### AMP 141 CANDU/PHWR REACTOR ASSEMBLY (VERSION 2021)

### Programme Description

Based on the current understanding of degradation mechanisms of the reactor assembly in CANDU and PHWR, this AMP provides ageing management strategies, technically feasible inspection and maintenance activities to ensure that ageing effects are discovered and corrected (repair or replacement) before the loss of intended function of the critical reactor assembly components through intended period of operation.

### Evaluation and Technical Basis

1. ***Scope of the ageing management programme based on understanding ageing:***

For the purposes of this programme, the reactor assembly consists of the calandria vessel, end shield, shield tank/calandria vault, guide tubes, moderator inlets and outlets, calandria end shield support, reactivity control units, calandria relief ducts, lattice tubes, and calandria tubes (CT). The scope of the programme is to manage the ageing effects on the components mentioned above. The ageing management programme for fuel channels (including pressure tubes (PT) and end fittings) is covered by AMP 139.

1. ***Preventive actions to minimize and control ageing degradation:***

Loss of material caused by general corrosion, pitting, and crevice corrosion, and stress corrosion cracking can be prevented or mitigated by managing pH, chlorides and fluorides of moderator and pH, chlorides and dissolved oxygen of shield cooling water below the allowable limits based on the chemistry control procedures for moderator system and shield cooling system.

Methods for water chemistry control are established to control and monitor any adverse effects of the water chemistry conditions on the ageing effect. The programme description and evaluation and technical basis of monitoring and maintaining reactor moderator chemistry are addressed in AMP 103.

The moderator cover gas system provides an inert, non-corrosive helium gas atmosphere in parts of the system not filled with water, including the relief ducts. Proper function of the system will minimize oxygen and the formation of nitric acid in the calandria by purging out any ingressing air, and reduces the formation of Ar-41 in the system.

1. ***Detection of ageing effects:***

Inspection can reveal cracking, erosion, corrosion, leakage, wear, relaxation of fitted connections, changes in clearances/settings, physical displacements, loose or missing parts, debris, or loss of integrity at bolted or welded connections.

1. Visual inspection of calandria vessel and end shield - The objective of the inspections is to determine if the calandria is fit for continued operation, and to find out if any corrective measures are needed. Refurbishment and large scale fuel channel replacement (LSFCR) outages, which occur after approximately 25-30 years of operation, provide practically the only opportunity to conduct the calandria vessel, and end shield inspection. See also AMP 119. The inspection scope of the calandria vessel includes the general visual examination of the calandria, and a more detailed inspection of the following regions and components:

* Reactivity mechanism locators at the bottom of the calandria - The locators are subjected to continuous dynamic loads which can result in cracking of welds connecting locators to the calandria shell. The scope is a limited visual examination of selected locators.
* Flow splitter at the end of horizontal flux detectors - During normal operation, flow splitters installed at the far end of horizontal reactivity mechanisms are exposed to continuous dynamic loads caused by turbulent flow of the moderator. The scope is limited to the visual inspection of the condition of all flow splitters.
* Manhole at the bottom of the calandria - The manhole nozzle and cover, having a sink shape and being located at the bottom of the calandria, is the most likely region for the collection of debris. Debris can cause crevice corrosion and also is a major indicator of damage degradation elsewhere in the calandria. The scope includes the visual inspection of the condition of the manhole and for any evidence of debris.
* Calandria main welds - Indications that were observed in the main welds of the calandria shell during the original installation are reviewed. The scope includes re-examination of these indications to identify any significant changes.
* Lattice tubes - The condition of the lattice tubes can be visually inspected during LSFCR as the removal of fuel channel (FC) and CT will provide access for the inspection. The condition of the lattice tube and the need of any corrective measures can be determined after the inspection.

1. Inspection of calandria tubes - An in-reactor CT inspection is performed whenever there is a PT removal. PT removal is required every 4 years as per CSA N285.4 material surveillance programme [1]. The inspection involves visual inspection for scratches and damage including garter spring (GS) locations, and for foreign material.
2. Gap measurements between PTs, which are supported by the annulus spacers (garter springs), and CTs (refer to AMP139)
3. Gap measurements between CTs and nozzles of LISS
4. Measurement of the guide tube (GT) locator gap within the GT spring housing
5. Inspection of moderator inlet nozzles - Based on operating experience, moderator inlet nozzles are included in the inspection scope as a prudent measure to verify if they are affected by flow induced vibration.
6. Inspection of moderator inlet line - The scope of inspection could include visual, ultrasonic and liquid penetrant examinations of critical regions of moderator inlet lines.
7. Visual examination of the condition of the bottom region of the annular gap.
8. Inspection inside calandria vault / shield tank using inspection tools - This may include the calandria vessel, dump tank, dump ports, expansion bellows, balance, and spray cooling lines, ion chamber housing, reactivity mechanism thimbles, closure shielding plates and RTS vent lines.
9. Inspection of calandria relief ducts (CRDs) and cover gas return lines

* A visual inspection to detect signs of deterioration (e.g., corrosion and pitting, stress corrosion cracking).
* Swabbing of any forms of corrosion noted on the ID surface of the CRDs or the rupture discs for chemical analysis
* Metallurgical examination (replication of the duct and metallographic examination) of any areas of cracking.

1. Visual inspection of the lattice tubes.
2. ***Monitoring and trending of ageing effects:***

In accordance with the intervals suggested in the Guidelines for CANDU/PHWR Water Chemistry Control, the chemical species such as chloride, fluoride, dissolved oxygen, and pH level that can affect stress corrosion cracking, pitting, and crevice corrosion are monitored based on "Moderator System Chemistry Control Procedure", and "Shield Cooling System Chemistry Control Procedure", and maintained below allowable limits (see also AMP 103). Helium gas leakage to the vault may be indicative of cracking at the CRD or cover gas system return lines.

Both the PT and CT sag due to thermal and irradiation-induced creep and growth during plant operation, sag may lead to PT/CT contact, calandria tube/liquid injection shutdown system (LISS) nozzle contact, and fuel passage issues

Inspection is carried out as per the extent and schedule given in attribute 3. Gaps measured between CTs and nozzles of LISS are trended, against equivalent full power operating hours to predict gap reduction rates and the time before the minimum gap is reached.

Inspection results are evaluated to determine if additional inspections are needed to ensure that the degradation effects are adequately determined and corrective actions are adequately identified.

Calandria Internal Inspection System (CIIS) has been developed by Korea Wolsong NPP1, Korea which covers inspection of moderator inlet nozzles, calandria tube sheet weld, calandria vessel interior, LISS nozzles, calandria manhole cover to nozzle weld etc. [2].

1. ***Mitigating ageing effects:***

The inspection results are evaluated to determine the need for mitigating actions. The mitigating actions may include removal of surface indications, repair, replacement, operation with restrictions, change of water chemistry, and so on. Monitoring of the vault dew point and operation of vault dryers is performed to mitigate nitric acid corrosion of the calandria supports.

1. ***Acceptance criteria:***
2. Indications detected from nondestructive examination (NDE) that show no detectable change since the previous inspection are considered acceptable.
3. Indications detected from NDE that show material erosion/corrosion losses that do not exceed the limits specified for the design of the components until the next periodic inspection, are considered acceptable.
4. Unless otherwise specified, the acceptance criteria in accordance with national regulations or governing documents, such as [1,3-4], will apply.

Conditions that do not comply with the general acceptance criteria mentioned above may be considered acceptable provided that the fitness-for-service of the component has been demonstrated, to the satisfaction of the regulatory authority, until the next scheduled inspection.

1. ***Corrective actions:***

When the acceptance criteria for chemical managementare not satisfied, the causes are identified and appropriate corrective actions are implemented based on the AMP 103 and utility’s specific chemistry management procedures such as procedures of "Moderator System Chemistry Management" and "Shield Cooling System Chemistry Management".

The inspection results for indications are evaluated based on national regulations or governing documents, such as [1,3-4], and approved fitness-for service guidelines to determine the need for corrective action. If required, a corrective action plan which includes repair, replacement, operation with restrictions, or other mitigating actions, is developed and implemented.

1. ***Operating experience feedback and feedback of research and development results:***

This AMP addresses the industry-wide generic experience. Relevant plant-specific operating experience is considered in the development of the plant AMP to ensure the AMP is adequate for the plant. The plant implements a feedback process to periodically evaluate plant and industry-wide operating experience and research and development (R&D) results, and, as necessary, either modifies the plant AMP or takes additional actions (e.g. develop a new plant-specific AMP) to ensure the continued effectiveness of the ageing management.

The calandria internals such as moderator inlets nozzles, guide tubes, calandria tubes, LISS nozzles, and moderator relief ducts have been selected for inspections in Canadian nuclear utilities based on operating experience (OPEX) and research [5-8].

In past, Unit-2 of MAPS, India reported a calandria tube leak in 1988. Subsequent to this, failure in the inlet manifold of calandria was reported [9]. Measures were taken by use of sparger channels with extended insert arrangements. OPEX from refurbishment in Bruce and Point Lepreau reactors shown that reactor internals generally are in good condition after 25-30 years operation.

Transgranular stress corrosion cracking, believed to be due to chloride species being concentrated below carbon steel corrosion products, has been observed in the outlet calandria relief ducts at one unit.

The COG Calandria & Internals Working Group (CIWG) has been established to provide industry information exchange and to address generic issues related to the Fitness for Life Extension of the CANDU Calandria and Internals. A Candu Operating Group (COG) Joint Project (JP) 4271 assessed the Calandria vessel and internals fitness for life extension for 60 years of operation. [10] Known and potential degradation mechanisms such as corrosion, irradiation embrittlement and crack growth will be assessed for the entire calandria, internals and interposing systems to the extent possible. The CANDU industry will identify all equipment within the Calandria internals that cannot currently be shown to be fit for service for a 60 year operating period.

Inspection plans and bounding assessments where possible are developed to demonstrate the fitness for service for all identified components. All attributes that need to be addressed to achieve a 60 year life will be identified.

Sources of research and development activities relevant to this AMP include the Candu Owners Group (COG), Canadian Nuclear Laboratories (CNL) and CANDU Energy Inc. in Canada, as well as Bhabha Atomic Research Centre (BARC) in India.

The programme includes provisions for continuing review of plant-specific and industry-wide operating experience, and research and development results, such that impact on the programme is evaluated and any necessary actions or modifications to the programme are performed.

1. ***Quality management:***

### Administrative controls, quality assurance procedures, review and approval processes, are implemented in accordance with the different national regulatory requirements (e.g. CSA N286-05 [11]).

### References

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3. AMERICAN SOCIETY OF MECHANICAL ENGINEERS, Rules for Inservice Inspection of Nuclear Power Plant Components, The ASME Boiler and Pressure Vessel Code, ASME Section XI, as approved in 10 CFR 50.55a, ASME, New York, NY.
4. ATOMIC ENERGY REGULATORY BOARD, Inservice Inspection of Nuclear Power Plants, AERB/NPP/SG/O-2, AERB, Mumbai, India, March 2004.
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7. Materials Degradation and Related Managerial Issues at Nuclear Power Plants, Proceedings of a Technical Meeting, Vienna, 2005.
8. INTERNATIONAL ATOMIC ENERGY AGENCY, Nuclear power plant life management processes: Guidelines and practices for heavy water reactors, IAEA TECDOC – 1503, IAEA, Vienna, 2006.
9. T.S.V. Ramanan, Process Systems of PHWR: Indian Experience, Technical Committee Meeting on Exchange of Operation Safety Experience of Pressurized Heavy Water Reactors, Embalse, Cordoba, Argentina, April 3-5, 1991.
10. COG-JP-4271-004 A. Barakzai, N. Mano, A. Pandya: Calandria Fitness for Life Extension Guidelines: Phase 3, May 2013.
11. CANADIAN STANDADS ASSOCIATION, Management System Requirements for Nuclear Power Plants, CSA N286CSA, Toronto, Canada.