A Brief History of the NRU Reactor Vessel Leak and Repair

TRTR Conference

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Entire NRU Return To Service Team

2010 September 19-24

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Outline

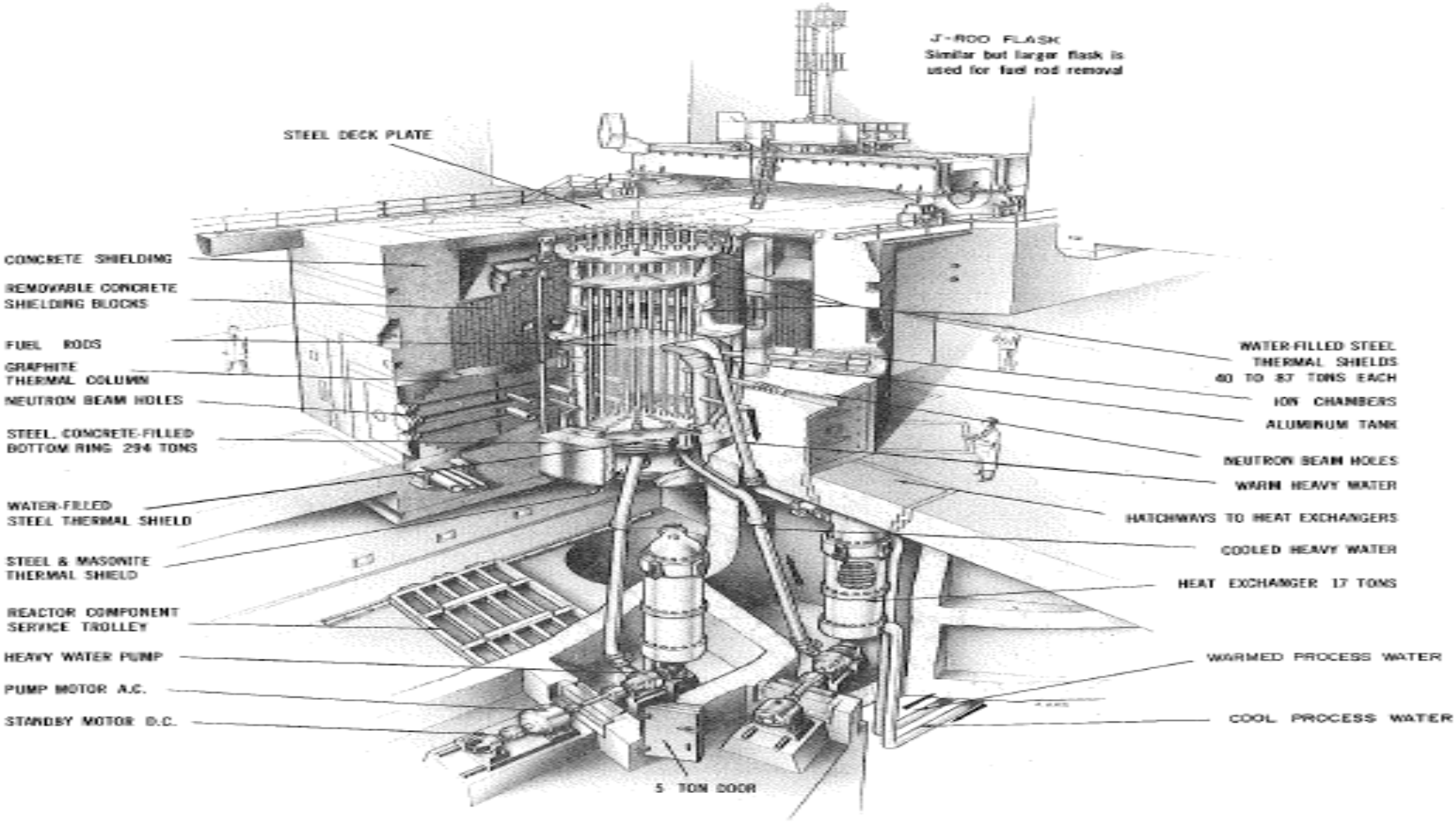
- Description of NRU
- Leak details
- Special tools developed
- Inspection of the vessel
- Corrosion mechanism
- Vessel cleaning and welding
- Future corrosion mitigation

- 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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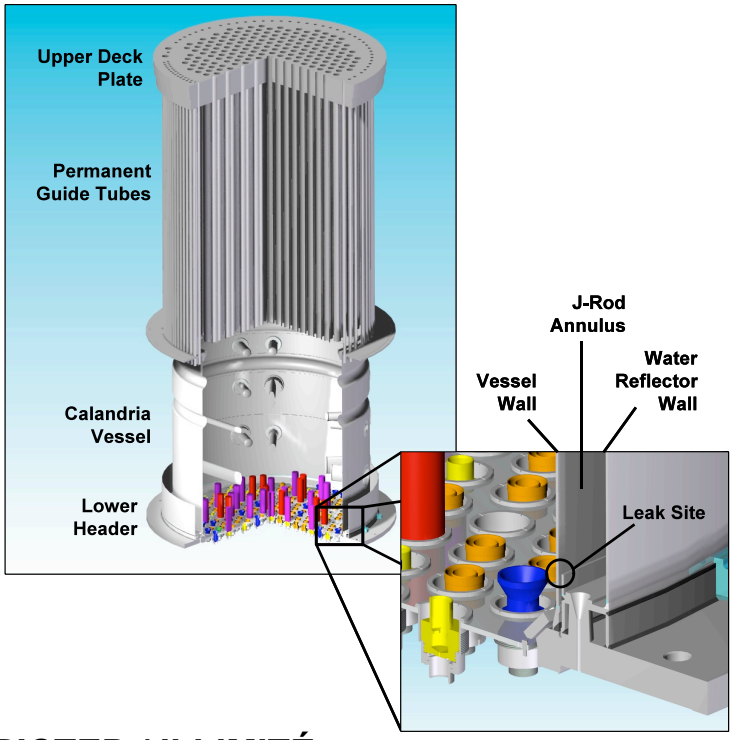
May 2009 Outage

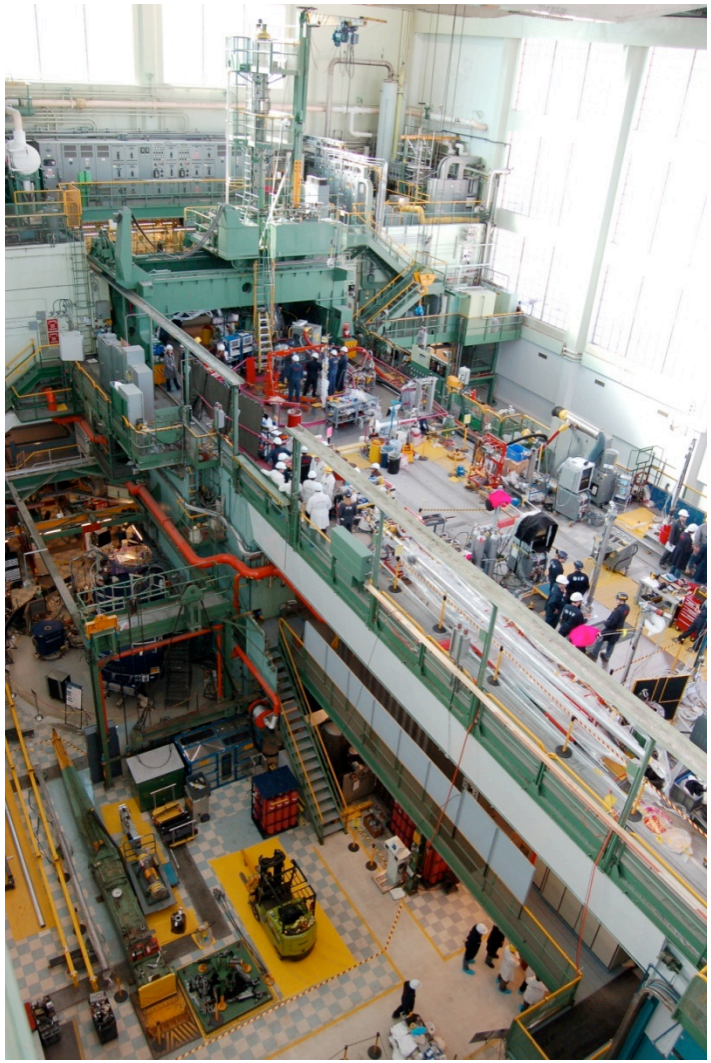
- Minor heavy water leak from the main vessel into the J-rod annulus detected
  - Visual inspection of the J-rod annulus determined that the leak site was in the vessel wall at the bottom of the J-rod annulus near position JR-41
  - Determined that the heavy water leak was due to corrosion of the reactor 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:

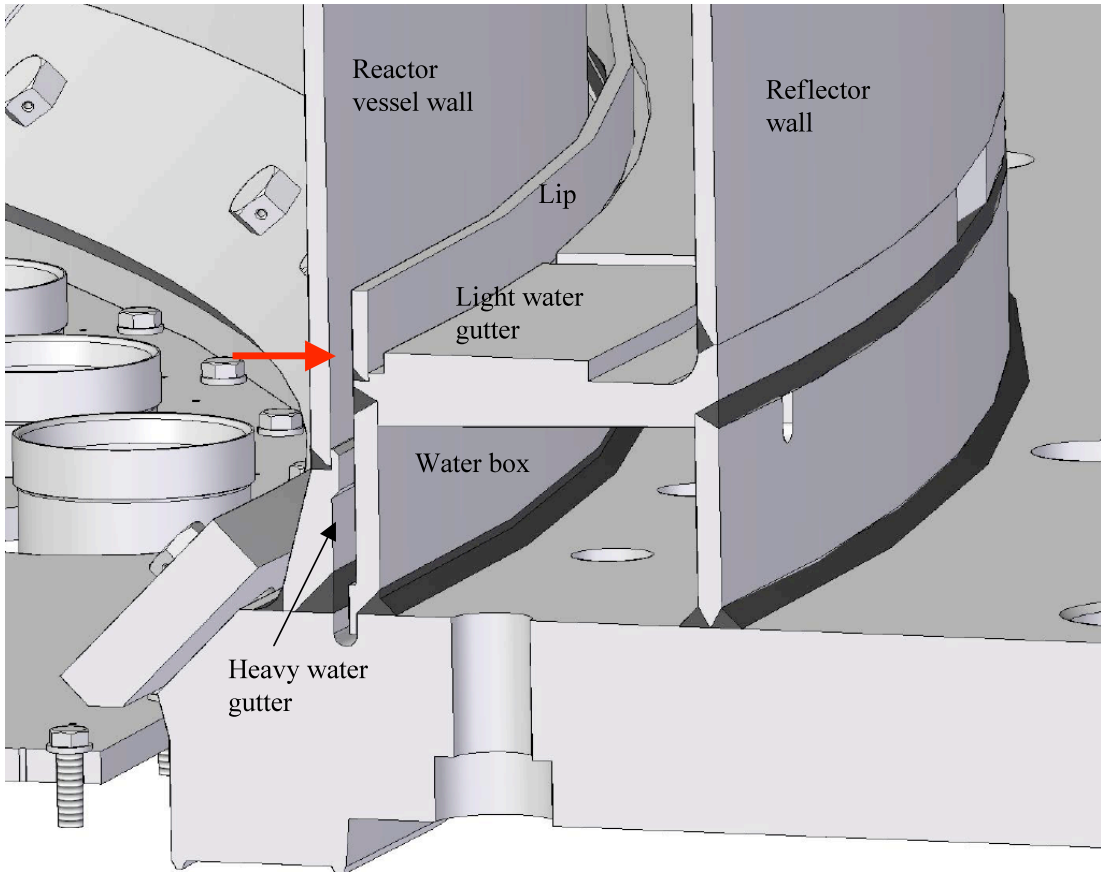
- Leak site is 30 feet below the deck plate at the base of the vessel
- Access through 4.75-inch dia. tubes
- High radiation environment





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



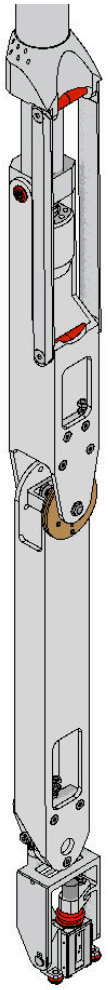
Condition Assessment of Vessel

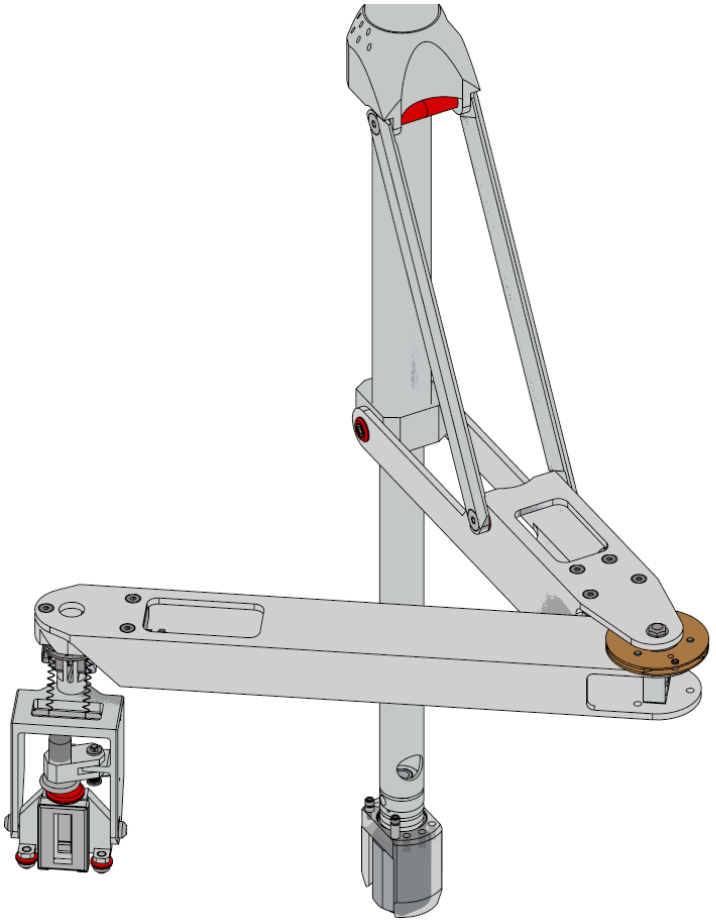
Non-destructive examination:

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

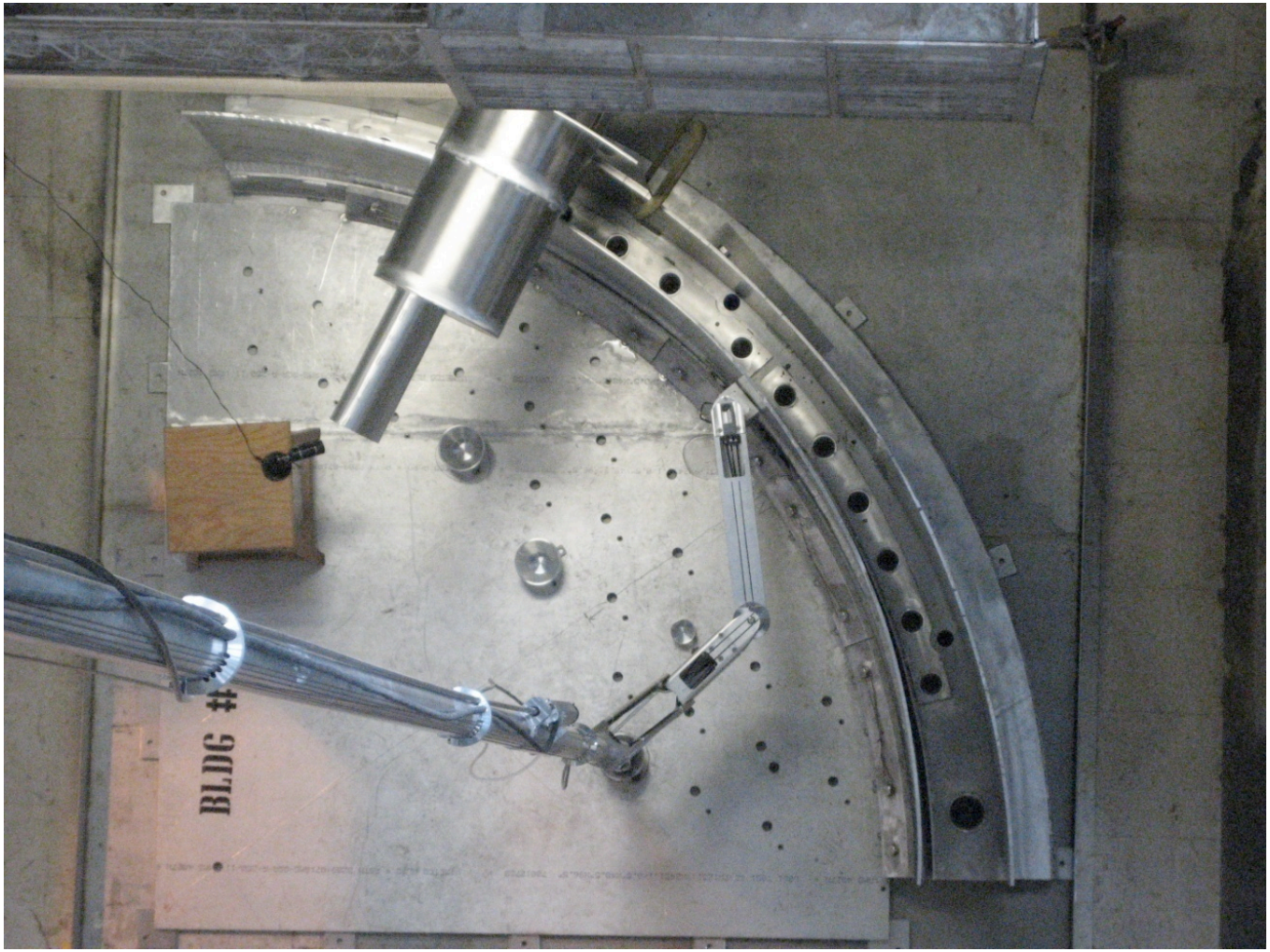
One of largest single NDE inspection campaigns ever carried out in the nuclear industry.

Mk II Inspection Tool





Mk II Inspection Tool in Mock-Up



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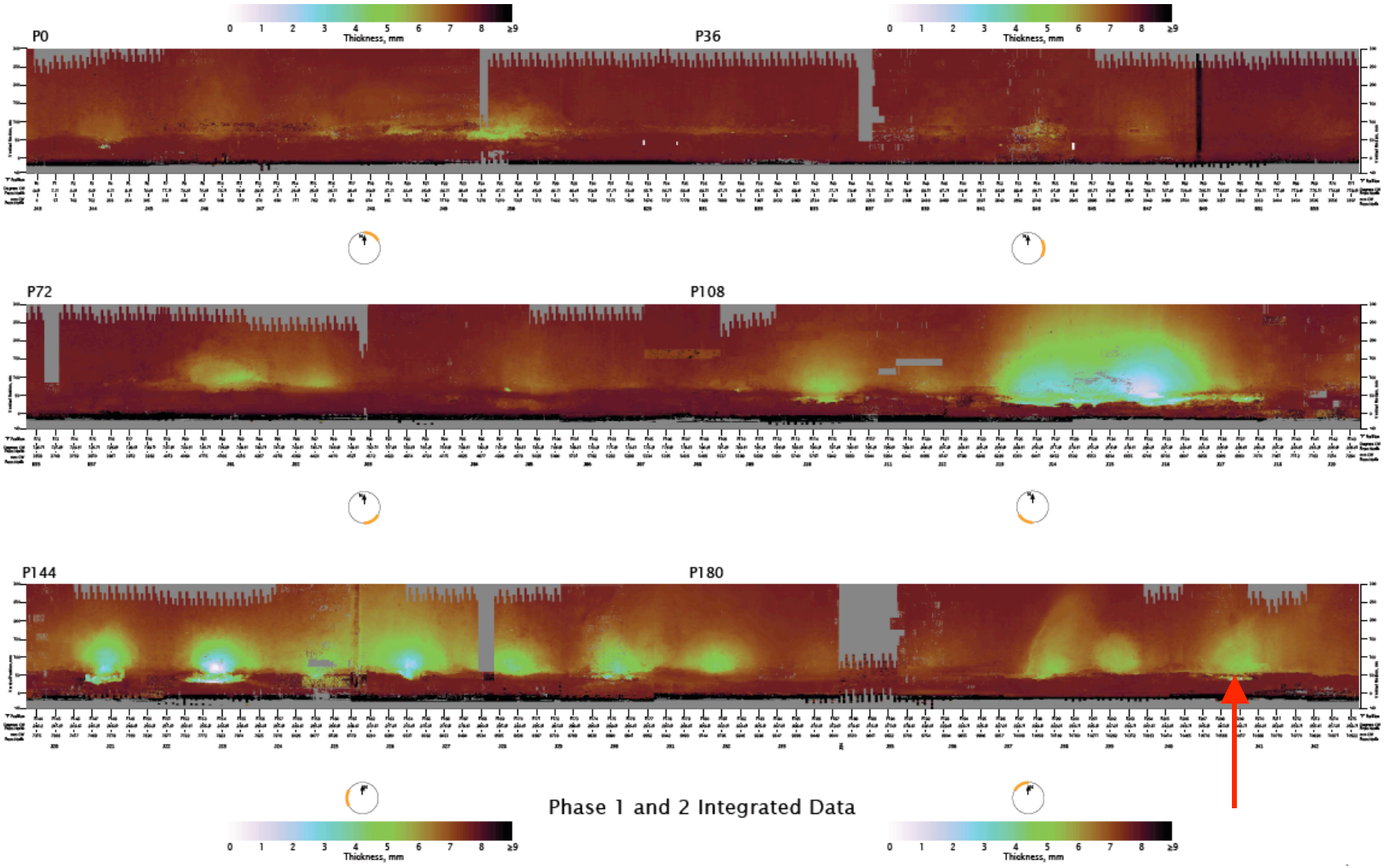
Map of Vessel Wall Thickness (UT/ ET Scan)



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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_2 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: $N_2 \rightsquigarrow N + N$

$$O_2 \rightsquigarrow O + O$$

$$N + O_2 \rightarrow NO + O$$

$$N + O_2 + M \rightarrow NO_2 + M$$

- Add Water:

$$H_2O \rightsquigarrow e_{aq}^-, H^+, \cdot OH, \cdot H, H_2O_2, \cdot O_2^-$$

$$\cdot OH + NO_2 \rightarrow HNO_3$$

$$\cdot OH + NO \rightarrow HNO_2$$

$$H_2O + NO_2 + NO_2 \rightarrow HNO_3 + HNO_2$$

- Forms nitric acid

Radiolytic Formation of Nitric Acid

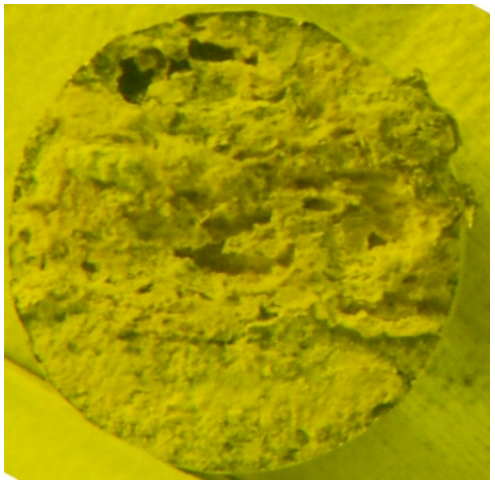
- Amount of nitric acid formed is dependent on:
  - Intensity of radiation field
  - Quantity of nitrogen
- Only sufficient water is required to dissolve nitrogen oxides
  - Mostly drying the atmosphere is not sufficient
- Minimizing nitrogen concentration is the key to minimizing nitric acid formation

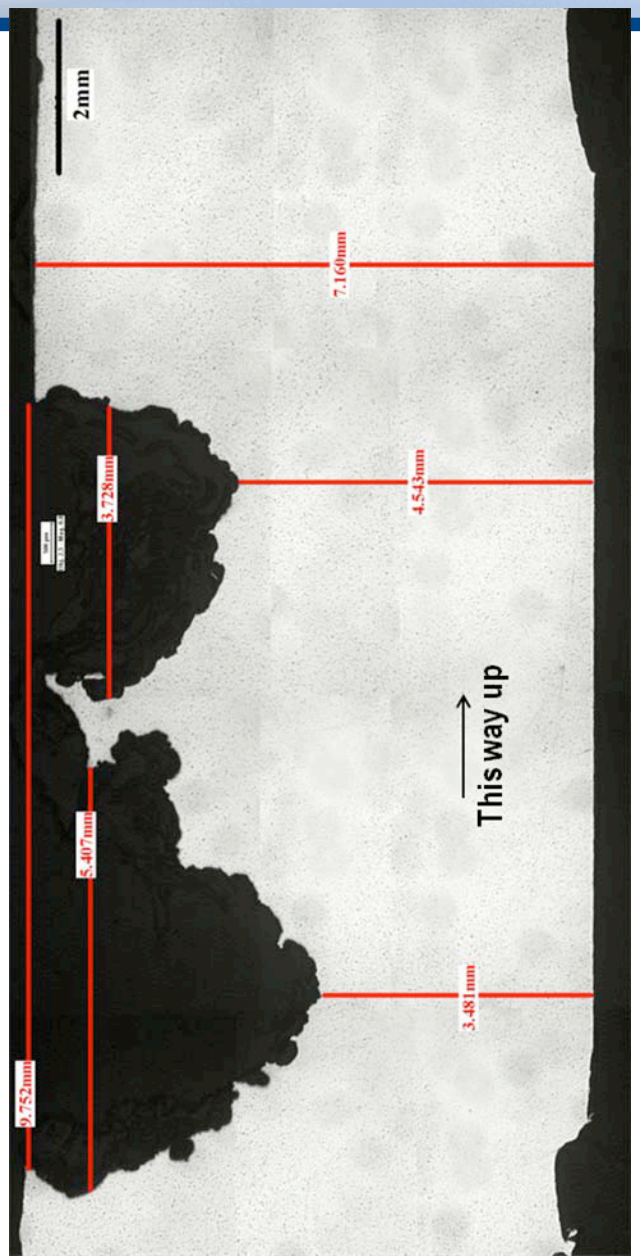
Localized Corrosion

- 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

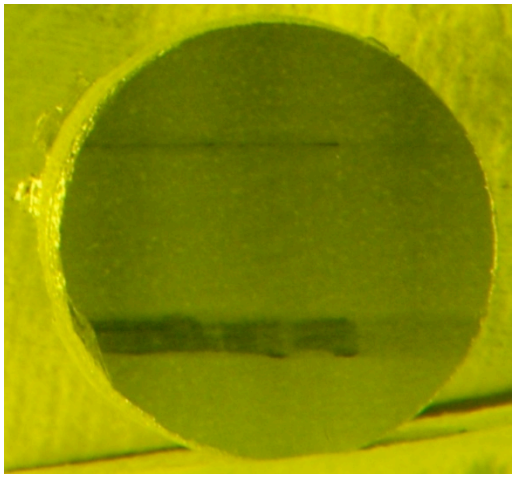
Removed Coupon from Vessel Wall

- J-rod Side

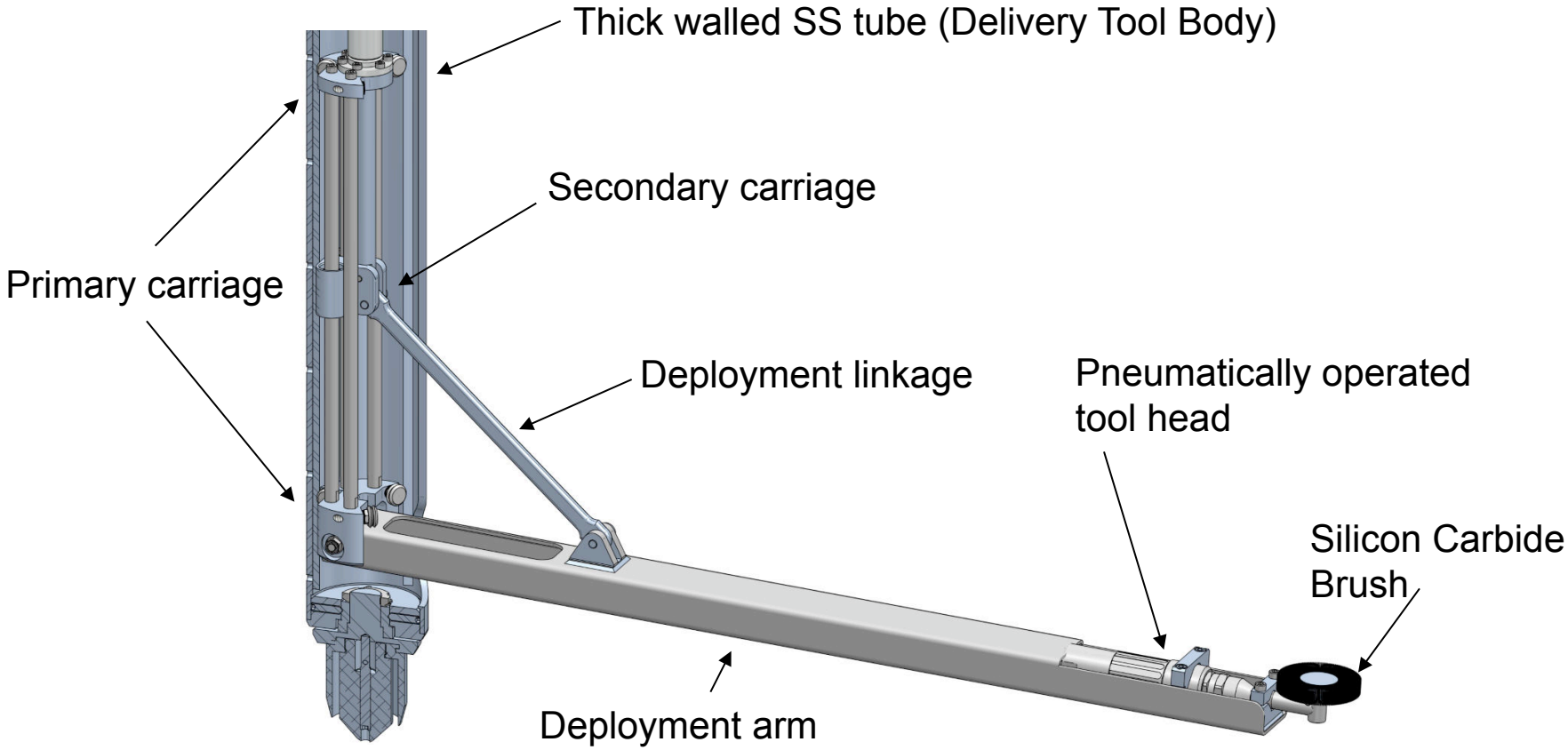




Heavy Water side



Cleaning Tool Deployment Arm

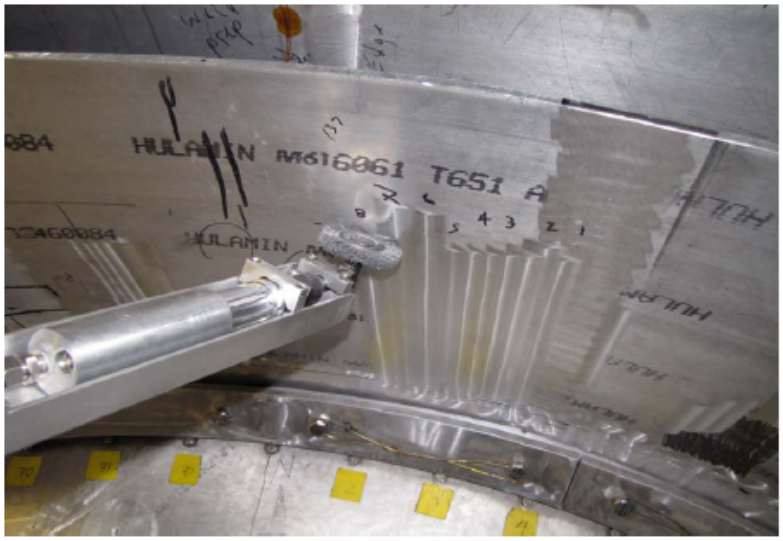


- Arm has 965 mm horizontal reach

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



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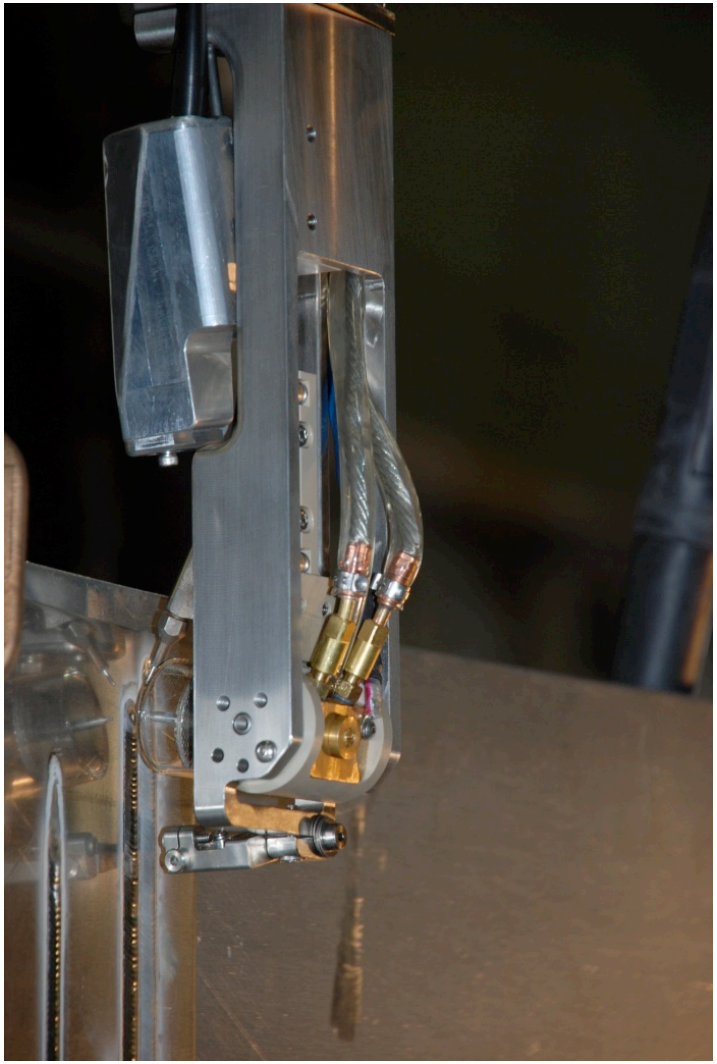
Welding Tool



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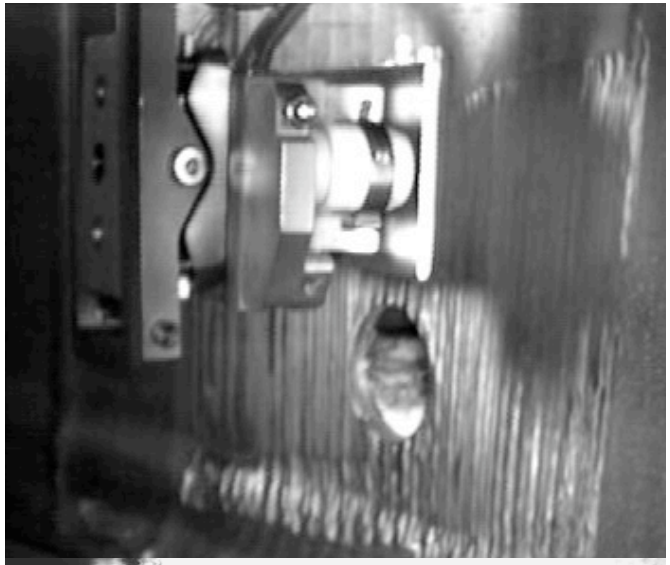
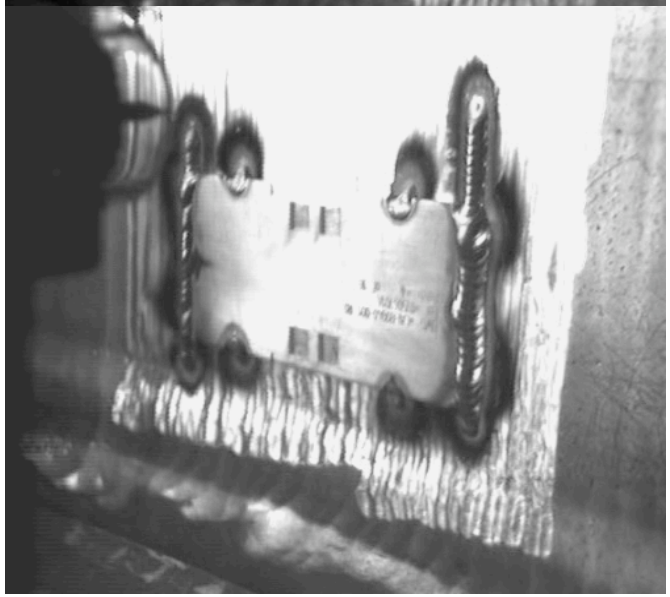
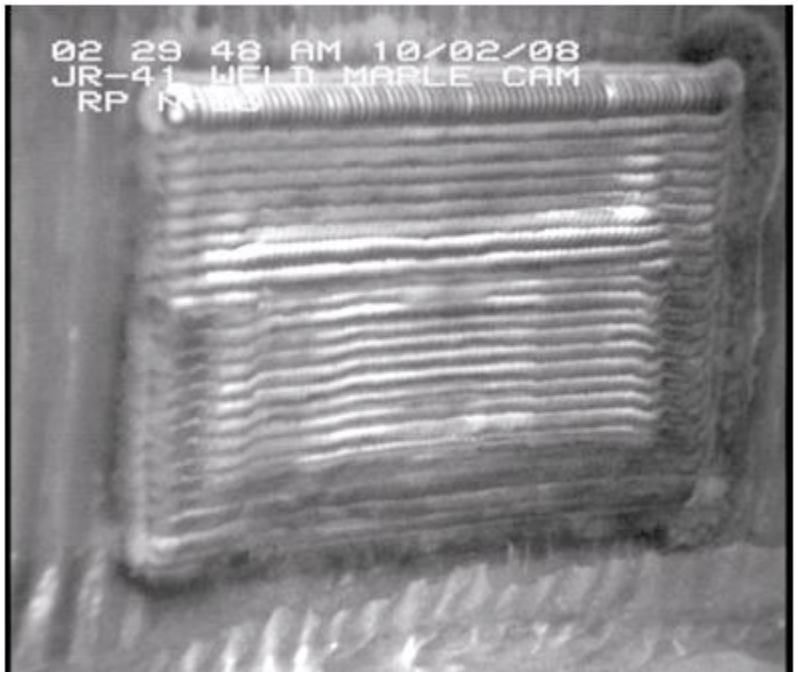
Repair at JR-41 – The Leak Site



Backing strip placement

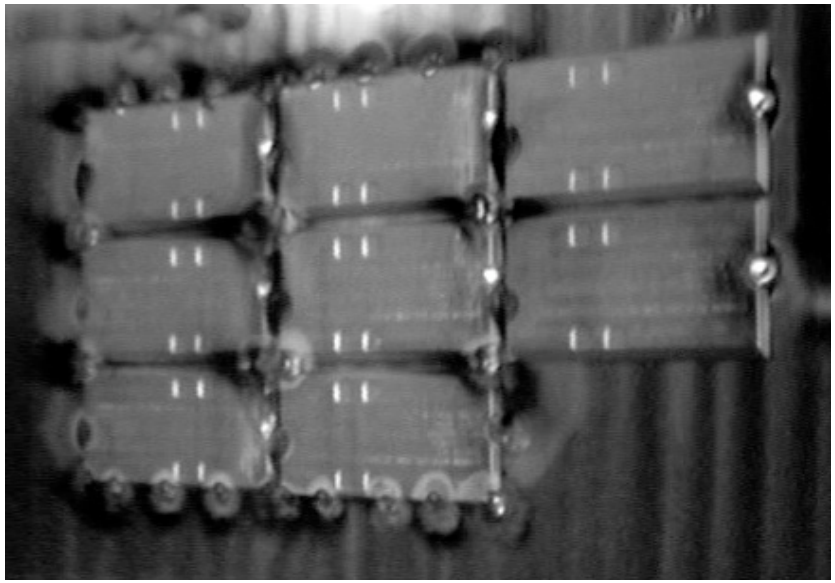


Backing strip welding

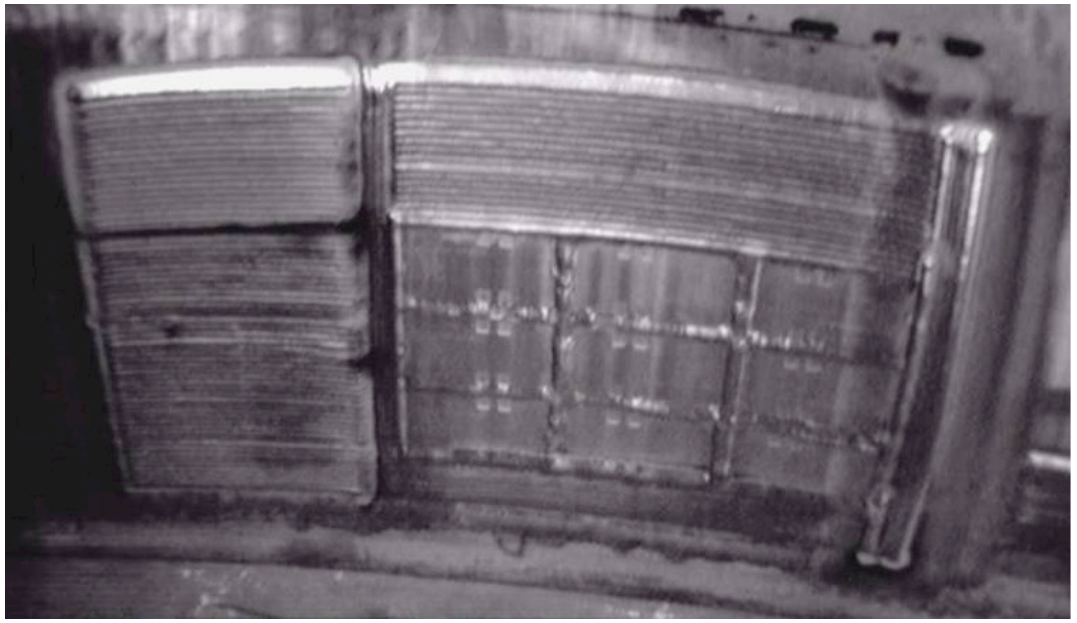


Final Weld Overlay

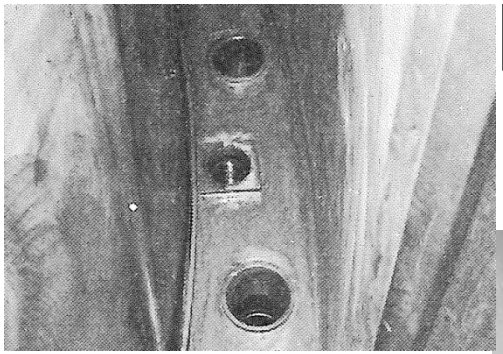
Repair at JR-13/17



1250 cm^2 repair area
3x3 array of structural plates
Nine unique welding processes

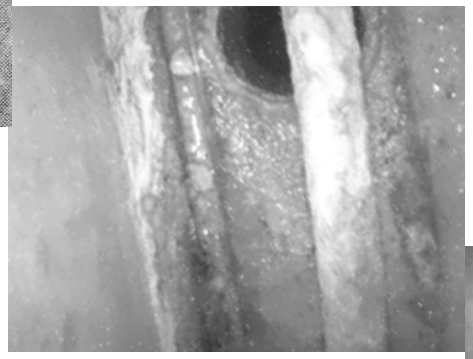


Vessel Annulus – Preventing Corrosion



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_2 volume, improved distribution, better sampling system

4 – remediation

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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

Thank You!

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