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1. Introduction

Koeberg Nuclear Power Station (KNPS) has several licence binding inspection requirements which forms the basis of the In-Service Inspection Programme (ISIP). The Nuclear Installation Licence (NIL) [14] is granted by the National Nuclear Regulator (NNR) in accordance with the NNR Act (Act No. 47 of 1999) to Eskom.

As part of the NIL, Section 15, subsection 15.1 d), Eskom must inspect, survey, test and monitor the Aseismic bearings.

The compliance of this requirement is further elaborated in the *Civil Ageing Management Programme Standard (KSA-128)* [4] which affirms that "inspections and surveillances shall be performed to detect and monitor degradation aging effects" and that for the Aseismic bearings the activities include:

- visual inspections of the Aseismic bearings, which include the use of appropriate industry best practices, methods as well as supplemental techniques and equipment, and
- specialised monitoring techniques and surveillances applicable to Aseismic bearings.

A new supplemental Civil Aging Management Programme Requirements Manual [2] for all in-scope civil SSCs, inclusive of the aseismic bearings, was developed to satisfy the aging management requirements in terms the regulatory guide RG-0027 [15] and the aging management gaps identified as part of the SALTO AMR/AME (based on IGALL AMPs and TLAAs up to 2018). This Civil Aging Management Programme Requirements Manual [2][1] considers the 9 attributes of an effective AMP for all in-scope civil SSCs.

The *Basis and Scope for License Binding Civil Surveillances at Koeberg Nuclear Power Station (KAU-030)* [1] defines these inspections to a further extent.

Moreover, KSA-128 and KAU-030 (and the associated lower tier procedures) serve as the Ageing Management Programme (AMP) for the aseismic bearings. Accordingly, the AMP of the Aseismic bearings is dictated by the NNR approved, KAU-030 [1].

Over the past years however, operational experience from CRUAS has indicated that their shear modulus testing shows an increase in shear modulus which is not experienced in the Koeberg shear modulus test results. The Koeberg AMP for the aseismic bearings therefore needs to be expanded to ensure that the bearing degradation effects are accurately monitored.

2. Supporting Clauses

2.1 Scope

The scope of the document is limited to the AMP of the Aseismic bearings.

2.1.1 Purpose

The purpose of this report is a review of the current ISI testing procedures by the Responsible Engineer, as recommended in 331-645 [11]. The review compares KNPS aseismic bearings' programme to the new IGALL AMP 314 (2020) [6] as well as the NUREG 7253 [10] guidance. It is also important to note that IGALL AMP 314 (2020) came into existence after SALTO AMR/AME Project, which was based on IGALL AMPs and TLAAs up to 2018.

Hence, the purpose of this document, is a follow-on AME assessment in terms of the new IGALL AMP 314 for the ASB. Gaps are also identified in this report and actions are raised accordingly.

This is achieved by providing an overview of the aseismic bearings' AMP and scrutinizing the requirements of *Basis and Scope for License Binding Civil Surveillances at Koeberg Nuclear Power Station* [1]. Appropriate recommendations are made where gaps are identified.

Furthermore, the limited number of available neoprene aseismic bearing test samples is considered and the testing for LTO, including 2034 and 2044, is proposed.

This report considers additional testing to address two aspects:

1. Ensure that the AMP properly monitors the ageing degradation during the period of LTO.
2. Additional tests to better understand the differences in the Cruas and KNPS results.

The above testing shall then guide the update of the Aseismic Bearing Monitoring Programme.

2.1.2 Applicability

This document shall apply to KNPS.

2.1.3 Effective date

Once Authorized

2.2 Normative/Informative References

Parties using this document shall apply the most recent edition of the documents listed in the following paragraphs.

2.2.1 Normative

[1] 240-149139512: Standard: Ageing Management Requirements for KNPS

[2] 240-165425812: Civil Ageing Management Programme Requirements Manual (CAMPRM)

[3] 240-166148961 (KAU-030): Basis and Scope for License Binding Civil Surveillances at Koeberg Nuclear Power Station

[4] 240-166151023 (KSA-128): Civil Ageing Management Programme Standard

[5] 331-656: Civil Engineering Inspection, Assessment, Trending and Reporting Standard

[6] IAEA IGALL AMP 314 Seismic isolation (Version 2020)

[7] KWR-IP-CIV-013: Aseismic Samples Bearing - Testing Procedure

[8] KWU-DE-015 Load Monitoring of Sample Bearings

[9] KWR-IP-CIV-044: Long-Term Monitoring of Aseismic bearings

[10] NUREG/CR-7253: Technical Considerations for Seismic Isolation of Nuclear Facilities

2.2.2 Informative

[11] 331-645: Elastomeric Aseismic Bearings - Current Position and the Way Forward

[12] IGALL AMP-306 Structures Monitoring (Version 2018)

[13] J43/87-002: Technical Manual for the Monitoring of the Aseismic Bearings

[14] Nuclear Installation Licence No. NIL – 01 (Variation 19)

[15] RG-0027: Ageing Management and Long Term Operations of Nuclear Power Plants

[16] SAR Chapter 1 Part II-1.9: Civil Works - Buildings

[17] SSG-48: Ageing Management and Development of a Programme for Long Term Operation of Nuclear Power Plants

2.3 Definitions

Responsible Engineer – The Responsible Engineer competent person, appointed in writing, in accordance with the requirements as set out in AMSE XI and ACI 349.

2.4 Abbreviations

Abbreviation	**Explanation**
AMP	Ageing Management Programme
IAEA	International Atomic Energy Agency
ISIP	In-Service Inspection Programme
KNPS	Koeberg Nuclear Power Station
KSAR	Koeberg Safety Analysis Report
NIL	Nuclear Installation Licence
NPP	Nuclear Power Plant
SSG	Specific Safety Guide

2.5 Roles and Responsibilities

N/A

2.6 Process for Monitoring

N/A

2.7 Related/Supporting Documents

None

3. Ageing Management Programme Guidance

The AMP of the Aseismic bearings will be assessed in accordance with the principals as set out in the International Atomic Energy Agency (IAEA) Specific Safety Guide (SSG-48) [17] and will be scrutinized against guidance from the IAEA International Generic Ageing Lessons Learned (IGALL) guidance document - *AMP 314* (2020) [6] and the United States Nuclear Regulatory Commission (U.S.NRC) *Technical Considerations for Seismic Isolation of Nuclear Facilities* (NUREG/CR-7253) [10], Section 9.

The implementation of the AMP will also be tested against the Eskom Ageing Management Requirements for KNPS [1]. Note that the 9 attributes of an effective AMP are embedded in the Civil Aging Management Programme Requirements Manual.

SSG-48 requires a “systematic approach” which is aimed at managing the effects of ageing. SSG-48 states that the AMP should provide a framework for coordinating all activities relating to the understanding, prevention, detection, monitoring and mitigation of ageing effects on the plant’s SSCs. The approach is illustrated in Figure 1 [17].

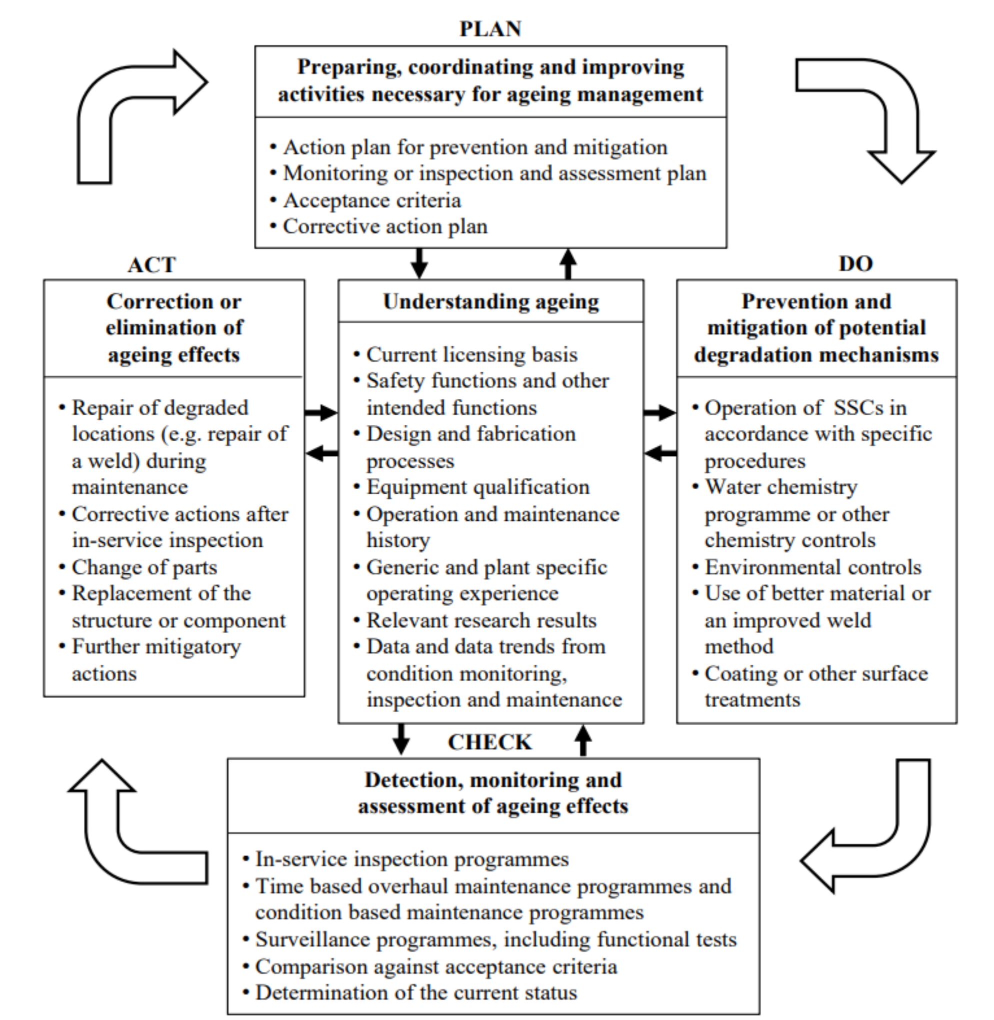

Figure 1: Systematic approach to ageing management [17]

3.1 Programme Basis, Structure and Implementation

The Civil Ageing Management Programme Requirements Manual (CAMPRM) [2] considers the general aspects of the AMP for the Civil AMP at KNPS and discusses the testing, inspections, trending of defects, etc. associated with the aseismic bearings. The CAMPRM considers the nine generic attributes of an effective ageing management programme. The nine attributes are as follows:

1. Scope of the civil ageing management programme based on understanding ageing,
2. Preventive actions to minimise and control ageing effects,
3. Detection of ageing effects,
4. Monitoring and trending of ageing effects,
5. Mitigating ageing effects,
6. Acceptance criteria,
7. Corrective actions,
8. Operating experience feedback and feedback of research and development results, and
9. Quality management.

The AMP of the aseismic bearings will be assessed against these 9 attributes in this report.

4. Current AMP for the Aseismic Bearings

KAU-030 provides the basis for the Monitoring of the aseismic bearings and references lower tier inspection procedures. These procedures are listed below:

- KWU-DE-015 Load Monitoring of Sample Bearings [8]
    - Describes the method of retorquing (loading and un-loading) of the aseismic sample bearing rigs.
- KWR-IP-CIV-013: Aseismic Samples Bearing - Testing Procedure [7]
    - Describes the handling and test methods employed to determine the Static and Dynamic Shear moduli of the neoprene aseismic sample bearings.
- KWR-IP-CIV-044: Long-Term Monitoring of Aseismic Bearings [9]
    - Describe the method of inspection to ensure long-term integrity of the aseismic bearings.

Furthermore, the 'Licence binding Activities' (monitoring activities) associated with the aseismic bearings are extracted from KAU-030 (with the KAU-030 section number shown in brackets) below:

4.1 Inspections and Surveillances on In-situ Bearings (§ 4.2.1)

The surveillances shall be carried out every five years [3] in accordance with the original monitoring program specified by the designers. It should be noted that some tests/surveillances included in the original bearings testing programme are no longer performed, most notably the friction couple testing which was removed from the testing programme, after the Friction Couple was removed from the SAR under SAR Change Request CN- 47.

Furthermore, the Shore Hardness tests have evolved to increase the sample size during 2004 and again in 2021 (sample size increased to 32 and 48 respectively, from 24 originally).

4.1.1 Visual Inspection (§ 4.2.1.1)

The bearings shall be visually inspected to determine:

- the presence or degree of corrosion on the stainless-steel plate cast into the Upper Raft
- bulging, tearing or cracking of the neoprene,
- the interface of the Bearium and cast-in stainless steel plate is still adequately sealed; and
- if cracking and deterioration of the upper raft, lower raft and the retaining walls have occurred.

It is noted that the inspection of the upper and lower rafts forms part of separate monitoring programmes.

4.1.2 Distortion Checks (§ 4.2.1.2)

Distortion checks shall be performed to verify that distortion of bearings is below the permissible

limit. The current permissible limit is 50mm, and the maximum distortion measure has been 8mm. The trend of the Distortion checks has been relatively flat, and the distortion is not deemed important for LTO, although measurements will continue to be taken and trended.

Furthermore, the distortion measurements will be repeated on the same sample size for each measurement interval.

4.1.3 Shore Hardness Test (§ 4.2.1.3)

Shore hardness tests shall be performed to measures the hardening of the neoprene layers. It is noted that no direct correlation exists between the Shear Modulus of the neoprene and the shore hardness; the Shore hardness is only deemed indicative of the hardening of the thin outer layer of the neoprene.

4.1.4 Additional Testing (§ 4.2.1.4)

The Aseismic Bearing Monitoring Programme shall be updated to include additional testing of bearings based on the advice of Subject Matter Experts (SMEs) and the Responsible Engineer, to consider the effects of ageing of the neoprene on the seismic response of the plant, and the requirement to verify the behaviour of the bearings for LTO.

The testing performed thus far is deemed acceptable and in-line with the original design intent and original testing procedures. Additional testing may be specified over time as the Responsible Engineer sees fit.

It is however recommended that different testing methods are investigated. That might provide less subjective results and/or interpretation of the ageing. One recommendation for investigation is a study into the practicality for determining the Shear Modulus of the in-situ bearings by direct measurement on the in-situ bearings (not using representative samples) and without necessarily removing the in-situ bearings.

4.2 Tests and Monitoring Activities Performed on Sample Bearings (§ 4.3)

A limited number of sample bearings were provided for testing at various stages during the original design life of the plant. These sample bearings are stored in rigs located in the same environmental conditions and that simulates similar stresses as the in-situ seismic bearings.The sample bearings are stored and located to adequately simulate and be representative of the ageing of the in-situ bearings.

As per the original monitoring program for the aseismic bearings, the last set of sample bearings was due for testing during the 2014 test series. Consequently, a technical evaluation of the aseismic bearings testing program in conjunction with the historical test data was performed, to provide the technical basis for extending the sample bearings testing program to accommodate plant life extension. A subsequent extension of the original testing programme for the aseismic bearings, was developed, presented to the NNR and adopted for the 2014 to 2024 and 2024 to 2034 test series (i.e 10-year intervals).

4.2.1 Re-torquing (4.3.1)

The retorquing of the stressing rigs in which the sample bearings are stored shall be carried out annually to ensure that the load on sample bearings remains representative of the stress condition of that of the in-situ bearings. The rigs are re-torqued yearly [8].

4.2.2 Dynamic and Static Shear Modulus Testing (4.3.2)

Dynamic and static shear modulus testing must be carried out at various stages during the plant life to determine if the shear modulus of the bearings is within the design parameters. The shear modulus testing of the sample bearings shall be carried out at 5, 15 and 30 years after the first criticality of Unit 1, in accordance with the original monitoring program specified by the designers.

The extension of the aseismic bearings testing programme, recommended a 10 yearly frequency using a combination of 50% used and 50% unused samples (the samples shall be rotated by 90 degrees in the test apparatus), which was adopted since the 2014 test series.

Dynamic shear modulus test shall only be undertaken if the acceptance criteria of the static shear modulus test are not met.

A recent investigation [11] (*331-645 Elastomeric Aseismic Bearings - Current Position and the Way Forward*) indicated the re-testing of previously tested neoprene sample bearings are feasible, and it is recommended that for the 2024 to 2034 test interval the approach of utilizing a combination of 50% used and 50% unused samples be repeated. The shear modulus testing for the 2024 to 2034 test interval will be performed on 50/50 used/unused samples as conducted in 2014 and accepted by the NNR.

The shear modulus testing for the 2034 to 2044 test will be performed on 100% used samples and 100% unused, friction bearing samples.It is noted that the friction couple interface may have to be removed to determine the shear modulus of the neoprene.

4.2.3 Visual Inspection (4.3.3)

A visual inspection of the sample bearings used for testing shall be performed before and after shear modulus testing.

During this investigation, it was however noted that, in the event of a plant shut down consequent upon a seismic event, one inspection to complete is to check at least thirty (30) bearing pedestals to confirm their position relative to their original position in respect of the retaining walls and in respect of one another.

These “original positions” are not available; therefore, it is recommended that a survey be performed of at least 30 pedestals to determine their positions and deem the survey as verification of their original positions.

5. Benchmarking the AMP against International Best Practice

5.1 NUREG/CR-7253 [10]

The following recommendations are extracted from NUREG/CR-7253 with regards to monitoring, ageing, long-term operation and inspections and comment is made with respect to the KNPS AMP:

5.1.1 Long-Term Changes in Isolator Mechanical Properties (§ 9.1.1)

The mechanical properties of the isolation should not vary over the lifespan of the NPP by more than ±20% from the best-estimate values from those assumed for analysis and design.

KNPS' acceptance criteria for the static and dynamic shear moduli, in accordance with the Koeberg Safety Analysis Report (KSAR) [16] are:

- Static shear modulus of the neoprene = 0.95 MPa ± 15%
- Dynamic shear modulus of neoprene = 1.30 MPa ± 15%

The KNPS tolerance is therefore enveloped by the NUREG/CR-7253 recommendation.

It is noted that the NUREG continues and states that:

If the change in isolator properties exceeds the range used in design, the system should be reassessed, and isolators should be changed out if sufficient safety margin cannot be demonstrated.

KNPS procedures will similarly require re-assessment of aseismic bearing effectiveness if acceptance criteria are not met.

5.1.2 Testing of Prototype and Production Isolators (§ 9.2.2)

Prototype tests should be performed individually on full size specimens of each predominant type and size of isolator unit in the isolation system.

KNPS has 60 neoprene sample bearings which were manufactured as part of the initial production for the specific purpose of testing the shear properties over the lifetime of KNPS. KNPS has additional samples which were earmarked for testing the friction between the stainless-steel and Bearium interface.

KNPS tests sample bearings are not full-size specimens, and therefore only partially complies with this requirement.

Prototype tests should be dynamic and to displacements equal to or greater than the clearance to the stop.

The shear testing of the samples at KNPS are currently being tested to static conditions, and only once the static acceptance criteria is not met, will dynamic tests be performed to determine if the samples meet the dynamic acceptance criteria.

KNPS therefore only partially complies with this requirement. The current testing is firstly based on static tests. The static tests have been deemed sufficient, however Eskom will consider the practicality and feasibility of performing both static and dynamic tests during the next ISI interval tests, planned for 2024Q3.

A sufficient number of prototype isolators should be tested to provide a minimum 90% confidence in the performance of the isolators.

As part of the original construction testing (at production), for a sample size of n=36, the confidence interval was determined to be between 95% and 99% for an infinite population. Accordingly, a further 60-samples were made available for periodic testing. A further 70 samples were manufactured which were initially earmarked for testing the friction at the couple interface.

The location of the reference bearings which are used to test for distortion and shore hardness represent the bearings sufficiently geographically (see § Appendix C [11]).

KNPS therefore complies with this requirement.

Appropriate quality control and quality assurance programs must be employed for all testing programs.

The tests are performed in accordance with KNPS quality standards and KNPS therefore complies to this requirement.

5.1.3 In-service Inspection, Replacement and Maintenance (§ 9.3.1)

Nuclear facility owners should maintain an adequate number of non-load-bearing isolators in the environment that is essentially identical to that of the in-service units. A representative compressive load should be maintained on the non-load-bearing isolators.

KNPS has three sets of representative samples of ‘non-load-bearing isolators’ which can be and has been used for the ISIP. This includes “periodic verification of mechanical properties of isolator devices to assess the effect of ageing on their performance”.

KNPS therefore complies with this requirement.

5.1.4 Monitoring of Foundation Deformations (§ 9.3.3)

Long-term foundation deformations should be periodically monitored, including movement of the moat walls, relative displacements between the basemat and foundation, and vertical displacements of the basemat and foundations.

The measurements mentioned in the NUREG are covered by the periodic topographic survey which KNPS performs 5-yearly and therefore complies with this requirement.

5.1.5 Operating Temperature (§ 9.3.5)

Seismic isolators should generally be installed in a dry air-conditioned space that is maintained at a temperature of between 40ºF and 80ºF (4 C° - 27 °C), unless an alternate temperature range was assumed and accounted for in the analysis, design and testing of the isolators and isolation system.

The temperature in the Aseismic Vault varies between 13-24°C [11]. This falls within the operating parameters recommended in USNRC 7253 of 40°F – 80°F (4.4°C – 26.7°C)

5.2 IAEA IGALL AMP 314 Seismic isolation

The IAEA AMP 314 “ageing management programme 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”.

AMP 314 seismic isolation is a condition monitoring programme The Guidance from AMP 314 is extracted below (the relevant section of AMP 314 is shown in brackets) and comment is made and compared with respect to the KNPS AMP.

5.2.1 Detection of Defects (§ 3)

- *The primary inspection method for aseismic bearings is visual examination complemented by mechanical tests on representative samples, where such samples exist.*

KNPS performs visual inspections and mechanical tests on representative samples, and therefore complies to this guidance.

- *Aseismic bearings are monitored for cracking, loss of material and hardening.*

This is performed through visual inspections, distortion measurements and shore hardness testing, and therefore complies with this guidance.

- *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.*

The inspection programme includes the measuring of the humidity and temperature of the nuclear island environment. "Radiation hardening" or "sustained vibratory loading" is not a concern and are not considered ageing mechanisms applicable to the aseismic bearings of KNPS.

Moreover, the test samples were placed in the immediate proximity of the actual bearings during construction.

Lastly, the neoprene sample bearings are tested for change in shear modulus properties, however material damping has not been part of the testing programme.

Therefore, KNPS is in partial compliance with this guideline.

- *Parameters monitored are commensurate with relevant national industry codes, standards, and in particular with the ageing hypotheses assumed for the plant design limits.*

At the time of the design and construction of KNPS, there were no 'relevant national industry codes, standards'. The design of the aseismic bearings does however incorporate ageing mitigation such as [11]:

- The edges of the internal reinforcing plates are protected by a neoprene cover of between 2 mm and 6 mm thick, and the edges of the external reinforcing plate by a neoprene cover of between 4 mm and 8 mm thick,
- the chemical composition of the neoprene was selected with a reduced activity of the double bonds on the principal chain because of the electronic weakening effect, which yields very high resistance to oxygen or ozone degradation and hence provides excellent aging characteristics,
- grease fillet was placed around the bearings at the intersection of the Bearium and Stainless Steel in order to seal the sliding surfaces from the atmosphere,
- some protective agents (anti-ozone, anti-heat, anti-ultra-violet) were incorporated into the polychloroprene base mix.

Furthermore, 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. There are no quantitative or qualitative requirements associated with this requirement, and therefore the KNPS testing ISI is deemed sufficient.

- *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, verical frequency, delamination of the elastomer from the reinforcing steel plates, corrosion, etc.*

KNPS monitors several of the above parameters applicable to the aseismic bearings design and the KNPS design basis. This includes static shear modulus, dynamic shear modulus (if the sample fails the static test), shore hardness and distortion.

- *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 current trend of the hardening is increasing [11] and the current test frequency of the shear modulus of the aseismic bearings is 10-yearly, with the next set of tests being planned for Q3/2024, in accordance with KAU-030. KNPS therefore complies with this guideline.

- *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.*

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

KNPS performs inspections on the bearings 5-yearly, with the next set of tests being planned for Q4/2024, in accordance with KAU-030 and therefore complies with this guideline. This includes an inspection of the sliding surface.

5.2.2 Monitoring and trending of ageing effects (§ 4)

The ageing management programme consists of the following elements:

- Visual Inspection
- Shear Modulus Tests
- Lower Raft Inspections

KNPS performs all the above and is in compliance with this guideline.

5.2.3 Mitigating ageing effects (§ 5)

It is noted that AMP 314 states:

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.

KNPS will identify plant specific actions based on the detailed monitoring and trending and additional testing where required as has been the case when the shore hardness values were too scattered, the Responsible Engineer increased the sample size.

A structural evaluation or assessment will be performed to evaluate the impact on structural performance if the testing regime indicates degradation that exceeds the acceptance criteria, in accordance with the applicable Eskom process. KNPS therefore complies with this Guideline.

5.2.4 Acceptance Criteria (§ 6)

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 testing and inspection results are evaluated by qualified engineering personnel in accordance with the appicable procedures and standards such as the Civil Engineering Inspection Standard [5] and KAU-030 [3].

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.

At Koeberg, the acceptance criteria is ±15% of the SAR Static and Dynamic Shear Modulus, specified by the original design.

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.

As illustrated, KNPS performs both visual inspections on in-situ bearings and conducting various prescribed tests on samples stored under the same in-situ conditions.

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.

Any visual defects are identified for trending to ensure engineering assessments can be performed where required. Furthermore, the distortion measurements has an acceptance criteria of a measured distortion angle of 63,4°.

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.

If the conditions do not meet the acceptance criteria and thus indicate a potential for degradation further evaluation will be initiated.

KNPS therefore complies with these aforementioned guidelines.

5.2.5 Corrective Actions (§ 7)

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.

If the ISIP identifies inspection results that do not satisfy established criteria, evaluation will be initiated accordingly, in accordance with KNPS processes.

5.3 Gaps between KNPS and NUREG and IAEA

The following gaps were identified during the review of the NUREG and IAEA guidance.

Table 1: Gaps of KNPS AMP

Reference	Guideline	Comment	Recommendation
NUREG [10] § 9.2.2	Prototype tests should be performed individually on full size specimens of each predominant type and size of isolator unit in the isolation system.	KNPS tests sample bearings are not full-size specimens	None – There are no full-size specimens, and therefore the requirement cannot be followed.
NUREG [10] § 9.2.2	Prototype tests should be dynamic and to displacements equal to or greater than the clearance to the stop.	The shear testing of the samples at KNPS are currently being tested to static conditions, and only once the static acceptance criteria is not met, will dynamic tests be performed to determine if the samples meet the dynamic acceptance criteria.	The current testing is firstly based on static tests. The static tests has been deemed sufficient, however Eskom will consider the practicality and feasibility of performing both static and dynamic tests during the next ISI interval tests, planned for 2024Q3.
IAEA [6] § 3	Test samples of the aseismic bearings placed in immediate proximity of the actual bearings during construction are tested for shear modulus and material damping.	The neoprene sample bearings are tested for change in shear modulus properties, however material damping has not been part of the testing programme	Material Damping shall be added to the next ISI testing interval.

5.4 Generic Attributes of Effective Ageing Management Programme

The following comment is made on the 9 5.4 Generic Attributes of Effective Ageing Management Programme:

Table 2: Generic AMP Attributes and KNPS Comparison

Generic Attribute	Comment
1. Scope of the civil ageing management programme based on understanding ageing	The ageing of neoprene and the consequence of the ageing is well understood. Reference [11] summarizes the ageing mechanisms of aseismic bearings and considers each mechanism duly.
2. Preventive actions to minimise and control ageing effects	The preventative actions to minimise and control ageing effects were well considered during the design phase. The AMP is therefore a “condition-monitoring programme”.

3. Detection of ageing effects	The AMP is a condition-monitoring programme which will detect ageing effects (increase in hardness and physical deterioration).
4. Monitoring and trending of ageing effects	The monitoring and trending of ageing effects are considered in accordance with Reference [3].
5. Mitigating ageing effects	The mitigation of ageing effects were well considered during the design phase with sufficient conservatism as illustrated through the sensitivity study presented in Reference [11].
6. Acceptance criteria	The acceptance criteria for the testing is documented in the Koeberg SAR.
7. Corrective actions	Corrective actions are considered, and if required, implemented in accordance with the applicable Eskom processes.
8. Operating experience feedback and feedback of research and development results	The most applicable operation experience applicable currently available is the results of Cruas' monitoring of the aseismic bearings at the French plant. The operational experience has differed from the KNPS results. Eskom has therefore set out to determine the difference in the operational experience.
9. Quality management	All the testing procedures are duly performed in accordance with the required quality management requirements.

6. Ageing Management of the Aseismic Bearings

The AMP of the aseismic bearings was originally developed in 1989 and updated in 1995. The *Technical Manual for the Monitoring of the Aseismic Bearings* [13] describes the Monitoring Programme of the Aseismic bearings as well as steps considered as part of the design and construction of KNPS.

The current AMP of the aseismic bearings is illustrated in Figure 2 in accordance with the framework provided in SSG-48 [17].

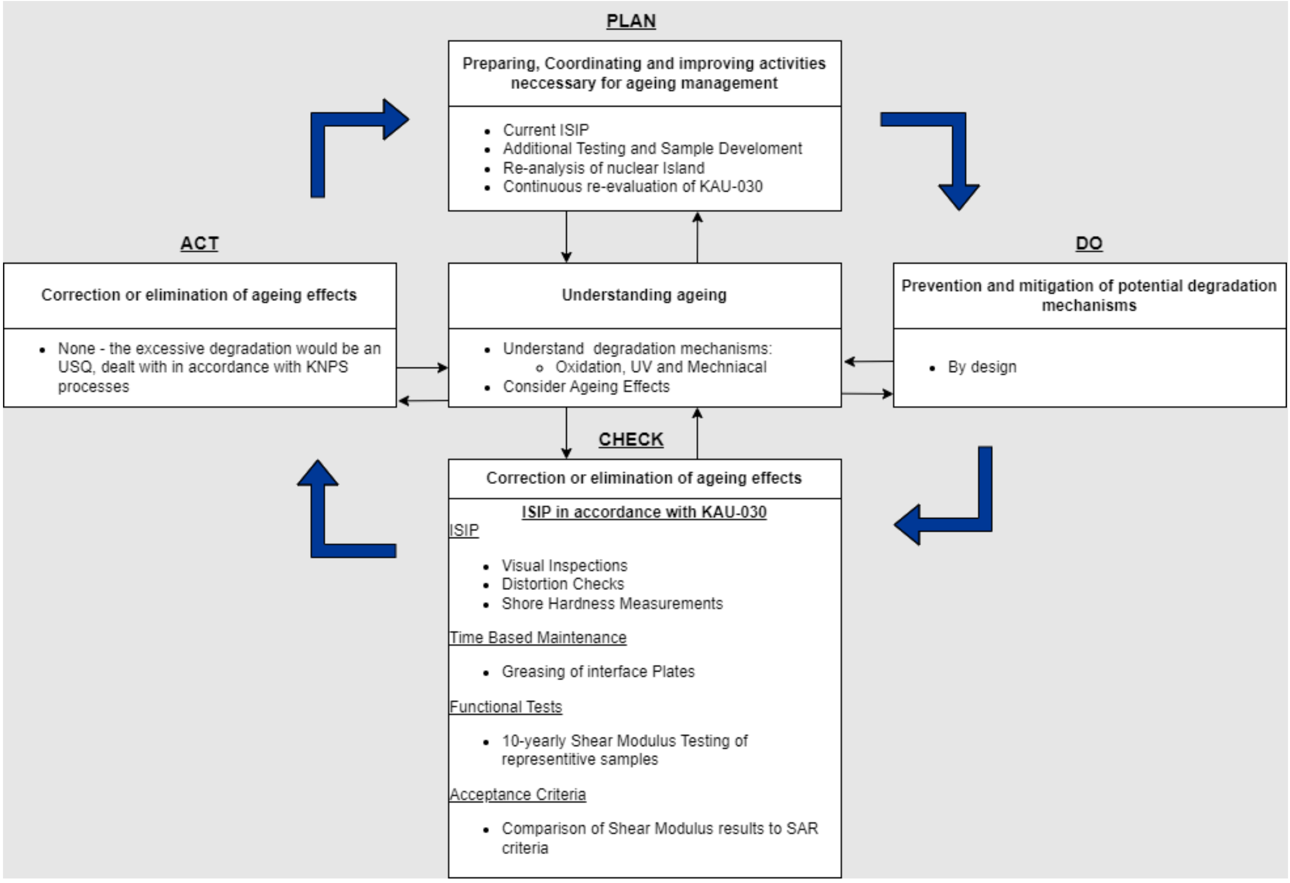

Figure 2: Systematic approach to ageing management of the aseismic bearings

It is noted that it is a closed loop which indicates the continuation and improvement of ageing management on the basis of feedback on relevant operating experience.

6.1 Tests Planned on Remaining Samples

6.1.1 Neoprene Samples

As part of the KNPS AMP for the aseismic bearings and the NNR approved KAU-030, the next interval of Shear Modulus testing is planned for Q3/2024 and the next round of visual inspections are planned for Q4/2024.

The shear modulus testing will be performed on 50% of samples which has been tested in the past, and 50% of samples that have not yet been tested, as accepted by the NNR. This will mean that the last of the 'untested' samples will be expended by Q3/2024 (covering the test interval 2024 to 2034), in accordance with the current approved plan.

It is noted that as part of the previous testing interval, performed in 2014, 50% of the samples tested were previously tested samples, and therefore by the end of the 2024 test interval, KNPS will have 40 neoprene samples which have been tested at least once, and 20 neoprene samples which have been tested at least twice (See Table 3).

Furthermore, it is noted that samples which are subjected to a second round of tests are tested at 90° of the previous tests.

The re-testing of some samples proved to be practical and feasible, and the results obtained by the re-tested samples were in-line with the samples tested for the first time (see § 5.5.5 of Reference [11]).

Therefore, the re-testing of samples during LTO is recommended.

6.1.2 Friction Samples

KNPS has a set of 70 friction samples which were also manufactured as part of the initial manufacturing of the aseismic bearings. These samples were initially earmarked for the continuous testing of the friction coefficient at the friction couple.

The tests were however discontinued as part of the removal of the friction couple from the design basis.

Eskom is however currently planning on performing tests on the Friction Samples to investigate the use of these samples for Shear Modulus Testing, in lieu of Friction coefficient tests:

Table 3: Available Samples

Samples	Number off. (Current)	Number off. (During LTO)
Neoprene Samples (Tested Once)	**40**	**40**
Neoprene Samples (Tested Twice)	**10**	**20**
Neoprene Samples (Untested)	**10**	**-**
Friction Samples (Untested)	**70**	**65***
Friction Samples (Tested Once)	**-**	**5***

6.2 Comparison between in-situ and sample bearing

As part of the original monitoring programme, the Friction and Neoprene Sample Bearings were manufactured to be representative of the in-situ bearings. The difference are summarized in Table 4.

* These values might change, pending on the testing being planned as part of current investigations

Table 4: Summary of Different Bearings [11]

Parameter	Neoprene Samples	Friction Couple Samples	In-Situ Bearings	Corrosion Couple Samples
No. Off	60	70	1829	40
Overall Dimensions [w × b × h (mm)]	150 × 200 × 52.5	300 × 300 × 115	700 × 700 × 155	325 × 325 × 175
Neoprene Layers [No., Thickness (mm)]	1, 10 1, 20	3, 15	2, 10 3, 20	2, 10 4, 20
Reinforcement Plates [No., Thickness (mm)]	1, 5	2, 5	4, 5	4, 5 1, 10
Base Plate (mm)	2.5	20	15	20
Bearium (mm)	15	15	15	12
Stress (MPa)	1.67	0.56	1.84 - 8.16	0.47
Shape Factor	2.14	5.00	8.75	4.06
Stainless-steel Plate	No	Yes, 25 mm	Yes, 25 mm	Yes, 26mm

6.3 Further testing

While shear modulus testing for the LTO period can be achieved with the existing neoprene samples as proposed in 4.2 and 6.1, Investigations into obtaining additional sample aseismic bearings to augment the testing programme, include:

6.3.1 Testing of the friction sample bearings

Testing of some of the remainder of sample bearings stored in the aseismic vault, i.e., the friction sample bearings are planned. Testing will be done as additional tests outside of the AMP to determine if the samples can be used as additional shear samples for the 2034 to 2044 test interval.

6.3.2 Continuous re-testing of neoprene samples

The tests of the friction samples can be supported by the re-testing of the neoprene samples, specifically the samples which were only tested once for the 2034 to 2044 test interval.

During the 2014 testing, the re-tested samples conservatively envelope the degradation of the samples that have only been tested once. It may therefore be practical to continue re-testing used samples once all the samples have been utilized at least once.

6.3.3 Development of new samples

KNPS is planning on developing new samples, by compounding new neoprene and artificially aging the samples, to determine if these samples can be used in lieu of the expended neoprene samples for the 2034 to 2044 test interval.

6.3.4 Development of an analytical model

A 2D analytical FEM model is planned for the evaluation of the nuclear island if the results of the Q3/2024 test regime is out of the acceptance criteria of KNPS.

7. Conclusion

The AMP and the ISIP of the KNPS aseismic bearings follow international best practice, specifically compared to the IAEA and NUREG guidance documents. Partial gaps exist, and recommendations are made, specifically:

1. Consider the practicality and feasibility of performing both static and dynamic tests during the next ISI interval tests, planned for 2024Q3, and
2. Material Damping shall be added to the next ISI testing interval.

Further improvements may be required as determined by the Responsible Engineer.

It is noted that the aseismic bearings of KNPS currently comply with the ISIP as approved by the NNR and the results of the previous shear modulus test results fall within the SAR acceptance criteria.

It remains uncertain why the KNPS and Cruas do not follow the similar trend, although testing is planned to further investigate the difference in OE.

8. Actions Raised

Action	Reference Number
Consider the practicality and feasibility of performing both static and dynamic tests during the next ISI interval tests of the aseismic bearings' neoprene samples.	GA 43118
Add Material Damping to the next ISI testing interval for the aseismic bearings neoprene samples.	GA 43119
Perform a topographic survey on at least 30 bearing pedestals to confirm their current positions. These positions shall be used as their 'original positions' if post-seismic event inspections are required per KBA09A2D53783, chapter V.	GA 43120
Investigate the practicality and feasibility to determine the shear modulus of the in-situ aseismic bearings with non-destructive methods.	GA 43121

9. Acceptance

This document has been seen and accepted by:

Name	**Designation**
Mr. A Kotze	Chief Engineer
Mr. A Nambiar	Chief Engineer
Mr. B Oaker	Engineering Consultant

10. Revisions

Date	**Rev.**	**Compiler**	**Remarks**
June 2023	1	SJ Venter	First Compilation

11. Development Team

N/A

12. Acknowledgements

N/A