### AMP 144 SAFETY-RELATED PUMPS (VERSION 2020)

### Programme Description

Some operators (e.g. WWER, CANDU) develop AMPs that are focused on components (such as reactor coolant piping, reactor pressure vessel, steam generator, pressurizer, etc.) not on individual degradation mechanisms. These “umbrella type” programmes are based on understanding of all degradation mechanisms relating to the specific component and describing all activities necessary to manage ageing. The main advantage of such an approach is knowledge of the overall state of the components.

This ageing management programme is a component-specific AMP for pumps that covers multiple degradation mechanisms the pumps may be subjected to and the activities necessary to manage the ageing mechanisms as such. This AMP refers to other degradation-specific and/or monitoring type of AMPs, that deal with particular degradation mechanisms and ageing effects.

The body of a safety related pump including its sealing parts has a passive safety function, the internals of the pumps perform the active function (e.g. circulation of coolant). All safety related components of safety related pumps are included in the scope of ageing management during the intended period of operation in accordance with [1].

The fulfillment of the active function of a safety related component may be monitored in the framework of an AMP, or in a separate active function monitoring system. For instance, in the USA, it is covered by the Maintenance Rule, in other member states with Maintenance Effectiveness Monitoring Systems it is out of the scope of Ageing Management Review (AMR).

The main objective of this programme is to provide for timely detection and mitigation of the ageing related degradation mechanisms (ARDMs) of safety classified pumps and to ensure the structural integrity and appropriate response of the pumps is maintained.

### Evaluation and Technical Basis

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

This programme is applicable to safety classified pumps in the scope of the intended period of operation including centrifugal and positive displacement pumps, including but not limiting to centrifugal horizontal-vertical unit pumps with radial-flow, axial-flow or mixed-flow impellers.

Following ageing degradation mechanisms are considered in this AMP:

* General corrosion;
* Stress corrosion cracking;
* Flow-accelerated corrosion;
* Erosion (including cavitation erosion);
* Wear;
* Fatigue (including low- and high cycle fatigue);
* Loss of preload, self-loosening;
* Boric acid corrosion (etc.)

General corrosion

Examples of critical locations for general corrosion of pumps are the casing, nozzles and bolting elements.

Stress corrosion cracking

Stress corrosion cracking is a complex phenomenon driven by the synergistic interaction of mechanical, electrochemical and metallurgical factors. Examples of critical locations for stress corrosion cracking of pumps are the casing, nozzles and bolting elements.

Flow accelerated corrosion

Flow accelerated corrosion is a corrosion mechanism which results in wall thinning in susceptible materials. Examples of critical locations for flow accelerated corrosion of pumps are the casing and nozzles.

Erosion

Erosion effects on wall thickness of hydraulic components of pumps.

Wear

Wear is characterized by loss of material due to contact between two moving surfaces, such as sliding, rolling, pushing or streaming. Degradation due to wear could be applicable to rotating parts and fitted connections such as bolts and keys.

Fatigue (including low- and high cycle fatigue)

Fatigue is caused by cyclic loading of system, structures and components (SSC) during operation. The critical locations for low-cycle fatigue of pumps are the body and the flanged joints. Critical locations for high-cycle fatigue are the rotating parts.

Loss of preload, self-loosening

Degradation due to loss of preload could be applicable to fitted connections such as bolts and keys.

Boric acid corrosion

Pump bodies and bolting used on pumps could be in carbon steel thus boric acid corrosion is a potential degradation mechanism.

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

The preventive actions are carried out during normal operation by established control of the water chemistry and by monitoring any adverse effects of the water chemistry conditions on the ageing mechanisms. The programme description and evaluation and technical basis of monitoring and maintaining reactor coolant chemistry are addressed in AMP 103.

Other preventive action is condition based maintenance or regularly scheduled maintenance (such as pumps overhaul, mechanical seals and gaskets replacement and visual inspection of internal parts) according to the internal procedures of each site, lubrication and calibration, periodic change of oil filter, and torque control of foundation bolts.

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

Pumps are inspected and tested according to the requirements of the in-service inspection programme of each site, following general guidelines (e.g. [2]).

Nondestructive methods such as visual examination, ultrasonic examination, capillary test to detect surface cracks, dimensional control, other type of tests and photographic records may be used for AM of passive safety function.

Plant walk downs during plant outages may also be performed.

It is expected that visual, surface or volumetric inspection performed in AMP 102 will detect cracking due to SCC, or fatigue, growth of defects, erosion by wall thickness measurement or common wear by inspecting for loose connections or missing parts.

The cumulative effect of low-cycle fatigue is addressed by AMP 101. The impact of boric acid leakage on bolting materials is addressed by AMP 110.

Detection of ageing effects covers all the subcomponents that make up the pumps: passive components (casing, nozzles, bolts/studs) and active components (shaft, impeller, bearings, seals, wear rings etc.).

Casing

Casings of pumps are made of carbon steel, and as such they are susceptible to general corrosion, stress corrosion cracking, crevice corrosion, flow related ageing mechanisms like erosion, cavitation erosion, FAC, liquid impact erosion, weathering and atmospheric corrosion can be detected through appearance (e.g. AMP 102).

Nozzles

Loss of material due to general corrosion, FAC, cracking due to stress corrosion cracking, can be detected on nozzles of pumps (e.g. AMP 102, AMP 114, AMP 107, AMP 111).

Bolts/Studs & Nuts/ Fasteners

Weathering, atmospheric corrosion and dynamic loading/vibration can cause loosening and breakage. These effects can be detected through condition monitoring such as bolt torque, vibration, axial position, noise etc. (AMP 115).

The active safety functions (and related components) of the pumps may be monitored by on line diagnostics in the framework of an umbrella-type AMP, or in a separate active function monitoring system.

Shaft

Shafts are made of stainless steel or steel. Fretting/wear can occur in the seals and bearing area. Pitting and crevice corrosion, electrical pitting, dynamic loading/vibration and fatigue cracking can be detected through appropriate methods including but not limited to rotational torque, appearance, developed heat, delivered flow, motor current & power, speed, vibration, balance, noise, surface indication and dynamic pressure.

Impeller

Cavitation erosion, liquid impact erosion, pitting, crevice corrosion, dynamic loading / vibration and fatigue cracking can be detected through appropriate methods including but not limited to rotational torque, appearance, delivered heat, delivered flow, motor current & pressure, speed, vibration, balance, noise, wear surface and fit clearance.

Bearings

Fretting/wear, electrical pitting, dynamic loading/vibration and fatigue can be detected through appropriate methods including but not limited to rotational torque, appearance, motor current power, vibration, lube oil purity, axial position, wear surfaces, noise, fit clearance, oil quality are major condition monitoring parameters.

Seals

Seals are replaced on a condition basis. Thermal embrittlement in elastomeric compounds may occur. Fretting/wear can be detected through appropriate methods including but not limited to rotational torque, appearance, motor current power, vibration, axial position, wear surfaces, noise, fit clearance are major CM parameters.

Wear Rings

Crevice corrosion and fretting/wear can be detected through appropriate methods including but not limited to delivered flow, motor current & pressure etc.

Pistons (positive displacement pumps [3])

Pistons are made of stainless steel in some cases with hard coatings. These components are subjected to periodic surface treatment or periodic replacement programmes.

Internals valves

Mostly made of stainless steel, the main degradation mechanisms are wear and fatigue.

Parameters for active safety function control

* Vibration control of pumps according to the internal procedures of each site which specify periodicity and check list of components.
* Pressure and flow control online by plant operator.
* Noise measurement by ultrasound according to the internal procedures of each site which specify periodicity and check list of components etc.

Vibration and current signature analysis are performed for fault diagnoses.

Lubrication and calibration is typically performed once a year. Lubrication with proper quality and quantity is essential to avoid bearings problems. Visual inspection of pump internals is typically performed based on manufacturer recommendations. Evaluation and qualification of non-destructive tests (NDT) operators are performed according to national standards (e.g. [4-7]).

Bearing oil analysis

To avoid water contamination of oil and for prediction of bearing wear and damage. See also AMP 136.

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

Timely and reliable detection of ageing degradation is provided by implementation of inspection and testing schedules in accordance with attribute 3, reliable examination methods, and qualified inspection personnel.

Monitoring and trending is performed as per the specific AMPs identified in attribute 3. In connection with the possibility of wear of rotating components due to vibration and / or precession, which is manifested in periodic сhanges of temperatures at the control points, it is necessary to ensure continuous monitoring of the rotation parameters (speed, vibration) with output to interface the appropriate parameters for the possible detection of abnormalities in the early stages and the prevention of deterioration related to the issues of rotation.

Performance indicators are defined to enhance the assessment and improving the implemented programmes. For example, statistics indicators like comparison between corrective and preventive maintenance efforts (in man-hours terms), the number of repetitive faults, etc. can be used.

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

Recommendations for mitigation of ageing effects are based on referred AMPs, and on results from performed analyses.

1. ***Acceptance criteria:***

It is considered that the component is not available for service if some of the following defects are detected. In that case corrective actions will be implemented.

* Pressure and flow below nominal values e.g. 5 %;
* Abnormal vibrations and noises;
* Current fluctuations in associated motors;
* Significant leakage, the acceptance criteria of fluid leakage is 0.5 l/h;
* Indication of flaws above the acceptance criteria of ISI programme.

Acceptance criteria are part of referred AMPs, on-line diagnostic programme (for active components, if existing) and maintenance procedures.

Any indication or relevant conditions of degradation may be evaluated for acceptance in accordance with the pertinent governing requirements or guidance documents as for example [8].

Examination results and flaws that exceed the acceptance criteria in the pertinent governing requirements or guidance documents may require repair or replacement activities, or further evaluation to demonstrate fitness-for-service of the component, to the satisfaction of the regulatory authority, until the end of the next periodic inspection interval.

1. ***Corrective actions:***

If the component fails in meeting the acceptance criteria, the abnormal condition will be immediately reported and a work order for timely repair will be issued and executed. For each acceptance criterion which is not satisfied, the procedure for resolution is defined or elaborated and consequently implemented.

At the end of the process the criterion is fulfilled and the requested state of the component is restored. Repair and replacement according to requirement of technical documentation of the components and according to guiding documents of the plant are part of possible corrective actions.

When suitable in some cases, changes to operational regimes could be applied.

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, and provides objective evidence that they are taken into account in the AMP. Research and development efforts and an effective experience exchange are important elements for implementing continuous improvement in this programme and in defining adequate corrective actions.

Operating experience about failures due to corrosion and cracking, and other relevant events in CANDU/PHWR auxiliary system pumps are reported in CANDU Owners Group (COG) and Electric Power Research Institute (EPRI) operational experience databases [9], or WANO Operating Experience Programme etc.

Observations of degradation of pumps include cracks due to local corrosion at pump housing components. It has been managed through improved ISI control, repair of pump housing surfaces. Appropriate water chemistry programme mitigates local corrosion of pumps.

Wear of bolting components and erosion of housing elements were observed for pumps. It has been managed through improved control of pre-load or repair of sealing and housing surfaces. Preventive action e.g. replacement of bolts and sealing rings precluded the effect of wear. Existing condition monitoring programmes of critical locations (ISI, maintenance programme) inspect for the extent of ageing effects of wear and erosion.

There are records of failure events in service water pump shafts due to fatigue corrosion [10]. Three shaft breaks occurred in pumps of the primary service water system. The analysis of the broken shafts revealed corrosion fatigue as dominant failure mechanism fostered by insufficient material properties of the shafts. Triggered by the first failure, the shafts of all primary service water pumps have been replaced. The new shafts are made of steel 1.7227. Ultrasonic testing of two of the preventively exchanged shafts showed one having slight crack indications, the other having significant cracks. Since inspections of the new shafts after a short time of operation showed signs of corrosion, most probably further corrective action will be required. Investigations were under way at the moment of event reporting. Material imperfections (e.g. slag inclusions) were a contributing factor for crack propagation and also chloride in the river water was stimulating corrosion. During winters the content of chloride in the water is elevated due to the widespread use of road salt. Also the primary service water system underwent a modification project, through which a major part of its piping was replaced by pipes made of improved material. Because of the changed piping layout it is suspected that changes in the spectrum and the amplitude of vibrations at the pumps locations may have accelerated the failure of the pump shafts. Enhanced corrosion due to modified electrochemical conditions, high surface roughness due to sand intake, loading/vibration behavior of the system due to the new system configuration after retrofitting, and throttling of the pumps contributed to the failures.

The programme includes provisions for continuing review of plant-specific and industry-wide operating experience, and research and development results, e.g. [11-14], such that impact on the programme is evaluated and any necessary actions or modifications to the programme are performed.

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

1. ***Quality management:***

Administrative controls, quality assurance procedures, review and approval processes, are implemented in accordance with the different national regulatory requirements e.g. [15-16].

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