### AMP 314 Seismic isolation (VERSION 2020)

### Programme Description

This ageing management programme (AMP) provides guidance for developing a plant specific ageing management programme for seismic isolation systems for nuclear facilities in order to ensure there is no loss of intended function during operation. Seismic isolation systems can broadly be categorized into building isolation and equipment isolation.

The ageing effects include the change of material properties of the elastomer material.

The AMP consists of mechanical tests on representative samples complemented by visual inspections performed by suitably qualified and experienced personnel. The test samples are made of the same material as the in-situ bearings and located as close as possible to in-situ bearings to ensure that they are exposed to same ageing conditions as in-situ bearings. Both static and dynamic tests are performed in order to evaluate the ability of the bearings to limit vibratory ground motion in such a way that all structures and equipment important to safety fulfill their intended function during and after a seismic event. Visual inspections are performed to detect degradation of aseismic bearings.

### Evaluation and Technical Basis

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

The scope of the programme includes seismic base isolation systems for nuclear island structures, seismically isolated administrative buildings used to implement post-earthquake activities, as well as seismic isolation systems for equipment supports. Three types of seismic isolators are in the scope of this AMP. These are Low Damping Rubber (LDR) bearings, Lead Rubber (LR) bearings, and spherical sliding Friction Pendulum bearings. Structural members associated with the isolation system are not covered in this AMP and are inspected in accordance with AMP 306.

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

The seismic isolation monitoring programme is a condition monitoring programme. However, preventive actions (if any) are provided by the manufacture of the seismic base isolation system. In some designs, protective screens have been installed around the bearing pedestals and covering areas between the top of the pedestals and the upper raft to limit the effects of oxidation and ozone degradation. Sufficient space between the bottom and upper rafts (i.e. aseismic vault) is provided to allow access to the bearings for inspection maintenance, and replacement if necessary. Thus, preventative actions also include limiting exposure of the bearings to adverse environmental conditions that could lead to ageing degradation.

1. ***Detection of Ageing Effects:***

In-service examinations (that can include visual inspections, testing and monitoring) and surveillance are essential elements for detection of ageing effects. The primary inspection method for aseismic bearings is visual examination complemented by mechanical tests on representative samples, where such samples exist. In some member states, test samples, in the form of small diameter cores, are extracted from the neoprene material of the installed bearings and subjected to chemical analysis and mechanical testing.

Aseismic bearings are monitored for cracking, loss of material and hardening. Aseismic bearings are also inspected for reduction or loss of isolation function due to humidity, radiation hardening, sustained vibratory loading, temperature outside limits. In addition, test samples of the aseismic bearings placed in immediate proximity of the actual bearings during construction are tested for shear modulus and material damping.

Parameters monitored are commensurate with relevant national industry codes, standards (for example [1-2]), and in particular with the ageing hypotheses assumed for the plant design limits. Depending on the specific design of the seismic isolation system, typical examples of parameters monitored may include, static shear modulus, dynamic shear modulus, static friction, dynamic friction, shore hardness, distortion, rupture strength (elastomer), elongation at rupture (elastomer), residual deformation after compression loading, horizontal stiffness (static), vertical stiffness (static), horizontal stiffness (dynamic), vertical stiffness (dynamic), horizontal frequency, vertical frequency, delamination of the elastomer from the reinforcing steel plates, corrosion, etc.

The shear modulus is monitored by performing shear modulus tests on sample bearings at the intervals defined in the licensing basis. The frequency of the periodic test depends on the results of the different campaigns: generally, this frequency is higher (for example 10 years) when the trending indicates hardening but the measurements on samples is more frequent in the case of softening.

The frequency for visual inspections depends on safety significance and condition of the seismic base isolation system. In general, visual inspections are performed at specific intervals (for example, every 5 years to be consistent with structures monitoring [3]) on an identified percentage of in-situ bearings. The visual inspection is performed to determine the visual effect of oxidation and other superficial degradation mechanisms, such as cracking of the elastomer, etc. The scope of visual inspections also includes general inspection of the space between the upper and lower rafts (i.e. the aseismic vault). This is done to detect the development of ambient and environmental conditions that may have an adverse impact on the integrity and long-term performance of the seismic bearings. Exceptional events such as flooding or fire may require specific inspections (more than visual) depending of the importance and type of event. A walk down (without quantified criteria) is performed every 5 years for all the bearings in order to detect exceptional event such as leakage/sealing that would not have been identified during current operation.

Sliding surfaces (if any) are inspected for indication of significant loss of material due to wear or corrosion, debris, or dirt.

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

The ageing management programme consists of the following elements:

* Visual Inspection: Visual inspections are performed by examining the condition of the seismic base isolation system; these inspections are intended to keep track of the condition of the in-situ bearings and detect any deterioration in their condition. Visual inspection is augmented by distortion and shore hardness measurements taken on selected bearings.
* Shear Modulus Tests: Tests on seismic base isolation system are performed periodically to determine the static and dynamic shear moduli of the elastomeric material, and to determine whether these parameters are still within the design basis throughout the period of operation. These samples are stored in the aseismic vault in the same conditions as the in-situ bearings. The test results obtained are trended and extrapolated. The values obtained after extrapolation are compared to the design values as documented in the licensing basis documents.
* Lower Raft Inspections: Periodic visual inspections of the lower raft on which the aseismic bearing pedestals are supported are performed to ensure that the raft is sound and that the leakage of water into the aseismic vault is within the required tolerances in accordance with AMP 306.
* Inspections following an extreme external event: Following an occurrence of a significant natural phenomenon such as tornado, flood, earthquake, hurricane, or intense local rainfall, a special inspection is performed of the aseismic bearings, lower raft, retaining walls and the upper raft impacted by the event.

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

This AMP is a condition-monitoring programme and neither general nor specific recommendations are provided to mitigate ageing effects. However, if the extent of degradation observed or detected 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 or and to evaluate the impact on structural performance. For example, if the change in isolator properties exceeds the range used in design, the system should be reassessed, and isolators should be changed out (if it is possible to do so) if sufficient safety margin cannot be demonstrated.

1. ***Acceptance Criteria:***

The ageing management programme calls for inspection results to be evaluated by qualified engineering personnel based on acceptance criteria selected for seismic base isolation system 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. For example, practices in some member states recommend that the mechanical properties of the isolation system (i.e., the force-displacement relationships) should not vary over the lifespan of the NPP by more than ±20% from the best-estimate values (with 95% confidence) from those assumed for analysis and design [11].

Evaluation is generally achieved by performing visual inspections on in-situ bearings or and conducting various prescribed tests on samples stored under the same in-situ conditions. An example of a recommended evaluation method and acceptance criteria is described in [4]. For more information about maintenance methods and control values of the building isolation refer to “Maintenance Standard for Seismically Isolated Buildings, Japan Society of Seismic Isolation (2007)” [5].

For visual inspection the acceptance criteria are based on qualified engineering assessment concluding that there is no degradation due to cracking, discoloration, leakage, etc. For the sample tests, the acceptance criteria are determined based on the limiting values used at the design stage. The test results are compared with the limiting values used in the design basis.

In case the conditions do not meet the acceptance criteria and thus indicate a potential for degradation and is included into the corrective action programme of the plant for further evaluation.

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 the absence of any plant specific requirements for corrective actions, the requirements in [6] 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 [7] as well as CHECWORKS Users Group (CHUG), Owner’s Groups, OECD-NEA, WANO, INPO, IAEA and NRC generic communications.

Operational experience on seismic isolation is available from Fukushima Dai-ichi and Dai-ni Nuclear Power Plants in Japan, Cruas Nuclear Power Plant in France, Koeberg Nuclear Power Plant in South Africa, Advanced Gas-cooled Reactor (AGR) fleet in the UK and the two EPR units currently under construction at Hinkley Point in the UK.

In response to the 2007 Niigataken-Chuetsu-Oki earthquake that impacted the Kashiwazaki-Kariwa Nuclear Power Plant (KKNPP), Japanese utilities decided to seismically isolate emergency operations buildings. As a result, seismically isolated emergency response centers have now been constructed at the sites of Japanese NPPs. Following the earthquake that occurred off the Pacific coast of Tohoku in March 2011, emergency response activities at both Fukushima Dai-ichi and Dai-ni Nuclear Power Plants were led by the emergency response headquarters established inside seismic isolated buildings. The seismic isolated buildings were effective in protecting staff from the threat of many aftershocks resulting from the earthquake [10].

In France, a lack of representative samples led to the manufacturing of new samples. So accelerated ageing by heating was performed on the new samples in order to ensure that their condition is representative of the in-situ bearings. The results of all the tests showed an increase of the shear modulus due to hardening, due to the potential impact of this hardening of bearing on plant safety (increasing of global frequency of system) the operator has justified that the remaining margin has enough to cover the seismic demand including requirements coming from post-Fukushima re-assessment. A flooding event at Cruas NPP affected sample bearings stored in the seismic vault, however, the installed bearings were not affected by the flood. Subsequent inspections on samples bearing revealed initiation of corrosion due to contact with water. This experience led to the improvement of storage requirements for sample bearings.

In South Africa, results obtained over the years by conducting shear modulus tests on samples produced during original construction showed a hardening phase followed by the on-set of a softening phase. This softening phenomenon may be caused by a possible suppression of various polymerization reactions, which occur at the molecular level of the polymer material [8].

In the UK, the concrete containment structures (prestressed concrete pressure vessels - PCPV) for the Advanced Gas-cooled Reactor (AGR) are isolated from their main foundations by a layer of supporting neoprene or rubber bearing pads. The operating conditions at the location of the PCPV bearings provide a generally dry and passive environment i.e. the bearings are not exposed to ultraviolet light, wetting, atmospheric conditions or significant irradiation. Accordingly, the UK operational experience to date has confirmed that the PCPV bearings are not exposed to a high risk of ageing-based degradation [9]. A representative sample of the visually accessible PCPV bearing pads has been inspected across the UK AGR fleet. This targeted surveillance has confirmed the generally good condition of the constituent bearing material and long term structural performance. A limited number of in-situ test samples, in the form of small diameter cores, has been taken from the neoprene material at one of the older AGR plants and subjected to chemical analysis and mechanical testing. No significant changes in the mechanical hardness properties or material composition of the bearings has been found across the UK AGR fleet [9].

The two EPR units currently under construction at Hinkley Point in the United Kingdom feature a Secondary Containment Enclosure Building (SCEB), which provides secondary containment around the primary containment dome. The SCEB at Sizewell B is supported on 85 pot or spherical bearings, which are made of machined steel components and elastomeric discs. The bearings are a passive and permanent component which could only be replaced with difficulty. The bearings act to seismically modify the dynamic response of the secondary dome under earthquake actions, are designed for all applicable loads of the SCEB. The operating conditions at the location of the bearings provide a generally dry and passive environment i.e. the bearings are not exposed to ultraviolet light, wetting, atmospheric conditions, significant irradiation or any lubrication fluid. The bearings are inspected by conducting 5 yearly periodic visual inspections on in-situ bearings only. as part of the inspection programme for the SCEB. However, the visual inspection is limited because the outer parts of the bearings cannot be readily observed, and the bearings are in a constrained location. There are no mechanical tests conducted on samples that are stored in similar conditions on site.

International and domestic research and development activities relevant to this AMP are discussed in Reference [11]. All accessible R&D information has been considered during the revision of this AMP.

1. ***Quality Management:***

Administrative controls, quality assurance procedures, review and approval processes, are implemented in accordance with the different national regulatory requirements (e.g., [4, 8]).

### References

[1] NF EN 15129 Anti-seismic devices, January 2010

[2] RCC-CW Rules for Design and Construction of PWR Nuclear Civil Works, Edition 2017

[3] AMERICAN CONCRETE INSTITUTE, ACI349-3R-02, United States, 2018

[4] AFCEN PTAN French Experience and Practice of Seismically Isolated Nuclear Facilities, France 2015

[5] JAPAN SOCIETY OF SEISMIC ISOLATION, Maintenance Standard for Seismically Isolated Buildings, Japan, 2007

[6] 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, Latest Edition.

[7] IAEA Nuclear Energy Series No. NP-T-3.5, “Ageing Management of Concrete Structures in Nuclear Power Plants” Vienna, Austria, 2016.

[8] National Nuclear Regulator (2008), Quality and Safety Management Requirements for Nuclear Installations. RD-0034, Rev 0. Centurion

[9] ENSREG Topical Peer Review of Ageing Management, “UK National Assessment Report”, EU, 2017.

[10] Japan Nuclear Energy Safety Organization (JNES). (2014). "Proposal of technical review guidelines for structures with seismic isolation." JNES-RC-2013-1002, Tokyo, Japan.

[11] UNITED STATES NUCLEAR REGULATORY COMMISSION (USNRC). (2019). “Technical Considerations for Seismic Isolation of Nuclear Facilities”, NUREG/CR-7253, Washington, DC. (ML19050A422).