

**CNSC hearing to consider AECL's
application for the restart of the
National Research Universal (NRU) reactor**

Opening Remarks

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[Slide 1 – Title Slide]

Good afternoon Dr. Binder and members of the Commission. For the record, my name is Bill Pilkington, Senior Vice-President and Chief Nuclear Officer. As Mr. MacDiarmid mentioned, we are here to provide you with an update on our progress on repairing the NRU reactor vessel and on preparations to return the NRU to service.

[Slide 2 – Outline]--

My remarks today will follow the outline on the slide with emphasis on the repairs conducted, future activities and why we are confident that the reactor can be safely returned to service.

[Slide 3 – pictures of leak in annulus and hole on inside of vessel]

On May 15, 2009, a heavy-water leak was detected from the NRU reactor. The leak was traced to the gas-filled annulus between the heavy-water filled reactor vessel and the light-water reflector. The picture on the upper left shows the water that was seen to be seeping through corrosion on the outside surface of the vessel. No corresponding hole could be seen on the inside of the vessel until the surface was prepared for repair, shown in the lower right picture. The consequences of the heavy-water leak were minimal as the water was collected and stored. Some tritium from evaporation was exhausted through the NRU ventilation system, but the amount remained well below regulatory limits.

[Slide 4 – Schematic and photograph of NRU]

This slide shows a picture of the NRU reactor, and a schematic illustrating the location of the leak in relation to the nearest access point on the upper deck plate, 9 meters above the bottom of the vessel. Access to the interior of the vessel is through apertures that are 12 centimetres in diameter (roughly the size of my hand). In addition, the reactor deck is only 3.7 m in diameter, limiting the area for staging and executing in-vessel work. One way to appreciate the difficulties of examining and repairing the vessel is to think of repairing the basement wall of a two story house by working from the roof through a length of drain pipe. In the case of the NRU vessel, the work was made more challenging by the high-radiation fields that pose a risk for staff and can damage electronic equipment.

[Slide 5 – Detailed Schematic of the Leak Site]

This is a detailed schematic of the base of the NRU vessel showing the annulus, light-water reflector and location of leak at the bottom of the annulus, shown by the red arrow. The black arrow below indicates the circumferential weld at the base of the vessel that is used as a reference elevation. Note that the vessel wall thickens below the circumferential weld. The actual condition of the inside surface of the vessel was relatively clean with about a 1 millimetre coating of gibbsite. Gibbsite is a corrosion product of aluminum that is formed in water.

Outside the vessel, there was corrosion product buildup on the lower vessel wall, the floor of the light water gutter, and the wall of the reflector. Also, the heavy water gutter was filled with corrosion products and the lip was corroded away in some areas.

[Slide 6 – Assessment of Vessel Condition]

The first step in assessing the vessel condition was a visual inspection of the full circumference of the NRU vessel. The pictures on this slide show a team of AECL staff using a remote camera to examine the vessel. The visual inspection was followed by a comprehensive NDE campaign undertaken over 5 months to determine the thickness of vessel wall. Progressively more sophisticated probes and delivery systems were used to expand the area of inspection and quality of data. This represents one of the largest NDE campaigns carried out in the nuclear industry on a single reactor component, with over 2 million data points collected.

[Slide 7 – NDE Results Showing Vessel Wall Thinning]

This is a composite of NDE data into one image of a band of the vessel wall from just below the lower circumferential weld to a height of about 250 mm above the weld. The original wall thickness was 8 mm as indicated by dark brown and darkens further as the vessel wall thickens below the circumferential weld. Lighter shading indicates the degree of wall loss. The remaining wall over most of the vessel is more than 7 mm.

Patches of regional wall reduction were found at the base of the vessel extending upward from the level of the floor of the J-Rod annulus about 50mm above the circumferential weld.

These show up as light coloured areas in the figure, with some pockets of highly-localized corrosion below the areas of regional corrosion. Areas to note are:

- JR-13/18 as the largest area of corrosion,
- the corrosion sites between JR-21 and JR-30, and
- the leak site at JR-41

[Slide 8 – Outline of Vessel Repair Activities]

With the challenges posed by the high radiation environment and limited access, proven remote welding technology was chosen as the preferred method of repair. All activities had to occur through a 12 cm hole, 9 metres away. The picture shows the congestion on the top of the NRU reactor in carrying out in-vessel work. Parallel development was carried out on mechanical repair, welded structural plates and weld build-up. All have proven valuable. In November, 2009 localized weld build-up was selected as the primary repair strategy.

Extensive qualification and practise were undertaken before going to the reactor, using bench tests, and integrated tests in full-scale mock-ups. Hundreds of AECL and contractor staff worked around the clock for more than a year. Through the course of the inspection, tooling development and repair more than 350 contractor staff have provided tooling and services.

[Slide 9 – Photograph of Mock-Up]

A number of mock-ups were built to develop and test tooling and procedures. The photo is a full-height mock-up in the NRX reactor hall. Another full-height, partial mock-up, was built in the mechanical equipment design building, specifically to test tooling developed at CRL, and 3 full height stations were set up at the supplier of welding technology, Liburdi Automation. They did this by cutting a hole in their roof and erecting a tent to house the weld control stations and accommodate the full height of the tools. In addition, three full height mock-ups were built adjacent to the NRU vessel to carry out final weld development and training with in-vessel tools.

[Slide 10 – Removing Samples from Vessel Wall]

A full-wall section coupon was required to determine the corrosion mechanism that caused deep penetrations like the one that led to the leak. In the picture on the left, the hole saw for cutting the coupon is seen being tested in a mock-up. The actual cutter is indicated by the blue box. The tooling was designed to fold up to fit through the 12 cm aperture and then unfold to deploy in the vessel.

Irradiation of the NRU vessel has modified the original material properties through transmutation and alteration of the microstructure. Tooling was developed to remove thin “scoop” samples about the size of a Canadian quarter from the vessel wall. In the picture on the right, the scoop cutting wheel is highlighted by the green circle and the scoop sites by the blue box. Each scoop is large enough to study material properties without requiring repair of the vessel. Scoops were used to confirm there was no material sensitization or intergranular corrosion, and to determine mechanical properties of the wall material for structural analysis and welding. In addition, a

sample weld was carried out on a scoop which was sectioned to examine the properties of the weld and its Heat-Affected Zone.

[Slide 11 – Scoops and Coupon]

On the left is a picture of the site where the vessel wall scoops were removed; from typical vessel wall material, from the weld, and from the heat-affected zone at one of the vertical seam welds. One of the removed scoops is shown in a metal sample holder.

On the upper right is a picture of the coupon hole next to leak site taken from inside the vessel. You can see the corrosion in the J-Rod annulus. The bottom right picture is the coupon in the cutting tool and you can see the corrosion on the surface of the coupon.

[Slide 12 – Tooling to Clean Vessel]

Specialized tooling was required to clean the vessel wall in preparation for welding, and to vacuum the vessel after repairs had been completed. The picture on the left shows staff manipulating tooling through a 12 cm hole, with the indexing portion of the cleaning tool on the left. The picture on the right is the head of a cleaning tool being tested in a mock-up.

[Slide 13 – CAD Models of Weld Tooling]

A number of different tools were developed to carry out the repair steps, including from left to right, grinding, plate placement , and a vertical weld tool. The right-hand schematic illustrates how the tools were designed to pass through the 12 cm aperture, work around in-vessel obstructions, and deploy accurately and reliably to the vessel wall. The tools also had to meet stringent AECL standards for use in a reactor, undergo Foreign Material Exclusion inspections and retract reliably to be able to exit the vessel after completing a task.

[Slide 14 – Weld tools in a mock-up]

Mock-ups were used extensively to ensure high quality welding operations could be performed reliably. For the final repair site, over 100 test plates were welded in the mock-ups before executing the repair in the vessel.

[Slide 15 – Location of sites requiring repair]

A preliminary fitness for service assessment was used to determine the sites on the vessel wall that required repair to re-establish leak tightness, structural integrity and corrosion allowance. This slide shows the locations of the 10 repair sites, and the location of a test weld. These areas are outlined in red.

[Slide 16 – Picture of Test Weld]

Each repair site required a complex sequence of weld development, welder qualification & reliability testing, integration testing, actual repair work, NDE & certification of the repair.

Before any repairs were undertaken, in-vessel welding was proven with a test weld carried out December 03, 2009. Full NDE confirmed the in-vessel weld process was acceptable. In addition, a scoop sample was removed to examine the condition of both the weld material and the heat-affected zone adjacent to the weld. Metallography results were reviewed by AECL and external materials and welding experts to confirm the material condition was acceptable and repairs could proceed.

[Slide 17 – Horizontal and Vertical weld build-up]

The basic repair technology used weld overlay to build up the wall thickness and re-establish mechanical strength. The overlay could be vertical or horizontal, depending on desired features and in-vessel constraints. In the month of December, 5 sites were welded and NDE completed to confirm quality

repairs. The expectation was that, as the welders gained experience, their skill and confidence would improve to offset the challenges posed by the increasing size of later repair sites. However, application of a prudent and rigorous approach to the larger and more complex sites required a unique repair design for each site.

[Slide 18 – JR-41 Weld Repair]

JR-41 was the original leak site, and the location where the through wall coupon was removed to identify the corrosion mechanism causing deep corrosion pockets. A 1.5mm thick backing strip was used to cover the hole at the leak location and the adjacent coupon removal site.

- The upper left shows tacking the backing strip in place
- The lower left shows additional tacks and fillet welds to secure the backing strip
- The picture on the right shows the build-up applied to complete the repair

[Slide 19 – JR-23 Weld Repair]

In addition to repairing the holes at JR-41, backing strips were used to support weld build-up in regions of very thin vessel wall. At JR-23, this repair technology reached its limit of application. With the thin vessel wall, achieving a quality repair was very challenging. A new concept was developed to provide a repeatable repair. This concept was based on putting a window-frame of weld build-up around the plates, as shown in the centre photo, followed by a weld overlay of the plates and window frame to complete the repair as shown on the right.

JR-23 was the last site that could use full weld overlay as the stresses for larger weld areas approached the allowable limits to avoid disturbing the lower vessel seal.

[Slide 20 – Structural Plates]

For the larger repairs, structural plates were welded to the vessel to reduce the extent of weld overlay and resulting stresses. In this approach, the plates were thicker and designed to re-establish mechanical strength of the vessel wall without a covering of weld overlay.

The first application was the JR-25/27 repair site using 4 plates 3mm thick. Tooling used to install plates had to be modified to tack structural plates in place as shown in the lower right picture taken in the vessel following plate installation. New weld and NDE techniques also had to be developed to ensure qualified structural welds at plate edges and between plates.

The completed test plate #24 produced in a mock-up is shown in the upper left picture. In all, more than 30 test plates were produced prior to completing the JR-25/27 repair in the vessel.

[Slide 21 – JR-13/17 final repair]

JR-13/17 was the last and most complicated repair covering an area more than twice the size of the next largest repair. To understand the discussion that follows, you have to know that the plates were numbered in order of installation, in vertical rows starting from the top left.

--- **Show Plate Numbering Scheme**

A 3x3 array of 4 mm thick structural plates was used to reduce welding stress on the vessel lower seal. This was an evolution of previous repairs, but still required development of nine specific welding processes plus NDE procedures for the unique “groove welds” between plates.

The top left picture shows 8 of 9 plates installed. The tack on the 6th plate melted through the thinned vessel wall requiring a modification to the placement of the 9th plate.

The bottom left picture shows the complete installation of the plates and the horizontal and vertical “window frame” of 4mm weld buildup in the vessel.

The bottom right picture shows the addition of a large area of horizontal 3mm buildup on the left side to complete the repair.

JR-13/17 is the only repair site that required significant rework after the initial welding was complete.

Post weld Eddy Current Testing indicated a surface breaking flaw between plates 8&9 extending across into the groove between plates 5&6 and down between plates 6&9. These are all located in the lower right corner of the repair.

[Slide 22 – Crack at JR-13/17]

Follow-up visual inspection showed a crack in the groove welds. The cracking is believed to have occurred as the large weld buildup was being carried out on the left side of the JR-13/17 repair. Displacement during the large area of weld buildup, as shown on the finite element model, combined with lack of fusion is believed to have caused the crack. Note that the deflections shown in the finite element model have been exaggerated to them visible in this figure.

The two horizontal and one vertical crack tip were ground out and welded. The length of the crack was then excavated to a depth of 2mm and rewelded. Two attempts were required to achieve an acceptable weld. Portions of the rework weld were then ground to improve NDE capability.

Visual inspection was repeated for the full JR-13/17 repair area. Eddy Current Testing was repeated over the repair area and for the groove weld between plates 7&8.

Prior to declaring “Repairs Complete”, given the challenges and complexity of the JR-13/17 repair, a workshop was held including internal and external experts to consider if sufficient repair and inspection had been carried out to assure a quality repair. Consensus supported declaring the repair complete.

[Slide 23 – Weld Inspection Results (summary table)]

Post-weld inspection results have demonstrated the success of the weld repair program. Engineering has assessed the small areas of lack of fusion and determined they do not affect the effectiveness of the repair. One reportable indication was

identified in the heat-affected zone of the JR-23 repair and will require follow-up monitoring.

[Slide 24 – Leak Test Results]

Following declaration that the repairs were complete, the NRU vessel was refilled with water. An in-service leak test, witnessed by the responsible authority, did not find any evidence of water leakage from the vessel.

Trace amounts of tritium were measured in the J-Rod annulus between the vessel and reflector, during vessel fill but there were no signs of moisture. Ongoing monitoring over several days with the vessel full indicated tritium levels trending toward background. Additional visual inspections were undertaken of the inside of the vessel in the region where tritium was detected – no flaws or imperfections were found.

Tritium readings remained close to background levels when the vessel was refilled following the visual inspection.

[Slide 25 – Corrosion Mechanism]

We'll now turn to the source of the degradation of the NRU vessel. Two related corrosion mechanisms have been identified.

First, there is regional wall loss that results in a “scalped” reduction in wall thickness illustrated with NDE results on the left picture at the JR-41 leak site.

Second, as shown in the cross-section of the coupon removed from JR-41, localized corrosion pockets can form below the regional wall loss, at a level that would correspond to the water-line in the annulus.

[Slide 26 – Corrosion Mechanism – Related aspects]

Based on evidence from the corrosion coupon and experience with corrosion in the annulus between the vessel and reflector, both the regional corrosion and the localized corrosion pockets result from nitric acid formed by irradiation of air in the presence of light water from reflector leaks. Carbon dioxide is distributed into the annulus to displace air, but the delivery has not always been effective.

Regional corrosion, shown here in NDE results for JR-13/17, is due to contact of acidic water with the vessel, for example due to splashing or spraying.

The corrosion pockets, shown in the magnified view of NDE results from JR-41, result from an electrochemical cell where acidic water running down the vessel wall contacts oxygen-rich water from reflector leaks. Analysis of the coupon from JR-41 confirmed that no other contaminants were driving the electrochemical process (copper, iron, indium)

[Slide 27 –Vessel Annulus – Preventing Corrosion]

The series of pictures from top left to bottom right show the condition of the J-Rod annulus; first when the vessel was installed, then an area of typical corrosion, next increased corrosion at the leak site, and finally the improvement achieved through vacuuming in the annulus.

The strategy to reduce and arrest corrosion is based on reducing air and water ingress. Immediate action has been taken to address water leaks and clear drains to eliminate pooling and splashing on the vessel wall. Action has also been taken to reduce air leaks and to improve delivery of CO₂.

Going forward, CO₂ purity and pH of water drained from the annulus will be closely monitored. Further reductions of water and air ingress will be achieved through physical improvements during regular planned maintenance outages.

Additional mitigation measures are under consideration – including application of a cold spray sacrificial aluminum coating, repair of reflector leaks and changes to reflector water chemistry.

[Slide 28 – Condition Assessments]

Recognizing that corrosion was not anticipated in the vessel condition assessment performed in 2004/05, AECL undertook actions to ensure there are no concerns with assessments of other NRU systems. First, the condition assessment process was reviewed to ensure there is no generic problem with the process – nothing was found. Second, an independent process of review was carried out by an expert panel to validate results of the condition assessments – no additional gaps of safety significance were found.

Going forward, the Integrated Safety Review that is currently underway in support of license renewal will address gaps to modern codes and standards. The Isotope Supply Reliability Program is improving Plant Life Management including the Maintenance Program and System Health Monitoring.

[Slide 29 – NRU Fitness for Service]

In assessing the NRU vessel's fitness for service, regional corrosion compromised the vessel's ability to withstand specified loads. The top graphic on the slide shows results of finite element analysis used to determine sites requiring repair. The lower graphic shows acceptable mechanical performance following repair.

Continued fitness for service will be verified through in-service inspections conducted during planned maintenance outages.

In the future, the reliability of NRU operation will be enhanced through longer planned maintenance outages. These longer outages will start within 9 months of return to service, and occur annually thereafter, subject to review based on NRU performance and outage experience. The duration of annual maintenance outages will be set by critical path activities and are expected to be about 4 weeks in duration.

[Slide 30 – Addressing Corrosion Pockets]

In-service inspection will monitor wall thickness and thereby assure ongoing structural integrity. The inspection program and ongoing mitigation reduces, but does not eliminate, the potential for highly-localized corrosion pockets. Such corrosion pockets do not impact structural integrity, but could lead to a heavy-water leak. Tooling is being developed to effect a mechanical repair of a small leak without defuelling and draining the reactor.

[Slide 31 – Organizational Improvements]

Causes for the NRU leak event have been assessed and found to be consistent with opportunities for improvement identified in a 2008/09 Safety Culture Survey. Corrective actions have been rolled into AECL's improvement program called Voyageur Phase II. Broad elements of the program are:

1. Improve equipment reliability – to ensure a low tolerance for equipment issues, eliminate work-arounds, improve maintenance programs, spares, and System Health monitoring
2. Reinforce desired organizational behaviours, such as a questioning attitude, and use of event free tools
3. Improve problem identification and corrective action, to consistently identify and address problems with a low significance level
4. Improve use of Operating Experience to learn from internal and external events

5. Improve standards for operation, for example through improved procedural adherence, outage planning, and the WANO peer review process
6. Improve leadership and oversight, through the strengthening of our Leadership Academy, change management, and observation and coaching.

Measures of improvement will include site and departmental level Event Free Day Resets, interim safety culture surveys, equipment reliability indicators, and a health index for the Corrective Action Program.

Human resources, equipment upgrades to address obsolescence and equivalency, spare parts and program improvements, are all funded through the Isotope Supply Reliability Program.

[Slide 32 – Extended Activities Program]

The NRU outage provided an opportunity to carry out maintenance and inspection activities that cannot be completed within the normal operating cycle. Safety and reliability improvements were made to the Main Heavy Water System, Process Water System, Fuel Rod Flask and Control Rod Systems.

All outstanding maintenance activities requiring the reactor drained and defuelled were completed.

To address CNSC staff inspection findings, comprehensive system walkdowns were completed on the Seven NRU Safety Upgrades during the outage and all findings have been reviewed and dispositioned.

As we proceed with the NRU return to Service program, the Safety Upgrades will be confirmed fully operational, fully tested and fully capable of performing their safety functions.

[Slide 33 – Return to Service]

As part of the NRU return to Service program, the NRU readiness for service process will assure all systems are fully operational and fully tested. A detailed, integrated, plan has been produced for all maintenance, testing, system configuration and training activities and is being executed as shown by the workdown curve. A dedicated team was assembled in September 2009, to put together the step-by-step procedures, supported by checklists, needed to safely and efficiently return systems to service. Operating experience from the restart in 1991 was reviewed and included in the development of procedures and checklists. More than 2000 activities have been identified and scheduled. The return to service is supported by a dedicated outage control centre, and fix-it-now teams to address emergent issues on equipment that has been layed up for a year.

[Slide 34 – Training Activities]

Training associated with the NRU Return To Service includes both update training on new procedures that have been developed associated with restart activities, and refresher training on activities that have not been routinely performed during the outage. Training is being delivered close to the time it is required for maximum benefit. This chart shows the over 400 training activities leading up to refilling the reactor vessel. Similar programs are being delivered prerequisite to starting re-fuelling activities and prior to restarting the reactor to low power operation.

[Slide 35 – Assurance of Fuel Performance]

In the months prior to the May 14, 2009 shutdown, it was suspected that there was one or more defects in NRU driver fuel. The current driver fuel design has had excellent performance since it was introduced in NRU in the early 1990's. Until coolant activities rose in late 2008, there has been no record of defects.

Suspect fuel was removed from the reactor in January through March of 2009, and fission product activity in the coolant was decreasing consistent with the defects having been removed from core. Subsequent examination of the suspect fuel removed has confirmed there were fuel defects. A total of 4 defects have been found and all are similar to the one shown on the slide. They occur at the ends of the fuel elements as a split in the aluminum fuel sheath in an area where the sheath has bulged.

The defect mechanism appears to occur early in the service interval of the fuel. Defects are limited to batches of fuel manufactured before February 2008. Based on the location

and nature of the defects, the most likely cause is organic contamination introduced during the manufacturing process.

No fuel from the batches with known defects will be re-loaded in to NRU for startup. Steps have been taken to ensure the likelihood of fuel failure following restart is acceptably low. The majority of the fuel to be reloaded was in NRU when the shutdown occurred, and was demonstrating good performance.

As a further contingency measure, the procedure for responding to rising coolant activity levels, which may indicate a new defect, has been enhanced, to assure appropriate measures are taken, in the unlikely event of future fuel defects.

[Slide 36 – June 23 Earthquake]

The June 23 earthquake was magnitude 5, centred north of Ottawa. A Government of Canada seismic monitoring station is located on the CRL site. The peak ground acceleration at CRL was 0.006 g, where g is the acceleration due to gravity. This would equate to an earthquake with a magnitude between 3 and 4 centered at Chalk River. NRU's safety functions have been qualified for an earthquake of magnitude 6. In addition, NRU has a seismic trip set at 0.06 g.

Nuclear facilities and buildings were walked down by Operations following the earthquake and assessed by Engineering to confirm no damage had occurred.

At the time of the earthquake the in-service leak test was in progress. To provide assurance of vessel integrity, those areas that had been completed were re-inspected. Also, the vessel was drained and an additional visual inspection was performed that included the larger repair sites, with no anomalies found.

[Slide 37 – Up-to-date Status and Communications]

Regular updates have been provided to the public and stakeholders, generally on a weekly basis to ensure they were kept informed of progress. Update #63 was released June 30.

AECL set up the www.NRUCanada.ca website in July 2009 with frequent updates to provide a wealth of information to all stakeholders.

Weekly briefings have been held with senior government officials to report progress on the repair and return to service.

Phone-in meetings have been arranged with health-care stakeholders and local officials when significant developments have occurred which may impact their constituents – for example extensions in the repair schedule, or major milestones such as completion of repair.

AECL is in regular communication with the other major isotope producers on projections for the NRU return to isotope production through the Association of Imaging Producers & Equipment Suppliers (AIPES) in Brussels.

[Slide 38 –Summary]

In summary, the NRU vessel has been successfully repaired and is fit for service.

AECL is confident that all requirements for safely restarting the NRU have been met.

We respectfully request approval to reload fuel past the guaranteed sub-critical condition, thereby allowing full return to service, and resumption of NRU operation and medical isotope production.

Thank You Mr. Chair