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1. Introduction

Effective ageing management during the service life of structures, systems, and components (SSCs) requires the use of a systematic approach that provides a framework for coordinating programmes and activities. These relate to the understanding, prevention, detection, monitoring and mitigation of ageing effects on the plant SSCs, and include maintenance, in-service inspection, testing and surveillance, as well as operations, technical support programmes (including analysis of any ageing effects and degradation mechanisms) and external programmes such as research and development (R&D). It is for these reasons that Koeberg Operating Unit (KOU), Nuclear Engineering (NE) has embarked on an initiative to ensure that an effective cable ageing management programme (CAMP) is implemented to ensure that required safety functions of SSCs are fulfilled over the assumed original operating time, including the long term operation (LTO) of the power plant.

The CAMP provides the means to identify adverse localised environments, adverse service conditions, and the management of significant ageing effects to preclude early and in-service cable failure. The electrical (power, control, instrumentation and measurement) cables, connectors, earthing circuits, and associated terminations may deteriorate to the extent that they may not meet their functional requirements under the conditions produced in the adverse localised environments and by adverse service conditions. The adverse localised environments and adverse service conditions include, but are not limited to the following:

- Previously unidentified damaged cables (mechanically damaged cables can introduce a delayed failure mechanism).
- Exposure to harmful chemicals.
- Exposure to sunlight (open cable trenches, on the side of or between buildings).
- Localised elevated temperature and/or high nuclear radiation environments under normal operating conditions.
- High conductor temperature from ohmic heating.
- High manipulation frequency (disconnecting and connecting more often or frequently).
- High resistance connections at terminations.
- Long-term exposure to moisture ingress.
- Long-term wet environment (partial, permanently, or submerged).
- Normal usage and Design Basis Accidents (DBA).

Koeberg Operating Unit (KOU) shall implement the established CAMP to manage the ageing of the cable systems, i.e., electrical cables, connectors, and associated terminations as defined in the following paragraphs.

2. Supporting Clauses

2.1 Scope

The scope of this document covers the high level CAMP requirements for Medium Voltage (MV), Low Voltage (LV), Fibre Optic, Instrumentation & Control (I&C), Measurement cables and cable systems that are important to safety at Koeberg Nuclear Power Station (KNPS).

The CAMP scope includes cables supplying Systems and Components (SCs) classified in accordance with 240-89294359, “Nuclear Safety, Seismic, Environmental, Quality, Importance and Management System Level Classification Standard”, as follows:

- Class 1E.
- Non Safety Function (NSF).

2.1.1 Purpose

The purpose of this standard is to document the requirements for the standard approach to the establishment, development, implementation, and review of an effective cable ageing management and condition monitoring programme for safety related and availability related electrical (power, control, instrumentation and measurement) cables and cable systems.

2.1.2 Applicability

This document shall apply to the Koeberg Operating Unit.

2.1.3 Effective date

This document is affective from the authorisation date.

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] 238-6: KOU Documentation and Records Management Standard.
[2] 240-98789629: Cable Ageing Management Manual for Instrumentation, Control and Measurement Cables and Cable Systems.
[3] 240-98789276: Cable Ageing Management Manual for Low Voltage Electrical Cables and Cable Systems.
[4] 240-89294359: Nuclear Safety, Seismic, Environmental, Quality, Importance and Management System Level Classification Standard.

[5] 331-3: Nuclear Engineering Documentation and Records Management Work Instruction.
[6] 331-311: Cable Ageing Management Manual for Medium Voltage Cables and Cable Systems.
[7] 331-148: Programme Engineer's Guide.
[8] 331-289: Ageing of Electrical Cables.

2.2.2 **Informative**

[9] 10 CFR 50.65: Requirements for Monitoring the Effectiveness of Maintenance at Nuclear Power Plants.
[10] Ageing Management for Nuclear Power Plants: International Generic Ageing Lessons Learned (IGALL) by International Atomic Energy Agency (IAEA), Safety Reports Series (SRS) No.82.
[11] 331-86: Design Changes to Plant, Plant Structures or Operating Parameters.
[12] 331-93: Guide for classification of plant components, structures and parts.
[13] 331-94: Importance Category Classification Listing.
[14] 331-143: The Equivalency Process to Change Plant.
[15] D4550.32 13/0644: EDF Maintenance Doctrine. Monitoring of Electric Cable Ageing.
[16] GGR 0992: Plant Safety Regulations.
[17] IAEA Safety Reports Series No.82; Ageing Management for Nuclear Power Plants: International Generic Ageing Lessons Learned (IGALL).
[18] IEEE 383: Standard for Qualifying Class 1E Electric Cables and Field Splices for Nuclear Power Generating Stations.
[19] IEEE 400.2: IEEE Guide for Field Testing of Shielded Power Cable Systems Using Very Low Frequency (VLF).
[20] INPO EPG 16: Engineering Programme Guide, Electrical Cable Reliability.
[21] INPO 15-003: Conduct of Engineering Programs at Nuclear Power Stations.
[22] INPO SEN 272: Underground Cable Ground Fault Causes Forced Shutdown.
[23] ISO 9001:2008 Quality Management Systems - Requirements.
[24] KAA-688: The Corrective Action Process.
[25] KBA 0915 K09 016: Power Control, Measurement cables for DBA conditions.
[26] KBA 0915 K09 001: Power Cables of 6.6 kV Rated Voltage, Technical Specifications.
[27] KBA 12 16 J10 256: General Electric Installation – Scope and Supply.
[28] KSA-012: The Storage and Preservation of Spare Parts at Koeberg Nuclear Power Station.
[29] KSA-038: Requirements for Quality Records.
[30] Medium Voltage Cable Ageing Management Guide: EPRI, Palo Alto, CA: 2008. 1016689.

[31] Methodology and Installation of Radiation and Temperature Monitors: Research for Installed Cables at U.S. Nuclear Power Plants in Support of Long-Term Operations. EPRI, Palo Alto, CA: 2015. 3002005517.
[32] NEI 06-05: Medium Voltage Underground Cable White Paper.
[33] NUREG/CR-7000: Essential Elements of an Electric Cable Condition Monitoring Program.
[34] NUREG/CR 7153: Expanded Materials Degradation Assessment (EMDA). Volume 5: Ageing of Cables and Cable Systems.
[35] Low Voltage and Instrumentation and Control Cable Ageing Management Guide, Revision 1. EPRI, Palo Alto, CA: 2017. 3002010641.
[36] Plant Engineering: Aging Management Program Guidance for Medium-Voltage Cable Systems for Nuclear Power Plants, Revision 1. EPRI, Palo Alto, CA: 2013. 3002000557.
[37] Regulatory Guide 1.218: Condition Monitoring Program for Electric Cables Used in Nuclear Power Plants.
[38] SANS 10142-1: Part 1: Low voltage installations.
[39] SANS 10142-2: Part 2: Medium-voltage installations above 1 kV a.c. not exceeding 22 kV a.c. and up to and including 3 000 kW installed capacity.
[40] SAR: Safety Analysis Report: SAR III-4.3.2, SAR III-4.3.3, and SAR III-4.3.4, SAR II-11.3.1, SAR II-11.3.2, SAR II-11.3.4, SAR II-11.3.5.
[41] SPT- 6325/09: Impact of Water Ingress on Power Cables Susceptible to Moisture.
[42] SSG-48: Ageing Management and Development of a Programme for Long Term Operation of Nuclear Power Plants.
[43] TR -10-69: INPO Topical Report, Cable Ageing and Monitoring.
[44] US NRC Generic Letter (GL) 2007-01: Inaccessible or Underground Power Cable Failures that Disable Accident Mitigation Systems or Cause Plant Transients.
[45] US NRC Regulatory Guide 1.211: Qualification of Safety-Related Cables and Field Splices for Nuclear Power Plants.

2.3 Definitions

2.3.1 **Accessible:** When cables and connections can be approached and viewed easily without the opening of junction boxes or control panels.

2.3.2 **Adverse Localised Conditions**: A condition in a limited plant area that is significantly more severe than other areas in the rest of the plant. This condition would tend to increase the rate of ageing of a component or have an adverse effect on its intended function.

2.3.3 **Ageing Effect:** An ageing effect is a net change in a component's characteristics (due to specific processes that gradually change the characteristics of a component with time or use) that could cause the component to lose its intended function prior to the end of its operating life.

2.3.4 **Ageing Management:** Engineering, Operations, and Maintenance actions that control ageing degradation of SSC's to within acceptable limits.

2.3.5 **Ageing Mechanism:** The ageing mechanism is a specific process that gradually changes the characteristics of a system, structure, or component with time or use. For example: thermal degradation of an organic insulation material is a chemical process that adversely affects the insulation resistance properties of a cable due to a reduction in its dielectric strength.

2.3.6 **Cable Ageing:** Cable ageing is a process that is induced by adverse localised environments and adverse service conditions, introducing ageing mechanisms that result in the ageing effects and cause a cable to age.

2.3.7 **Cable Systems:** Cable systems include terminations, connectors, terminal boxes, ladders and supports, protection systems such as tie-downs, trays, conduits, and ducts. Each of these affects the operability of the cable systems under normal and accident conditions and must be considered when addressing cable ageing.

2.3.8 **Chemical Agents**: Chemical agents can be in the form of temperature, oxygen, and radiation that as a result of chemical reaction, long polymer chains breakdown in a process called depolymerisation. There can also be new cross-linking bridges formed that make insulation more brittle.

2.3.9 **Design Basis Accidents:** Design basis accidents are a range of conditions or events taken explicitly into account in the design of a facility according to established criteria such that the facility can withstand them without exceeding authorised limits by the planned operation of safety systems. These events are referenced in the Koeberg SAR III-4.3.2, SAR III-4.3.3, and SAR III-4.3.4.

2.3.10 **Earthing Circuits:** The earthing circuits are installed to obtain better protection against perturbation currents conveyed by the metallic masses, these circuits consist of: General earthing network, electronic earthing network, telephone earthing network, electrical system neutral earthing.

2.3.11 **Electrical Trees:** Tree-like growths, consisting of non-solid or carbonised micro channels, that can occur at stress enhancements such as protrusions, contaminants, voids, or water trees subjected to electrical stress for extended time periods. At the site of an electrical tree, the insulation is damaged irreversibly, partial discharge may be present, and complete insulation breakdown may be only a question of time.

2.3.12 **Harsh Environment**: Harsh environments are the result of a Loss of Coolant Accident (LOCA) or High Energy Line Break (HELB) including Steam Line Break (SLB) inside containment and post-LOCA or HELB outside containment. They also include areas of high humidity, excessive steam, elevated temperatures, accumulated dust, chemical spills, high radiation and long-term wetting.

2.3.13 **Hot spot:** A type of adverse localised environment characterised as a localised heat source. In the cable applications, heat is comprised of both an external component in the form of ambient temperature and an internal component in the form of ohmic heating. Ohmic heating is usually associated with power cable applications. Instrumentation circuits characteristically operate at such low currents that no appreciable ohmic heating occurs.

2.3.14 **Low Voltage:** Means a voltage not exceeding 1000 volts, ac, or dc.

2.3.15 **Medium Voltage (MV):** MV is a voltage where line-to-ground potential exceeds 1 kV (1000 V) up to 22 kV (22000 V).

2.3.16 **Service Conditions**: Service conditions are the normal physical influences that can affect a component over its service life. For the purposes of this procedure these service conditions include the environmental stressors of heat, radiation, vibration and moisture.

2.3.17 **Surface Contamination:** Surface contamination is the presence of a foreign substance such as oil, caustic chemical, corrosion, etc. that could adversely affect the insulation resistance properties of a cable.

2.3.18 **Water Treeing:** In the presence of moisture, water treeing is a tree-like structure of electro-oxidation that can occur at stress enhancements such as protrusions, contaminants, or voids in polymeric materials subjected to electrical stress and moisture. At the site of a water tree, the insulation is degraded, partial discharge is not present at this stage, and complete insulation breakdown may subsequently occur when the water tree induces an electrical tree.

2.3.19 **Wet Environment:** An environment where cables are subjected to the presence of water either through a direct buried application or an application in an underground conduit/duct bank which may have standing water.

2.4 Abbreviations

Abbreviation	Explanation
AMP	Ageing Management Programme
CAMP	Cable Ageing Management Programme
DBA	Design Basis Accident
EPRI	Electric Power Research Institute
HELB	High Energy Line Break
IAEA	International Atomic Energy Agency
IGALL	International Generic Ageing Lessons Learned
I&C	Instrumentation & Control
INPO	Institute of Nuclear Power Operators
KNPS	Koeberg Nuclear Power Station
KOU	Koeberg Operating Unit
LOCA	Loss of Coolant Accident
LTO	Long Term Operating
LV	Low Voltage
MV	Medium Voltage
OE	Operating Experience
SAR	Safety Analysis Report

2.5 Roles and Responsibilities

The CAMP roles and responsibilities are documented in 331-198, “Process for Cable Ageing Management Programme at Koeberg Operating Unit”.

2.6 Process for Monitoring

The CAMP Programme Engineer has a primary responsibility of developing the programme requirements and provides programme oversight to the implementation of the programme in accordance with the guide 331-148, “Programme Engineers Guide”.

2.7 Related/Supporting Documents

Not Applicable.

3. Cable Ageing Management Programme Requirements

The cable ageing management programme (CAMP) shall be developed, established, implemented, and reviewed for effectiveness in accordance with the industry best practices, approved engineering guides, operating experience, and Koeberg Nuclear Power Plant specifics.

3.1 Programme Structure and Implementation

The CAMP shall be structured in accordance with the nine generic attributes of an effective ageing management programme which are defined in the guide 331-148, “Programme Engineers Guide”. These attributes are in line with the IAEA Specific Safety Guide SSG-48, “Ageing Management and Development of a Programme for Long Term Operation of Nuclear Power Plants”. The nine generic attributes include:

1. *Scope of the AMP based on understanding ageing.*
2. *Preventive actions to minimize and control ageing degradation.*
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.*
9. *Quality management.*

The Ageing Management for Nuclear Power Plants: International Generic Ageing Lessons Learned (IGALL) by International Atomic Energy Agency (IAEA), Safety Reports Series (SRS) No.82, informs that the approach used to establish ageing management priorities, specifically the balancing and integration of ageing management programmes (AMPs) and maintenance, in-service inspection, testing and surveillance activities, depends on the regulatory requirements in each Member State.

3.2 Electrical Cables Specifications

The electrical cables and cable systems at Koeberg shall meet the specifications of KBA 0915 K09 016, "*Power, Control, Measurement Cables for DBA conditions*", and KBA 0915 K09 001, *"Power Cables of 6.6 kV Rated Voltage, Technical Specification*". If specified otherwise, the equivalency process 331-143, *"The Equivalency Process to Change Plant",* and the design change process 331-86, "*Design Changes to Plant, Plant Structures or Operating Parameters*" shall be followed.

3.3 Classification of Electrical Cables

As a general rule and industry practise, cables are classified according to the classification of the supplied or controlled system or component.

The classification standard 240-89294359 (KSA-010), *"Nuclear, Seismic, Environmental and Importance classification standard",* in conjunction with the classification guide 331-93 (KGA-003), *"Guide for Classification of Plant Components, Structures and Parts",* shall be used for classification of Systems, Structures and Components (SSCs) which are supplied by the cables within the scope of CAMP.

3.4 Condition Monitoring of Electrical Cables

Condition monitoring of electrical cables shall be implemented in line with NUREG/CR-7000, NUREG/CR-7153, EPRI guidance, and industry best practices. Condition monitoring refers to activities performed to assess the functional capability/operational readiness of equipment. It provides information on the status of the cable which is representative of the degree of degradation of the cable materials.

The condition monitoring of electrical cables include periodic cable condition monitoring, inspections and tests, in-service testing, cable operating environment monitoring, and cable-related operating experience.

The condition monitoring requirements of electrical cables shall be incorporated in the following cable ageing management manuals:

- 331-311, *"Cable Ageing Management Manual for Medium Voltage Cables and Cable Systems".*

- 240-98789629, *"Cable Ageing Management Manual for Instrumentation, Control and Measurement Cables and Cable Systems".*
- 240-98789276, *"Cable Ageing Management Manual for Low Voltage Electrical Cables and Cable Systems".*

3.5 Monitoring of Environmental Conditions

An environmental conditions monitoring programme shall be initiated in line with IAEA-TECDOC-1188, IAEA NP-T-3.6 and additional guidance from EPRI report 3002005517. The environmental condition programme shall include activities that need to be carried out to identify the environmental and service conditions for electrical cables. The aim is to identify the actual conditions to which these cables are subjected during operation, particularly those that may be less conservative than considered in the original design of the plant. This would include localized areas (hot spots) that could result in significant cable degradation.

3.6 Use of Operating Experience

Continuous review of internal and industry operating experience (OE), including research and development results is required in order to evaluate the impact on the programme and improve. As the results, the necessary actions and modifications to the programme shall be performed. An applicable OE shall be reviewed and lessons learned be incorporated in accordance with the corrective action process KAA-688, "*The Corrective Action Process"* and other existing KOU processes.

3.7 Training Requirements

Personnel that support the cable ageing management shall be trained in accordance with the existing Koeberg processes. The external OE guide shall be used where applicable to enhance the personnel awareness.

3.8 Qualification of Electrical Cables for harsh environment

Environmentally qualified cables shall have a qualified life established based on all applicable ageing mechanisms through the qualification tests. The document 331-219, *"Environmental Qualification Maintenance Manual",* prescribes the qualified life of the safety related electrical and I&C cables located in harsh environment, and minimum requirements for maintaining the qualification.

3.9 Electrical Cable Systems Testing

The electrical cables shall be tested in order to detect any degradation that may be caused by ageing mechanisms. Approved maintenance testing procedures that details the test methods and

testing techniques for all voltage levels, cable types and terminations shall be used. The following standards and guides shall be used to determine the condition of the cable insulation:

- IEEE 400.2, *"IEEE Guide for Field Testing of Shielded Power Cable Systems Using Very Low Frequency (VLF)",* shall be applied where considered appropriate.
- Relevant *IEC/IEEE, SANS* and other applicable standards can be used.
- EPRI report 3002000557,"*Ageing Management Program Guidance for Medium-Voltage Cable Systems for Nuclear Power Plants".*
- EDF Maintenance Doctrine, D4550.32 13/0644, "*Monitoring of Electric Cable ageing*" was issued under the formal information sharing between EDF and KOU. This document shall be used to benchmark and conduct electrical tests defined.

The Tan Delta (TD) test technique is recommended for water trees detection and the Partial Discharge (PD) for discharges when water trees have converted to electrical trees. Line resonance analysis (LIRA) can be used on shielded and non-shielded triplexed cable (a cable composed of three individually insulated electric conductors, twisted together and having a common outer protective covering), to detect the effects of localised thermal damage.

3.10 Installation and Maintenance Control

SANS 10142-1, "*Part 1: Low voltage installations"* is concerned with ensuring the basic safety of electrical installations. It requires that the designer of an electrical installation be aware of the operating environment of each part of the installation and the characteristics of the power supply.

In particular, the standard describes the environmental conditions, installation requirements (methods of cable installation, correction factors for direct solar radiation) and installation of conductors. SANS 10142-2, *"Part 2: Medium-voltage installations above 1 kV a.c. not exceeding 22 kV a.c. and up to and including 3 000 kW installed capacity*", contains minimum requirements and additional information with regard to the safe operation, and to ensure acceptable reliability of the medium voltage part of an electrical installation. The standard covers the system engineering and erection, particularly concerning the safety aspects, of the said electrical power installations.

The requirements for the storage and preservation of spares are documented in KSA-012, *"The Storage and Preservation of Spare Parts at Koeberg Nuclear Power Station."*

KBA 1216 J10 256, "General Electric Installation – Scope and Supply" is one of the original commissioning documents, an informative reference that shall be used in conjunction with the SANS mentioned above and other relevant documents.

For MV and LV cable junctions KBA 0015 K06 001, "MV–LV Cables Junctions Typical Principle Drawing" shall be used, unless specified otherwise and the equivalency process is followed.

Safety Analysis Report (SAR) relevant sections as listed in the references shall be consulted.

3.11 Ageing Management Matrix

An interface shall be established between the Cable Ageing Management Programme and the programmes matrix, 240-101650256, *"Ageing Management Matrix".* The Ageing Management Matrix (AMM) is used to identify the ageing mechanisms and the SSCs that are affected by ageing mechanisms or degradations that can impact equipment life or capability.

3.12 General Requirements

In addition to the nine generic attributes defined in the 331-148, it is crucial for the KNPS to take the following general requirements into consideration:

- Defining the potential adverse environments for MV, LV, and I&C electrical cables, which include elevated temperatures, radiant energy conditions (for example, routings close to high-energy lines without sufficient thermal insulation on adjacent pipes), high nuclear radiation, the presence of chemical agents, the continuous submergence of medium-voltage cable, and the potential for physical damage.
- Identifying electrical cables installed in adverse environments and in underground and inaccessible locations.
- Analysing the effects of these environments on the equipment concerned.
- Continuous programme improvement.
- Prioritising and scheduling the list of interventions (including regular and once off testing) based on analysis, historical data, cable significance, and installed conditions.
- Monitoring the performance and condition of cable systems against KOU requirements, in a manner sufficient to provide reasonable assurance that they are capable of fulfilling their intended functions.
- Establishing the testing methodologies, procedures, assessment criteria along with possible corrective actions that could be implemented.

3.13 Records

The Cable Ageing Management Programme records, documentation, charts, photographs, and testing history shall be generated and maintained in accordance with the requirements of 331-3, *"Nuclear Engineering Documentation and Records Management Work Instruction.* The maintenance records shall be stored in accordance with KSA-038,*" Requirements for quality records".*

The data collection and record keeping system should be established in the early stages of the lifetime of the plant (ideally, data should be collected from the construction stage onwards) in order to provide information for the following accomplishments:

- Identification of fabrication, construction and environmental conditions that could adversely affect the ageing of SSCs, including any periods of delayed construction or suspended operation;
- Identification of relevant fabrication records, such as heat treatment history and certified reports on material tests;
- Identification and evaluation of degradation, failures and malfunctions of components caused by ageing effects;
- Decisions on the type and timing of maintenance actions, including calibration, repair, refurbishment and replacement;
- Optimization of operating conditions and practices that prevent or minimize ageing effects;
- Identification of all ageing effects before they jeopardize plant safety or reduce the service life of SSCs;
- Records of configuration and modification management, maintenance, surveillance and in-service inspection results.

To facilitate obtaining the necessary quality and quantity of ageing related data from plant operation, maintenance and engineering, representatives of the operations; maintenance and engineering divisions should be involved in the development and maintenance of data collection and record keeping system.

4. Acceptance

This document has been seen and accepted by:

Name	Designation
N Ryland	Materials Reliability Manager
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5. Revisions

Date	Revision	Compiler	Remarks
April 2019	2	N Bongelo	The Standard is revised to comply with the nine generic attributes of an effective ageing management programme defined in the International Atomic Energy Agency (IAEA) references. The standard is also due for revision.
December 2015	1	N Bongelo	This document was updated to align with Eskom Documentation System Requirements.
March 2013	0	N Bongelo	New standard written to facilitate the development of the Cable Ageing Management Programme.

6. Development Team

Not Applicable

7. Acknowledgements

Not Applicable