Tooling Development at the Chalk River R&D Laboratories in Support of the NRU Vessel Leak Repair Project

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Introduction – What is NRU?

- National Research Universal (1957) located at the Chalk River Laboratories
- 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.
NRU Leak

- A heavy water leak was reported in May 2009
- Leak was a result of corrosion of the vessel wall due to nitric acid accumulation in the J-Rod annulus.
- Corrosion resulted in thinning areas of the vessel wall and 1 through wall penetration
NRU Vessel

- Wall thickness is 8 mm (aluminum)
- Leak site is 30ft from Deck Plate at base of Vessel
- Access to vessel through 4.75 inch pipe
NRU Vessel Section

Cups to accommodate:
• Fuel Rods
• Bismouth Rods
• Control Rods

J-Rod Annulus
MED branch and IMD branch partnered to produce inspection tooling:
  – Eddy Current (ET) Probes (IMD)
  – Ultrasonic (UT) Probes (IMD)
  – Inspection Delivery Tool (MED)

ET & UT are complementary techniques
1\textsuperscript{st} set of Inspection Tools were ready to be deployed within 2 \textit{weeks} of request

Vessel was full of water

Probe was a UT/ET combination probe to maximize amount of information obtained

Deployment tool was the Mk 1 tool
Mk I Inspection Tool

- Manually operated
- Enters in collapsed configuration & articulates to reach vessel wall
- Probe situated at the wrist
- Foot sits in cup
Inspection Delivery Tool

• Access port is only 4.75 inches in diameter
• Tool Handler will be on the deck plate (~30 ft)
• Inspection probes must be in contact with the wall
• Imperative to know where the probe is at all times to ensure complete inspection
• Tool was designed, manufactured, assembled and tested at CRL
Testing in NRU Mock-Up

- Vessel mock-up in the tower area was used to test each tool and train tool handlers.
Limitations of Mk I Tool

- Tool was unable to reach behind objects in vessel
- Data from UT/ET could not be collected in these areas
- Mk II inspection tool was designed while the Mk I was in use
Mk II Tool

- Mk II tool designed with an additional degree of freedom – an elbow
- Same access restrictions:
  - 4.75 inch access port
  - Manual operation from the deck plate (30ft)
- This tool was used “dry”
- Different ET and UT probes were constructed for use with this deployment tool
Mk II Inspection Tool
Mk II Inspection Tool

- Tooling controls are on the deck plate and operated by 2 people

Elbow control

wrist control
Mk II Inspection Tool

- Simulation of Mk II inspection tool deployed in NRU
Mk II Inspection Tool in Mock-Up
Mk II Inspection Tool in Mock-Up

- Probe in contact with wall of mock-up
Inspection Teams

• Vessel inspection is a complex operation that requires many people
• Staffing an inspection requires (per shift):
  – 3 tool operators + 1 tool mechanic
  – 1 probe specialist/mechanic
  – 1 shift supervisor
  – Several analysts
• Coverage was 24h/day, 7-days a week (3 teams)
Top of Reactor Photos

• Mk I deployment

• Mk II deployment

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In the background staff were:

- Analyzing data collected
- Developing next series of probes
- Collaborating with contractors at site to develop new probes and analyze data
- Addressing technical issues with tool (redesigns, replacement parts, repairs)
- Coordinating, scheduling, training, providing RP support etc…
NDE Inspection Identifies Leak

- NDE Inspection provided a map of wall thickness for the vessel
- Vessel wall is thinned in some areas & there is a through wall leak site
- Visual inspection showed that there is a layer of Gibbsite on the inside wall
- Vessel repair technique chosen - welding
- Welding requires a very clean surface.
Cleaning Tools

- Development of cleaning tools was required – which ones?
- Technical considerations:
  - How easy will it be to remove the Gibbsite?
  - Will the cleaning be mechanical or some other technique?
- Several cleaning tools developed – some by MED and some by external vendors in collaboration with AECL
Cleaning Tools

• MED developed 2 cleaning tools:
  – Dry Ice “Blaster”
  – Mechanical Cleaning Tool
• Mechanical Rotating Brush Cleaning Tool was successfully used to clean the repair sites inside the vessel
Inner Vessel Wall Cleaning Criteria

- Access restricted to 4.75 inch access port
- Tool operated from the top of the deck (~30 ft)
- Tool must be robust enough to apply pressure to the wall for cleaning BUT must have control of the pressure (<5 lbs force)
- Brush head must not deteriorate or shed bristles
- Must be able to remove Gibbsite
• Brushes under consideration:
  – Stainless steel wire brush wheel
  – Silicon carbide wheel
  – Aluminum oxide wheel

• Laboratory Testing to determine:
  – Robustness and effectiveness
  – Time to “failure”
  – Orientation and angle of brush
Rotating Brush – Lab Testing

- Silicon Carbide wheel chosen
- Brush must be changed every 2h of use
- Tool designed for quick release of brush head
Mechanical Cleaning Tool

Actuation/ Control Dive

Quick Disconnect

Delivery Tool Body

Deployment Mechanism

Tool Head

Deck Plate

Cups

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Arm has 965 mm horizontal reach
Cleaning Tool Elevator

- Elevation drive motor
- Elevation drive lead screw
- Support frame/guide rails
- Elevation drive linear guides
- Worm drive (Arm deployment)

• Elevator has 400 mm vertical span
Cleaning Tool Testing in Mock-Up
Laser Profilometer

- Profile of the inner vessel wall surface was needed prior to welding
- Cleaning tool adapted for laser profilometry
  - Arm, linkages, central actuator post and worm drive removed
- Off-the-shelf laser head used to measure displacement
- Software developed to collect data
• Off-the-shelf laser situated within the tool
• Quick release of laser head to minimize worker dose
Foreign Material Removal Tool

- Foreign Material Exclusion: Can not leave anything behind in the vessel
- During inspection and cleaning, an FME check is conducted on the tools periodically even though they are designed to minimize this risk.
- Tool designed to “pick up” things from inside the vessel
  - Ex. Wires or fasteners from tooling
Foreign Material Removal Tool

• Development of this tool is challenging because the designer must anticipate all removal needs with one tool.

• Foreign Material Removal Tool was designed to allow for 3 different heads:
  – Manipulator head with interchangeable jaws
  – Magnetic tool
  – Motorized manipulator jaws for higher gripping force or finer adjustment
Foreign Material Removal Tool

- Tool Body:
  - Aluminum pipe with a central solid SS pull rod
  - Articulation of the tool is achieved using a rigid tension rod
  - Handles and controls designed to be ergonomic
Foreign Material Removal Tool

- Handwheel & grip lever controls arm articulation & jaw actuation

- Allows for different tool heads
Manipulator Tool Head

- Off-the-shelf item
- Aluminum body with riveted connections
Alternate Manipulators

• Alternate manipulators designed to reach different regions in the reactor vessel

• Quick release of manipulators minimizes worker dose
Magnetic Tool Head
Motorized Tool Head
Welding tool
Questions?

- If you would like to learn more about the NRU and the vessel repairs, please go to NRUCanada.ca for additional information and informative videos.