**AMP 312 CONCRETE EXPANSION DETECTION AND MONITORING SYSTEM (VERSION 2020)**

### Programme Description

Alkali Aggregate Reaction (AAR) and Delayed Ettringite Formation (DEF) can lead to concrete expansion and degradation in susceptible structures. The expansion in concrete leads to degradation of tensile, shear, compressive, and bond strength of the concrete. In addition, the modulus of elasticity of concrete is also reduced. The extent of degradation of different mechanical properties and elastic modulus is not uniform; therefore, the original design of AAR and DEF affected concrete structures that is based on implicit relationships between compressive strength of concrete, and other mechanical properties are re-evaluated.

Concrete Expansion Detection and Monitoring Programme provides for management of ageing effects due to the presence of AAR and DEF. The programme consists of inspection and monitoring by qualified personnel to identify indications of the reactions. Additional testing and evaluation may be required to confirm the presence of AAR and DEF. Preventive actions may also include protecting structures from water, which is a necessary component of the reactions.

AAR is an irreversible chemical reaction that covers two different types of degradation: alkali-silica reaction (ASR) and alkali-carbonate reaction (ACR). The more common is the alkali-silica reaction. ASR involves the formation of an alkali-silica gel which expands when exposed to water. The gel often causes a dark discoloration of the cement paste surrounding the crack at the concrete surface. Micro cracking is generated through forces applied by the expanding aggregate particles and/or swelling of the alkali-silica gel within and around the boundaries of the reacting aggregate particles. AAR does not necessarily mean expansion: expansion needs water to occur. High temperature will accelerate the reaction. Since the reaction depends on chemical components, the risk can be evaluated on the basis of concrete constituents (cement + aggregates) and an environment analysis.

DEF is a case of chemical sulphate reaction where the source of sulphate ions happens to be internal. Cases of DEF are likely to happen when concrete temperature during curing is higher than 65 °C. This can occur for thick elements due to the exothermic nature of the reaction cement undergoes during the curing process. In fact, ettringite is not stable above 65-70 °C, and the released ions during its decomposition are absorbed by calcium-silicate hydrate [1]. Later, during service when sulphate ions are desorbed, the re-formation of ettringite causes expansion with possible cracking. Again, water is necessary for expansion to occur.

### Evaluation and Technical Basis

1. ***Scope of the Ageing Management Programme based on understanding ageing:***

The scope includes all the concrete structures that are initially inspected in accordance with AMP 302, AMP 306 and AMP 307, and determined to have cracking patterns that may indicate the presence of AAR or DEF.

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

This AMP does not rely on preventive actions. However, when possible, measures may be implemented to reduce expansion of AAR and DEF susceptible concrete to come into contact with moisture or groundwater. This may be accomplished with installing/repairing waterproofing membranes or installing dewatering systems in the areas adjacent to the structures preventing the inflow of groundwater into the structure.

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

Ageing effects due to concrete expansion include cracking, increased porosity and permeability, loss of material, reduction in concrete anchor capacity, and building deformation.

Symptoms of AAR or DEF are usually detected by visual observation of cracking on the surface of the concrete. The cracking is typically accompanied by the presence of moisture and efflorescence. Concrete affected by expansive ASR is typically characterized by a network or "pattern" of cracks.

Maximum crack width, a cracking index, pop outs, and a description of the cracking pattern including any visible surface discoloration can indicate the presence of ASR or DEF. DEF can be distinguished from ASR by the lack of pop outs and absence of gel in the cracked area. Petrographic examination of concrete core samples is required to confirm the presence or absence of ASR in concrete with pattern cracking and visible discoloration of concrete. Note that issues such as equipment misalignments, dimensional changes, etc can also be indications of building deformations due to ASR. A Cracking Index can be used as a preliminary indicator for accessible surfaces exhibiting pattern cracking. The process for determining the Cracking Index (CI) is described in References [2-4]. Note that the internal deterioration may be different than the degradation observed at the surface and that the expansion observed is strongly dependant of the presence and orientation of reinforcement.

Expansion can be monitored with a system based on strain measurements. DEF can be detected if strains sensors such as vibrating wire strain gauges, have been embedded in the central area of the concrete section and strain data is collected for a long period.

ASR and DEF in inaccessible areas of concrete structures such as base slabs of buildings, water intake and discharge structures, service water pump house, and below grade walls of the spent fuel pool covered with a liner plate, can be monitored with embedded strain sensors. If sensors are not available in inaccessible structures, a special evaluation is needed to determine the extent of concrete degradation. The acceptability of inaccessible areas is evaluated when conditions are found in accessible areas that could indicate the presence of, or could result in, degradation in such inaccessible areas.

The impact of ASR on a structure are based on in situ measurements, laboratory tests and a detailed evaluation. The details and timing of these tests are approved by the member state regulatory authority.

Building deformations are monitored and assessed. Specific monitoring activities could include concrete expansion measurements, plant dimensional measurements, measurement of width of seismic gaps, and measurements of off-sets and misalignments in equipment and conduits.

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

The progression of ASR/DEF degradation of the concrete is an important consideration for assessing the long-term implications of ASR and specifying monitoring intervals. A commonly used method for monitoring and trending low levels of ASR affected concrete is to determine the number of pop outs, CI, and crack widths on a periodic basis. However, a more effective method is to attach sensors and monitor the deformation of ASR affected structures. Note that the degree of reinforcement in the structure will dictate the main direction of expansion (can also be through wall). In many cases, monitoring the alignment of equipment attached to the surface can be an effective strategy for areas that may be inaccessible and when sensors cannot be attached. Another method to supplement the in-situ measurements is to extract cores from the ASR affected concrete area periodically and perform quantitative petrographic examination to determine the Damage Rating Index (DRI). Reference [3] provides details and guidance for measuring DRI. The rate of change in the embedded strain gauges (if any) can also be used for monitoring and trending of ASR and DEF.

A baseline inspection of the ASR/DEF affected concrete in conjunction with the previsions of AMP 302, AMP 306, and AMP 307 as applicable, is performed to document the pop out, CI, and crack widths. As a preliminary indicator, measurements of the pop outs, CI, and crack widths in the same areas as the baseline can be performed at an appropriate frequency until a trend in expansion rate is established. Note that this method is not applicable for through wall expansion, high levels of ASR and heavily reinforced structures. Thereafter, sensors can be installed in selected locations to trend the structure deformation, while measurements of equipment displacement can be recorded and monitored. The trend data can then be used to determine the rate of progression and any change in frequency of the inspection. Documentation and trend data will be maintained in accordance with the requirements of the appropriate member state regulatory authority.

Specific monitoring activities include concrete expansion measurements, plant dimensional measurements, measurement of width of seismic gaps, and measurements of off-sets and misalignments in equipment and conduits.

1. ***Mitigation 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. Additional actions may be necessary for concrete water‑control structures, such as installing a liner or moisture barrier.

1. ***Acceptance criteria:***

References [1-6] describe screening methods to monitor expansion and determine when structural evaluation of the ASR affected structures is appropriate. Some of these screening methods suggest limits for the crack width, cracking index and pop outs. Acceptance criteria for concrete expansion is location specific; however, acceptance criteria for monitoring systems based on strain measurement needs to be developed based on a detailed analysis of the structure and the level of reinforcement. As a minimum, monitor and trend the width and extent of cracks in ASR affected structures. Unless a specific criterion is specified in each member state codes, standards, and regulations, for crack width more than 0.15 mm (0.006 in) and/or crack index more than 0.5 mm/m, perform tests to determine the degradation of mechanical properties, and evaluate the structure design using the degraded mechanical properties.

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 absence of any plant specific requirements for corrective actions, the requirements in the US Code of Federal Regulations, 10 CFR Part 50, Appendix B [7], can be used.

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:

IAEA Nuclear Energy Series on Ageing Management of Concrete Structures in Nuclear Power Plants [8].

ASR has been identified at Seabrook Nuclear Station in USA and Gentilly 2 Nuclear Station in Canada. Available OPEX for these two cases can be found in [9, 10].

Delayed Ettringite Formation (DEF) has been detected at an NPP in France. This expansion was detected by the Monitoring system installed in the basemat of the containment. No visual damage nor cracking has been observed, but extrapolation has been performed based on the measurements over a sufficient period of time. The expansion, which is only in the basemat, appears to be linked to both the significant thickness of the concrete section and presence of water.

Cracking was discovered in the turbine generator foundation of Ikata unit 1 in Japan in 1979 after the start of operation. A change in the distance between the generator rotor axis and the bearing on the table deck was observed and expansion measurements were performed to confirm the cracking condition. Additionally, laboratory tests were conducted on extracted concrete cores. Through evaluation of these concrete cores, it was confirmed that cracking was caused by ASR expansion. This condition did not affect the intended function of the turbine generator foundation. The structural integrity for continued operation was confirmed by continuous condition monitoring.

Patterns of thin cracks were observed during a visual inspection of the columns of a turbine deck at Dukovany Nuclear Station in the Czech Republic. Eight cores were extracted and tested in the laboratory. Early phases of ASR were found in few of those cores. For trending purposes, new coring and subsequent testing will be performed after seven years and a visual inspection will be done every three years.

ASR with low reactivity has been identified in an individual core obtained from the containment bottom slab at Ringhals Unit 2 in Sweden. Petrographic studies showed a low proportion of low reactive aggregate. The aggregates identified consisted mainly of amphibole- and biotite gneisses and granitic rocks. The reactive aggregate consisted of fine grained quartz. Microcracks of 0.03 to 0.05 mm filled with ASR gel were identified in the sample. However, no gel was identified in the air voids. Overall, the analysis indicates a weak to moderate reactivity that wholly or partially may have stalled. Inspections on the visible parts of the construction and pressure strength tests showed no signs of cracking or affected strength. Other samples or inspections have not shown the presence of ASR.

In France, a report dedicated to concrete expansion reactions in NPP is written every five years. These reports are a major piece of the demonstration of the plant capacity for another 5 years period and are a part of the plant AMR.

French utilities use the following acceptance criteria adapted from [1, 5]. A specific structural evaluation and test programme is suggested if more than 10 pop outs are found in one square meter area. If degradation is due to DEF and cracking index CI is > 0.5, then a specific structural evaluation is required. If degradation is due to ASR and the structure is exposed to an aggressive environment, the following criteria for CI and crack width (ei) is used:

* CI < 0.5 and ei > 0.6 mm: a specific study and test programme is required;
* CI < 0.5 and ei > 0.3 mm: the cracked area is monitored at a frequency of six months;
* CI < 0.5 and ei < 0.3 mm: the cracked area is monitored by AMP 302 or AMP 306 or AMP 307;
* CI > 0.5 and ei > 0.3 mm: a specific study and test programme is required;
* CI > 0.5 and ei < 0.3 mm: the cracked area is monitored by AMP 302 or AMP 306 or AMP 307.
* For structures that are not exposed to ground water infiltration and or alternate drying and wetting, following criteria for CI and crack width (ei) is used:
* CI < 0.5 and ei > 1.0 mm: a specific study and test programme is required;
* CI < 0.5 and ei > 0.6 mm: the cracked area is monitored at a frequency of six months;
* CI < 0.5 and ei < 0.6 mm: the cracked area is monitored by AMP 302 or AMP 306 or AMP 307;
* CI > 0.5 and ei > 0.6 mm: a specific study and test programme is required;
* CI > 0.5 and ei < 0.6 mm: the cracked area is monitored at a frequency of six months.

Appropriate source(s) of R&D related to this AMP are:

* The Electric Power Research Institute has several guidance reports with regards to ASR:

1. the use of non-destructive techniques to monitor and test the progression of ASR [11];
2. ageing management tools for early detection and management of ASR affected structures [6, 12];
3. mitigation and repair options for ASR affected structures [13].

* RILEM committee TC I259-ISR is working on four aspects related to the prognosis of deterioration and loss of serviceability in structures affected by alkali-silica reaction. These four areas are: 1) Materials testing; 2) Numerical Modelling 3) ASR Monitoring; and 4) Large Scale Testing [14].
* IFSTTAR which is the French government institute for research in civil structures has published several state-of-the-art reports such as references [2,15].

Research relevant to this AMP is currently ongoing under OECD/NEA/CSNI Assessment of Structures Subject to Concrete Pathologies (ASCET) working group. The objective of the ASCET programme is to assess and validate evaluation techniques for nuclear structures with degraded concrete. Phase I and II have been completed [16, 19].

A large amount of information and advanced scientific development in the field of ASR comes from the hydroelectricity industry where expansion reaction is more severe than in NPP, see references [17, 18].

1. ***Quality management:***

Site quality assurance procedures, review and approval processes, and administrative controls are implemented in accordance with the different national regulatory requirements (e.g., 10 CFR Part 50, Appendix B [7]).

**References:**

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