### AMP 151 CANDU/PHWR primary heat transport INSTRUMENT TUBING (VERSION 2021)

### Programme Description

The objective of the programme is to assure the integrity of instrument tubing used for measuring, monitoring and sampling various process parameters of the primary heat transport (PHT) heavy water coolant in CANDU/PHWR.

CANDU/PHWR contain a large number of instrument lines of small-bore tubing which are routed in close proximity to each other in the feeder cabinets located at each end of the reactor. In CANDU/PHWR reactors equipped with a Failed Fuel Location system, also called the Delayed Neutron (DN) system, uses an instrument line sampling PHT coolant from the outlet feeder of each fuel channel (i.e. 380 DN system instrument lines in a CANDU 6 reactor). Impulse tubing used in flow measurement venturis and level and pressure transmitters, are also located within and penetrating the feeder cabinets. The PHT instrument tubing may experience fretting damage due to contact / interference with other tubing or with feeder piping, supports and other hardware, which can result in leakages from the PHT system and increased tritium activity released inside the feeder cabinet and reactor vault. Under certain material-environment-stress conditions, there can be potential for stress corrosion cracking of PHT instrument tubing.

This AMP relies on developing a specific strategy, involving preventive measures, inspections, and mitigating and corrective actions for managing ageing of PHT instrument tubing.

### Evaluation and Technical Basis

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

The scope of the programme covers instrument line tubing and transmitter impulse line tubing which contain PHT coolant, such as Failed Fuel Location / DN system tubing.

The ageing mechanisms and effects for the PHT instrument tubing include wall loss due to fretting, and stress corrosion cracking. Both of these effects can result in leakages from the PHT system and increased tritium activity inside the feeder cabinet or reactor building, which can necessitate a forced shutdown of the reactor.

The instrument tubing may experience fretting damage due to contact / interference with other tubing or with feeder piping, supports and other hardware inside the feeder cabinet or reactor vault. The tubing comes in contact as a result of the close spacing between items, differential thermal expansion of these components during operation, and shifting due to creep elongation of the fuel coolant channels. Relative vibratory movement induced by the operation of the PHT pumps, local chillers and from structures, causes rubbing / friction between the contacting parts which can lead to wall loss at the tubing contact points.

Under certain stress-environment-material conditions, there may also be potential for stress corrosion cracking, though these have been more isolated cases than fretting damage. The instrument tubing is usually austenitic stainless steel. SCC requires the presence of oxidizing species such as from halogens (e.g. from contaminated tooling, examination and cleaning fluids, or mineral wool insulation) and the presence of high residual tensile stresses such as due to plastic deformation at seismic clamps, tube bends or welds.

The programme includes procedures or administrative controls to assure the integrity of instrument tubing is maintained.

The programme includes water chemistry (AMP 103) to monitor and control the PHT coolant chemistry. The programme, or aspects of the programme, may also be performed in association with AMP 140 and AMP 146.

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

Preventive actions can be implemented during the construction phase or during refurbishment of the plant, and include:

The PHT instrument tubing is designed, manufactured and installed to high quality standards and Class 1 requirements as stipulated in national requirements and codes such as reference [1].

Strict controls and improvements in tube fabrication, welding, bending and clamping methods, to reduce the levels of residual stresses.

Careful planning, routing, installation and supporting of tubing to ensure adequate gap clearances that account for relative movement due to thermal expansion of components and creep elongation of fuel channels, adequate for the intended period of operation.

Quality control of materials to ensure that tooling, cleansing, or insulation will not cause potential chloride contamination of tubing.

Preventive actions during the operation phase include preventive maintenance and inspections. A comprehensive inspection strategy / checklist is prepared and managed in accordance with relevant procedures to implement systematic checks. This checklist covers the regions where wear ring or fittings are already installed or fastened, in addition to those regions where contacts between tubes or fretting are expected / at risk to occur, or regions at risk of SCC. Visual inspections are performed to check the condition of the fasteners, wear rings and contacting areas, and for signs of tube damage due to fretting. The tubes identified to have suffered degradation may be locally strengthened by cutting out the area where fretting occurred and fastening fittings. Tubing interference and contacts can also be prevented by careful routing / positioning or replacement of sample lines.

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

Proactive detection of ageing degradation of the instrument tubing, prior to through-wall leakage, is performed by walk downs and visual inspections during every preventive maintenance outage. Major items monitored or inspected include contacts between sample lines, their fretting status, and wear ring installation status. Degradation of the sampling line tubing by fretting damage does not occur if there is no contact between the lines. Checks and records are made of any contact between tubing, degree of fretting, and wear ring status by visual inspection and by physical feel/movement of the tubing. For the regions that are not easily accessed, a mirror or a video scope may be employed to detect contacting lines and signs of fretting damage.

Some of the primary locations to check the failed fuel location/DN system tubing for damage are as follows:

Penetrations (chafing shield) contacting feeder cabinet;

Crossing regions between tube bend at lower part of feeder cabinet and tube;

Those tubes which can contact adjacent tubes due to tube expansion caused by high temperature;

The crossing region between tube supports and tubes, and the region where a tube bend contacts adjacent tube;

Where a wear ring is installed on only one of the crossing tubes;

Where the wear rings are not properly located at the tube contacting point, or are rotated or displaced;

Where the wear ring has an indication of a gap or where there is concern the sharp edge of wear ring can damage another tube;

The crossing region between a straight tube and a round or U-shape tube region heading downward from an upper tube bundles to a lower tube bundle;

The region where contacts occur between tubes due to vibration of tubes induced directly or indirectly by the air flow from the local air cooler;

The crossing region between tubes where access is difficult as safe space is not secured at the lower part/side of DN tube bundle outside (reactor side);

The region where detailed inspection and strengthening works are limited due to narrow working space at part of the area in front of delayed neutron tube bundle as the safety railing and channel temperature monitoring system terminal box are installed there;

The region where 1/4" tubes, which are linked to penetrations, cross.

The results of the checks are recorded, and checking tags are attached on the regions where fretting occurred. In the case of wear rings, the occurrence of fretting, and the ring position / rotation and displacement is recorded and managed. The tube-to-tube and tube-to-support clearances are recorded and classified as above 30mm and below 30mm to manage the checking results.

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

The condition of PHT instrument tubing is monitored as described in Attributes 2 and 3. It is possible to analyze ageing trends of sample lines by monitoring inspection results and preventive and corrective maintenance activities.

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

For the regions of PHT instrument tubing that are degraded or expected to be degraded, strengthening of fittings and adjustment of the tubing supports can be attempted to reduce or eliminate contact between lines in accordance with relevant management procedures. In cases where the degree of wall loss is assessed to be acceptable (see Attribute 6), the installation of a wear ring of similar material as the tubing can be used to mitigate the degradation of tube. In cases where the degree of wall loss due to fretting no longer meets acceptance criteria, corrective actions are taken as outlined in Attribute 7.

1. ***Acceptance criteria:***

For the fretting degradation of instrument tubing for the failed fuel/DN detection system, the following acceptance criteria are applied:

Tubing lines are supported satisfactorily;

The possible cause of ageing degradation is removed;

The wall loss due to fretting is not higher than the limits established in accordance with national regulations or governing documents.

1. ***Corrective actions:***

Corrective actions are taken based on the assessment of the degree of wall loss due fretting in accordance with relevant procedures. In cases where the wall loss due to fretting is assessed to be acceptable, further degradation of tube can be prevented by following the mitigating action as described under Attribute 5. In cases where the degree of fretting no longer meets acceptance criteria, corrective maintenance actions are implemented, including cutting out the worn out region and/or strengthening it with fittings in accordance with plant corrective actions programme, quality assurance procedure, plant examination and approval, and administrative control. If cracking is detected, the corrective actions are taken to replace the damaged tubing. The reviewer confirms whether corrective actions, confirmation procedure, and administrative control satisfy the requirements.

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 number of plants have experienced pin-hole leaks in sampling lines of the failed fuel location / DN system caused by tube fretting [2-6]. The leaks were detected by elevated tritium levels inside the feeder cabinet or reactor building. In some cases, the heavy water leakage rate approached the technical specification limits, resulting in a forced shutdown. Based on these events, the regulatory authority recommended confirmation of the damage to the failed fuel location system tubing. Visual inspections are performed to check the status of the sampling lines and to ensure their integrity of the sample lines, and spacers were added at the tube contacting points to prevent recurrence.

There have been reported cases of D2O leakage from PHT instrument tubing due to transgranular stress corrosion cracking (TGSCC) caused by chloride contamination of the tube surface with chloride after the metallurgical examination, for example [7]. Based on this OPEX, SCC is also included in this programme.

Appropriate sources of external operating experience are Korea Institute of Nuclear Safety (KINS), IAEA International Reporting System (IRS), the CANDU Owners Group (COG), Canadian Nuclear Laboratories and Candu Energy Inc. in Canada, as well as Bhabha Atomic Research Centre (BARC) in India.

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

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 N286-12 [8]).

### References

1. AMERICAN SOCIETY OF MECHANICAL ENGINEERS, Rules for Construction of Nuclear Facility Components, The ASME Boiler and Pressure Vessel Code, ASME Section III, Division 1, Subsection NB - Class 1 Components, ASME, New York, NY.
2. KOREA INSTITUTE of NUCLEAR SAFETY, Operational Performance Information System of Nuclear Power Plant #2007-16, 2007.
3. INTERNATIONAL ATOMIC ENERGY AGENCY, International Reporting System for Operating Experience #8425, 2012.
4. INTERNATIONAL ATOMIC ENERGY AGENCY, International Reporting System for Operating Experience #8066, 2009.
5. CANDU OWNERS GROUP, Operating Experience #272: Unplanned Outage due to D2O Leak from a Tubing of Delayed Neutron Monitoring System, 2000.
6. M. H. Song, H. K. Kim, W. S. Ryu, Y. H. Lee, “Evaluation on Wear Reliability for Delayed Neutron Tubing in Pressurized Heavy Water Reactors”, Transactions of the Korean Nuclear Society Spring Meeting, Taebaek, Korea, May 26-27, 2011.
7. R Singh, Ed., “Weld Cracking in Ferrous Alloys”, pages 349-351, Woodhead Publishing Ltd., Cambridge, England, 2009.
8. CANADIAN STANDARDS ASSOCIATION, Management System Requirements for Nuclear Power Plants, CSA N286-12 CSA, 2012.