## AMP 320 VIBRATION AND CYCLIC LOADING ON CIVIL STRUCTURES (VERSION 2021)

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### Programme Description

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

The scope of the programme includes the concrete and non-concrete structures and structural concrete commodities within the scope of AMP 301, AMP 302, AMP 303, AMP 318 and AMP 319 for ageing effects due to vibration and cyclic loads. It may be differentiated with AMP 101 which mainly deals with thermal and pressure transients occurring in mechanical components like pressure vessels, steam generators and primary piping.

Fatigue and vibration are mechanical stressors due to the fluctuations in loading, temperature, and moisture content. The large-scale concrete failure due to fatigue is manifested by excessive cracking, excessive deflections, and brittle fracture. Vibration on concrete structures occurs at foundation pad of diesel generator and at the supports for the piping system and the pumps and turbines.

Fatigue due to load cycles and vibration is the other cause of liner plate and structural steel degradation. Generally, the design and manufacturing of liner plates and structural steel have adequately addressed the fatigue issues. Fatigue problems occur as a result of unforeseen circumstance such as material flaws and stress concentration factors. For liner plates, the possible fatigue sites include:

Base metal delamination;

Weld defect areas;

Shape changes near penetrations;

Structural attachments;

Concrete to floor boundaries.

For structural steel members, the possible fatigue sites are the large containment penetration framing and the liner anchorages near vibrating load conditions.

Cyclic loads include:

Containment building interior temperature variation during heat-up and cooldown;

LOCAs;

Outdoor temperature variations;

Seismic loads;

Pressurization from periodic integrated leak rate tests;

Freeze thaw cycling: Repeated freezing and thawing of water can cause degradation of concrete, characterized by scaling, cracking, and spalling. The cause is water freezing within the pores of the concrete, creating hydraulic pressure;

Cyclic loading due to ground water fluctuations;

Thermal exposure / Thermal cycling.

The 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 [1-4]. General guidance in this regard has been provided by organizations such as the International Atomic Energy Agency [5]; the Electric Power Research Institute [6-7]; International Union of Laboratories and Experts in Construction Materials, Systems, and Structures [8]; and Nuclear Energy Agency Committee on Safety of Nuclear Installations [9].

Concrete structures subjected to fluctuations in loading, temperature or moisture content can be damaged by fatigue. Concrete exhibits good resistance to fatigue, so fatigue failure is unusual and concrete structures are designed using codes limiting design stress levels to values below concrete’s endurance limit [10, 11]. However, as structures age, there may be instances of local fatigue damage at locations where reciprocating equipment is attached, or at supports for pipes exhibiting flow induced vibration. Fatigue damage initiates as microcracks in the cement paste, close to large aggregate particles, reinforcing steel or stress risers (e.g. defects). With continued or reversed load application, these cracks may propagate to form structurally significant cracks, exposing the concrete and reinforcing steel or producing increased deflections. Ultimate failure by fatigue will occur as a result of excessive cracking, excessive deflections or brittle fracture. As concrete ages and gains strength, for a given stress level, the cycles to failure will increase. If concrete is reinforced or prestressed, steel properties will tend to control structural performance since the steel carries tensile loads.

Fatigue of the mild reinforcing system would be coupled with that of the surrounding concrete. The result of applied repeated loadings, or vibrations, is generally a loss of bond between the steel reinforcement and concrete. For extreme conditions, the strength of the mild steel reinforcing system may be reduced, or failures may occur at applied stress levels less than yield. However, there have been few documented cases of fatigue failures of reinforcing steel in concrete structures and those published occurred at relatively high stress/cycle combinations. [12]. Because of the typically low normal stress levels in reinforcing steel elements in NPP safety-related concrete structures, fatigue failure is not likely to occur [13].

The evaluation methods and acceptance criteria recommended in [1,3-4,10-11] can be used in the absence of, or to supplement, the guidance provided in the plant licensing documents. The programme includes preventive actions for degradation and failure of structural bolts subjected to vibration and cyclic loads. Guidance provided in applicable industry standards and guidance documents, including references [14-17] can be used to ensure structural bolting integrity.

### Evaluation and Technical Basis

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

The monitoring programme is applied to concrete and non-concrete structures, structural components, component supports, and structural commodities subjected to vibration and cyclic loads.

Structures, structural components, and commodities in the scope of the programme are concrete and steel structures, structural bolting, anchorages, component support members, pipe whip restraints and jet impingement shields, panels and other enclosures, doors, penetration seals, and tube tracks.

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

Effective preventive and mitigative actions for damage due to vibration and cyclic loads consist of careful identification of the possible locations where this type of damage could occur. When possible, locations are identified, the reduction of the excessive loads and/or the repair of deteriorated areas including cracks are appropriate preventive actions.

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

In-service examinations (that can include inspections, testing and monitoring) and surveillance are essential elements for detection of ageing effects due to vibration and cyclic loads. The significant ageing effects are cracking and changes of material properties. This ageing effects can result in reduction or loss of isolation function, excessive deflection, damping or loss of sealing function.

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.

There may be degradation at suppression pool steel liner above water line. The fatigue may cause leakage of radioactive gases.

Periodic visual inspection of the concrete structures is performed to monitor and detect the presence of, abrasion, erosion, cavitation, excessive deflections and settlements, cracking, pop-outs and voids, spalling, scaling, in the anchorage components. Acceptance criteria are in accordance with applicable industry codes and standards of each member state.

[1,3] provide acceptable basis for selection of parameters to be monitored or inspected for concrete and steel structural elements and for steel liners, joints, coatings, and waterproofing membranes.

The inspection frequency depends on safety significance and the condition of the structure. In general, all structures 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.

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

The consequences of ageing due to vibration and cyclic loads are localized damage, excessive deflection, brittle fracture etc. 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. ***Mitigating ageing effects:***

This AMP is a condition monitoring programme and no generic recommendations are included to mitigate ageing effects. Where practical, effective mitigation methods and technology for vibration and cyclic loads on SCs include repair, replacement or retrofitting of affected SCs. If necessary, design changes to accommodate vibration and cyclic loads may be implemented.

1. ***Acceptance criteria:***

The monitoring programme for vibration and cyclic loads calls for inspection results to be evaluated by qualified engineering personnel based on acceptance criteria 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 [1,3,5,10-11] 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.

Elastomeric vibration isolation elements are acceptable if there is no loss of material, cracking, or hardening that could lead to the reduction or loss of isolation function.

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 [20] 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 [5] as well as CHECWORKS Users Group (CHUG), Owner’s Groups, OECD-NEA, WANO, INPO, IAEA and NRC generic communications.

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

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[14]).

### References

[1] AMERICAN CONCRETE INSTITUTE, Evaluation of Existing Nuclear Safety-Related Concrete Structures, ACI Standard 349.3R-02 (Reappeared 2018), ACI, Detroit, MI,2018

[2] AMERICAN CONCRETE INSTITUTE, Guide for Conducting a Visual Inspection of Concrete in Service, ACI Standard 201.1R, ACI, Detroit, MI,2008

[3] AMERICAN SOCIETY OF CIVIL ENGINEERS, Guideline for Structural Condition Assessment of Existing Buildings, SEI/ASCE 11-99, ASCE, Reston, VA, 1999

[4] CANADIAN STANDARD ASSOCIATION, Requirement for Safety-Related Structures for CANDU Nuclear Power Plants, CSA N291-08 (R 2013), CSA, Canada, 2013

[5] INTERNATIONAL ATOMIC ENERGY AGENCY, Nuclear Energy Series No. NP-T-3.5, “Ageing Management of Concrete Structures in Nuclear Power Plants” Vienna, Austria, 2016

[6] Electric Power Research Institute, Aging Identification and Assessment Checklist, TR 1011224, EPRI, Palo Alto, California, January 2005

[7] Electric Power Research Institute, Aging Assessment Field Guide, TR 1007933, EPRI, Palo Alto, California, December 2003

[8] Naus, D. J. “Considerations for Use in Managing the Aging of Nuclear Power Plant Concrete Structures,” Editor - D.J. Naus, Report 19, RILEM Publications S.A.R.L., Cachan, Cedex,1999.

[9] NUCLEAR ENERGY AGENCY, Report of the Task Group Reviewing International Activities in the Area of Ageing of Nuclear Power Plant Concrete Structures, NEA/CSNI/R(95)19, Nuclear Energy Agency of the Organisation of Economic Cooperation and Development, Issy-les-Moulineaux, France, November 1995

[10] ACI COMMITTEE 215, Considerations for Design of Concrete Structures Subjected toFatigue, ACI 215R-74, American Concrete Institute, Detroit, MI,1974.

[11] AMERICAN CONCRETE INSTITUTE, Fatigue of Concrete Structures, SP-75 (Shah,S.P. Ed), ACI, Farmington Hills, MI, 1982.

[12] C. B. Oland and D. J. Naus, Summary of Materials Contained in the Structural Materials Information Center, ORNL/NRC/LTR-94/22, Martin Marietta Energy Systems, Inc., OakRidge National Laboratory, Oak Ridge, Tennessee, November 1994.

[13] NUREG/CR-6424 ORNL/TM-13148, Report on Aging of Nuclear Power Plant Reinforced Concrete Structures, USNRC, Washington, D.C,1996.

[14] UNITED STATES NUCLEAR REGULATORY COMMISSION, Resolution of Generic Safety Issue 29: Bolting Degradation or Failure in Nuclear Power Plants, NUREG-1339, USNRC, Washington, D.C.1990

[15] Electric Power Research Institute, Degradation and Failure of Bolting in Nuclear Power Plants, Volumes 1 and 2, EPRI NP-5769, EPRI, Palo Alto, CA, 1988

[16] ELECTRIC POWER RESEARCH INSTITUTE, Good Bolting Practices, A Reference Manual for Nuclear Power Plant Maintenance Personnel, Volume 1: Large Bolt Manual; Volume 2: Small Bolts and Threaded Fasteners, NP-5067, EPRI, Palo Alto, CA,1990

[17] Electric Power Research Institute, Bolted Joint Maintenance & Application Guide, EPRI TR-104213, EPRI, Palo Alto, CA, 1995

[18] UNITED STATES NUCLEAR REGULATORY COMMISSION, 10 CFR Part 50, Appendix B, Quality Assurance Criteria for Nuclear Power Plants and Fuel Reprocessing Plants, National Archives and Records Administration, USNRC, USNRC, Washington, D.C, Latest Edition.