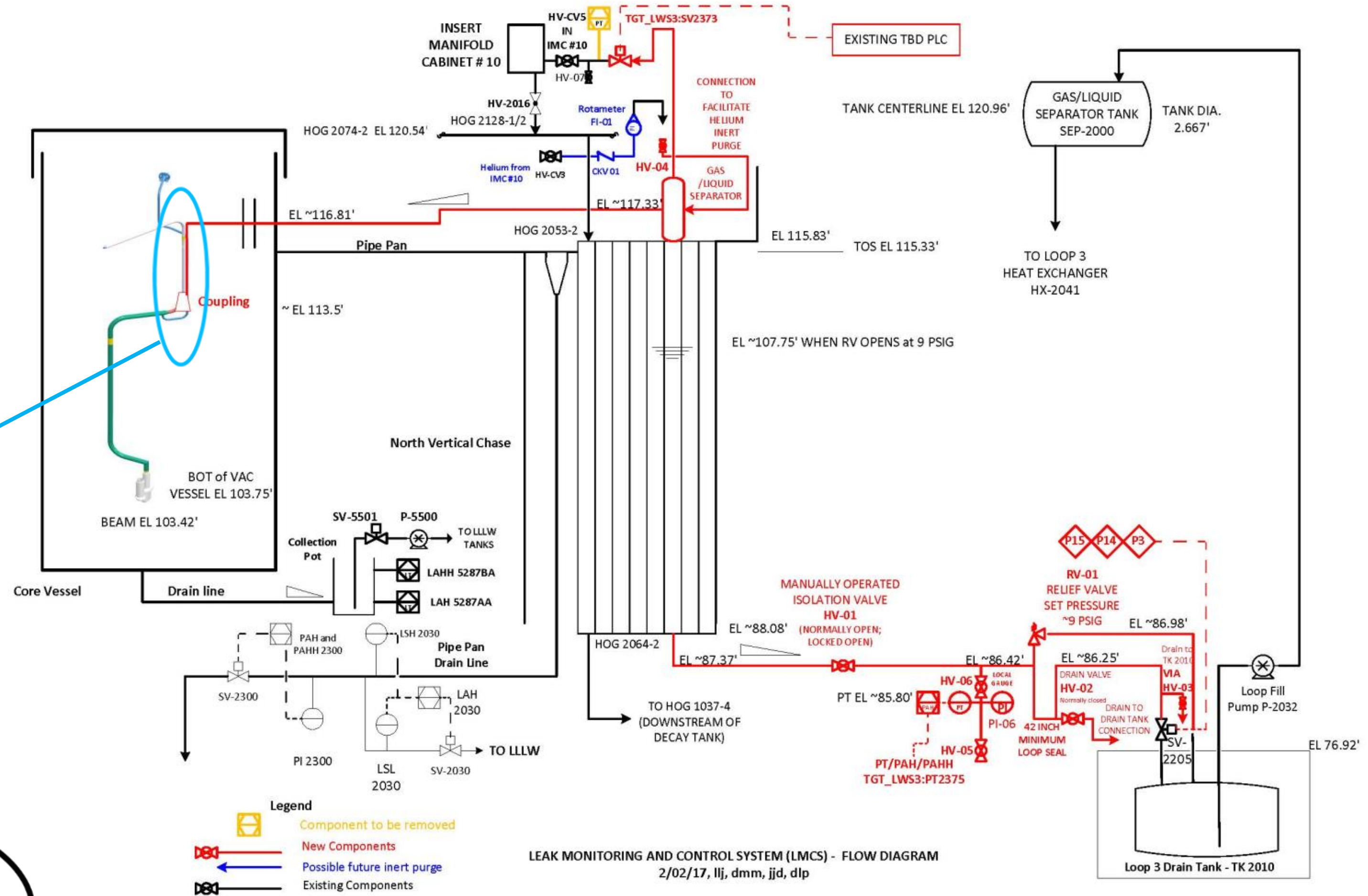


Hydrogen Transfer Line Vacuum Jacket



Hydrogen Transfer Line Helium Tube

Clamp installed at helium/vacuum tube interface (leak location)

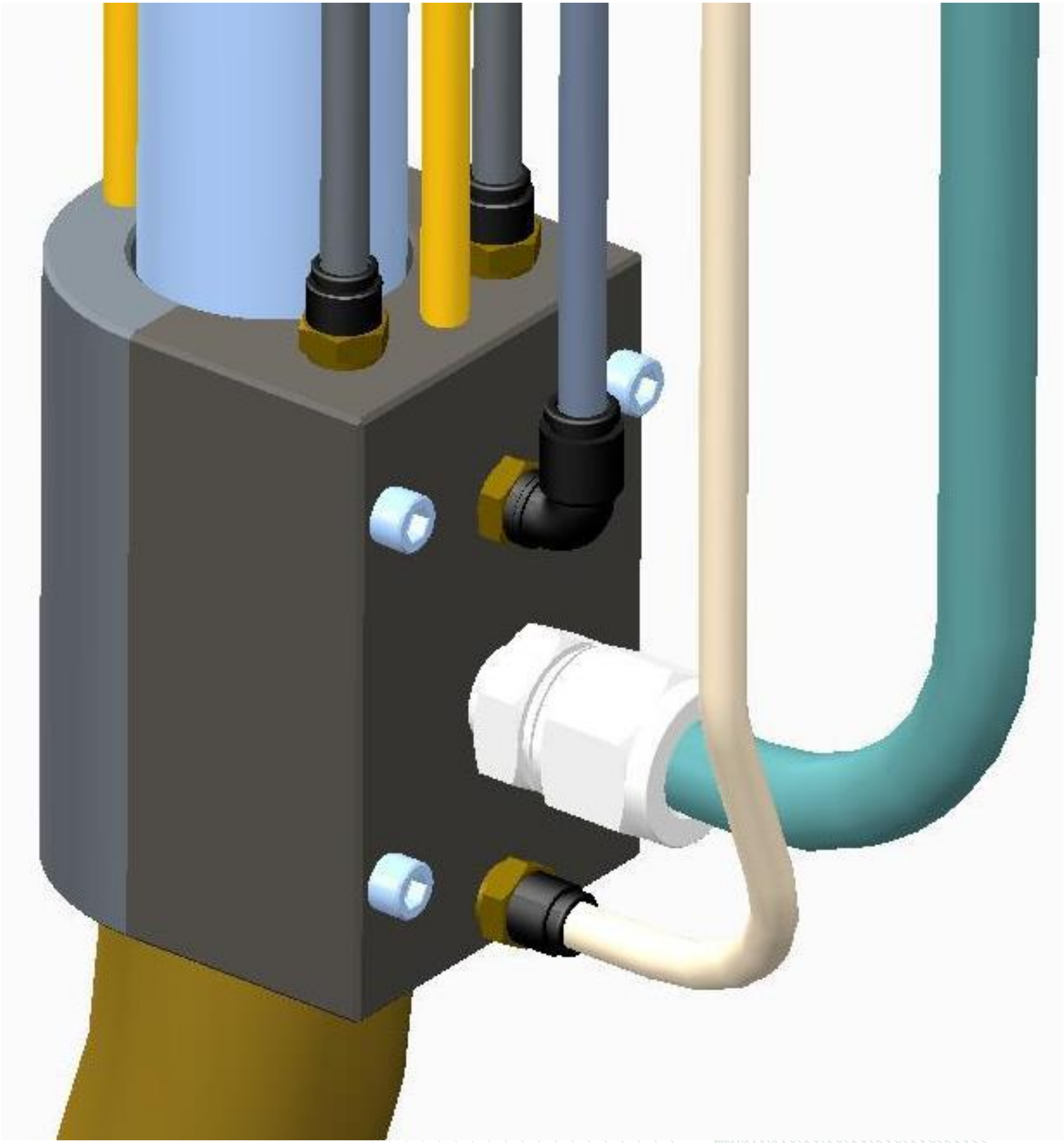


LMCS Flow Diagram
(components in red represent new hardware)

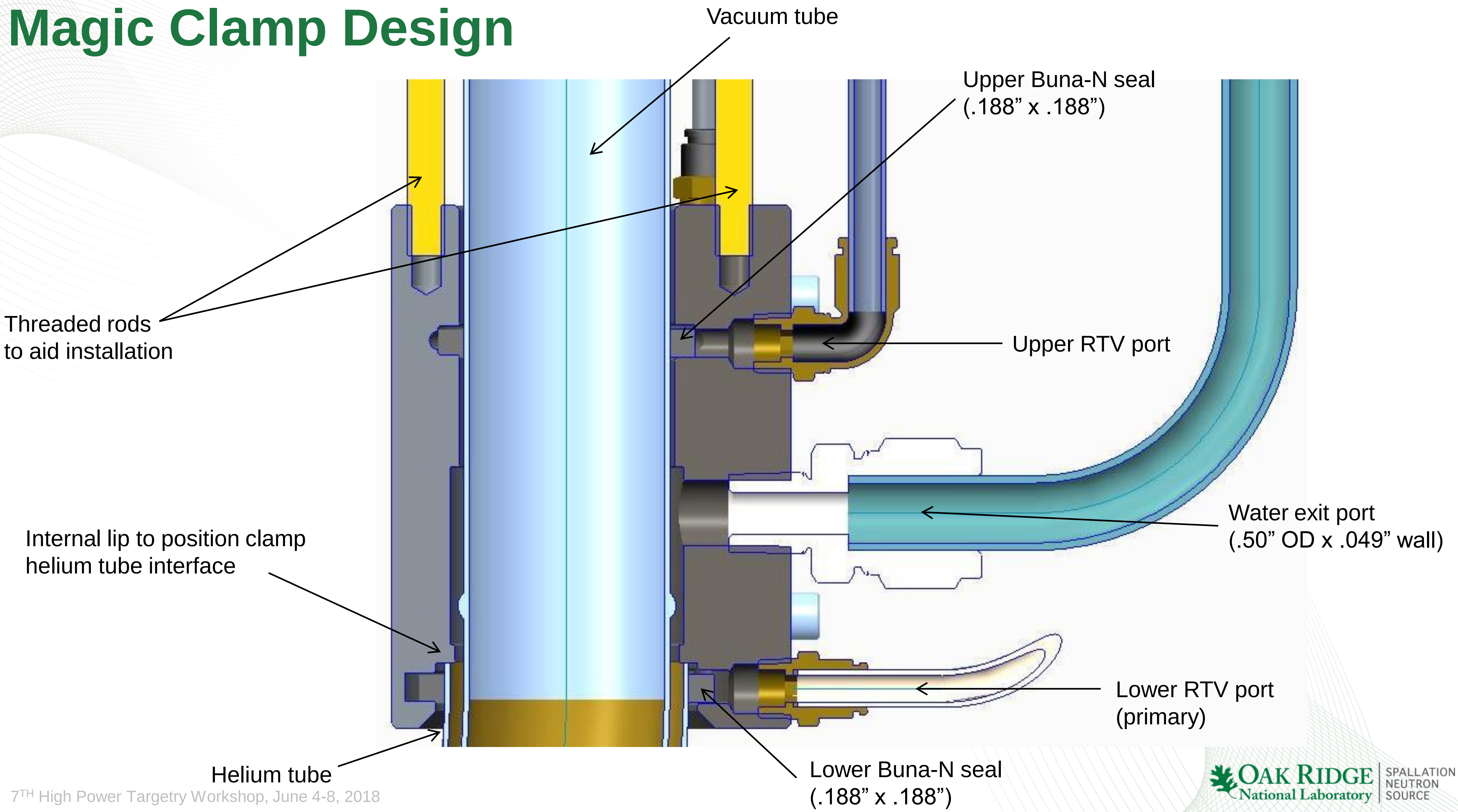
Magic Clamp Design

- Challenges:
  - Access to leak location
  - Non-concentric tubes at leak point
  - Devising a robust sealing method
  - Actual installation in Core Vessel
- Basic Design Features:

  Two-piece clamp design
  - Buna-N seal rings for vacuum and helium tubing
  - Ports to enable injection of RTV sealant to supplement the Buna-N seals
  - .5” port for water exit tube
  - Fabricated from 300 series stainless steel
  - Includes interface for threaded rods to aid in installation



Magic Clamp Design

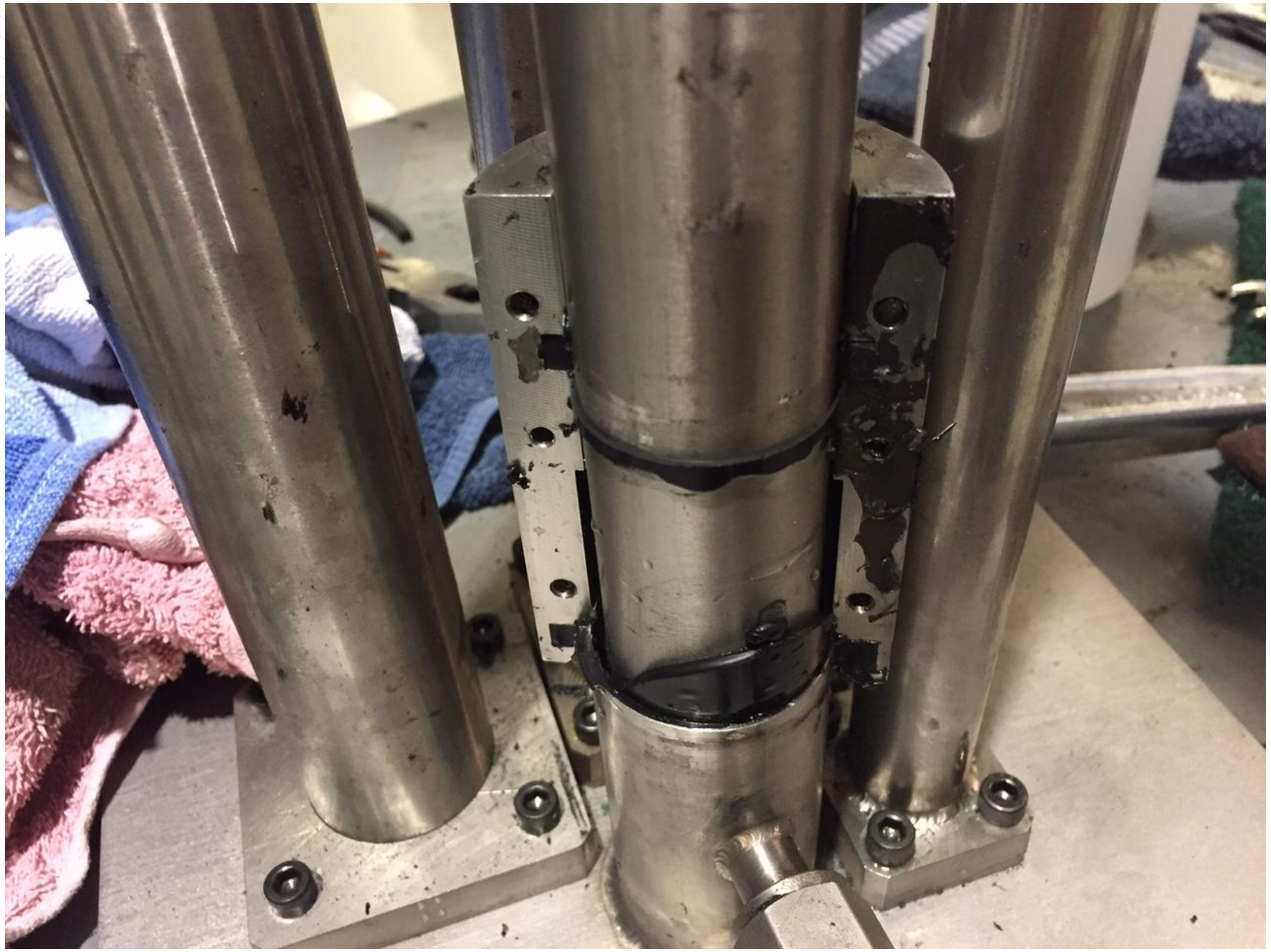


Mockup Testing

- Two competing seal designs were originally fabricated for evaluation
- A mockup was designed and fabricated to:
  - Assess feasibility/ease of installation of the two designs
  - Leak test clamp designs once installed
- Both designs were evaluated for ease of installation
  - Evaluation revealed that both clamps could be installed within the confines of the existing tubing

Installation and Leak Testing

A mockup was made to replicate the actual tubing configuration to validate installation method and access



The ability to pump RTV to the installed location and the ability of the RTV and gasket combination to seal under pressure was evaluated

- Several iterations were performed to understand exactly how much RTV was required and to determine the correct amount to be pumped remotely

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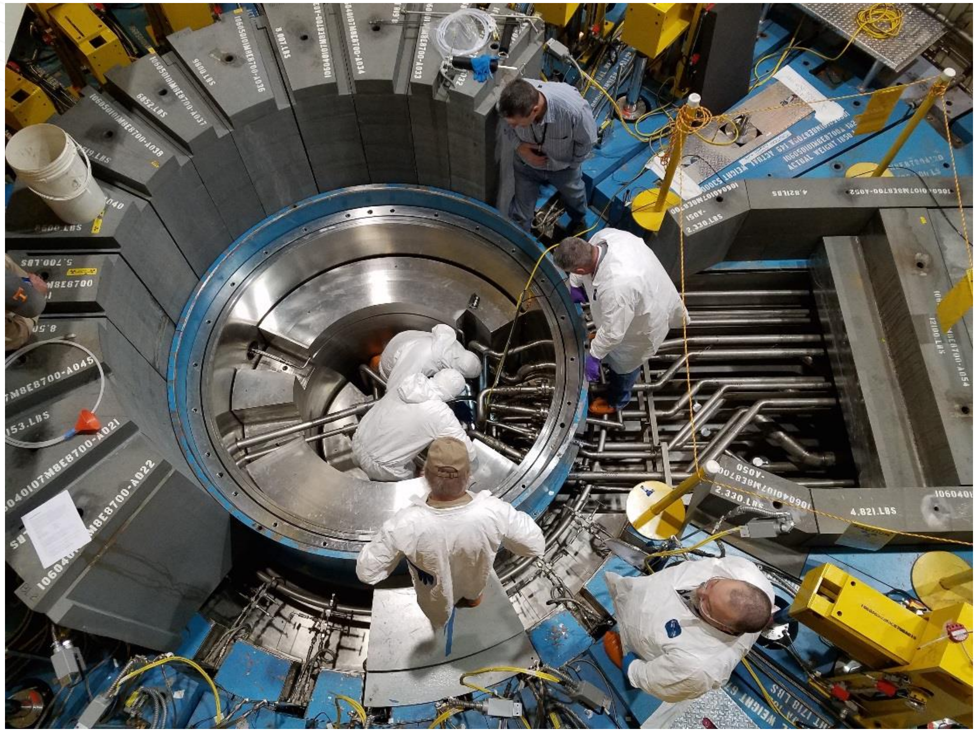
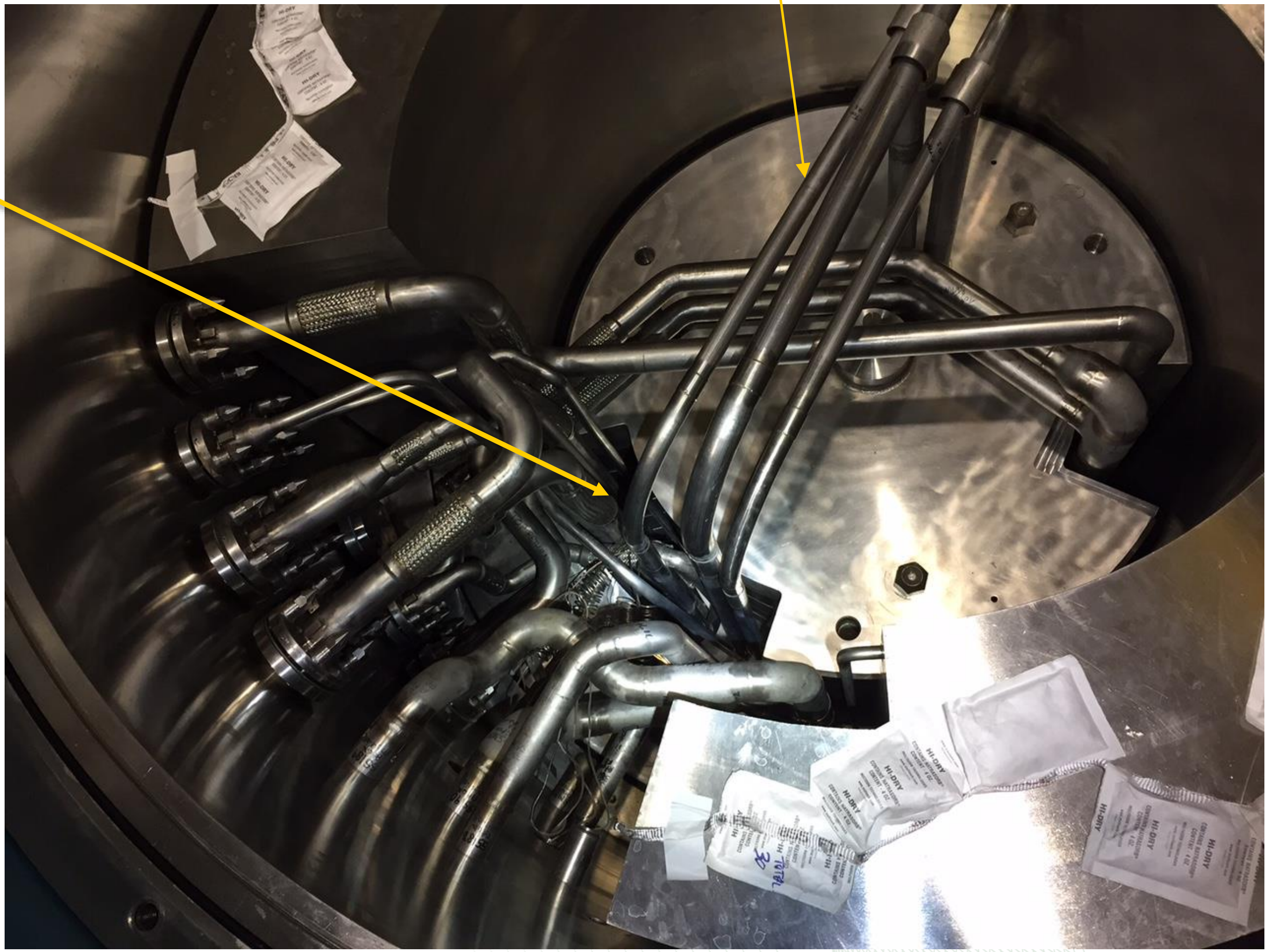
Clamp Installation was Very Difficult

- Installation location is approximately 1 meter below this point, down the pipe chase on the side of the IRP



Top Downstream Moderator Hydrogen Transfer Line



Dose rates were approximately 25 mR/hr (.25 mSv) at pipe chase

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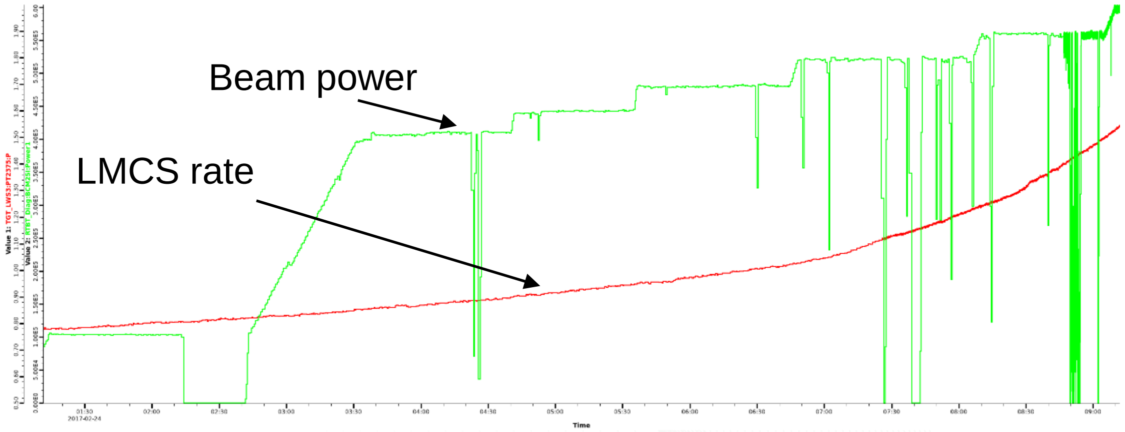
Successful LMCS Integration

- The clamp was successfully installed and leaking LWS#3 water now being routed to the drain tank for re-use rather than to LLLW tanks for disposal
  - Design, fabrication, testing and installation of the entire system was accomplished in less than 5 weeks



- The problem was that the leak into the Core Vessel persisted? The PBW was replaced?
  - Either the clamp was leaking, or something else was leaking…

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Leak Management Operations

- Moving into neutron production, we knew:
  - The LMCS was moving water (gallons/hr) into the LSW#3 drain tank
  - We still had a leak of approximately .02 gallons/hr into the Core Vessel
  - BL-4B was "dry" with neutron flux restored
- We didn't know:
  - What was the source of the Core Vessel leak?
    - Was the LMCS clamp leaking? LMCS rates were increasing…
    - Did we have another leak of unknown origin?
- Efforts continued to parse data to determine the source of the leak into the Core Vessel and monitor LMCS leak rates

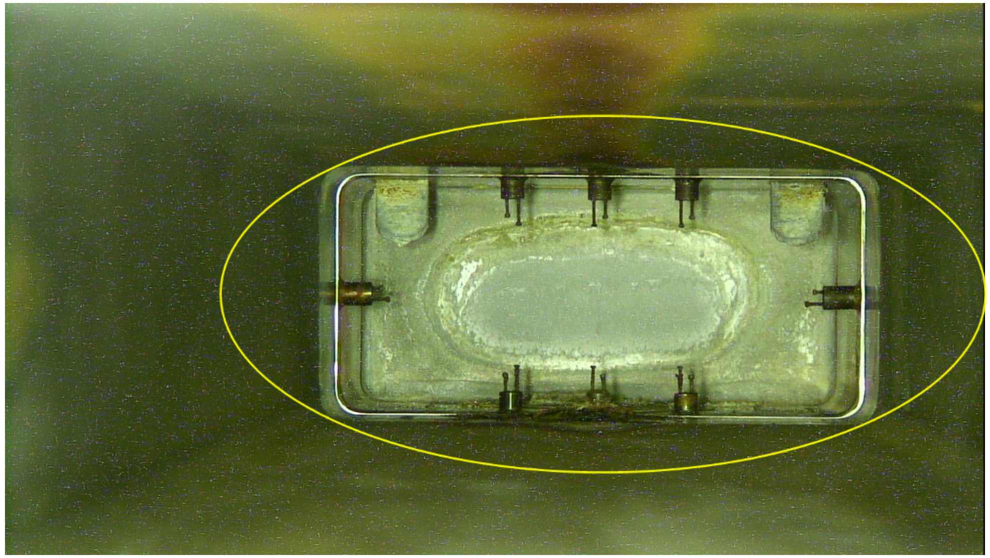
Evidence of yet another leak…

- Evidence began pointing to a leak in HWS#4
  - Trending data over time showed distinct drops in the Gas Liquid Separator for loop 4 versus the other two loops
  - Targets removed from service showed signs of water staining
  - BL-4B began filling with water again
- Testing during the June 2017 outage indicated a leak in a HWS#4 circuit internal to the IRP
- Remediation would have to wait until IRP replacement (winter 2018)

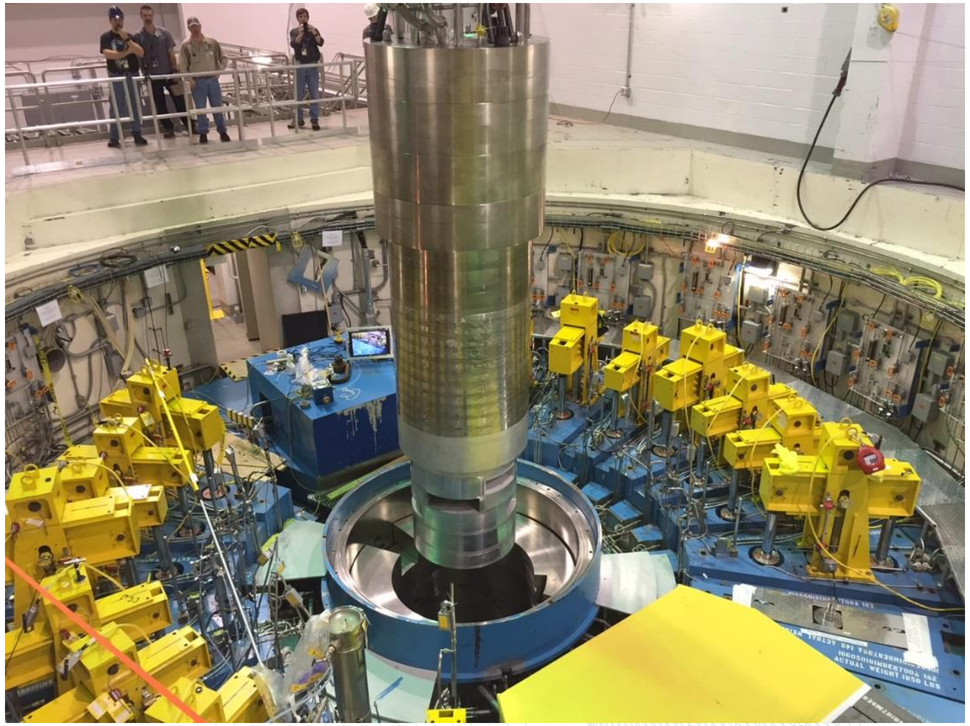
Water Stains Visible on Target Water Shroud

IRP Replacement Outage Corrects all Leaks

- Initial inspection of LMCS clamp revealed a slight leak
  - LMCS hardware was removed from the Core Vessel
- Remote inspection of the Core Vessel revealed discoloration and corrosion on aluminum components
- BL-4B was dried again

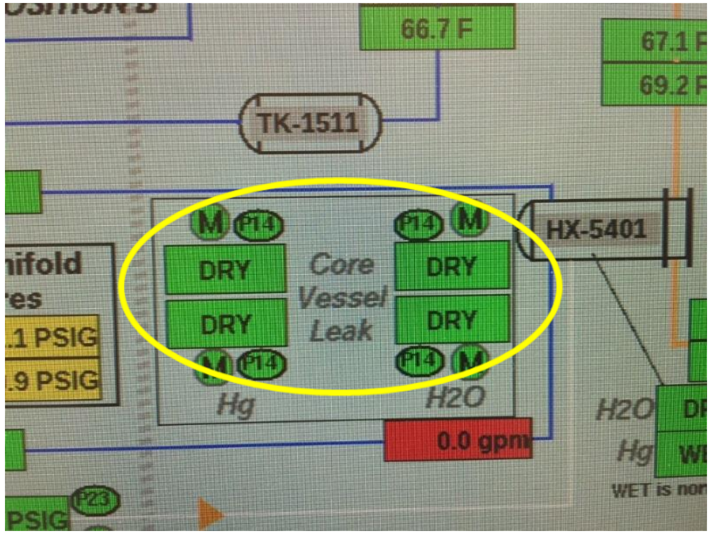


Installed PBW



IRP-2 Installation

Success, but Lessons Learned



DRY!

- Currently there are no leak indications within the Core Vessel!
- Lessons Learned:
  - Each of our leaks manifested themselves in components that were operated well beyond their planned lifetime
  - Being able to detect the presence of water is valuable, but it is also important to be able to identify the source
    - Our ability to find the source of the leaks was very limited which impacted operational decisions and mitigation strategies
  - Unintended consequences:
    - Adverse effects for BL-4B (instrument was shut down)
    - Corrosion to Core Vessel components
    - Disposal of thousands of gallons of waste water was expensive

Thank You!