**AMP 318 CONCRETE STRUCTURES MONITORING (VERSION 2021)**

### Programme Description

This document provides guidance for developing a plant specific ageing management programme for the nuclear power concrete structures and structural components such that there is no loss of structure or structural component intended function.

The structures monitoring programme consists of periodic visual inspections and non-destructive examination as necessary, by personnel qualified to monitor structures and components for applicable ageing effects in accordance with industry codes and standards of each country, such as [1-5]. General guidance for developing a condition assessment programme for managing ageing of NPP concrete structures has been provided by organizations such as the International Atomic Energy Agency [6]; the Electric Power Research Institute [7-8]; International Union of Laboratories and Experts in Construction Materials, Systems, and Structures [9]; and Nuclear Energy Agency Committee on Safety of Nuclear Installations [10].

The evaluation methods and acceptance criteria recommended in [1, 3-5, 11] can be used in the absence of, or to supplement, the guidance provided in the plant licensing documents. The person responsible for performing the structural evaluations is a qualified structural engineer, knowledgeable in the design, evaluation, and in-service inspection of concrete structures and performance requirements of nuclear safety-related structures and meet the qualification requirements of the appropriate member state regulatory authority. The personnel performing the inspections or testing at the plant, under the direction of the responsible structural engineer, is qualified structural engineers who have over one year of experience in the evaluation of in-service concrete structures or quality assurance related to concrete structures, and meet the qualification requirements required by the regulatory authority regarding the evaluation of in-service structures.

The programme includes periodic condition assessment for concrete exposed to a marine environment and aggressive waters containing acids and chemical by-products from industrial processes, with the common deleterious ions being sulfate, chloride, etc. The concrete may deteriorate excessively as a result of combined effects of chemical action of seawater constituents on cement hydration products, alkali-aggregate expansion if reactive aggregates are present, crystallization pressure of salts within concrete if one face of the structure is subject to wetting and others to drying conditions, frost action in cold climates, corrosion of embedded steel reinforcement, and physical erosion due to wave action or floating objects [12].

The programme also includes periodic sampling and testing of groundwater and the need to assess the impact of any changes in its chemistry on below grade concrete structures [13]. Ageing of structure’s foundation and evaluation of its condition is inherent part of the structure monitoring programme. Where such factors are present that can lead to degradation, foundation’s condition is explicitly addressed.

If protective coatings are relied upon to manage the effects of ageing for any structures included in the scope of this AMP, or if degradation of coating can affect safety functions of the structure, monitoring programme is to address protective coating monitoring and maintenance. Otherwise, coatings on structures within the scope of this programme are inspected only as an indication of the condition of the underlying material.

### Evaluation and Technical Basis

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

The scope of the programme includes the following concrete structures and structural concrete commodities except those that are covered by AMP 302, AMP 307, AMP 312, AMP 315 and AMP 319.

a. Safety-related structures and components that are required to remain functional during and following design-basis events to ensure the integrity of the reactor coolant pressure boundary; or the capability to shut down the reactor and maintain it in a safe shutdown condition; or the capability to prevent or mitigate the consequences of accidents which could result in potential offsite exposures beyond the design basis of the plant.

b. All non-safety related structures and components whose failure could prevent satisfactory performance of safety related structures and components.

c. All structures and components relied on in safety analyses or plant evaluations to perform a function for fire protection, environmental qualification, pressurized thermal shock, anticipated transients without scram, and station blackout.

The AMP applies to secondary containment and the Anti-Plane Crash (APC) shell which is reinforced concrete structure designed to have capability of impact resistance against aircraft. It can protect inner structure and equipment inside the building from shock damage, and prevent concrete scabbing from the rear face of structure walls damaging systems and components. Examples of these structures are outer containment and outer structure covering fuel building and electrical building, sharing a common concrete raft with reactor building.

The AMP also includes steel elements embedded in concrete, such as reinforcement and anchor plates.

The applicant is to specify other structures or components that are in the scope of its structures monitoring programme. The scope of this programme includes periodic sampling and testing of groundwater and may include inspection of masonry walls and water-control structures provided all the attributes of AMP 305 and AMP 307 are incorporated in the attributes of this programme.

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

The structures monitoring programme is a condition monitoring programme and no specific preventive actions are required.

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

In-service examinations, which can include inspections, testing, monitoring and surveillance, are essential to detect concrete ageing effects, which the most significant are listed below, as well as their respective degradation mechanisms.

* *Loss of material* manifested as spalling, scaling, rust staining, pitting, and erosion, as a result of one or more degradation mechanisms, such as freeze-thaw, abrasion or cavitation, elevated temperature, aggressive chemicals and corrosion of embedded steel and steel reinforcement.
* *Cracking* that may occur as general cracking, map cracking, hairline cracking, pitting, and erosion, as a result of one or more degradation mechanisms, such as freeze-thaw, reaction with aggregates, delayed ettringite formation, shrinkage, settlement, elevated temperature, irradiation, fatigue and sustained vibratory loading.
* *Loss of material properties* evidenced as increased permeability, increased porosity, reduction in pH, reduction in tensile strength, reduction in compressive strength, reduction in modulus of elasticity, and reduction in bond strength, as a result of one or more degradation mechanisms, such as leaching of calcium hydroxide, aggressive chemicals, elevated temperature, irradiation and creep.

Visual inspections also include periodic mapping and measurements to provide a history of crack appearance and development that can assist in identifying their cause and establishing whether a crack is active or dormant.

For each structure/ageing effect combination, the specific parameters monitored or inspected depend on the particular structure, structural component, or commodity. Parameters monitored or inspected are commensurate with industry codes, standards, and guidelines and consider industry and plant-specific operating experience.

Periodic visual inspection of the concrete structures is performed to monitor and detect the presence of leaching, chemical attack, abrasion, erosion, cavitation, excessive deflections and settlements, cracking, pop-outs and voids, spalling, scaling, and signs of corrosion in the steel reinforcement and anchorage components. Acceptance criteria are discussed in attribute 6.

If initial visual examination of structures indicates patterned cracking indicative of alkali silica reaction (ASR), petrographic examination of concrete samples from the affected structures to confirm presence of the ASR is performed. If the presence of ASR is confirmed, AMP 312 is implemented to manage the ageing of the structures. This includes increased frequency of inspection, tracking of the width and extent of cracking, tests to determine the degradation of mechanical properties, and structural evaluation of the affected structures.

The structures monitoring programme addresses detection of ageing affects for inaccessible structural elements. With regard to access for routine visual examination of steel and concrete structures and components, areas considered inaccessible are, but not limited to:

* Below-grade surfaces exposed to foundation soil/material, backfill, or groundwater;
* Portions of concrete surfaces that are covered by metallic liners;
* Portions of surfaces where visual access is obstructed by adjacent permanent plant structures, components, equipment, parts, or appurtenances;
* Portions of steel components, supports, connections parts, and appurtenances that are embedded or encased in concrete or encapsulated or otherwise made inaccessible during construction or as a result of repair/replacement activities.

Wetted surfaces of submerged areas or areas covered or obstructed by insulation, protective coatings, microorganisms, bio foliage or vegetation are not considered inaccessible.

Groundwater chemistry (pH, chlorides, and sulfates) are monitored periodically to assess its impact, if any, on below grade concrete structures. For plants with non-aggressive groundwater/soil, the programme recommends: (a) evaluating the acceptability of inaccessible areas when conditions exist in accessible areas that could indicate the presence of, or result in, degradation to such inaccessible areas and (b) examining representative samples of the exposed portions of the below grade concrete, when excavated for any reason. For plants with aggressive groundwater/soil and/or where the concrete structural elements have experienced degradation, a plant-specific AMP accounting for the extent of the degradation experienced is implemented to manage the concrete ageing during intended period of operation. Codes and standards in each member state may have different criteria for classifying the groundwater/soil as aggressive. However, in absence of any other criteria, groundwater/soil with pH < 5.5 or chlorides > 500 ppm or sulfates > 1500 ppm can be designated as aggressive.

The inspection frequency depends on safety significance and the condition of the structure. In general, all structures and groundwater quality are monitored on a frequency not to exceed 5 years. The programme includes provisions for more frequent inspections of structures and components to track the degradations that are beyond the acceptance criteria identified in attribute 6 below. Some structures of lower safety significance, and subjected to benign environmental conditions, may be monitored at an interval exceeding five years; however, they are identified and listed, together with their operating experience.

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

The condition of the structures and structural components is monitored by periodic examination. In addition, the condition of structure is monitored and trended if the extent of degradation is such that the structure may not meet its design basis or, if allowed to continue uncorrected until the next normally scheduled assessment, may not meet its design basis.

[1, 3] provide acceptable basis for selection of parameters to be monitored or inspected for concrete structures

Optical aids, such as fiberscopes and borescopes, allow inspection of inaccessible regions. Optical aid selection depends on factors such as object geometry and access, expected defect size and resolution requirements. Video cameras can be used to record current conditions for future reference.

Such a system has been developed for monitoring cooling towers in Belgium [14]. Monitoring is based on results obtained from topographic surveys, inventory of deterioration types and analysis of structure materials.

A video microscope with image acquisition, image display and image analysis capabilities has been developed for monitoring cracks in structures [15].

Useful guides are available to help recognize and classify different types of damage as well as probable causes [1-2, 16-18].

Concrete through wall leakage is monitored. If through-wall leakage or groundwater infiltration is identified, liquid inventory, leakage volumes and chemistry are monitored and trended for signs of concrete or steel reinforcement degradation.

Periodic measurements of radiation level for concrete structures proximate to reactor pressure vessel (e.g. primary/biological shield wall, sacrificial shield wall, and the reactor vessel support/pedestal) are performed due to irradiation. Further evaluation is performed to determine whether a plant-specific programme is necessary to manage ageing effects (e.g., potential cracking, reduction of strength and loss of mechanical properties of concrete) of irradiation if the estimated (calculated) fluence levels or irradiation dose received by any portion of the concrete from neutron or gamma radiation exceeds the respective threshold level as given in NUREG 2192, section 3.5.2.2.2.6 [13] during the subsequent period of extended operation or if plant-specific OE of concrete irradiation degradation exists that may impact intended functions.

Quantitative baseline inspection data are established per preset acceptance criteria. Previously performed inspections that were conducted using comparable acceptance criteria are acceptable in lieu of performing a new baseline inspection.

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

This AMP is a condition monitoring programme and no generic recommendations are included to mitigate ageing effects. However, if degradation of structures and components is detected that exceeds the acceptance criteria, plant specific actions can be identified based on detailed monitoring and trending, and structural evaluation to mitigate the root cause or source of degradation.

For instance, cathodic protection systems can be installed to help prevent or mitigate corrosion of concrete rebar, other concrete reinforcement or concrete pipe. Systems can either use sacrificial anode cathodic protection (SACP), impressed current cathodic protection (ICCP), or both. SACP systems connect the protected metal to a more easily corroded sacrificial metal to act as the anode. The sacrificial metal then corrodes instead of the protected metal [6].

1. ***Acceptance criteria:***

Several countries and organizations, including ACI, CEN, CSA etc. have developed the criteria for evaluation of concrete structures.

For instance, [1] is a widely used report that provides comprehensive three-level acceptance criteria for the evaluation of existing nuclear safety-related concrete structures. Its focus is on commonly occurring deterioration conditions which are illustrated in [2] e.g, chemical attack, popouts, voids, scaling, passive cracks etc. The three-level evaluation criteria are provided in terms of acceptance without further evaluation, acceptance after review (i.e., additional inspection and testing to identify cause, activity, and effect of deterioration), and further evaluations required (i.e., more extensive application of testing and analytical methods to assess current capabilities and develop a remedial measure program, when required). Also included in the guideline are suggested periodic evaluation intervals (i.e., generally at 5 or 10 year intervals, but shortened if deterioration has occurred), qualification requirements of the evaluation team, and considerations for damage mitigation (i.e., repair, monitor at increased frequency, or replacement).

The structures monitoring programme calls for inspection results to be evaluated by qualified engineering personnel based on acceptance criteria selected for each structure/ageing effect to ensure that the need for corrective actions is identified before loss of intended functions. The criteria are derived in accordance with industry codes and standards of each country, and design bases codes and standards, as applicable, and consider industry and plant operating experience.

References [1-5, 11] provide acceptable basis for selection of acceptance criteria.

The criteria are directed at the identification and evaluation of degradation that may affect the ability of the structure or component to perform its intended function. Applicants who elect to use plant-specific criteria for concrete structures that are different from the design basis codes and standards and/or [1] describe the criteria and provide a technical basis for deviations from those criteria in these codes and standards.

1. ***Corrective actions:***

Evaluations are performed for any inspection results that do not satisfy established criteria. Corrective actions are initiated in accordance with the corrective action process if the evaluation results indicate there is a need for a repair or replacement. In addition, the corrective actions include assessment for mitigating the root cause of the degradation.

In absence of any plant specific requirements for corrective actions, the requirements in [19] can be used to address the corrective actions.

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.

Appropriate source(s) of external operating experience are Ageing Management of Concrete Structures in Nuclear Power Plants (IAEA Nuclear Energy Series No. NP-T-3.5 [6] as well as CHECWORKS Users Group (CHUG), Owner’s Groups, OECD-NEA, WANO, INPO, IAEA and NRC generic communications.

Although in many plants, structures monitoring programmes have only recently been implemented, plant maintenance has been ongoing since initial plant operations. NRC’s NUREG-1522 [20] documents the results of a survey sponsored in 1992 by the NRC Office of Nuclear Regulatory Regulation to obtain information on the types of distress in the concrete and steel structures and components, the type of repairs performed, and the durability of the repairs. Licensees who responded to the survey reported cracking, scaling, and leaching of concrete structures. The degradation was attributed to drying shrinkage, freeze-thaw, and abrasion. [20] also describes the results of NRC staff inspections at six plants. The staff observed concrete degradation, corrosion of component support members and anchor bolts, cracks and other deterioration of masonry walls, and groundwater leakage and seepage into underground structures. The observed and reported degradations were more severe at coastal plants than those degradations observed at inland plants, as a result of proximity to brackish water or seawater.

In Units 3 & 4 of Turkey Point NPP (USA), a Cathodic Protection System (CPS) was installed during original construction to protect the containment-liner plate, reinforcing steel, and tendon assemblies. The system is presently exhibiting low to very low readings in some of the anodes. readings (indicating lack of significant corrosion activity) [20].

In Diablo Canyon 1/ 2 NPP (USA), seawater intake structure was replaced twice since 1996 due to adverse impacts of saltwater attack on concrete. Refurbishment plans in 1996 included concrete repairs and installation of cathodic protection anodes at various locations [20, 21].

In San Onofre 3 NPP (USA), exterior concrete walls of intake structure and concrete beams supporting service water pumps cracked extensively due to chloride ion penetration that caused corrosion of embedded steel reinforcement. Walls were reinforced with exterior steel plates anchored to concrete and cathodic protection sacrificial zinc anodes were placed into steel plates to protect against corrosion. Later inspections found new areas of cracking and rebar corrosion, but degradation was not as great [20, 21].

Ringhals NPP has an own harbor (not safety classified building) for transportation of big components as well as used fuel. The harbor consists of a quay, a concrete structure that is founded with concrete piles. The piles transmit the loads of the quay to the seabed and down to the rock foundation. The piles are in general in an aggressive environment, as the construction is exposed to seawater, erosion and freezing. To protect the upper ends of the piles, which is in the most exposed splash zone, this part of the piles is provided with an ice protection made out of concrete. The piles status is recurrently visually inspected by divers as part of Ringhals preventive maintenance strategy. Experience from these inspections shows that erosion is a major degradation mechanism in the splash zone, where heavy loss of concrete material of the ice protection concrete is palpable after more than 30 years. An analysis of samples that has been taken out from the piles shows that the chloride concentrations are consistently high in the piles. But even though high chloride concentration has been found at all levels of the piles, few corrosion related damages has been reported in the submerged zone.

In Canada, some safety related structures are founded on steel driven end-bearing piles. The environment is generally non-aggressive. There is continuous monitoring of environmental parameters to verify condition of environment (boreholes for water samples, soil and air testing). The biggest aggressive agent that was established over the years was salt from de-icing performed in the winter. The salt was replaced with non-corrosive agent. As part of life extension, the utility is performing more verification. Due to the long duration of operation, the pile zone around ground water level (which has some natural fluctuation) is of most concern. The utility has some positive evidence for the condition but is pursuing for more verification of the data/condition. The constraint is that the soil around the piles is not disturbed as this will increase the air/oxygen around them.

The main cause of deterioration of marine structures is ingress of chloride ions from sea water, which in time will cause rebar corrosion. In some countries (e.g. Scandinavia), tidal variations are quite small with the result that splash zones essentially remain in a permanent state of high moisture content (i.e. no significant drying period). This may inhibit oxygen ingress, thus reducing the risk of corrosion. Submerged structures normally have a low risk of rebar corrosion due to low oxygen levels. If, however, concrete is of poor quality (e.g. a high water to cement ratio and low resistivity) a macrocell may be created between above and below water reinforcement. Reinforcement above water will receive atmospheric oxygen and fuel the corrosion process at the submerged anodic reinforcement.

Many licensees in the USA have found it necessary to enhance their structures monitoring programme to ensure that the ageing effects of structures and components are adequately managed during intended period of operation. There is reasonable assurance that implementation of the structures monitoring programme described above will be effective in managing the ageing of the in-scope structures and component supports through the intended period of operation.

1. ***Quality Management:***

Administrative controls, quality assurance procedures, review and approval processes, are implemented in accordance with the different national regulatory requirements (e.g., 10 CFR 50, Appendix B [19]).

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### References

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