**AMP 103 WATER CHEMISTRY (VERSION 2021)**

**Programme Description**The main objective of this programme is to mitigate loss of material due to corrosion, including flow-accelerated corrosion (FAC), cracking due to stress corrosion cracking (SCC) and related degradation mechanisms, and reduction of heat transfer due to fouling in components exposed to a treated water environment. Minimizing the deuterium ingress and delayed hydride cracking in the pressure tubes of CANDU/PHWR plants is a further objective of this programme. The programme includes periodic monitoring of the treated water and control of known detrimental contaminants below the levels known to result in loss of material or cracking.

The water chemistry programme for all types of nuclear power plants with water-cooled reactors relies on monitoring and control of reactor water chemistry based on several guidelines. IAEA Safety Guide SSG-13 [1] provides Member States with general recom­mendations and guidance for water chemistry activities to ensure that in-scope systems, structures and components (SSCs) are available to perform their functions in accordance with the assumptions and intent of the design. IAEA TECDOC-1505 [2] provides an overview of the methods for development, qualification, and implementation of data processing technologies for water chemistry and corrosion control. Moreover, several specific industrial guidelines exist. For BWRs these are e.g. EPRI 3002002623 (BWRVIP-190, Rev. 1) [3], and VGB-R 401 J, part 2 [4]. Corresponding guidelines for PWRs are EPRI 3002000505 (PWR Primary Water Chemistry Guidelines) [5], EPRI 3002010645 (PWR Secondary Water Chemistry Guidelines) [6], and German VGB-R 401 J, part 1 [4]. For PHWR plants, guidelines are given in AERB/NPP-PHWR/SG/D-8 [7]. Further information on PHWR water chemistry is provided in IAEA TECDOC-667 [8]. There are no specific non-proprietary guidelines for water chemistry of CANDU plants, however a good summary of the chemistry control philosophy and specifications in existing and new-build CANDU plants is provided in [9]. Other water chemistry guidelines may be used for specific systems or circumstances.

The water chemistry programmes are generally effective in keeping the concentrations of impurities low in intermediate and high flow areas. The IGALL report identifies those cir­cumstances in which the water chemistry programme is to be augmented to manage the effects of ageing. For example, the water chemistry programme may not be effective in low flow or stagnant flow areas. Accordingly, in certain cases, verification of the effectiveness of the chemistry control programme is undertaken to help to ensure that significant degradation is not occurring and the component’s intended function is main­tained during the period of extended operation. For these specific cases, an acceptable verification programme is a one-time inspection of selected components at susceptible locations in the system, in accordance with AMP 119.

**Evaluation and Technical Basis**

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

The programme includes components in the reactor coolant system, the engineered safety features, the auxiliary systems, and the steam and power conversion system. This programme addresses the components subject to ageing management review that are exposed to a treated water environment controlled by the water chemistry programme.

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

The programme includes specifications for chemical species, impurities and additives, sampling and analysis frequencies, and corrective actions for control of water chemistry of the reactor coolant system, the engineered safety features, the auxiliary systems, and the steam and power conversion system. Water chemistry is controlled to minimize contaminant concentration and to mitigate loss of material due to general, crevice, pitting, and flow-accelerated corrosion and cracking caused by SCC. For BWRs, maintaining high water purity reduces susceptibility to SCC. In several countries chemical additive programmes such as hydrogen water chemistry in conjunction with or without noble metal chemical application are also used to reduce susceptibility to SCC [10]. For PWRs and CANDU/PHWR, additives are used for reactivity control and to control alkalinity to inhibit corrosion.

The concentrations of corrosive impurities are monitored and maintained within certain limits to mitigate loss of material, cracking, and reduction of heat transfer. Water quality also is maintained in accordance with the guidance. Chemical species and water quality are monitored by in-process methods or through sampling. The chemical integrity of the samples is maintained and verified to ensure that the method of sampling and storage will not cause a change in the concentration of the chemical species in the samples.

PWR Primary Water Chemistry: The guidelines for PWR primary water chemistry (e.g., [4-5]) typically recommend that the concentration of chlorides, fluorides, sulphates, lithium or potassium, and dissolved oxygen and hydrogen are monitored and kept below the recommended levels to mitigate SCC of austenitic stainless steel (SS), Alloy 600, and Alloy 690 components. Some PWR primary water chemistry guidelines also provide recommendations for chemistry control in PWR auxiliary systems, such as the boric acid storage tank, refuelling water storage tank, spent fuel pool, let-down purification systems, and volume control tank.

CANDU/PHWR Primary Heat Transport (PHT) and Moderator Heavy Water Chemistry: The guidelines for CANDU/PHWR heavy water chemistry (e.g., [7-9]) typically recommend that the concentration of pHa or dissolved lithium [Li+], dissolved deuterium [D2], chlorides, fluorides, sulphates, dissolved oxygen and hydrogen, and conductivity are monitored and kept within the specified ranges to mitigate in-core fouling, reduce the rate of FAC of carbon steel (CS) SA106 or SA333 outlet feeder piping, minimize D2-uptake of zirconium alloy pressure tubes, and mitigate SCC of austenitic stainless steel (SS), martensitic steels (400-series), Monel 400, Alloy 600, and Alloy 690 components. Some CANDU/PHWR primary heavy water chemistry guidelines also provide recommendations for chemistry control in Primary Heat Transport auxiliary systems. The guidelines for moderator heavy water cover Guaranteed Safe Shutdown (GSS) and Non-GSS conditions, and the parameters monitored include gadolinium [Gd] concentration, moderator D2O conductivity and D2O pHa, moderator D2O isotopic purity, and moderator tritium levels.

PWR and CANDU/PHWR Secondary Water Chemistry: The guidelines for PWR and CANDU/PHWR secondary water chemistry are similar and generally recommend monitoring and control of chemistry parameters (e.g., pH level, cation conductivity, sodium, chloride, sulphate, lead, dissolved oxygen, iron, copper, and hydrazine or other oxygen scavengers) to mitigate steam generator tube degradation caused by denting, intergranular attack (IGA), outer diameter stress corrosion cracking (ODSCC), or crevice and pitting corrosion. The monitoring and control of these parameters, especially the pH level, also mitigates general and flow-accelerated corrosion (FAC) for steel components as well as crevice, and pitting corrosion of the steam generator shell and the balance of plant materials of construction (e.g., steel, SS, and copper alloys).

BWR Water Chemistry: The guidelines for BWR reactor water (e.g., [3-4]) generally recommend that the concentration of chlorides, sulphates, and dissolved oxygen are monitored and kept below the recommended levels to mitigate corrosion. The two impurities, chlorides and sulphates, determine the coolant conductivity; dissolved oxygen, hydrogen peroxide, and hydrogen determine electrochemical potential (ECP). The guidelines recommend that the coolant conductivity and ECP are also monitored and kept below the recommended levels to mitigate SCC and corrosion in BWR plants. The guidelines for BWR feedwater, condensate, and control rod drive (CRD) water recommend that conductivity, dissolved oxygen level, and concentrations of iron and copper (feedwater only) are monitored and kept below the recommended levels to mitigate SCC. Some guidelines also include recommendations for controlling water chemistry in auxiliary systems: torus/pressure suppression chamber, condensate storage tank, and spent fuel pool.

**3. Detection of ageing effects:**

This is principally a mitigation programme. However, the concentrations of corrosive impurities listed in the EPRI water chemistry guidelines are monitored to mitigate loss of material, cracking, and reduction of heat transfer. Water quality also is maintained in accordance with the guidance. Chemical species and water quality are monitored by in-process methods or through sampling. Furthermore, the chemistry surveillance also provides information on ageing effects such as primary to secondary water leakage due to through-wall defects resulting from SCC, wear, etc. by measurement of the activity; small condenser leaks due to through-wall defects by sensitive on-line monitoring; or high general corrosion and/or FAC by monitoring the Fe-level in the feedwater circuit.

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

Chemistry parameter data are recorded, evaluated, and trended in accordance with the different water chemistry guidelines.

**5. Mitigating ageing effects:**

The main objective of this programme is to mitigate loss of material due to corrosion and corrosion-assisted cracking in components exposed to a treated water environment. For this reason, the monitoring methods and frequency of water chemistry sampling and testing is performed in accordance with the above-mentioned water chemistry guidelines and based on plant operating conditions and operating experience.

**6. Acceptance criteria**

Maximum levels for various chemical parameters are maintained within the system-specific limits as indicated by the limits specified in the corresponding water chemistry guidelines and / or the design requirements for specific components.

**7. Corrective actions:**

Any evidence of ageing effects or unacceptable water chemistry results is evaluated, the cause identified, and the condition corrected. When measured water chemistry parameters are outside of the specified range, corrective actions are taken to bring the parameter back within the acceptable range (or to change the operational mode of the plant) within the time period specified in the water chemistry guidelines. Whenever corrective actions are taken to address an abnormal chemistry condition, increased sampling or other appropriate actions may be used to verify that the corrective actions were effective in returning the measured water chemistry parameter, for example the concentrations of chlorides, fluorides, sulphates, dissolved oxygen, and hydrogen peroxide, to within the acceptable ranges.

**8. 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 guideline documents have been developed based on operating experience and results of research and development and have been shown to be effective over time with their widespread use.

The world-wide operating experience with mechanical components in light water reactors is described in several component and/or mechanism specific documents. Relevant information for several main components of different designs is provided in IAEA TECDOCs (e.g., [11-19]). Moreover, NEA/CSNIR (2010)15 [20] contains a recent evaluation of the operating experience with different corrosion-assisted cracking mechanisms. The specific examples of operating experience are as follows:

* BWR: Intergranular stress corrosion cracking (IGSCC) has occurred in small- and large-diameter BWR piping made of unstabilised and stabilised austenitic stainless steels and nickel-base alloys. Significant cracking has occurred in recirculation, core spray, residual heat removal systems, and reactor water cleanup system piping welds. IGSCC has also occurred in a number of vessel internal components, including core shroud, access hole cover, top guide, and core spray spargers.
* PWR Primary System: The potential for SCC-type mechanisms might normally occur because of inadvertent introduction of contaminants into the primary coolant system, including contaminants introduced from the free surface of the spent fuel pool (which can be a natural collector of airborne contaminants) or the introduction of oxygen during plant cooldowns. Ingress of demineralizer resins into the primary system has caused IGSCC of Alloy 600 vessel head penetrations. Inadvertent introduction of sodium thiosulfate into the primary system has caused IGSCC of steam generator tubes. SCC has occurred in safety injection lines, charging pump casing cladding, instrument nozzles in safety injection tanks, and safety-related SS piping systems that contain oxygenated, stagnant, or essentially stagnant borated coolant. Steam generator tubes and plugs and Alloy 600 penetrations have experienced primary water stress corrosion cracking (PWSCC). IGSCC-induced circumferential cracking has occurred in PWR pressurizer heater sleeves.
* CANDU/PHWR Primary System: FAC of the carbon steel feeders at the outlet of the reactor core resulted in a decision to reduce the upper limit on pHa to 10.4 (corres­pon­ding to a Li+ concentration of 0.55 mg/kg). The specification for Cl- is kept below < 0.2 mg/kg to < 0.05 mg/kg to mitigate the risk of SCC of the martensitic stainless steel end fittings (although no cracking has been experienced to date). Sulphate has been implicated in strain-induced corrosion cracking (SICC) of low-alloy carbon steel in high-­temperature water, thus it is considered prudent to introduce limits for SO42- to mitigate the risk of SICC in the primary coolant system feeders. Steam generator tubes and plugs and Alloy 600 penetrations have experienced primary water stress corrosion cracking (PWSCC).
* PWR and CANDU/PHWR Secondary System: Steam generator tubes have expe­rienced outside diameter stress corrosion cracking (ODSCC), intergranular attack (IGA), wastage, and pitting. Carbon steel support plates in steam generators have experienced general corrosion. The steam generator shell has expe­rienced pitting and stress corrosion cracking. Extensive build-up of deposits at steam generator tube support holes can result in flow-induced vibrations and tube cracking. Flow-accelerated corrosion occurred particularly in feed-water and condensate lines made of carbon steel.

Such operating experience has provided feedback to revisions of the different water chemistry guideline documents.

Although no relevant R&D was identified at the time of the development of this AMP, the various groups with responsibility for water chemistry guidelines are expected to continue to enhance their guidelines and periodically issue revisions. As new revisions of relevant guidelines are issued, the plant evaluates the revisions to assess the need to enhance the plant AMP.

**9. Quality management:**

Site quality assurance procedures, review and approval processes, and administrative controls are implemented in accordance with the different national requirements (e.g., 10 CFR Part 50, Appendix B [21]).

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