## AMP 321: MONITORING OF CONCRETE STRUCTURES DURING DELAYED CONSTRUCTION (VERSION 2021)

### Programme Description

This document provides guidance for developing a plant specific ageing management programme (AMP) in order to ensure that the prolonged delays in the construction of a nuclear power plant do not result in irreversible or irreparable damages due to changes in environment or effects of stressors to structures (including structural elements) and civil components. The programme will ensure that the civil constructions in course, which are suspended for a given period of time, will have the right maintenance, conservation and preventive maintenance necessary following this period of delay.

The expected future functionality of civil structures (including structural elements) and civil components is ensured and the safety margins, which were established at the time of design, may not be reduced due to degradation mechanisms, for example, corrosion of reinforcement.

Additionally, when work is reinitiated, the structural integrity of these structures is ensured in order to obtain, at the end of the construction, a structure that is capable of meeting its design function.

Therefore, this AMP addresses the effects of ageing of civil SCs of a nuclear plant whose construction is involved in prolonged delays in the construction or has been stopped for any reason (e.g. economic, financial, political).

### 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 masonry block walls, constructed completely or partially, that are subject to ageing degradation.

* 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.

Some examples of concrete components/commodities used in nuclear power plants are building columns, beams, floors, walls, roof slabs, equipment foundations, pipe trenches, electrical duct banks, embeddments, hatches, missile shields, tank foundations, water intakes and discharges, spillways, cooling towers and masonry block walls.

More specific elements for inspection are:

* Reinforced concrete retaining walls protecting deep excavated shafts;
* Large concrete drainage shafts and channels that work under water pressure;
* Underground pedestrian and technical concrete canals for inspection;
* Prestressed concrete building structures and all their elements (ropes, anchors, sensors);
* Concrete foundations under turbines, engines and other massive machines and their components (anchors, bolts and hole supporting structure from below),

# Industrial concrete trestle (overhead roads) for pipes,

* Concrete ventilation stacks.

Concrete may be used in many different structures and structural members that are exposed to a variety of environments.

The environmental conditions applicable to concrete structures and structural members may include: concrete below grade (that can be in direct contact with soil, subgrade or backfill materials), concrete exposed to water (that can be sumerged in water or exposed to flowing water), concrete protected from weather (that are inside buildings and facilities) and concrete exposed to weather (that is not located in buildings and is exposed to weather).

According to Table 7 of SRS 82 [1] , SCs exposed to various environments such as “Air Indoor Uncontrolled” “Air Outdoor”, “Air-moist”, “Concrete”, “Ground water-Soil” and ”Water flowing” are considered.

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

Different practices that respond to preventive actions whose final objective is to minimize or control ageing degradation are detailed below:

*Exposed reinforcement bars.*

Among the civil components subject to degradation are the steel reinforcements on standby of those structural elements for which the execution wasn’t completed and were exposed to the surrounding environment.

A preventive action for said reinforcements is to proceed to cover the steel bars with mortar, to protect them from environmental conditions, avoiding corrosion.

Basically, the work consists of applying on site a cement mortar with the shotcrete technique which is the controlled projection of a mortar with air pressure and high speed through a hose (suitably supported) on the steel’s reinforcements.

The related operational experience elaborated in attribute 8 has shown that it is possible to continue the execution of work without the removal of mortar from the bars.

The resulting continuation of work has no harmful effects on the the concrete structure. Moreover, the design performance of the reinforcement will not be affected also.

*Housekeeping Activities and periodic cleaning.*

The subject activities have to be carried out in all of the buildings, both in nuclear and conventional areas, especially including roofs, gutters, and discharge channels of the buildings, as well as the implementation of pumping systems to avoid rain water accumulation.

Therefore, in the horizontal surfaces such as terraces, adequate drainage is provided. In this regard, special attention to critical zones e.g. joints and seals is required, where the passage of water over these areas is avoided. In the same way, the contact between concrete elements and runoff waters (rainfalls) is avoided as far as possible.

With regards to the storm drains, the objective of periodic cleaning is to ensure the adequate water runoff from rainfalls. In this way, no obstructions are generated in funnels on the roofs and discharge pipes and water flows properly to the low points of the site.

Also, with regards to the roof, a common problem is the breeding of birds which is necessary to avoid. Bird droppings contain chemical compounds (nitrates, sulphates, etc.), which is a growth medium of fungi and bacteria. These compounds are capable of creating favorable conditions for microorganisms that can live without oxygen (anaerobic) and deteriorate exposed concrete surfaces as well as metal surfaces, thus generating ageing and degradation processes. Therefore, those elements need to be protected by coatings (paint).

The correct way to prevent and maintain the ecological control of avian pests is through falconry. It has been found that the use of prey (for example falcons) is more effective than any other method e.g. installation of anti-posting spikes in openings, use of ultrasound technique, etc..

Activities of cleaning of accumulated soil on the facilities layered over time by winds and the natural movement of air currents is considered in order to prevent the development of vegetation in joints, roofs, vents and holes in the structure.

Also, prevention against the formation of ice dams on the roof and other roof surfaces of structures during the winter season is required. When the water freezes, melts and then freezes at the edge of the roof, an ice dam is created, which can create many different problems for buildings in areas during cold winters and temperatures below -5 degrees at night.

*Closure of openings.*

It is ensured during delayed construction periods that exterior openings of buildings are closed or covered. It is a general practice to seal them with waterproof products avoiding, in this way, water infiltration.

*Precast concrete members.*

In the construction of nuclear power plants, the precast concrete members are commonly used, which are generally stored at a specific location of site. These are usually equipped with metal inserts for lifting them.

A preventive action for precast elements consists of the protection of its metal inserts from the water, as well as the maintenance of the bulking itself, replacing if necessary, the wooden blocks and wedges that support and sustain said elements. In this way, the precast elements are unable to move and consequently do not crack or break which would cause them to be unusable.

*Cracked concrete surfaces and state of the concrete cover.*

Both the monitoring of cracks and the repair of cracked concrete surfaces are important preventive activities for the preservation of structures. Cracks generally act as a conduit for aggressive components to reach the steel reinforcement and reduce the depth of passivation.

Also, as a preventive measure, it is necessary that the condition of the concrete cover is checked and repaired immediately, if required. It is due to the fact that the cover (quality of the concrete and existing thickness) is one of the most important factors to avoid corrosion of the steel bars.

A suitable cover will protect the reinforcement from the action of the environment, ensuring a pH that is sufficiently alkaline to avoid corrosion of rebars. It also provides the necessary adhesion for the transfer of forces between steel and concrete at the time that the structure is in service, as well as ensuring safety against fire action.

The concrete cover depends on exposure conditions and is closely linked to the durability of the structures. It constitutes a barrier to the penetration of aggressive agents for the reinforcements such as the corrosion by carbonation or by the action of chlorides.

The minimum values of the concrete cover vary slightly in the international codes. Also, there are differences according to the environmental condition or lifetime specified for different elements that compose a structure.

In general, the concrete cover depends on the type of structure (in-situ concrete, pre-stressed or not, and precast concrete), the type of environmental exposure (contact with open air, contact with the ground, or without possibility of contact with these elements) and the type of structural element in question.

There are models that predict the depths of the corrosion entry with the passage of time, and propose the thickness of the cover as a design parameter for durability of concrete structures.

The European Committee of Concrete establishes that the process of carbonation and the attack of chlorides have mechanisms of penetration to the interior of the concrete which is related with the square root of the time. It follows that if the concrete cover is reduced by half, the danger of corrosion will be reached in less than a quarter of the time [2].

Reference [3] provides measures to protect reinforcing steel in concrete against corrosion due to carbonation or by penetration of chlorides in the concrete through its pores. For concrete repair information, please see reference [4].

*Concrete below grade exposed to ground water.*

As regards below grade concrete exposed to ground water, a periodic sampling and testing of ground water similar guideline given in AMP318 for plants in operation could be done, if required or if necessary, in order to determine a baseline data.

*Prestressing system.*

Like steel reinforcement, the prestressing system can experience corrosion, for both ducts and tendons (cables). If the ducts stay in place too long before being filled with cement paste or grease (operation that normally takes place after tensioning of the tendons), the potential for corrosion could exist at the inner face of the duct (the outer face being protected by the concrete). So, for structures reinforced with prestressing steel, preventive actions to protect those ducts using dry air circulation, or grease film for example, are considered to avoid the corrosion process.

As well, if no precaution is taken for the tendons (cables), corrosion can occur,  when the tendons (cables) are stored or remains in the duct for a long periods of time before injecting concrete grout or grease. For the tendons (cables), long storage periods before tensioning are avoided.

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

The potential ageing effects in concrete structures are loss of material, cracking and changes of material properties. AMP318 describes the ageing effects and degradation mechanisms in detail. This AMP identifies the degradation mechanisms that are not applicable during delayed construction periods of NPPs.

Loss of material is manifested in concrete structures and structural members as scaling, spalling, rust staining, pitting and erosion. These effects are the result of one or more ageing mechanisms such as freeze-thaw, abrasion or cavitation, elevated temperature, aggressive chemicals and corrosion of embedded steel (for example inserts, embedded plates) and steel reinforcement (rebar). However, the ageing mechanism related to elevated temperature do not apply to the delayed construction condition as they occur during operation.

Cracking may occur in concrete structures and structural members as general cracking, map cracking, hairline cracking, pitting and erosion. These effects are the result of one or more ageing mechanisms such as freeze-thaw, reaction with aggregates, delayed ettringite formation, shrinkage, vertical displacements (settlement or up-heave), elevated temperature, irradiation and fatigue. However, elevated temperature, irradiation and fatigue do not apply to the delayed construction condition because they are related to the operating condition of the plant.

Changes of material properties is evidenced in concrete structures and structural members 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. These effects are the result of one or more ageing mechanisms such as leaching of calcium hydroxide, aggressive chemicals, elevated temperature, irradiation and creep. However, elevated temperature, irradiation and creep do not apply to the delayed construction condition as they are related to the operating condition of the plant.

Reference [5] provides the definitions of different ageing mechanism as described above.

In-service examinations (that can include inspections, testing and monitoring) and surveillance are essential elements for detection of ageing effects.

For civil structures that are under delayed construction, periodic visual inspections are carried out according to references [6], [7], [8] and [9] that provides information and guidelines applicable to such inspections.

An adequate approach to visual inspection involves activities such as: gathering background information, design information and the environment conditions, planning the analysis to be performed, establishing a control grid over the structure that will serve as basis for recording observations.

Regarding cracking in structures, visual inspections also include activities of periodic mapping and measurements to provide a history of crack’s appearance in order to help the person responsible for developing the evaluations to identify their cause and establish if a crack is active or dormant.

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

The monitoring and trending of ageing effects is carried out to gather enough information to enable timely corrective action or mitigation of the effects of ageing if these have occurred.

It is important to determine what parameters will be monitored, what data will be collected, and which methods will be used to analyze the data.

Reference [10] provides acceptable basis for selection of parameters to be monitored or inspected for concrete structures. It also includes relevant references in chapter 9 for further research if needed. Also, references [7] and [10] provide useful guidance to help recognize and classify different types of damage as well as its probable causes.

Special equipment (like borescopes) and developings (video microscope for example) for monitoring are mentioned in AMP318. Also, it provides a useful guide regarding concrete structures monitoring.

In the case of monitoring of corrosion of steel reinforcements, the most commonly used parameters are the depth of carbonation and the chloride content. The results obtained make it possible to approximate the time when corrosion has begun and to predict future evolution. One way of obtaining this data will be by using non-destructive testing techniques.

Conditions assessments of the corroded structures can be carried out with non-destructive techniques, obtaining relevant information, such as: location and size of the reinforcing steel, corrosion activity and possible corrosion rate of the steel reinforcement [11].

In many cases of constructions in progress, it is possible to install specific instrumentation to monitor phenomena related to corrosion [12].

Likewise, the monitoring and measurement of possible cracks in a structure are important, and their location in the structure, extension over the structural member and the shape are considered.

It is relevant in the analysis of a crack system to establish whether it is active (occurs when one of its dimension lengths, width and/or depth varies) or whether it is a passive state (when there is no change in its dimensions).

By direct observation, there are fissurometers or crack rulers that allow to measure changes and displacements, or the evolution of cracks and crevices on the surface from a gradated ruler.

Plaster samples can also be installed (not in the case of outdoor environments) or of a rigid material – such as glass – adhered to both sides of the crack. This sample will break when the crack experiences movement, although this could also occur in the case of accidental breakage or due to thermal variations.

With regard to the periodic review of these samples, it is usual to do so after 7, 14, 30, 60 and 90 days. If, after this time, there are no signs of movement, the cracks will be considered inactive and will be repaired. If otherwise, the cause of the movement is analyzed and a solution to the source of the movement is given.

In relation to the data and trend obtained through monitoring, Reference [13] reviews the application of softwares during collection and storage of data. In general, the frequency of routine inspections to detect and prevent the effects of ageing on structures do not exceed 6 months.

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

This AMP is a condition monitoring programme and no recommendations are provided to mitigate ageing effects. However, if degradation occurs exceeding the acceptance criteria, plant specific actions are taken based on the monitoring carried out and the trending observed, leading to an evaluation in order to mitigate the root cause or source of degradation and analyse the impact on the integrity of the SCs.

In case of delayed construction, housekeeping tasks and periodic cleaning is a part of the preservation and maintenance activities, in order to preserve the good condition of the installations and structures at site, keeping all the building areas neat and orderly, removing waste materials and avoiding stagnant water.

The implementation of pumping systems on site to avoid the accumulation of water of any nature (example: rainwater) is not only a preventive action but also a mitigating action.

In general terms, a house keeping plan allows mitigating the effects of ageing on different elements that make up structures and their components.

Also, the presence of dirt and garbage in buildings, deterioration of temporary enclosures that protect work sectors from adverse environment conditions, channels presence, gutters and drains that are obstructed, sectors that could be flooded, the breakage of temporary closures against the entry of birds, presence of corroded points on metal surfaces, and localized damages to masonry and concrete surfaces, are general examples of triggers to take timely and appropriate mitigation actions.

It is possible to mitigate the effects related to ageing in steel reinforcements by covering them with mortar. This action will allow in the future continuing with the concreting activities without removal of this protective layer.

In the case of cracks on the concrete surfaces, once the causes that originated them have been identified, and resolved, the activities of repairing passive cracks, by injecting products according to each case, are actions that will allow the mitigation of detected effects of ageing or degradation in these structures.

Different cathodic protection systems could be installed in SCs in order to prevent or mitigate corrosion of reinforcement as mentioned in AMP318.

Reference [14] provides a summary and description of different strategies of mitigation for corrosion in reinforced concrete structures.

1. ***Acceptance criteria:***

The acceptance criteria are defined for each element subject to degradation, in order to assess the need for corrective actions and, if such case, to ensure that these are implemented before the element loses its original intended functionality.

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

For instance, [6] provides a summary of the acceptance criteria for visual inspection as set out in reference [10].

The acceptance criteria presented in Chapter 5 [10] provides recommended guidelines for the treatment of conditions and findings that might result from an evaluation. That acceptance criteria includes three tiers into which a concrete structure can fall, based on the defect detected: Tier 1: Acceptance without further evaluation, # Tier 2: Acceptance after review and # Tier 3: Conditions requiring further evaluation. More information about the three-level acceptance criteria is provided in AMP318.

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 [10] describe the criteria and provide a technical basis for deviations from those criteria in these codes and standards.

The “plant-specific programme” considers sufficient details of the acceptance criteria in consonance with attribute 8.

Regarding concrete structures affected by any of the three types of AAR (alkaly aggregate reactions) or by DEF (delayed ettringite formation), it is known that such reactions typically result in expansion and cracking of concrete. In those particular cases, AMP312 provides useful guidance for managing the effects of these chemical reactions.

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.

The operating organization is responsible for the engineering, construction and commissioning of the nuclear power plant, but also responsible for preservation activities.

Therefore, it is understood that, despite the usual long delay in time to re-initiate works on site, the organization will have sufficient and trained staff in place to carry out the inherent requirements of these corrective actions (and in general for compliance with all points of this AMP), without waiting the reactivation of contracts with construction companies.

In all cases, the corrective interventions of the structures have the objective of re-establishing the characteristics and performance initially foreseen in the phases of conception, planning and design of the same ones for which, it will be important to carry out an adequate previous analysis (correct diagnosis of the problem, evaluation of materials and procedures to be used) to avoid the failure of the actions that are intended to be executed.

It is necessary to elaborate a detailed design of the solutions, with clear specifications of materials and work procedures, all of this supported by a rigorous control and quality assurance in the work (Quality Control and Quality Assurance).

In the case of intervention in structures with corrosion in steel reinforcement problems, procedures considers substrate preparation, cleaning, application, finishing and final protection activities.

In the case of steel reinforcements, the criterion most commonly used on site is direct protection of the steel, i.e. solutions applied directly to the steel reinforcement.

Protective coatings can be organic or inorganic, some contain corrosion inhibitors, and others have zinc in their composition, which provides additional cathodic protection.

Epoxy coatings are the most common physical barriers applied on site to the surface of steel bars. Also, in widespread use, are cementitious coatings that include adhesion improvers.

For corrective intervention, the cracks that represent a reduction of resistance, tightness or durability for the concrete structure or that affect its functionality are mainly considered.

Also, [9] establishes that, based on a careful evaluation of the magnitude and causes of the concrete cracking, it is possible to select repair procedures that achieve objectives such as restoring and increasing strength, improving functionality, providing waterproofing conditions, and preventing the development of corrosive environment in steel reinforcements.

Metal elements such as anchor plates, laminated profile beams and other carbon steel inserts, which are embedded in concrete and show visible damage, are adequately treated by surface protection systems for the purpose of appropriate corrective intervention. Prior to this, the substrate has to be free of grease, oil, moisture and mill scale. Delayed construction for non-concrete structures and components SCs such as metal elements is managed by AMP322.

In all cases, the durability of the repair techniques implemented as corrective actions on those elements that require them, will depend on the durability of the material used, the installation procedure applied and the effectiveness of quality controls on site.

It is also necessary to prepare a follow up plan of the interventions, in order to know if they have been successful, if they failed due to causes attributed to poor design, by use of inappropriate materials, lack of supervision and control, or inappropriate methods to execute them.

In absence of any plant specific requirements for corrective actions, the requirements in [15] 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 of external operating experience is the IAEA TECDOC in reference [16]. It describes the experiences of Member States managing the nuclear power plant’s ageing during 3 (three) specific periods, one of which is “delayed construction”. The Annex I “Delayed Construction Member State Experiences” provides the experience of 6 (six) Member States in that period.

In Atucha II NPP (ARGENTINA), an appropriate source of R&D was the “Research on the practice of mortar coating of steel reinforcements on standby”[17]. This research involved the execution of laboratory test through which the possible influence of the mortar (concrete slurry) in the periphery of the bars was analyzed with respect to the adhesion of the concrete. The resistance of the concrete breakout strength was timely evaluated.

Concrete cubes of 23 cm side were prepared with steel bars in vertical position in their central part. The concrete with the same materials and specifications as used on site provided compressive strength of 29.3 MPa at the age of 14 days. Accordingly, the steel bars of 25 mm diameter were obtained from site which had the mortar applied after the construction at NPP was stopped. The comparison of the adhesion behavior of steel bars without the removal of mortar and with removal of mortar by sandblasting was carried out. It has been found that, at the age of 14 days, the breakout strength stresses from concrete-bar adhesion with mortar with respect to the breakout strength stresses from sandblasted concrete-bar adhesion have been higher, on average 22% higher.

Finally, comparison through graphs corresponding to breakout stresses versus deformations of the tests was carried out. Reference [18] provides description and details of this research work.

This OPEX and related research work assures the effectiveness and suitability of the application of mortar on the steel bars when the construction of the nuclear power plant is stopped.

Finally, in the NPP aforementioned, a procedure was implemented to manage the repair of cracks in concrete. To re-establish the structural integrity, the crack is demonstrated to be passive (or dead) and in those cases, epoxy based resins were usually considered. On the other hand, for active cracks, flexible resin products were applied to obtain the sealing condition. Therefore, the use of epoxy resins to seal cracks was the common practice on site.

Reference [19] provides a guide for the selection of different types of polymer adhesives for different cases including the repair of cracks in concrete.

1. ***Quality management:***

Site quality assurance procedures, review and approval processes, and administrative controls are implemented in accordance with different national regulatory requirements (e.g. 10CFR 50, Appendix B [15]).

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