### AMP 148 CANDU/PHWR REACTOR SHUTDOWN SYSTEMS (VERSION 2020)

### Programme Description

The main objective of this programme is timely detection and mitigation of ageing degradation of mechanical components of the reactor shutdown systems in CANDU/PHWR, to ensure their integrity and functional capability through plant service life. Ageing management guidelines for nuclear power plants are also given in guiding documents [1-3].

CANDU/PHWR employ two independent, diverse, and physically and functionally separate effective shutdown systems as special safety systems to rapidly make the reactor subcritical in case of plant upset. The Primary Shutdown System or Shutdown System 1 (PSS or SDS-1) uses mechanical neutron-absorbing shut off rods to provide shutdown capability to the reactor with an adequate margin so as to hold the reactor in a shutdown state for a prolonged period of time. The Secondary Shutdown System or Shutdown System 2 (SSS or SDS-2), also called Liquid Poison Injection System (LPIS) or Liquid Injection Shutdown System (LISS), injects gadolinium nitrate solution in the heavy water moderator in the calandria to terminate reactor power. Some earlier CANDU/PHWR designs employ a moderator dump as the 2nd emergency shutdown system. With moderator dump, the moderator D2O from the calandria is dumped into a tank located underneath the calandria vessel to rapidly shut down the reactor.

This AMP provides ageing management strategies, technically feasible inspection and maintenance activities to ensure that ageing effects are identified and corrected (repair or replacement) before the loss of intended function of the critical shutdown system components throughout plant service life including long-term operation.

### Evaluation and Technical Basis

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

For the purposes of this programme, the mechanical components of the SDS-1 consists of the shut-off rod units which include the shut-off rod assembly, guide tube assembly with locater, standpipe-thimble assembly, and drive mechanism housing, cable, gears, bearing and shaft. The mechanical components of the SDS-2 consists of helium supply tank, helium header, helium piping and quick-opening valves, poison tanks, poison solution piping, and poison injection units including LISS nozzles, thimble assembly and bellows assembly.

The ageing degradation mechanisms and effects covered under this programme are:

1. Irradiation creep and growth of SDS-1 guide tubes and SDS-2 liquid injection nozzles;
2. Flow induced vibration of SDS-1 guide tubes and SDS-2 liquid injection nozzles;
3. Fatigue;
4. Reduction of neutron absorbing capacity of shut-off rods;
5. Mechanical wear including fretting;
6. Distortion;
7. Erosion;
8. Corrosion; and
9. Irradiation embrittlement.

The programme includes water chemistry (AMP 103) to monitor and control the moderator chemistry. The programme, or aspects of the programme, may also be performed in association with AMP 139 (calandria tube - LISS nozzle contact), AMP 141, AMP 146, and AMP 119. Technological obsolescence, which can be an issue for replacement parts of shutdown systems (e.g. rod drive mechanism, gear boxes, etc.) is managed in accordance with TOP 401.

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

Preventive actions include design, materials and manufacturing practices, commissioning, operation, and preventive maintenance practices aimed at slowing down potential degradation mechanisms and ensuring availability of system.

The reactor shutdown systems are call for very high reliability of operation as well as effectiveness throughout the reactor life span. Hence the components of these systems are designed, constructed, and environmentally qualified to very high quality and engineering standards as stipulated in national requirements and codes such as [4-6]. Materials, such as austenitic stainless steel and zirconium alloys are carefully selected for many of the components to minimize the effects of corrosion and embrittlement by radiation.

Cleanliness during manufacture and construction and refurbishment, and strict controls on chemistry (moderator D2O, helium gas, gadolinium nitrate) and atmospheric conditions during operation, maintenance and shutdown are important for preventing and mitigating corrosion and other ageing effects. For example, loss of material caused by general corrosion in the SDS-2 helium tank is prevented by managing the quality of the helium gas.

For SDS-1 components, preventive maintenance requirements are limited to shut-off rods and drive mechanism, which are accessible during reactor shutdown. The modular concept employed in the design of shut-off rod drive mechanism facilitates inspection, calibration or replacement of its sub-assemblies. An inspection or replacement of the shutoff rods is carried out before they reach their design cycles limit.

For SDS-2, preventive maintenance requirements are limited to components outside the core / vault, such as pre-defined servicing, refurbishment, or replacement of quick-opening, poison injection tank, helium isolation and other valves important to the reliability of the system.

Inspection or maintenance of the many of the in-core components is limited or not expected during reactor life span, except perhaps during a refurbishment outage (see AMP 119). These components are designed with sufficient strength and margins to ensure they function for the intended period of operation. For example, the SDS-1 guide tube locator receptacle is designed to be stronger compared to the pins on guide tube bottom which are attached to it during installation.

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

The programme detects degradation of components during condition monitoring, preventive maintenance, performance / reliability testing, and in-service inspection by using various non-destructive examinations (NDE) methods.

In-Service Inspections are performed in accordance with national regulations or governing documents, such as [7-9]. Examinations/testing required for detection of the ageing degradation effects listed in section 1 are described as follows:

1. Visual examinations which include inspections for determining corrosion, distortion, position, alignment, wear, leakage, and deterioration by methods such as inspection by direct visual and using visual aids (e.g. telescope, closed-circuit television);
2. Dimensional checks which include inspections for configuration, distortion, wear, alignment, corrosion, by direct measurement (e.g. use of calipers/gauges) and indirect measurement (e.g. use of ultrasonic and electronic methods); creep and growth of guide tubes may be monitored at about midlife (> 20 years) of the reactor;
3. If determined to be necessary by engineering assessment, surface and volumetric examinations which include inspections for determining discontinuities of accessible welds by methods such as liquid penetrant, magnetic particle, ultrasonic, radiographic, and eddy current;
4. Reliability testing to demonstrate shutdown system availability and operating performance. Changes in test performance, such as SDS-1 rod drop time, may be indicative of ageing effects such as wear, corrosion, distortion of parts.

SDS-1 guide tube assemblies are accessible for visual inspection from inside after removal of shield plug assembly. Partial visual inspection of standpipe-thimble assembly from outside is conducted.

Visual inspection of gear and bearings for wear/ageing is to be performed and its functioning is to be checked during maintenance. Complete freeness of the upper chamber is to be checked for gear and bearing healthiness.

SDS-1 stainless steel cables are visually inspected periodically. Reliability testing is done to ensure SDS-1 shut-off rod drive mechanism (DM) freeness.

Dashpot healthiness is ensured during overhauling of drive.

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

Monitoring for SDS-1 and SDS-2 components is covered in this program. Inspections, testing and preventive maintenance are performed as per the extent and schedule given in attributes 2 and 3. The active components in the shutdown systems such as valves, drive mechanisms are tested at specified frequency as established in consultation with the manufacturers and in accordance with reliability programme requirements. The results of these activities are monitored and trended for ageing effects which degrade the performance and functioning of the shutdown systems as described below.

During reactor operation, the SDS-1 system is continuously monitored by instrumentation. Readiness and availability of the shut-off rods is ensured with an on-line clutch release test facility. The parked position of shut-off rods is indicated by direct position indicators. The corresponding drop time will be recorded and checked using an off-line programme. The health of the dashpot is monitored using single-turn potentiometers attached to it during rod drop as well as withdrawal. During the on-line surveillance test, one selected shut-off rod (one at a time) is partially dropped, arrested and driven back without disturbing the reactor power operation.

The guide tube assemblies are accessible for visual inspection from the inside after removal of shield plug assembly. The health of the guide tubes can also be monitored by:

1. Monitoring the drop time of primary shut off rods which could indicate corrosion or bowing;
2. Measurement of creep/irradiation growth of the guide tube assembly from deck plate elevation after removal of the drive mechanism. This is done by measuring the vertical distance between thimble top and guide tube extension top and comparing with reference data taken during reactor commissioning.
3. Monitoring of the moderator chemistry can be used to detect fretting wear of the guide tubes caused by bowing of the tube, which then comes into contact with a calandria tubes with flow-induced vibration.

For SDS-2, the relative gaps between the calandria tubes and the liquid injection system nozzles are required to be monitored to avoid contact. This requirement gets more importance in those NPPs which are close to the end of their original intended design life time. Elongation due to irradiation creep and growth of the LISS nozzles in axial direction can be monitored by measuring the compression and relaxation of the bellows, which are located in the accessible area. Limited access for inspections by remote camera is provided through viewports in the calandria vessel, which can provide data for CT-LISS nozzle contact assessments and predictions.

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 [9-10].

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

The inspection and test results of SDS-1 and SDS-2 are evaluated to decide the mitigating actions which can include:

1. Removal and replacement of guide tube assembly. The guide tube is designed to function for the full life of the reactor. Provision is made to remove and replace the guide tube assembly, though such a requirement is not expected;
2. Removal and replacement of shut-off rod assembly;
3. Removal, repair and servicing/overhauling of the drive mechanism with new or refurbished units. Clutches, bearings, gears, worm wheel, dashpot, O-rings etc. are replaced as per acceptance requirement during overhauling. In case major repairs are be carried out, the entire drive mechanism is replaced with new or refurbished unit during planned shutdown. The new installed drive mechanism is then tested `in situ' to confirm its calibration and ensure its performance;
4. Removal and replacement or refurbishment of SDS-2 system valves;
5. The LISS nozzles are kept under tension. The tension can be adjusted to maintain the gap between the nozzle and the calandria tube.
6. ***Acceptance criteria:***

Unless otherwise specified, the acceptance criteria in accordance with national regulations or governing documents, such as [7-9], will apply.

Periodic testing of the shut off rod satisfies the criteria of rod reaches about 90 % of travel within specified time as per regulatory requirement of the national design standard.

Indications detected from NDE that show material degradation will not exceed the limits specified for the design of the components up to the next scheduled inspection, are considered acceptable.

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, up to the next scheduled inspection.

1. ***Corrective actions:***

The inspection results for indications are evaluated based on the acceptance criteria in attribute 6 to determine the need for corrective action. If required, a corrective action plan, which includes repair, replacement, operation with restrictions, or other 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.

With many CANDU/PHWRs approaching the original intended (nominal) design life for FCs, there is a particular need for research and development programmes to address safe operation for extended service life. This includes extending the knowledge base of ageing degradation mechanisms and effects for longer service life and their impact, as well as developing improved methodologies and analytical tools for predicting-end-of-life degradation levels and fitness for service evaluations, such as for CT-LISS nozzle contact [11-14].

OPEX from refurbishment in Bruce, Point Lepreau and Embalse reactors shown that reactor internals generally are in good condition after 25-30 years of operation. 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 has been initiated to assess the Calandria vessel and internals fitness for life extension for 60 years of operation.

The OPEX at Embalse NPP, related to Calandria internal inspection could be summarized as follows. During a shut down, previous to the refurbishment outage, the calandria internals visual inspection was performed to check the remaining gap between some CT-LISS. As a conclusion of the inspection, one CT was in contact with one LISS. After this, the fuel elements were removed from the fuel channel, then this channel was replaced and a flow restrictor was installed inside the new channel to keep the same delta P, as if the fuel elements were still installed. The station operated in this configuration until the refurbishment project started. During the refurbishment outage, one of the main tasks included the replacement of all the fuel channels and the calandria tubes. Once this action was concluded, the lack of gap between both tubes was eliminated. Nowadays, Embalse NPP is running at full power and no further internals inspections has been planned in the following years.

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 Korea Institute of Nuclear Safety (KINS) and 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 [15]).

### References

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