**AMP 225 CONDITION MONITORING OF ENVIRONMENTALLY QUALIFIED ELECTRICAL PENETRATION ASSEMBLIES (Version 2021)**

**Programme Description**

This AMP provides guidance for the condition monitoring of environmentally qualified Electrical Penetration Assemblies (EPAs) that are provided with leakage monitoring system used in nuclear power plants, to provide assurance that the intended functions, i.e. electrical continuity and pressure boundary are maintained despite the effects of in-service ageing throughout the lifetime of the plant. EPAs are environmentally qualified because they are part of containment barrier against the release of radioactivity during design basis accidents or design extension conditions.

EPAs provide passage of electric conductors through a single aperture in the nuclear containment structure, while providing a pressure boundary between inside and outside of the containment structure.

In general, EPAs consist of insulated electric conductors, associated seals, terminal (junction) boxes, terminal blocks, connectors and cable supports, and splices which are designed and furnished as an integral part of the assembly. The assembly may also include optical fibers and fiber seals [1]. However, not all the aforementioned components are necessarily present in each EPA. At the time this AMP was being written, no ageing experience was available for EPAs employing optical fibers.

EPAs are seated in cylindrical sleeves of carbon steel that extend radially from the containment centre and are attached to the containment steel liner. Based on the design, EPAs can be either welded or bolted to the cylindrical sleeves. The former arrangement provides leak tight seal at the nozzle penetration interface but sacrifices flexibility in maintenance procedures, whereas the latter arrangement provides such flexibility but with the requirement of providing either organic or inorganic O-ring seals at the mating surface for leak tightness.

Several designs of EPAs are employed in the nuclear industry but Modular and Canister type EPAs are the most widely used designs. The modular design comprises of individual feedthrough modules for passage of electrical conductors. The feedthrough modules house and protect the conductors. Each module acts as an individual penetration through the header plate and is sealed to avoid leakage from the containment atmosphere. The canister type EPAs consists of tubular steel canister formed by two end plates of which electrical conductors pass through. The pass through types are often sealed using metallic or ceramic seating for leak tightness but their use hinders the removal of individual conductors after installation.

Most EPAs are provided with a leakage monitoring system to monitor the inert gas atmosphere of these penetrations for leakage. Any variation in gas pressure that is not attributed to ambient temperature changes indicate leakage and a possible breach of containment boundary. The inert gas, apart from monitoring leakage also prevents any moisture within the penetration to avoid any deleterious effects like oxidation, leading to corrosion and degradation of insulation.

EPAs mostly fail due to mechanical damage or thermal exposure, while the failure mode is either the leakage of inert gas from penetration module or assembly or the damage of insulation, which often result in shorting or grounding of conductors. However, it is noted that EPAs are very sturdy components with very few incidents of failure throughout the history of nuclear power plants given their population proportion [2].

Stressors that act on EPAs generally include mechanical, chemical, electrochemical, thermal, electrical effects, moisture, and radiations. Oxygen and its allotrope ozone, humidity, dust and other forms of contaminants also act as stressors for EPAs; however, they do not produce any stress directly, but augment the aggravating effects of mechanical, chemical, electrochemical, thermal, and electrical stressors, resulting in accelerated deterioration.

This AMP deals with EPAs provided with leakage monitoring system and includes all components of the penetration, with the exception of terminations (terminal blocks, connectors, splices etc.), terminal (junction) boxes and containment nozzles/ sleeves. The terminations’ insulation are covered separately in AMP201 and terminations’ mechanical connections are covered in AMP206. Whereas, containment nozzles/ sleeves are covered in AMP301.

The table below summarizes significant stressors along with corresponding ageing effects and significant potential failure modes for EPAs.

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| **Component** | **Applicable Stressors** | **Degradation Mechanisms** | **Ageing Effect** | **Potential Failure Modes** |
| Electrical leads (including conductor, insulation, jacketing, shielding and related components) | Heat, oxygen | Thermal/thermo-oxidative degradation of organics | Embrittlement, cracking, melting, change in colour, Reduced Insulation Resistance (IR) or dielectric strength | Loss of electrical function |
| Radiation, oxygen | Radiolysis of organics; radiation induced oxidation | Embrittlement, cracking, change in colour, change in dimension, reduced IR or dielectric strength | Loss of electrical function |
| Electrical transients | Voltage-induced degradation/electrical treeing | Reduced IR or dielectric strength | Loss of electrical function |
| Voltage, moisture, contaminants | Surface tracking | Change in colour, reduced IR or dielectric strength | Loss of electrical function |
| External Mechanical Stresses [4] | Abrasion, cutting or nicking of insulation | Reduced IR or dielectric strength | Loss of electrical function |
| Organic sealing components and compounds | Heat/ radiation, oxygen, compressive stress | Compression set and Volumetric changes | Change in dimension | Loss of sealing function |
| Heat, oxygen | Thermal/thermo-oxidative degradation of organics | Embrittlement, cracking, melting, change in colour | Loss of sealing function |
| Radiation, oxygen | Radiolysis of organics; radiation-induced oxidation | Embrittlement, cracking, change in colour, change in dimension | Loss of sealing function |
| Chemical contaminants | Chemical degradation of physical properties | Change in colour, change in dimension, loss of mechanical properties | Loss of sealing function |
| External Mechanical Stresses | Abrasion, cutting or nicking of sealing components | Damage to sealing components | Loss of sealing function |
| Metallic structural components (header plate, feedthrough module) | Moisture, Oxygen and dissimilar metals | Corrosion | Oxidation, pitting, Loss of material in severe cases | Loss of mechanical properties,  Loss of sealing function (if occurring on sealing surfaces) |

**Evaluation and Technical Basis**

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

This AMP applies to environmentally qualified EPAs that are provided with leakage monitoring system and documents the proven industry practices for condition monitoring of EPAs.

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

This is a condition monitoring programme and no actions are taken as part of this programme to prevent or mitigate ageing degradation. However, periodic actions are taken to prevent EPAs from being exposed to moisture, loss of pressure boundary, thermal degradation from loose connections, etc. EPAs are to be be periodically visually inspected for signs of degradation based on plant specific or industry operating experience, or applicable research.

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

As EPAs serve the purpose of providing electrical interface for the equipment inside containment while maintaining the containment pressure boundary, the condition monitoring activities focusing on these functions may include leak rate testing, monitoring of environmental conditions as required, visual/physical inspection and measurement of electrical properties.

Fundamental priority is given to the leakage monitoring of EPAs and frequency of monitoring/ testing may vary based on the requirements found in design documents or technical specifications of the plant.

Periodic visual/physical inspection is another technique for evaluating EPAs components condition, because the effects of many degradation stressors (including heat, chemicals, radiation, mechanical stress, moisture, and contaminants) are readily detectable in this fashion. Components of EPAs like fasteners, leads and terminations and pressure monitoring equipment may be considered for the visual inspection. For medium voltage EPAs arcing, burning, and change of colour around high power insulators may also be checked which is indicative of electrical tracking, and may result in flashover if not addressed.

Electrical circuit continuity in EPAs exists via conductors that pass through the penetration assembly to terminations on either end. These conductors are similar in both materials and configuration to bulk cable installed throughout the plant. Accordingly, many of the techniques applicable to cable aging management may in some cases be applied to penetration leads (and associated terminations) [2].

Very low frequency tangent delta testing has been effective in detecting thermal degradation of cables, leads, and mechanical bolted connections of medium voltage EPAs.

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

With the ageing of EPAs, the probability of leakage increases. Therefore, trending of measured leakage rate for each EPA is of prime importance. It is important to note that the trend of leakage rate may not follow linear fashion but often exhibit a step change which indicate degradation of the sealing performance [3]. In addition to above, monitoring and trending of environmental conditions i.e. ambient temperature and dose rate during normal operation of the plants may be performed to ensure that EPAs remain within the limits of their qualification basis.

Trending of very low frequency tangent delta tests results can be used to identify degradation of medium voltage insulation of EPAs.

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

This programme is a condition monitoring programme. This programme has no specific operation, maintenance, repair or replacement mitigation aspects.

1. ***Acceptance criteria:***

Any indication or relevant conditions of degradation may be evaluated for acceptance in accordance with the limits specified in technical specifications of the plant or design/ vendor documents. Examination results and flaws that exceed the acceptance criteria in relevant governing requirements may require repair or replacement activities, or further evaluation to demonstrate that the component will continue to perform its intended function through the period of long term operation.

1. ***Corrective actions:***

An engineering evaluation is performed, and corrective actions are taken when unacceptable conditions are found. The evaluation is to consider the age, operating environment of the component and design change if any that resulted in working of EPA beyond its original specification e.g. substitution of an equipment inside containment with a higher power equipment without taking into consideration the current carrying capacity of EPA conductor. Corrective actions may involve removing and replacing the defective parts with new parts of the correct, adequately qualified type.

For the EPAs exceeding the leakage rate limits as defined in the design document or technical specifications of the plant, corrective actions may include repair of the leak, replacement of seals/ O-rings, feedthrough modules or the entire EPA itself.

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.

1. ***Quality management:***

Site quality assurance procedures, review and approval processes, and administrative controls are implemented in accordance with the different national regulatory requirements.

**References**

1. INSTITUTE OF ELECTRICAL AND ELECTRONICS ENGINEERS, IEEE Standard for Electrical Penetration Assemblies in Containment Structures for Nuclear Power Generating Stations, IEEE Std. 317-2013.
2. ELECTRICAL POWER RESEARCH INSTITUTE, Aging Management Guidelines for Commercial Nuclear Power Plants—Electrical and Mechanical Penetrations. EPRI, Palo Alto, CA: 2002. 1003456.
3. ELECTRICAL POWER RESEARCH INSTITUTE, Plant Engineering: Electrical Penetration Assembly Aging Management Guide Update, 2016. 3002007992.
4. ELECTRICAL POWER RESEARCH INSTITUTE, Cable Polymer Material Handbook—Instrument Cable. EPRI, Palo Alto, CA: 2018.3002013173.