## AMP 145 CANDU/PHWR MODERATOR AND MODERATOR PURIFICATION HEAT EXCHANGERS (VERSION 2021)

### Programme Description

The moderator system, which is unique to the CANDU and PHWR design, circulates the heavy water moderator (D2O) surrounding the calandria tubes (with fuel channels) in the Calandria through heat exchangers to remove the heat generated in the moderator during reactor operation. The moderator system includes two 100 percent capacity pumps and two 50 percent capacity heat exchangers (hereinafter referred to as “moderator heat exchangers”). The moderator heat exchangers are U-tube in shell type heat exchangers. The heavy water moderator passes on the tube side, while the shell side carries light water re-circulated cooling water (RCW) or low-pressure service water (LPSW). The moderator heat exchangers are considered critical components as they support the functions of the moderator system by removing heat from the moderator fluid and are important to maintaining system inventory.

The moderator purification system in CANDU/PHWR maintains the purity of the heavy water moderator and minimizes corrosion of components and crud activation by controlling the pD (pH) and by removing impurities presented in the D2O. The moderator purification system is also used to adjust the concentration of neutron poisons, and to remove the soluble gadolinium poison following the operation of Shutdown System 2 (SDS2). The moderator purification system consists of a filter, ion exchange columns, and a moderator purification heat exchanger of U-tube in shell type. The moderator purification heat exchangers cool the moderator purification fluid to resin specifications and are important to maintaining system inventory.

This programme is to manage the ageing of the moderator heat exchangers used in moderator system and the moderator purification heat exchangers used in moderator purification system in CANDU/ PHWR. The programme requires that the heat exchangers performance be monitored, ageing effects be discovered, a corrective action plan be developed and implemented to ensure that they continue to perform their required functions and meet performance objectives throughout the target life of the plants.

**Evaluation and Technical Basis**

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

This programme is applicable to the managing the ageing of heat exchangers of shell-and-tube type used in moderator system and moderator purification system in CANDU/PHWR. The active or potentially active degradation mechanisms in the moderator heat exchangers and the moderator purification heat exchangers include erosion and erosion*/*corrosion, pitting, general uniform corrosion, microbial induced corrosion (MIC), fouling, fretting, stress corrosion cracking (SCC), and fatigue. Periodic assessment of ageing degradation mechanisms associated with heat exchanger tubes, tube sheets, tube joint welds, shell, nozzles, internals, channel heads, divider plates, and fasteners is performed.

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

This programme includes preventive actions for addressing degradation. Preventive measures include performance and condition monitoring, and preventive maintenance.

Service water in the shell side is strained open service water. Trash racks and a travelling screen are used to prevent ingress of debris. Chloride injection (e.g., shock treatment) is periodically performed to combat mussel growth and to remove accumulations of biofouling agents, corrosion products, and debris.

Chemistry in the tube side is controlled to minimize concentrations of ionic impurities that promote D2O radiolysis and to minimize corrosion of moderator system materials. Periodic grab sampling and chemical analysis are performed for verification of the moderator chemistry.

If unacceptable indications and deterioration are found in inspection, expansion of inspection area, and increase in frequency of inspection and leak testing are considered.

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

Inspection and leak detection for the moderator heat exchangers and the moderator purification heat exchangers is conducted in accordance with national regulations or governing documents. The inspections detect degradation of the heat exchangers by using following non-destructive examinations (NDE) methods [1-3]:

* 1. Visual — this includes inspection for evidence of erosion, corrosion, fouling, and damaged coatings by methods such as direct visual inspection and inspection using visual aids (e.g., video probe);
  2. Dimensional — this includes inspection for determining shell or nozzle wall thickness, using ultrasonic technique; and
  3. Surface and volumetric — this includes inspection for determining wall thinning and discontinuities by eddy current method, or other methods (such as liquid penetrant, magnetic particle, and ultrasonic).

Degradation of heat exchangers tubes can also be identified through leak testing in accordance with applicable procedures (e.g., Helium Leak Test Procedure) and Technical Specifications specified by manufacturers of the heat exchangers.

1. ***Monitoring and trending of ageing effects:***

The ageing of the moderator heat exchangers and the moderator purification heat exchangers is routinely assessed and monitored through a combination of Periodic Inspection Programme, Leak Testing Programme, and / or Performance & Condition Monitoring Programme.

Thermal performance can be regularly monitored to determine if the thermal capacity of the heat exchangers is degraded.

Vibration monitoring programmes can be used to assess any structural integrity, foundation or component looseness issues. The frequency of monitoring actions, walkdowns, inspections and leak testing is adjusted based on the results of the degradation detected and in accordance with national regulations or governing documents. Routine or enhanced chemistry monitoring can be used to detect potential degradation (e.g. leaks or corrosion).

Wall thinning is monitored to ensure the limits within the design basis are met.

Also, reduced shell side flow rate and shell side pressure drop may indicate the occurrence of fouling. Therefore, a monitoring programme for inlet/outlet temperature and pressure/flow rate can be implemented to detect any increase or decrease at inlet/outlet.

Changes of the Temperature Control Valve (TCV) position may indicate changes in the thermal conditions of heat exchanges. Changes in the thermal conditions may indicate a reduction to shell side flow which could result from fouling. Therefore, monitoring of the TCV position is performed.

Samples of both LPSW on the effluent from the moderator heat exchangers and HPSW on the effluent from the moderator purification heat exchangers are taken to monitor the level of tritium, which could indicate a tube leak.

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

The inspection results are evaluated to determine the need for mitigating actions, such as periodic chlorination, cleaning and inspection.

If fouling is identified in the shell or on the outside of tubes, deposits and sludge are analysed, and if necessary these affected surfaces are cleaned.

If inspection results reveal a deficiency of the chemistry control programme, the programme is reviewed and adjusted accordingly.

1. ***Acceptance criteria:***
2. Indications detected from 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 at the end of the next periodic inspection interval, are considered acceptable.
4. Unless otherwise specified, the acceptance criteria in accordance with national regulations or governing documents, such as the ASME *BPVC*, Section XI [2], 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 planned inspection.

1. ***Corrective actions:***

The inspection results are evaluated in accordance with national regulations or governing documents and approved fitness-for service guidelines to determine the need for corrective action such as identifying where the leak is. Also, if required, corrective action plans, which can include tube plugging, tube sleeving, or other repair, replacement or mitigating actions, are 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.

A mechanism that ensures timely feedback of operating experience as well as research and development results provides objective evidence that they are taken into account in the AMP.

Appropriate sources of external operating experience are NRC, WANO, SNL, EPRI, etc.

NRC issued the requirements of on-going programmatic actions for the service water heat exchanger from Generic Letter 89-13 [4-5] to reduce flow blockage due to biofouling via surveillance and control technique, to verify heat transfer capability through a test program, and to ensure that corrosion, erosion, silting, and biofouling cannot degrade performance of the service water system via routine inspection and maintenance.

Tube failure has occurred in the external tube side of the moderator heat exchanger due to erosion such as wall thinning caused by a foreign object [6]. To manage ageing this effect, visual inspection or FME process is implemented.

Related to this AMP, a comprehensive review of currently available information regarding heat exchangers used in nuclear power plants is presented in [7], where common characteristics of heat exchanger designs and service applications are examined to establish groupings for ageing mechanism and ageing management programme*/*technique evaluations. All ageing mechanisms for the heat exchanger applications are investigated to determine which are non-significant, and which are significant; and ageing management programmes*/*techniques are examined to determine which are effective for detecting and*/*or mitigating the significant ageing mechanisms.

Operating experience are reported in CANDU Owners Group (COG) and Electric Power Research Institute (EPRI) operational experience databases. In addition, EPRI overview and guidelines for heat exchanger maintenance, testing, and performance monitoring are documented in References [8-12].

At the time when this AMP was produced/reviewed, no relevant R&D was identified.

1. ***Quality management:***

Site QA procedures, review and approval processes, and administrative controls are implemented in accordance with the different national regulatory requirements (e.g., CSA N286-12 [13]).

### References

[1] CANADIAN STANDARDS ASSOCIATION, Periodic Inspection of CANDU Nuclear Power Plant Components, CSA N285.4-19, CSA, Toronto, Canada, 2019.

[2] AMERICAN SOCIETY of MECHANICAL ENGINEERS, ASME Section XI, Rules for Inservice Inspection of Nuclear Power Plant Components, The ASME Boiler and Pressure Vessel Code, 2013 edition as approved in 10 CFR 50.55a, New York, NY.

[3] ATOMIC ENERGY REGULATORY BOARD, Inservice Inspection of Nuclear Power Plants, AERB/NPP/SG/O-2, AERB, Mumbai, India, March 2004.

[4] NUCLEAR REGULATORY COMMITTEE, Generic Letter 89-13, Service Water System Problems Affecting Safety Related Equipment, 1989

[5] NUCLEAR REGULATORY COMMITTEE, Generic Letter 89-13, Supplement 1, 1990.

[6] WORLD ASSOCIATION of NUCLEAR OPERATORS, Operating Experience: Moderator Heat Exchanger Tube Failure, 2007.

[7] SANDIA NATIONAL LABORATORIES, Aging Management Guideline for Commercial Nuclear Power Plants - Heat Exchangers, SAND93-7070, SNL, 1994.

[8] ELECTRIC POWER RESEARCH INSTITUTE, Nuclear Maintenance Applications Center: Heat Exchanger Maintenance Guide EPRI 1018089, EPRI, Palo Alto, CA, 2009.

[9] ELECTRIC POWER RESEARCH INSTITUTE, Preventive Maintenance Basis, Volume 32: Heat Exchangers – Tube Type, EPRI TR-106857-V32, EPRI, Palo Alto, CA, 1998.

[10] ELECTRIC POWER RESEARCH INSTITUTE, Balance-of-Plant Heat Exchanger Condition Assessment and Inspection Guide EPRI-TR 108009, EPRI, Palo Alto, CA, 1999.

[11] ELECTRIC POWER RESEARCH INSTITUTE, SW Heat Exchangers Testing Guideline, TR-3002005340, EPRI, Palo Alto, CA, 2015.

[12] ELECTRIC POWER RESEARCH INSTITUTE, Heat Exchangers Performance Monitor Guidelines, EPRI NP-7552, , EPRI, Palo Alto, CA, 1991.

[13] CANADIAN STANDARDS ASSOCIATION, Management System Requirements for Nuclear Power Plants, CSA N286-12, CSA, Toronto, Canada, 2012.