### AMP 218 Electronic Equipment NOT SUBJECT TO ENVIRONMENTAL QUALIFICATION REQUIREMENTS (VERSION 2021)

**Programme Description**

The purpose of this AMP is to describe several methods that are used to ensure the maintainability of electronic equipment installed in I&C systems with respect to IEC 62342 [1]. To achieve this objective, the following tasks are performed:

* Mitigation of aggressive environmental and climatic conditions (humidity, temperature, corrosive atmosphere, etc.) and avoid mishandling.
* In-situ detection of generic failure mechanisms.
* End-Of-Life prediction of the most critical components.

In practice, these tasks are associated to at least one (or more) technical solutions applied on one or several electronic components.

Electronic equipment embedded in I&C electronic systems ageing management is required for two main reasons:

1. Ageing means that a failure mechanism has an increasing influence on the failure rate of the systems. This failure mechanism might be possibly generic, i.e., it may affect a certain type of components so that the failure may be repetitive. Such failure mechanisms therefore may induce a loss of safety level when redundancy is not sufficiently used, result in a high loss of availability, or at least cause an increase of the maintenance cost. The measurement of ageing indicators prevents generic ageing phenomena and prevents it from spreading over different types of modules and systems when adequate corrective or preventive actions are engaged.
2. Two main limitation factors impact the life time of I&C systems: obsolescence (of components, modules, skills) and physical ageing (obsolescence is treated in TOP 401). The ageing mechanism may be due to environmental conditions, manipulations, poor quality, inappropriate assembly or one or more at the same time. The general ageing level of an electronic system is considered as being a significant indicator, and the ability to diagnose it is therefore needed to decide and plan any renovation programme.

To collect sufficient indicators, ageing management needs:

1. Tools and guidelines to assess the ageing level of a system. This requires a very good knowledge of the physics of failures due to ageing. It is important to note that the operating conditions of NPP electronic systems are usually not in harsh environments. The ageing mechanisms occur generally on the long term and are activated in low stress conditions. Note that these ageing conditions are usually not studied by scientists and engineers who are mostly interested in ageing in high stress conditions such as for aeronautics, military area, space craft, automobile…,
2. Guidelines to recommend corrective and preventive actions to control the ageing kinetic. The present AMP indicates some generic recommendations aiming at increasing the lifetime of equipment, according to the approach developed in the IAEA TECDOC-1147 [2].

The table below summarizes stressors, degradation mechanisms and ageing effects relevant to electronic equipment:

|  |  |  |
| --- | --- | --- |
| **Stressors** | **Degradation mechanisms** | **Ageing effects** |
| Temperature (T) | Thermal fatigue (board and/or components)  (Board and components age more with rapid temperature variations)  T is an accelerating factor for corrosion  Whiskers | Characteristic change of electrical parameters (gain, leakage current…)  Loss of electrical function  Elastomer degradation |
| Humidity  (RH for relative humidity) | Corrosion of contact surfaces. (this makes soldering process more difficult)  Electrostatic static discharge  Whiskers | Loss of electrical function (such as open circuits, short circuits, bad contact of connectors) |
| Chemical contamination  Fouling | corrosion (this makes soldering process more difficult) | Loss of electrical function (Open circuits, short circuits) |
| Vibrations | Vibrational fatigue | Loss of electrical function (Open circuits, short circuits)  PCB Cracking |
| Overvoltage | Insulation degradation caused by over-voltage events such as e.g. transients, switching or lightning effects | Loss of electrical function (open circuit or Short Circuit), Increased Current to ground |

This AMP does not cover the software of programmed electronic equipment.

**Evaluation and Technical Basis**

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

Only components known to be sensitive to ageing are considered [3]. It is well-known that some electronic component families are more sensitive to ageing than others. This report is considered as a collection of component failures which may be used by maintenance staff for diagnosis or for planning preventive and corrective maintenance programs.

Several actions are achieved to provide information for the establishment of an ageing data base which are described as follows:

* Action #1: identification of critical component references (according to safety class, operating feedback and nature of the component technology).
* Action #2: periodical functional tests.
* Action #3: failure analysis reports to determine the nature of the failure (breakdown or parameter drift) and its impact on the component reference (isolated or generic failure).
* Action #4: residual lifetime evaluation, if required.
* Action #5: environmental monitoring to determine most sensitive components.
* Action #6: periodical visual inspection in order to detect visual ageing signs prior to functional degradation.

In order to serve actions #1, #2 and #4, this AMP addresses especially the following parts of I&C systems which can be considered as the most critical regarding their ageing kinetics, their impact on equipment functionality and their ability to apply ad hoc tests:

* Passive electronic components
  + Capacitors
  + Resistors
  + Coils
  + Transformers
* Active silicon components
  + Integrated circuit
  + Discrete diodes and discrete transistors
  + Operational amplifiers and comparators and voltage regulators
  + Non-Volatile memories
  + Surge protective Device (SPD) [10]
* Printed circuits
  + Edge board connectors
  + On board connectors
* Batteries
* Optoelectronics
  + Optocouplers
  + LED
* Power electronic components
  + Thyristors
  + Diodes
  + Power transistors
* Electrical contact components
  + Electromechanical relays
  + Potentiometers
  + Connectors
  + Push buttons, switches
  + DIP switch
* Quartz cristal

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

In order to minimize the impact of the relevant phenomena described in §1 which may accelerate ageing (action #5 of section 2.1), normal environmental conditions are respected and are recommended in different standards, such as [4-6].

Regular preventive or periodic replacement of electronic components, for example Electrolyte Capacitors, Electronic Boards, SPD.

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

Periodic visual inspections are to be performed at regular intervals, to make an evaluation of the equipment’s appearance. Samples of electronic boards are visually controlled. These visual inspections can highlight several defects such as design defects (unobserved when new; example: defects observed on several specimens throughout the plant, thermal effects due to boards being too close, etc), fabrication defects, mishandling, improper repairs, pollution, wear, detection of improper materials (ex: unprotected metal), effects due to poor environmental conditions, etc.

The tools to perform such inspections include:

* A magnifier with at least a 5 X magnification,
* An antistatic protection (carpet and bracelet),
* Mounting tools (screwdrivers, tweezers…),
* Camera taking pictures of specific defects whose evolution is followed with time.

To complete visual inspections, in-situ electrical and/or thermal tests are also performed in order to detect prior signs of ageing. Basically, other non-intrusive tests are carried out as well (ex: magnetic field measurements, vibrations, temperature, humidity, etc.). Moreover, environmental conditions are measured and tracked during a mid/long-term period in order to know if ageing has accelerated.

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

Actions #2 and #6 which are defined in section 2.1 are used to monitor the potential ageing effects that may occur inside the electronic equipment.

Thus, periodical electric measurements (action #2) and periodical visual inspections (action #6) are performed in order to first determine for which electronic components failures are identified (information is traced in the data base), and secondly to monitor their failure rate over time.

Concerning periodical electric measurements, they are performed by using one of the following methods:

* In-situ test bench dedicated to the considered system,
* Independent mobile test tools like multimeters, analyzers, etc.

Visual inspections are performed as described in section 2.3.

For electronic components listed in section 2.1, visual and electric criteria may be the ones defined below.

| **Components** | **Ageing indicators and criteria** | **Test procedures / notes** |
| --- | --- | --- |
| Capacitors | Capacitance C 🡾[[1]](#footnote-1) (limit = Cx0.8)  ESR[[2]](#footnote-2) 🡽 (limit = ESRx2)  Visible electrolyte flooding | Capacitor impedance measurement as a function of the frequency may be performed without unsoldering the component. Any drift of the impedance is interpreted as an ageing sign. |
| Resistors | Impedance drift or increase 🡽 (electrical resistance value is included in the manufacturer tolerance) | Electrical resistance needs to be measured in DC mode with a 2-wire or a 4-wire method. |
| Silicon based active components | Functional characteristics 🡾  Current consumption 🡽 | System functional characteristics can be checked with the dedicated functional test bench used during periodical measurements. Considering the component, ad-hoc functional checking and current consumption measurement can be performed using a specific tester with the dedicated test algorithm. |
| Non-volatile memory | Loss of memory bits 🡽 | Test is performed by using a non-fixed programmer/reader of non-volatile memory. In this way, only components mounted on a soldering socket (interface between PCB and the memory) can be tested considering that the component needs to be unplugged. |
| Printed Circuit Boards | Visual aspect of the printed circuit board 🡾 | Regular visual inspection of the boards. It is recommended to inspect the boards with a X5 magnifier and to select a representative sample of the boards in operation with a specific focus on the following degradations: corrosion, delaminating, electro-migration, metallic migration. |
| Batteries | Internal resistance 🡽  Self-discharge rate 🡽 | Periodic visual inspection to detect electrolyte leakage and avoid excessive corrosion of circuit boards.  Measurement of the internal resistance using IEC 61951-1. The use of an impedance meter which measures the impedance of the battery as a function of the frequency is also relevant. |
| Optocouplers | CTR[[3]](#footnote-3) 🡾 | Periodic measurements of the CTR drift with the dedicated tool. |
| LED | Visual aspect of the LED 🡾  Brightness, luminosity 🡾 | Regular visual inspection of the LED (observations performed with supplied voltage). |
| Power electronic components | Thermal resistance 🡽  For thyristors, gate current threshold 🡽 | Periodic measurements of the relative increase of the dissipated heat with infra-red cameras.  Measurement of the gate current with a dedicated tool. |
| Electromechanical relays | Insulation resistance 🡾  Bouncing time 🡽  Switching time 🡽  Contact resistance 🡽  Coil resistance 🡾  Thermal resistance 🡽 | Periodic measurements of the relative increase of the dissipated heat with infra-red cameras (without removing the relay of its socket).  Signals visualization using an oscilloscope for time delay measurements (bouncing, switching times).  High voltage generator and ohmmeter for insulation, contact, coil resistances measurements. |
| Connectors | Visual aspect of the connector 🡾 | Regular visual inspection of the connectors (with the board removed). Specific focus on the following degradations: pin damages, overheating marks. |
| Potentiometers | Difficulty to tune 🡽 | Maintenance staff feedback analysis to know if the potentiometers are difficult to tune or not. |
| Surge Protective Devices | Over Voltages🡪Electrical Short Circuit leading to protective actuations: Circuit Breaker trip / Blown Fuse  Environmental Ageing-degradation of insulation or electric insulation connecting to higher leakage to ground, sparks, arcing leads | Increased leakage current to ground  Voltage ramp test <90% >120% of pretest  Resistance Measurements (100Ω at lVdc) |

These actions are performed during NPP shutdowns (or on isolated systems) by specifically trained staff.

NPP defines how and when to select these components which require electric measurements and visual inspections. These need to be accomplished following a specific frequency. This periodicity may be different for each sensing element as it can be modulated according to the ageing trend recorded after a few cycles of monitoring. This can also affect the maintenance programme periodicity.

Collected data are registered in order to monitor the failure rate of each supervised equipment or component.

By defining a dedicated criterion, calculation of the failure rate can be then used to reevaluate the residual lifetime of the equipment/component (action #4 of section 2.1). It is important to note that the environmental conditions (temperature, humidity, etc, ) can be used to reevaluate the residual lifetime (cf., section 2.2). In this way, two identical equipment with the same reference can lead to different lifetimes if environmental conditions in which the equipment is installed are different.

Other monitoring techniques [7-8] can also be used.

1. ***Mitigating ageing effects***

A suggested mitigation action consists, via environmental monitoring of normal environmental conditions, to ensure recommended criteria are respected.

1. ***Acceptance criteria***

As presented in sections 2.3 and 2.4, different criteria are defined for both visual inspections and electrical measurements.

For periodic visual inspections, several categories assigned to the inspected circuit board are determined according to the number and the nature of the observed defects. In this way, four categories are possible: satisfying, medium high, medium low and non-satisfying.

Electrical criteria depend on its nature and functionality. Usually, time delays, voltage drops and current levels are the main followed characteristics but each of them could be associated to a specific criteria depending of the application or on the technology requirements (example: for a given digital circuit, voltage thresholds may be in accordance with TTL requirements).

1. ***Corrective actions***

Considering the different items analyzed during both periodic visual inspections and periodic electrical/functional tests exposed in sections 2.4 and 2.6, results lead to corrective actions depending of the nature and the number of detected defects and in accordance with the station’s corrective maintenance programme.

Concerning the periodic electrical/functional tests, corrective actions are performed as soon as the defect is detected. For instance, the practice consists in replacing such a device, and launching a more thorough work on design issues if several similar devices are concerned.

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.

Industry operating experience is continuously monitored in order to manage research and development studies. Several tools used by maintenance staff have already been designed such as the CTR measurement tool for optocouplers or the gate current measurement tool for thyristors.

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

1. ***Quality management***

Site quality assurance procedures, review and approval processes, and administrative controls are implemented in accordance with the different national regulatory requirements (e.g., 10 CFR 50, Appendix B [9]).

**References**

[1] IEC 62342:2007, Nuclear power plants – Instrumentation and control systems important to safety – Management of ageing.

[2] IAEA-TECDOC-1147, Management of ageing of I&C equipment in nuclear power plants, 2000.

[3] J. Naser, “Guidelines for the Monitoring of Aging of I&C Electronic Components – Final Report”, EPRI Project Report (2004).

[4] IEC 60068-1:2013, Environmental testing – Part 1: General and guidance

[5] JESD625-A, JEDEC STANDARD, Requirements for Handling Electrostatic-Discharge-Sensitive (ESDS) Devices.

[6] JESD201-A, JEDEC STANDARD, Environmental Acceptance Requirements for Tin Whisker Susceptibility of Tin and Tin Alloy Surface Finishes

[7] Hannaman, G. W., & Wilkinson, C. D. (2005). Evaluating the effects of aging on electronic instrument and control circuit boards and components in nuclear power plants (No. EPRI--1011709). Electric Power Research Institute (United States). Funding organisation: USDOE Office of Nuclear Energy

[8] IEEE Std 1205-1993. IEEE Guide for Assessing, Monitoring, and Mitigating Aging. Effects on Class 1E Equipment Used in Nuclear Power Generating Stations

[9] United States Nuclear Regulatory Commission, 10 CFR Part 50, Appendix B, Quality Assurance Criteria for Nuclear Power Plants, Office of the Federal Register, National Archives and Records Administration, USNRC, 2015.

[10] NUREG/CR-6340, BNL-NUREG-52463, Aging Assessment of Surge Protective Devices in Nuclear Power Plants, 1996

1. 🡽 Increase of the value, 🡾 Decrease of the value [↑](#footnote-ref-1)
2. Equivalent Series Resistance [↑](#footnote-ref-2)
3. Current Transfer Ratio [↑](#footnote-ref-3)