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NRU VESSEL REPAIR AND RETURN TO SERVICE: ENHANCING A CANADIAN R&D ASSET FOR THE FUTURE

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The National Research Universal (NRU) reactor was successfully returned to high power operation in 2010 August, after completing extensive inspections and repairs of the calandria vessel, in response to a small leak of heavy water that was discovered in 2009 May. The aluminum alloy vessel material had corroded from the outside surface over many years, and required application of weld build-up and plated weld repair at ten locations, executed by remote tooling deployed from inside the reactor vessel. Many specialized remotely operated tools were developed for inspection, sampling and repair operations. In parallel with the repair efforts, important maintenance activities were performed, enabled by the de-fuelled state with the heavy water drained from the vessel. Two annual inspection cycles have now been completed since the reactor was returned to high power operation, confirming the fitness of the vessel for continued operation. The NRU reactor is now entering its 56th year of operation and the current operating licence extends to 2016. Based on the outcome of a comprehensive Integrated Safety Review, AECL is continuing to implement major equipment upgrades and process improvements to support safe and reliable operation through 2021, for the benefit of Canadians and the world.

1. Background to the Leak

The 135 MW_{th} NRU reactor at Chalk River Laboratories began operation in 1957, and is one of the largest and most versatile research reactors in the world. Its multipurpose design has enabled it to play a vital role over five decades as:

- a reliable supplier of industrial and medical radioisotopes, including molybdenum-99, a critical isotope used for medical diagnoses;
- a dependable producer of neutrons for the National Research Council's Canadian Neutron Beam Centre, to investigate and non-destructively study all types of industrial and biological materials; and
- an engineering R&D test facility for nuclear fuel bundles and materials such as fuel channel components, to support design and operation of CANDU® power reactors.

The NRU core is cooled and moderated by heavy water contained in an aluminum 5052 alloy cylindrical vessel, 3.7 metres in diameter and 3.5 metres high with a wall thickness of approximately 8 millimetres. The calandria vessel is surrounded by an annulus filled with CO_2 gas and an outer vessel that contains light water as a neutron reflector (Figure 1). The bottom of the CO_2-filled annulus has drains that feed a collection system. Throughout the life of NRU, there have been light-water leaks into the annulus that have contributed to corrosion of components.

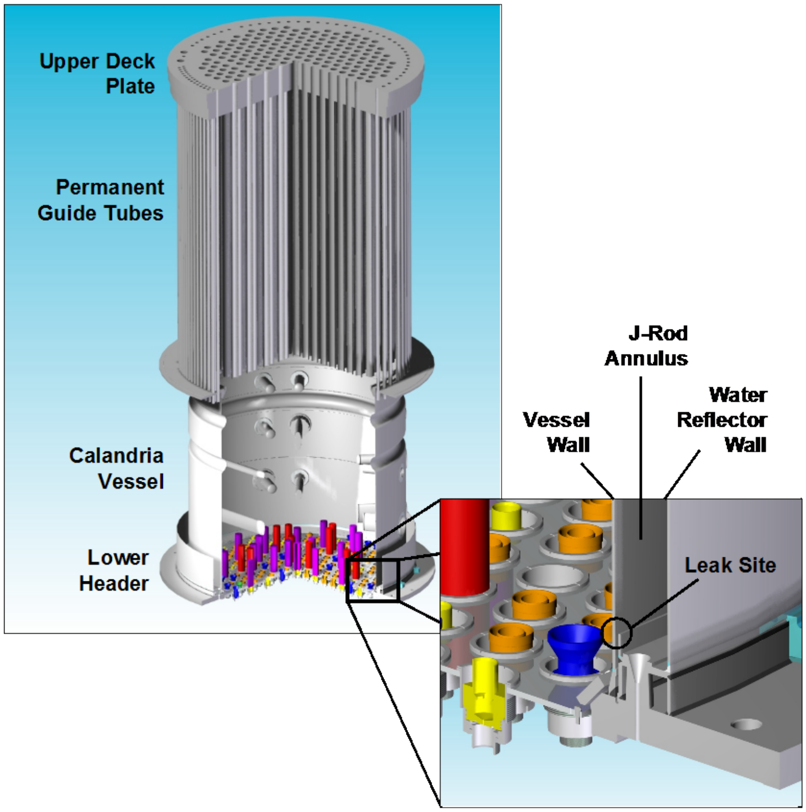

Figure 1: NRU Reactor and Geometry of the Leak Site.

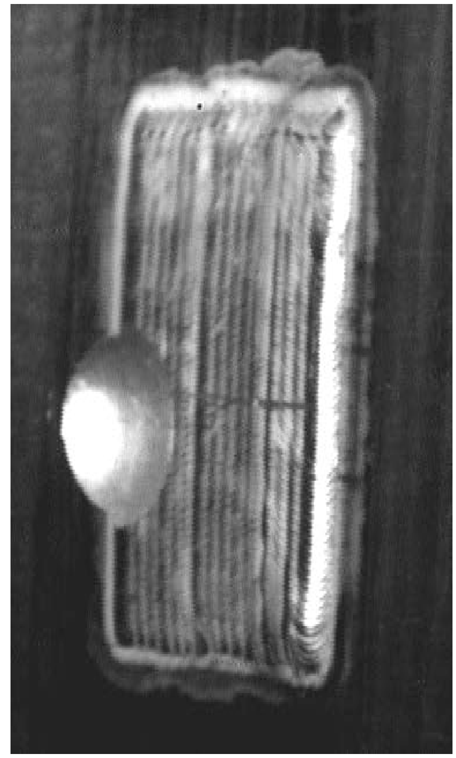

Figure 2: In-Reactor Weld Build-up with Scoop Sample Removed for Analysis

In 2009 May, a small heavy-water leak in the calandria vessel was detected at the bottom of the CO_2 annulus. The leak site was about 9 m from the top of the reactor deck, accessible only through small openings, either 9 cm or 12 cm in diameter, which became a significant constraint on development of the necessary inspection and repair tools.

2. Inspections and Sampling

Visual inspections by remote radiation resistant cameras were used to characterize the leak site until non-destructive examination (NDE) tooling could be developed to deploy through small openings in the deck plate 9 m above the leak elevation. Ultrasonic and eddy current inspections were performed around the entire inside circumference of the vessel in a band approximately 30 cm in height. The inspections were designed to measure the remaining thickness of the vessel wall to a precision of about ± 1mm and to detect any localized corrosion pits as small as 1.5 mm in diameter. Other inspections were performed in vertical bands from the bottom to the top of the vessel. The inspections confirmed the presence of a broad scalloped corrosion pattern restricted mainly to the bottom of the annulus, with some discrete pits. A repair by welding was selected because the extent of degraded wall material ruled out a mechanical repair approach. Analysis of the stresses induced by welding was required to prevent deforming the vessel or the lower header bolted connection [1].

The aluminum vessel alloy was modeled for radiation and transmutation effects (35 years of irradiation, as the vessel has been replaced in 1972), and determined to have become a unique alloy for which special weld development would be required. Tooling was developed to cut shallow hemispherical “scoop” samples from the inside surface of the vessel wall in order to obtain representative material for metallurgical evaluation and for use in weld development trials (Figure 2).

Specialized tooling was developed to cut a 70 mm diameter hole through the vessel wall, encompassing the leak site, in order to study the corrosion layers, microstructures and the topology of the corrosion site. Corrosion was concluded to be caused by air leakage into the annulus in the absence of a complete CO_2 purge, combined with moisture from the ingress of light water from the reflector, producing nitric acid by radiolysis in the high radiation fields of the annulus. After analysis of the vessel metallurgy, areas requiring repair were determined by a 3-dimensional engineering structural evaluation performed on the remaining vessel wall thickness as measured by NDE, after subtraction of a corrosion allowance. Ten regions were determined to require repair, ranging is size from approximately 8x6 cm to 20x70 cm.

3. Remote Weld Repair and Post-Weld Inspections

Welding proved to be the most demanding phase of the outage, taking seven months to complete [2]. The highly-irradiated aluminum presented specific challenges, further complicated by remotely welding with tools guided by arc-resistant viewing systems that provided a close-up view to the welders, who operated the weld torch and wire feed system from on top of the reactor. The success of aluminum welding is dependent upon good surface preparation. Two cleaning tools were developed; one for bulk cleaning and a second for final cleaning of the weld area just prior to welding.

To conduct the weld repairs, two types of remote welding tools were produced: one with a welding head that operated in a vertical direction and another with a welding head that operated horizontally. These tools provided flexibility in addressing the specific geometry of weld sites and in-vessel restrictions. A tool capable of deploying aluminum plates and tack welding them to the vessel wall was also developed.

Post-weld inspections of each repaired region, including the surrounding heat-affect zones, were done using qualified inspection techniques in order to verify the quality of the weld. Several inspection techniques were developed and certified for this purpose. This information, was used to prepare a rigorous Fitness for Service evaluation in support of the decision to return to operation.

4. Other Outage Work and Return to Service

In parallel with the efforts to inspect the vessel and develop repair methods, the reactor was de-fuelled, the heavy water was drained and replaced, and several important maintenance activities were performed on the main heavy water system, the process water system, the on-power fuel handling system, control rod systems and safety systems.

The CO_2 gas delivery system for the annulus was replaced with an upgraded system. The annulus itself was cleaned and vacuumed and drainage was improved. Repairs to the water box were also made to reduce light water ingress to the annulus; these improvements were all intended to provide conditions in the annulus that are less conducive to aluminum corrosion.

A comprehensive series of readiness-for-service assessments were conducted to verify that all systems were fully operational before proceeding to key milestones, including heavy water refill, loading of fuel, the controlled sequence of sub-critical instrumentation tests and start-up to low neutron level. High power operation was achieved on 2012 August 16.

There were many lessons learned during this challenging project to repair and restart the NRU reactor, related to technology and also to improvements in outage management and schedule integration [3]. Close communication with the Canadian Regulator (Canadian Nuclear Safety Commission), throughout the repair and return-to-service was essential. Without question, considering the technical complexity of the challenge in a forced outage situation, the project is viewed as a tremendous success.

5. Post-Repair and the Future of NRU

Since completing the repair and return-to-service, two annual inspection cycles of the weld repairs have now been completed. General wall thickness measurements have also been made to confirm that corrosion rates remain low, and are within the bounds of the structural analysis assumptions. These inspections have confirmed the fitness of the vessel for continued operation.

In 2011, NRU became a member of the World Association of Nuclear Operators (WANO) in order to utilize industry best practices in all aspects of its operation. Improvement initiatives are underway in several areas, including Human Performance, Operator Fundamentals, Equipment Reliability, Maintenance and Outage Management. NRU is the only research reactor with WANO membership.

The NRU reactor is now entering its 56th year of operation and the current operating licence extends through 2016 October. Based on the outcome of a comprehensive Integrated Safety Review, AECL is continuing to implement major equipment upgrades and process improvements to support safe and reliable operation of the NRU reactor through 2021, for the benefit of Canadians and the world.

6. References

[1] J. GOLDAK, M. Yetisir, R. Pistor, “The Role of Computational Weld Mechanics in the Weld Repair of Canada’s NRU Nuclear Reactor,” Proc. of the 10th International EPRI Conference, Welding and Repair Technology for Power Plants, Marco Island Florida, USA (2012).

[2] R. TODD, “How AECL Restarted the NRU with Custom Welding”, Nuclear Engineering International, Feature Article, December 2010.

[3] P. HEENEY, J. Turcotte, “Lesson Learned from the NRU Vessel Leak Repair and Return to Service Projects,” Proc. of the 9th International Conference on CANDU Maintenance, Canadian Nuclear Society, Toronto, Canada, (2011).