

# **A Brief History of the NRU Reactor Vessel Leak and Repair**

TRTR Conference

G.B. Wilkin

Entire NRU Return To Service Team

2010 September 19-24



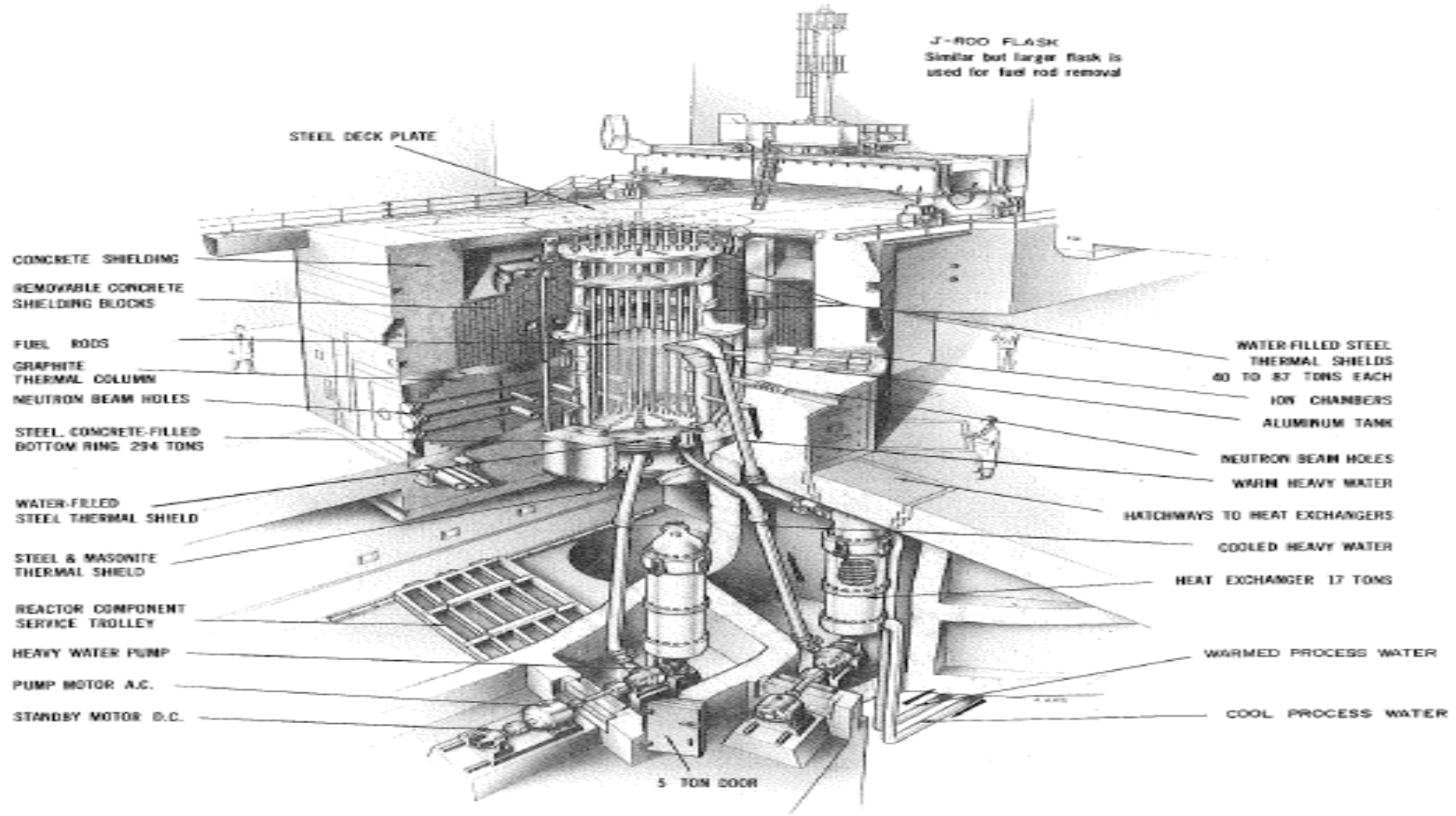
# Outline

- Description of NRU
  - Leak details
  - Special tools developed
  - Inspection of the vessel
  - Corrosion mechanism
  - Vessel cleaning and welding
  - Future corrosion mitigation
- 
- I was not involved in the NRU return to service project
  - “Only the facts”

# Introduction – What is NRU?

- National Research Universal Reactor (1957) located at the Chalk River Laboratories, Ontario, Canada
- Versatile research reactor
  - Support for existing CANDU® reactors
  - Support of new reactor & reactor technology and materials
  - National Research Council Canadian Neutron Beam Centre
- Medical isotope production
  - Benefits more than 70,000 people internationally each day
  - Used for cancer treatment and early cancer detection
  - Used to diagnose conditions of the heart, circulatory system & other organs

# Cross Section of NRU



## NRU REACTOR

ATOMIC ENERGY OF CANADA LIMITED - CHALK RIVER, ONTARIO

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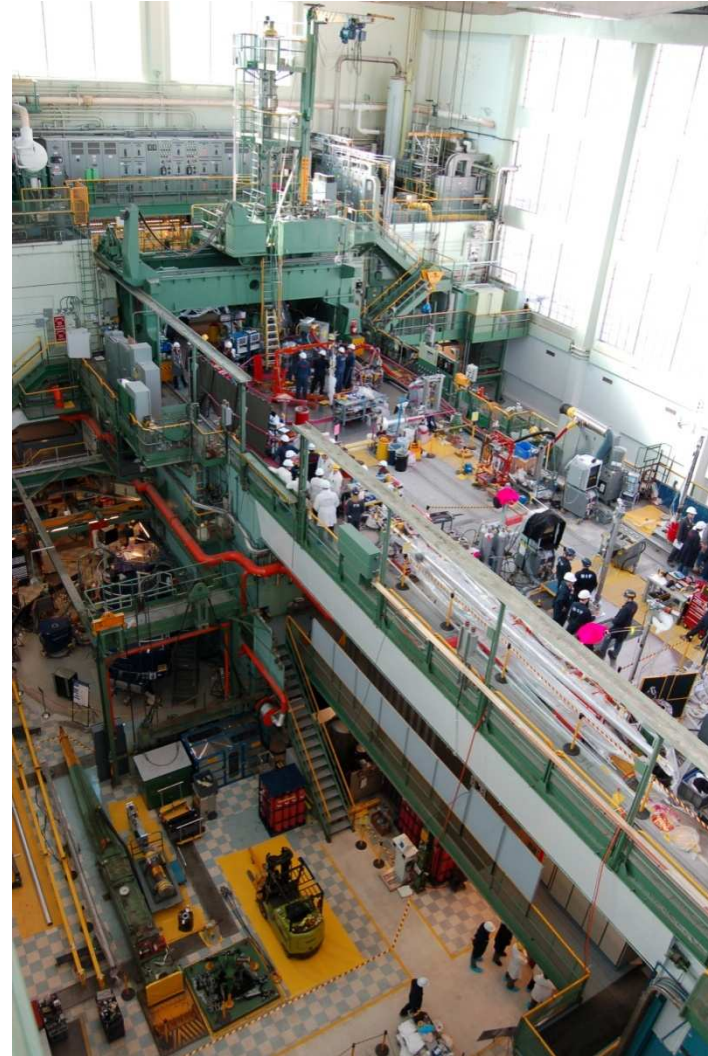
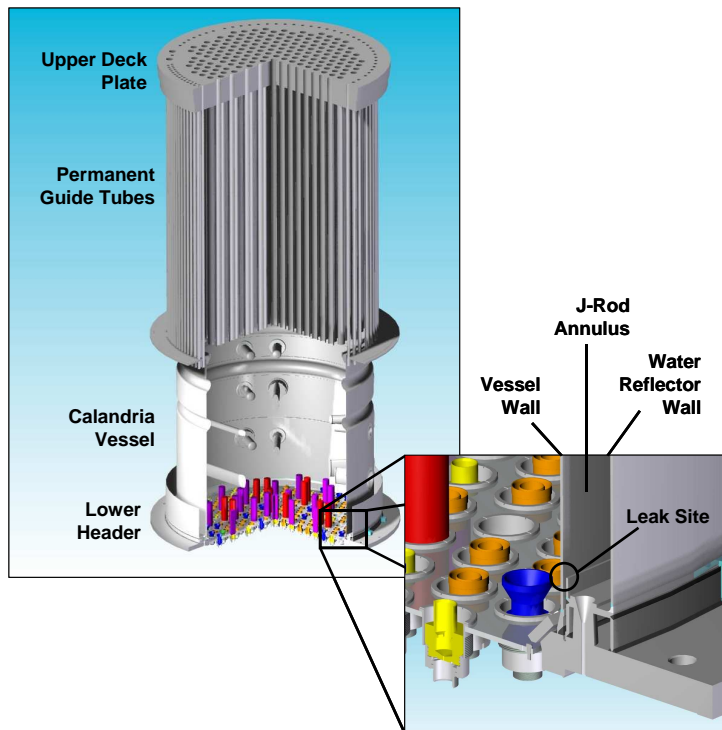
## May 2009 Outage

- Minor heavy water leak from the main vessel into the J-rod annulus detected
  - Visual inspection of the J-rod annulus determined that the leak site was in the vessel wall at the bottom of the J-rod annulus near position JR-41
  - Determined that the heavy water leak was due to corrosion of the reactor vessel wall from the outside
  - Additional areas of corrosion around the base of the vessel also required remediation
  - AECL decided to keep the NRU reactor shutdown for an extended period to repair the vessel

# Location of Heavy Water Leak

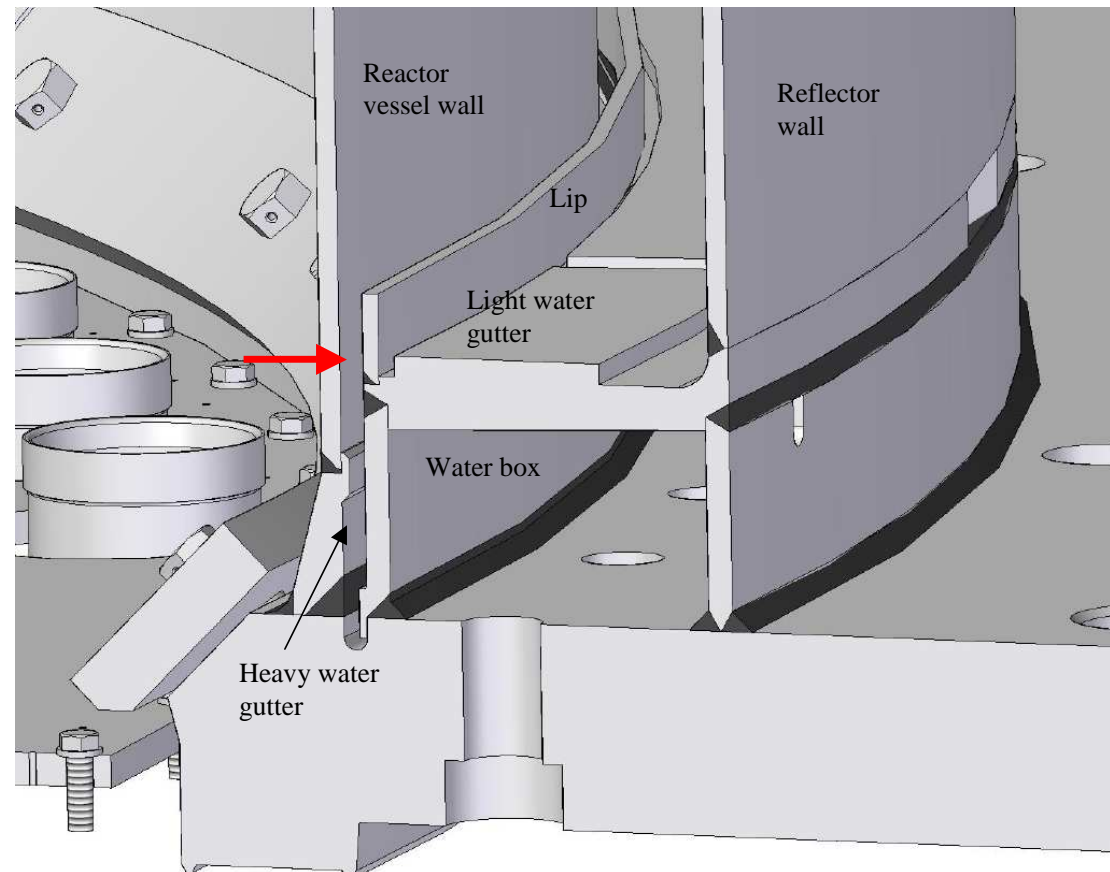
Accessing the leak site location:

- Leak site is 30 feet below the deck plate at the base of the vessel
- Access through 4.75-inch dia. tubes
- High radiation environment



# Leak Site

- Detailed non-destructive examination of lower vessel wall performed
  - Leak location determined accurately
  - Corrosion widespread in the lower portion of the J-rod annulus



# Condition Assessment of Vessel



## Non-destructive examination:

- Remote video inspections
- Ultra-sound examination
- Eddy current probes
- Over two million data points
- Four phases

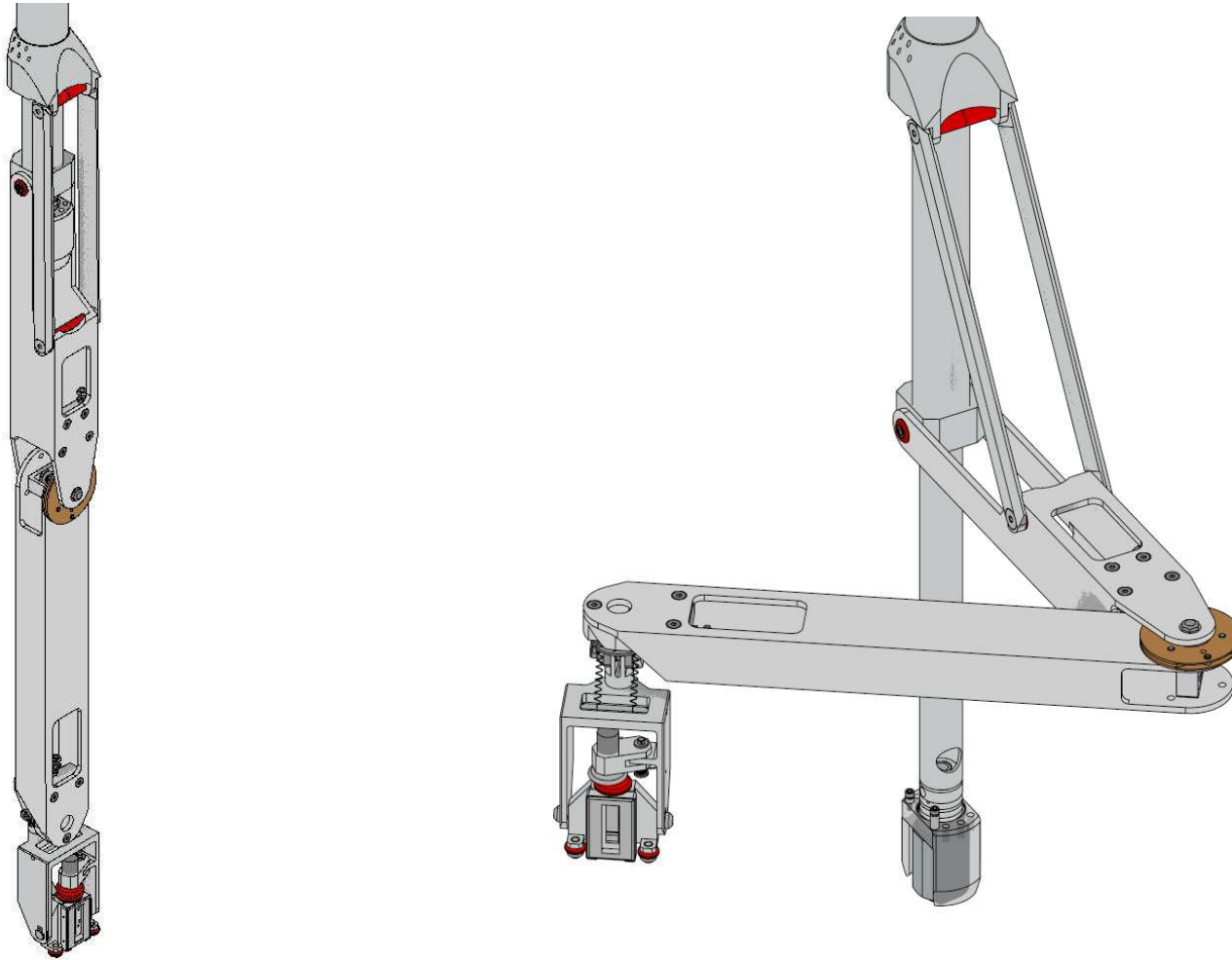
One of largest single NDE inspection campaigns ever carried out in the nuclear industry.

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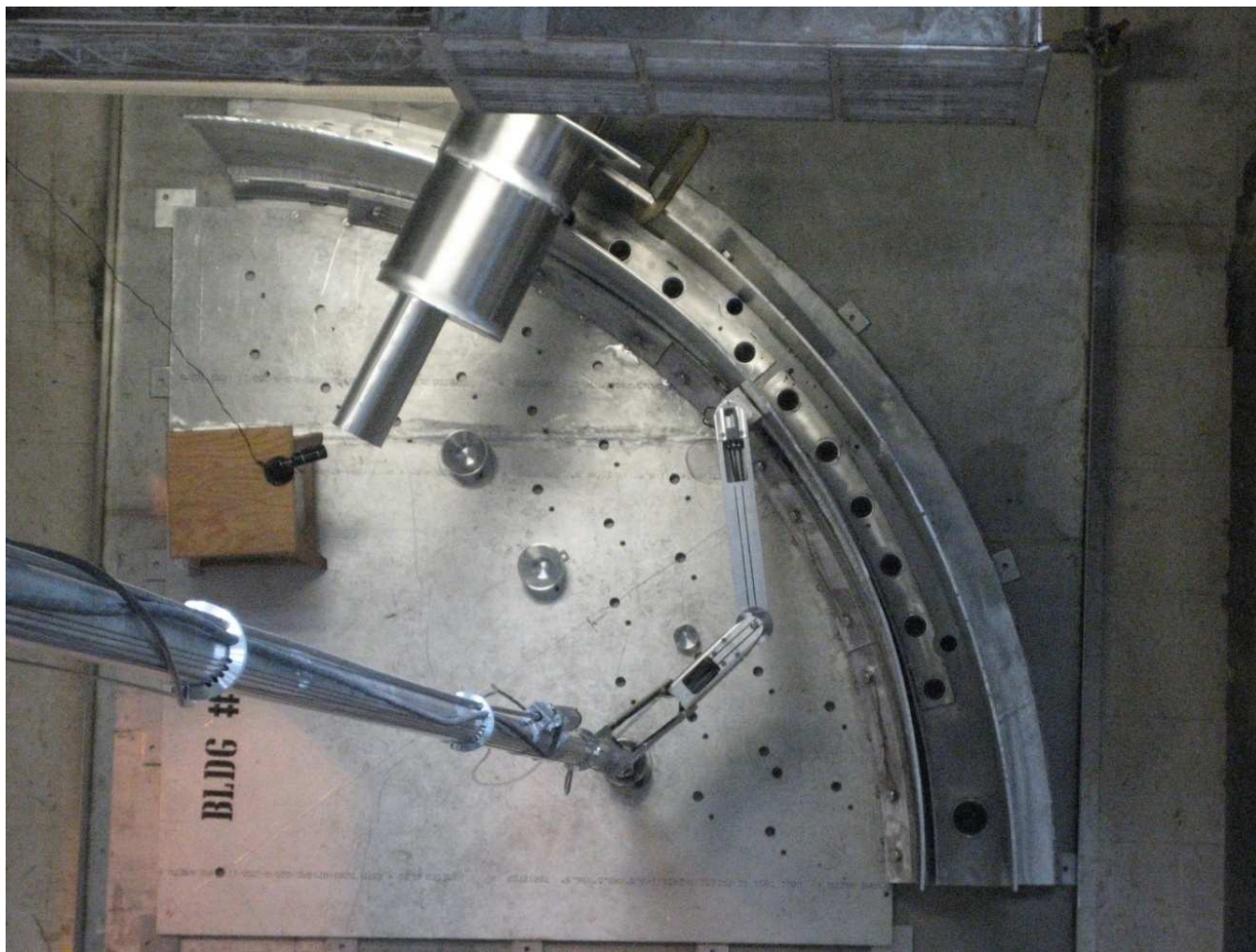


# Mk II Inspection Tool



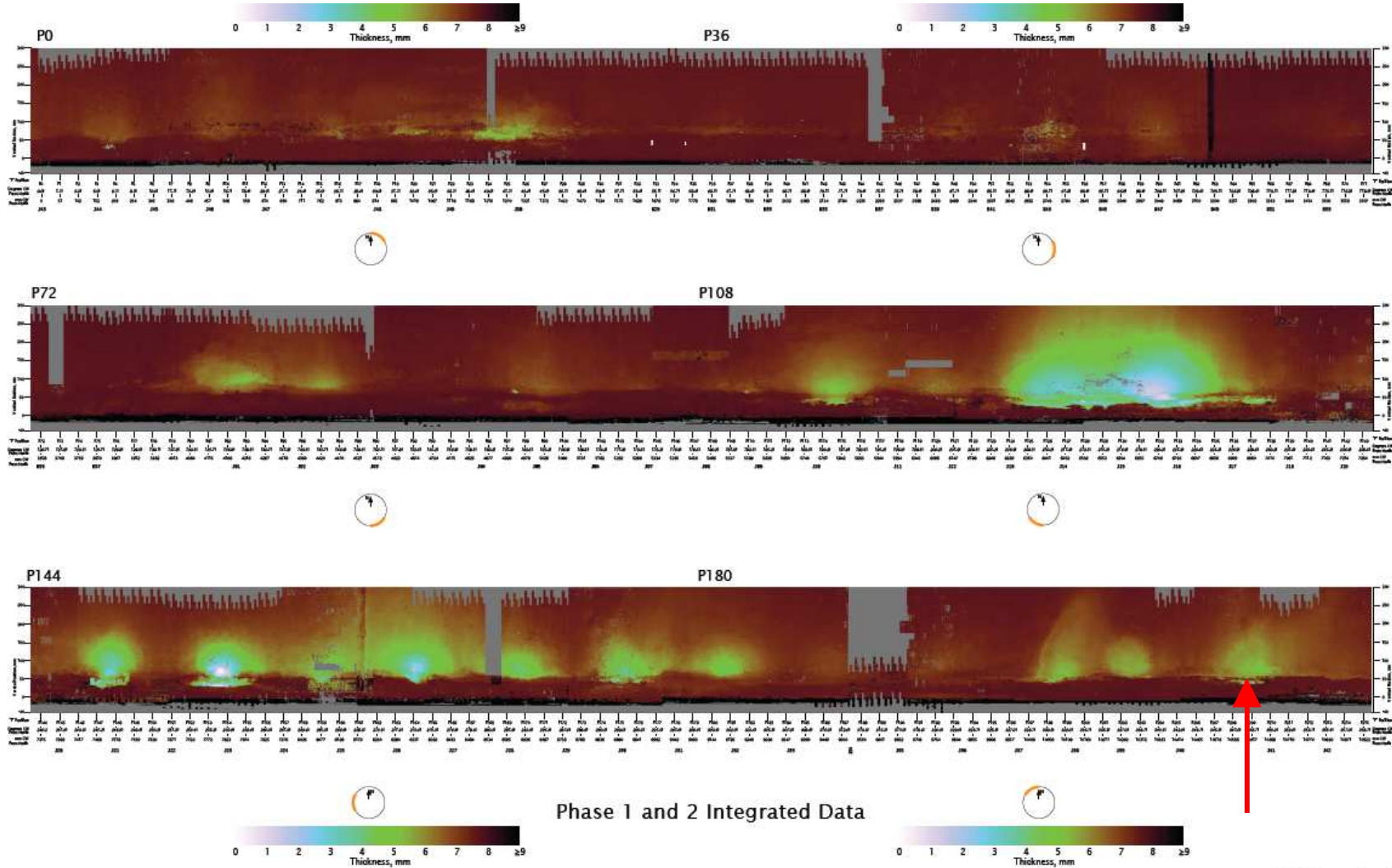
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# Mk II Inspection Tool in Mock-Up



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# Map of Vessel Wall Thickness (UT/ET Scan)



# Chemistry in NRU

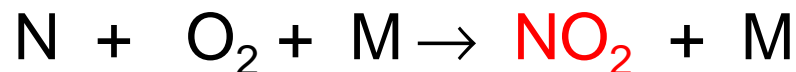
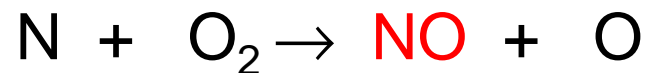
- Heavy water chemistry very similar to CANDU moderator
  - Low conductivity heavy water
  - Same fluid is coolant and moderator
  - Net radiolytic production of deuterium and oxygen – uses cover gas recombiners to remove radiolytically generated deuterium
- Main vessel surrounded by an annulus called the J-rod annulus
  - This space was filled with dry carbon dioxide
  - Effects of water and air ingress discussed below
- Reflector is aerated neutral pH light water

# Corrosion Mechanism

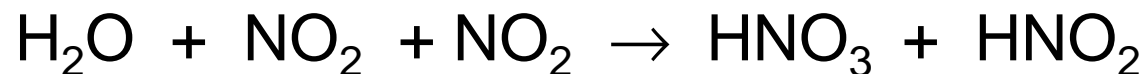
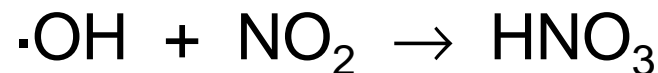
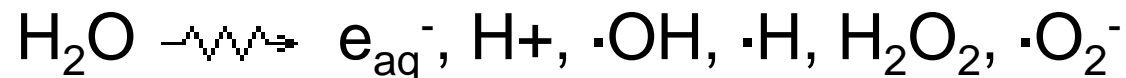
- J-rod annulus designed to be filled with carbon dioxide gas and kept dry
- However:
  - Aging of CO<sub>2</sub> system reduced gas flow
  - Light water ingress from reflector leaks into J-rod annulus
  - Air ingress from many openings in J-rod annulus
  - High radiation environment
- Created the conditions amenable to the radiolytic production of nitric acid

# Radiolytic Formation of Nitric Acid

- Gas phase chemistry:  $N_2 \xrightarrow{\gamma} N + N$



- Add Water:



- Forms nitric acid

# Radiolytic Formation of Nitric Acid

- Amount of nitric acid formed is dependent on:
  - Intensity of radiation field
  - Quantity of nitrogen
- Only sufficient water is required to dissolve nitrogen oxides
  - Mostly drying the atmosphere is not sufficient
- Minimizing nitrogen concentration is the key to minimizing nitric acid formation

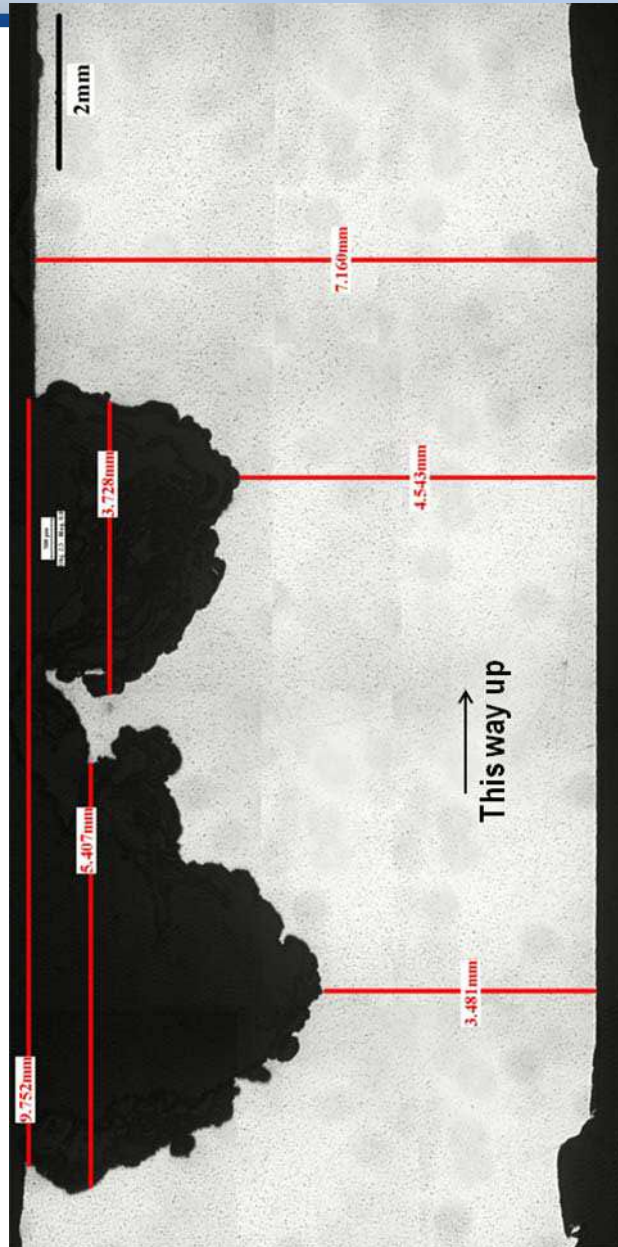
# Localized Corrosion

- Several mechanisms have been suggested to account for the localized pockets of corrosion
  - Material properties
  - Additional impurities (e.g. copper contamination)
  - Thermally induced nitric acid concentration mechanism
  - Localized corrosion cell enhancing nitric acid corrosion
- Enhancement of nitric acid corrosion mechanism by either concentration of the acid or formation of an electrochemical cell currently favored based on detailed examination of removed samples
  - No materials changes
  - No contaminants found
  - Nitric acid found in corrosion deposits

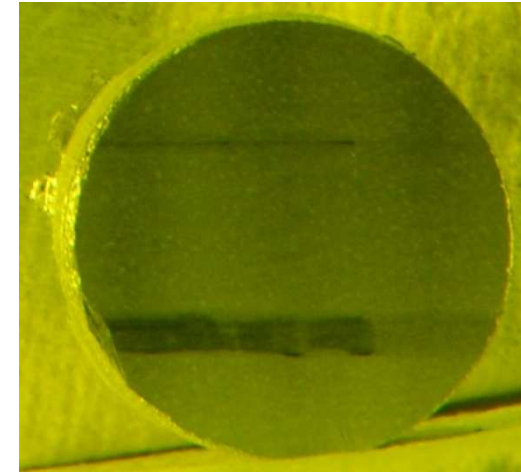


# Removed Coupon from Vessel Wall

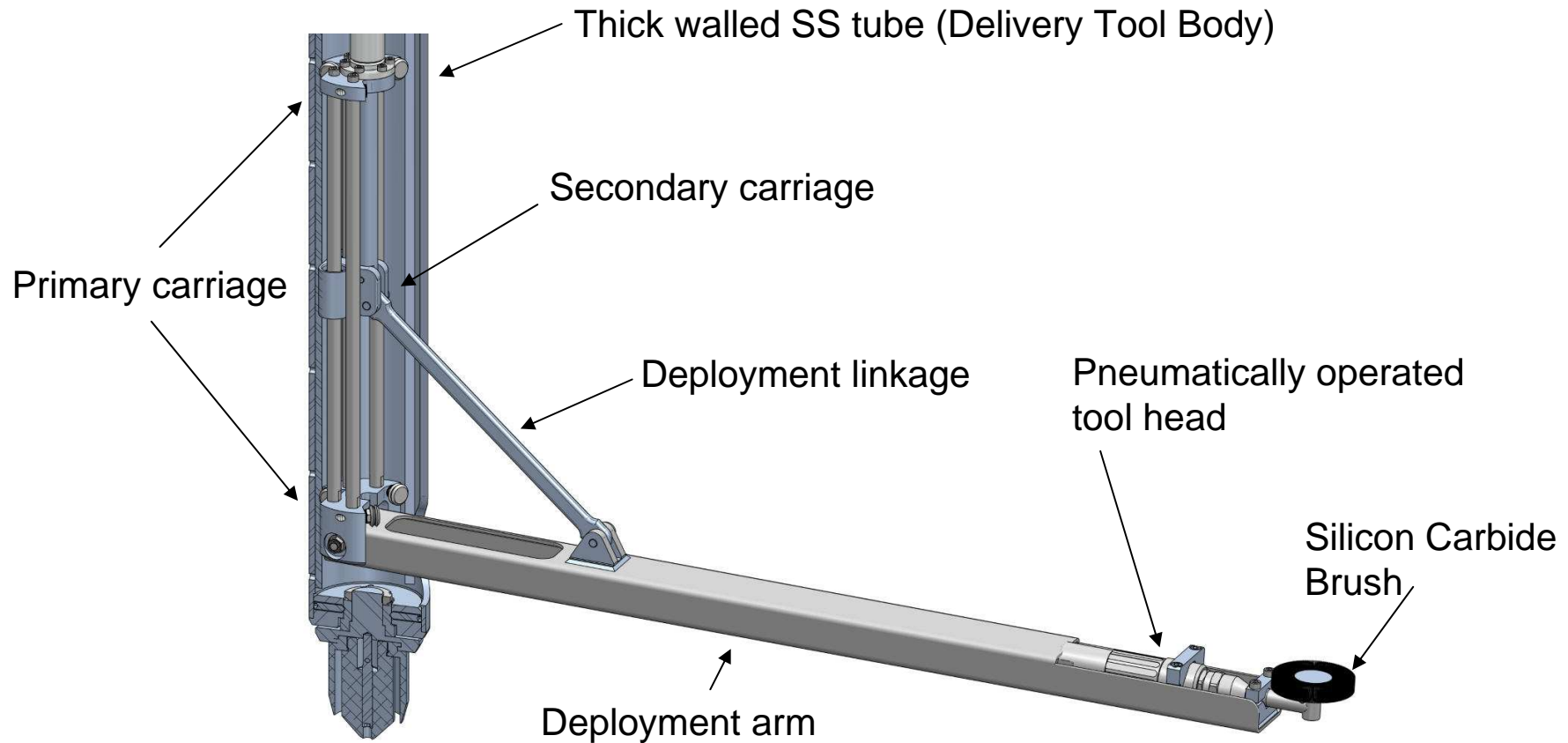
- J-rod Side



Heavy Water side



# Cleaning Tool Deployment Arm



- Arm has 965 mm horizontal reach

# Tooling to Clean Vessel Wall

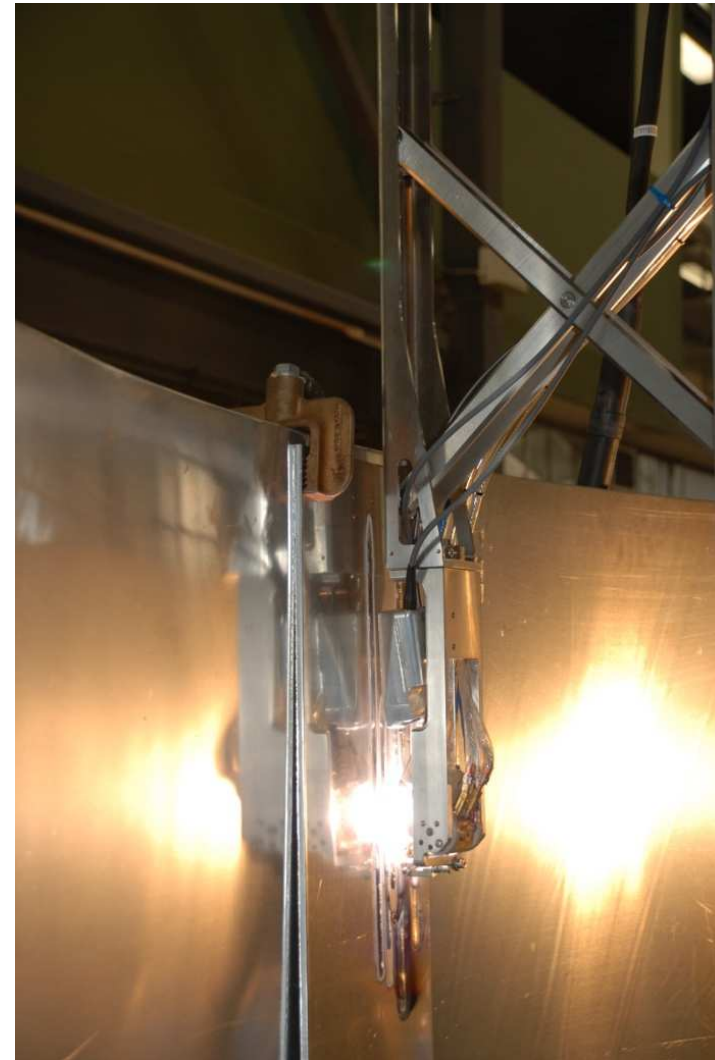
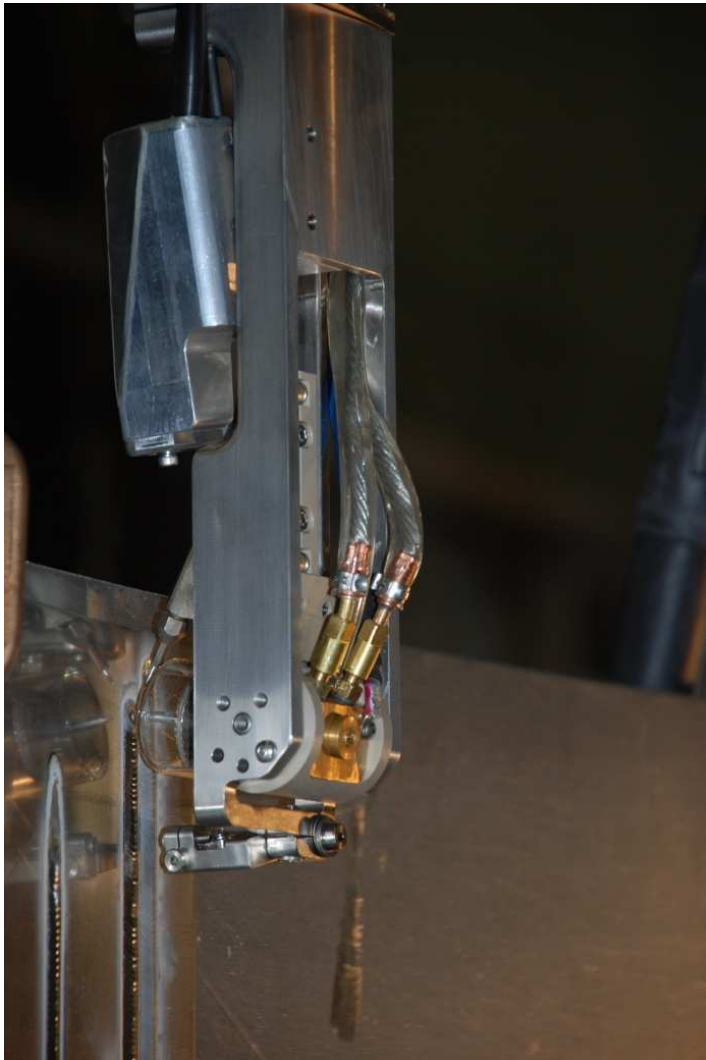


Cleaning of the vessel wall:

- Critical step in welding process
- Removes gibbsite layer from vessel
- Tool designed and built by AECL



# Welding Tool

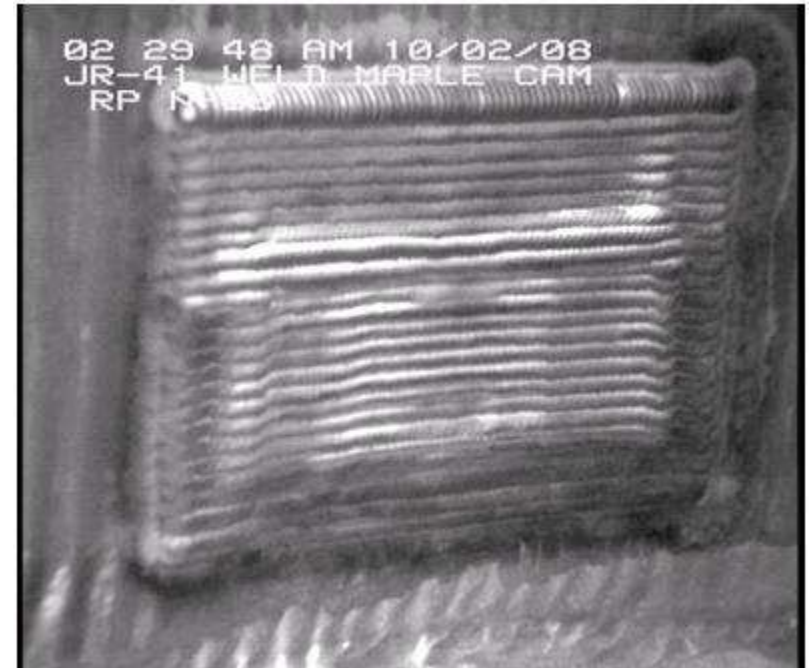


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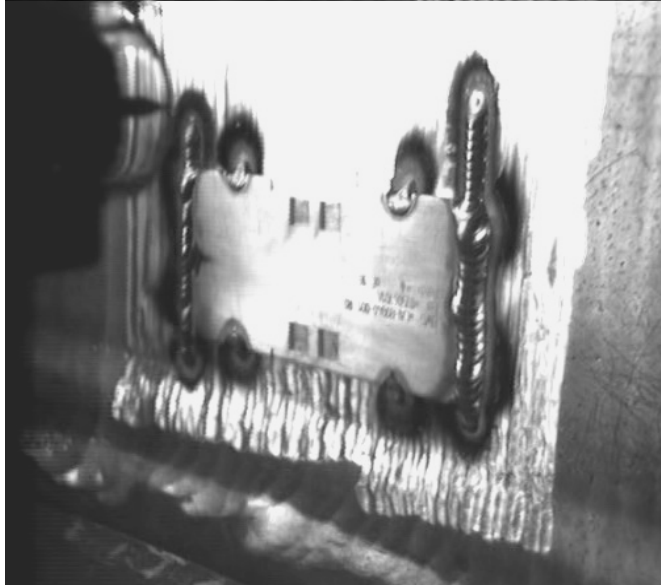
# Repair at JR-41 – The Leak Site



Backing  
strip  
placement

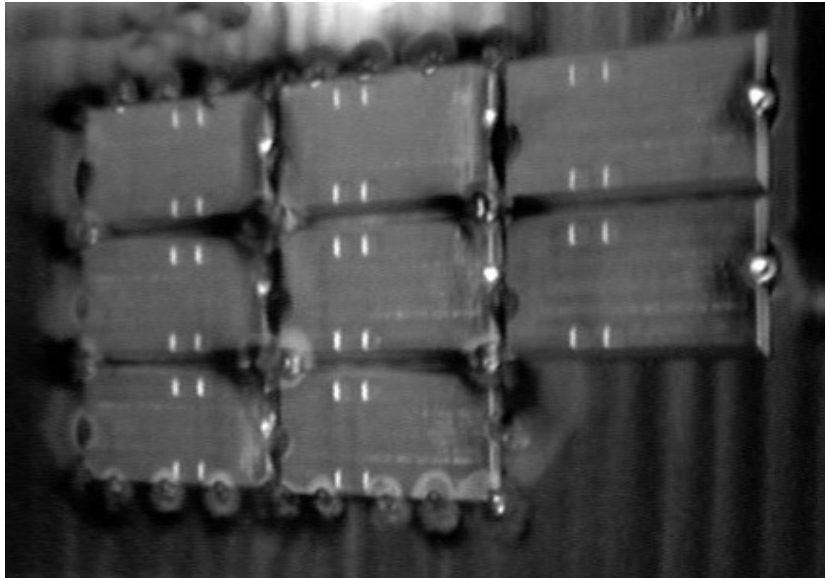


Final Weld Overlay



Backing  
strip  
welding

# Repair at JR-13/17

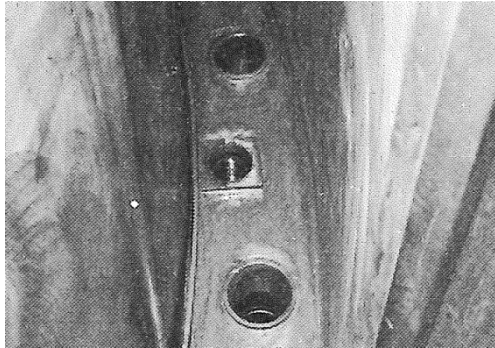


1250 cm<sup>2</sup> repair area  
3x3 array of structural plates  
Nine unique welding processes



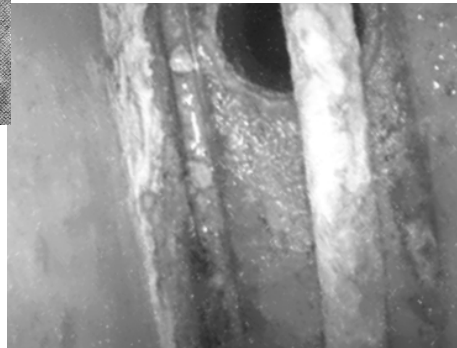
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# Vessel Annulus – Preventing Corrosion

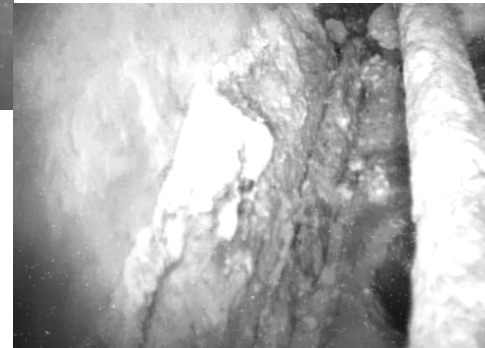


1 – as built

On going monitoring of condition of annulus will be integrated into annual maintenance outage of NRU



2 – May 2009



3 – leak location

Reducing water pooling and air ingress:

- clearing drains & reducing debris
- sealing water and air leaks
- higher CO<sub>2</sub> volume, improved distribution, better sampling system



4 – remediation

# Summary

- Shut down 2009 May, returned to service 2010 Aug
- Corrosion of aluminum vessel caused by nitric acid formed from air and water ingress into the high radiation environment of the J-rod annulus
- Radiation chemistry key to understanding the mechanism of corrosion in NRU and to help shape the corrosion mitigation methods
- Over 40 specialized tools designed, built, and tested for inspections, wall cleaning, welding, foreign material removal, and vacuuming the J-rod annulus



# Summary

- Work area located 30 feet below TOR accessible only through 4.75 inch diameter holes in the deck plate
  - Only 2.5 inches in J-rod annulus!
- Radiation Protection considerations: everything entering the vessel bagged and sent for decontamination; tool maintenance performed in tents on TOR; constant RP surveyor attendance
  - Very challenging repair job
- Work performed 24/7 for much of the repairs
- More information available at: [NRUCanada.ca](http://NRUCanada.ca)

**Thank You!**

 **AECL EACL**

