**AMP 311 CONTAINMENT MONITORING SYSTEM (VERSION 2018)**

**Programme Description**

IAEA Safety Guide for Ageing Management for Nuclear Power Plants [1] notes that “to maintain plant safety it is very important to detect ageing effects of SSCs, to address associated reductions in safety margins and to take corrective actions before loss of integrity or functional capability occurs”. This text explains also that “Understanding the ageing of a structure” is necessary to properly address the ageing effects.

This ageing management programme provides guidance for in-service inspection of devices which are judged necessary to address ageing effects of the containment structures which are pre-stressed with grouted tendons and which are periodically inspected for integrity following the option “A” philosophy of RG 1.90 [2].

In some Member States, for example France, the actual condition of the concrete containment structures with grouted pre-stress system is being monitored and trended by the use of permanent monitoring systems where the capacity of the monitoring systems themselves are evaluated. The monitoring system can be considered as a “part of the containment structures” for this kind of technical concept. For this last reason, this AMP deals with the monitoring system itself, and not the concrete structure for which the AMP 302 is applicable.

A standard monitoring system may consist of:

* Embedded devices, such as Vibrating Wire Strain Gages or Thermometers (thermocpouples, resistance probes…). These sensors are not accessible during operation;
* Junction boxes, electrical cabinets and transmission cabling;
* Surface sensors such as pendulum or Invar wire extensometers and linear variable differential transformer (LVDT);
* If online monitoring systems are used, a datalogger linked with a database where the readings are stored to be analysed;
* Prestressed tendons sensors, such as load cells or dynamometers.

Each system undergoes different ageing mechanisms, depending on the environmental and operating conditions. If accessible systems can be maintained following standard and quite conventional procedures, there is neither preventive action after construction, nor possible inspection (only corrective actions) for embedded sensors. For these embedded devices, the ageing management approach is based on the follow up of their actual availability, which leads to additional sensors if the minimum quantity [2] is reached. Embedded temperature probe failures can be compensated by the measurement of environment temperature within and outside the building. Embedded extensometers are replaced by surface extensometers, such as LVDT equipped systems presented in [3].

**Evaluation and Technical Basis**

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

This AMP deals with the ageing management of the monitoring system itself, and not the containment structures for which AMP 302 is applicable. This monitoring system is described in [4] or in chapter 8 of [5].

For example, in France, a reduced part of the whole monitoring system (actually a minimum set, also called ‘OSS’ for ‘Optimum Surveillance System’, described in [3, 5]) is considered necessary for the monitoring system to be functional. However, this AMP does not cover only the so called ‘OSS’, but all the elements that are still working to take benefit from a wider source of information. The minimum set is used as a criterion to launch corrective actions.

The scope of this AMP, based on the experience from France, includes the following kinds of monitoring equipment:

* The Vibrating Wires Strain Gauges (VWSG), embedded in the cylindrical wall and dome (to measure concrete strain);
* The thermometers to assess the volumetric strain due to temperature and adjust measurement for long term strain trending;
* The pendulums (or plumb lines) for horiztonal displacement monitoring;
* Linear variable differential transformer (LVDT) to measure the radial and circumferential deformation of equipment hatch and the openings;
* The Invar wires extensometers for containment height variation monitoring;
* Prestressed tendons sensors are mainly used to measure the change in presressing force of unbonded tendons protected with wax.

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

* Preventive actions for Vibrating Wire Strain Gauges (VWSG): There is no preventive action to minimize and control ageing degradation for VWSG during operation. However, during construction, suitable protection can be used in order to protect the gauge and its connection system from reinforcing bar handling and concrete placement;
* Preventive action for electrical systems dedicated to concrete strain and temperature measurement in order to prevent corrosion (these devices are accessible: cable, datalogger, junction boxes) As these devices are subject to corrosion that can affect the electrical signal transmission, anti-corrosion spray is used on plug connections and terminal points (frequency 2 years);
* Preventive actions for pendulums and Invar wire extensometers in order to prevent corrosion (accessible systems: wires, reading tables, anchorages, tank used to damp wire oscillation. For pendulum systems, specific care is taken to avoid corrosion of the tank used for preventing wire oscillation. The damping liquid is cleaned up periodically, for example when the liquid level is checked;
* Preventive actions for frequency measurement devices: the ageing mechanism is oxidation. The storage conditions of frequency measurement devices are checked (dry conditions).

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

Detection of ageing effects of VWSG (frequency specified by national regulation): The ageing effects for the gauges themselves can be caused by demagnetization of the vibrating wire, by a slacking effect on the wire due to out of range strain measurement or by an oxidation of the wire or of the coils. So, global performance tests are performed to test their ability to fulfill their function:

* + Every gauge is tested periodically (frequencies measurement) and the checking of the measurement is based on a dedicated procedure;
  + Two coils gauges can be used to cover the risk of one coil failure;
  + Specific processing can be used to screen the gauge response and retrieve information from noisy signals [6];
  + The detection of ageing effects of gauges (and thermometers sensors) are also based on results analysis. If the results are judged “inconsistent” with comparison of older results, the sensor is official declared “out of service”;
  + At the end of every periodic inspection analysis, every gauge is declared to be “out” or “in” service (both testing and analysis are performed to detect ageing - see attributes 6 and 8 for analysis).

Detection of ageing effects for electrical systems (cables, junctions, boxes, cabinets, dataloggers) dedicated to concrete strain and temperature measurement (frequency specified by national regulation):

* + Monitoring system component(s) installed in concrete can fail due to polymer degradation, loss of electrical isolation, contact oxidation or mobile part wearing. So, performance tests are performed to test their ability to fulfill their function;
  + The frequency measurement device is validated using a comparison point (metrological method). Calibration is done if metrological criteria are not met (electrical components test).

Detection of ageing effects for pendulums and Invar wires (frequency specified by national regulation):

The ageing mechanism is oxidation;

* The functioning of pendulums and Invar wires is checked after the measurement system is cleaned (see attribute 2 above). The wire is considered not be restrained by any material;
* Inspection is performed in accessible areas to detect any corrosion.

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

For the gauges and temperature sensors, the results of the monitoring measurements are the major data that are analyzed to detect sensor failures (see attributes 6 and 8). These data are also used to detect electrical additional equipment’s problem. Test functions of this equipment is also used.

1. ***Mitigation ageing effects:***

The main mitigation action is the replacement of the element that is considered to be failed. For the pendulums and the Invar wires, the replacement is calibrated in order to keep the previous measurement chronology.

For the gauge “replacement”, the first mitigation action to consider is the redundancy of the sensors at design stage. For operating containment, additional qualified surface sensors can be installed.

1. ***Acceptance criteria:***

Acceptance Criteria for all devices: These criteria are metrological criterion based on the device type, or basic criteria already discussed in attribute 3.

Acceptance Criterion for replacement in case of gauges failure: The acceptance criterion for replacement in case of gauge failure is to ensure the availability of minimum numbers of sensors as per requirement (e.g., OSS [3, 5]). Minimum numbers of sensors is defined in the plant programme documents, depending on containment type (with or without liner). For example, in France the basic principles of the definition of this “minimum operating monitoring” system are listed below:

* A minimum redundancy is ensured to be able to guarantee continuity of measurements in case of new failure (a sensor is considered as failed if the value of the measured strain is not valid as described in attribute 8);
* The locations of ‘OSS’ sensors are in standard areas in order to be able to interpret the results and to compare to theoretical values;
* Vertical wall, dome and gusset are monitored.

1. ***Corrective actions:***

The corrective action is to install new monitoring system element when the current one is considered to be failed. The new element is qualified taking into account the precision required and the operation condition. This replacement is mandatory when the available sensors are not adequate to meet the condition prescribed in dedicated document.

1. ***Operating experience feedback and feedback of research and development results:***

This AMP addresses the industry-wide generic experience. Relevant plant-specific operating experience is considered in the development of the plant AMP to ensure the AMP is adequate for the plant. The plant implements a feedback process to periodically evaluate plant and industry-wide operating experience and research and development (R&D) results, and, as necessary, either modifies the plant AMP or takes additional actions (e.g. develop a new plant-specific AMP) to ensure the continued effectiveness of the ageing management.

Appropriate sources of external operating experience are Ageing Management of Concrete Structures in Nuclear Power Plants such as [5, 7].

Operating experience from France shows the use of two types of reports. The first report captures the measurement data from the monitoring system (strain sensors). The second report (that is produced later) contains an analysis of the data and conclusions that can be made about the containment structural capacity and health. Consistency of data including lack of sensors are also addressed. The consistency discussion is based on the available recorded data and on the physical behavior (discontinuity or slope change is clearly explained and documented).

Assessment of the possible long term drift (beyond ten year operation period) of VWSG embedded in concrete is presented in [8].

In France, a minimum number of measuring points for strain or displacement monitoring is required. These sensors are referred as part of the Optimum Surveillance System (OSS). In the event of failure, a sensor belonging to the OSS is replaced. If the sensor is a pendulum or a Invar wire strain meter, it is easy to replace it by a similar device. However, if an embedded VWSG is malfunctioning, dedicated surface strain gauges are set in place, which are able to deliver readings consistent with VWSG (continuity of time series achieved) [5].

Routine maintenance allows limiting the unexpected failure of pendulum or Invar wire. For VWSG, the current failure rate within the French NPP is about 1 %/year (over about 3000 embedded sensors). If the initial failure (during the first year) is taken into account, the rate is increased to 2 %/year. For new installations, the failure rate has been at the lower level. This could be due to the improvement of sensor manufacturing and better practices for sensors mounting. However, overall, about one third of the total amount of the VWSG which were placed in French containments are no longer functioning (average age of French PWR: about 35 years).

To mitigate possible sensors failures in the future, EDF has decided to install surface strain gauges on all of the French containment, even though it is not a regulatory requirement. The OPEX on surface gauges (reliability, metrological performance) is considered satisfactory. The orders of magnitude and rate of concrete creep measured with surface meter are consistent with records from VWSG. As a result of Periodic Safety Review, some sensors have been replaced to fulfill the minimal set. However, with the use of this AMP, the continuity of the measurements has been achieved. The cause of the sensors failure remains unknown and sensors life-time seems to follow a random distribution law with time, but the mean failure rate is about 2 % per year. This rate remains constant with time, with a total population of approximately 3000 sensors embedded in all the French concrete containment structures.

EDF OPEX on fiber optics sensors for temperature and strain monitoring (distributed Brillouin and Raman technologies): 200 meters of fiber optics sensors have been installed within the EPR Flamanville 3 containment building. The installation phase is considered as a success, the current challenge is mainly data processing and comparison with VWSG to make sure that fiber optics are suitable as monitoring system. On the VERCORS mock up, 2 km of the same fiber optics have been embedded, with a fair failure rate (about 30 % of failure). After a few years of operation, the measurements provided by this fiber optics system have been shared with the scientific community [9, 10].

A research and development programme dedicated to new sensors validation (strain and temperature) has been launched by EDF and a new surface sensor design that has been qualified to be installed on the outer face of the concrete containment wall. Moreover, it has been decided to fit all the containement walls with these surface sensors, in order to anticipate embedded sensors failures included in the “OSS”. An advantage of this situation is the ability to compare surface sensors measurements and embedded VWSG readings during a quite long period. Then, the confidence in the surface extensometers will be enhanced once the VWSG are no more functional. The “OSS” devices performance and measurement quality are then ensured till the end of operation.

There are two prestressed concrete containments equipped with monitoring systems at Temelin NPP in The Czech Republic. A few sensors of the original Russian designed monitoring system (NDS) embedded in concrete are nonfunctional, unstable or measuring data are out of range. The monitoring system still meets minimal functional requirements and provides sufficient data. The sensors of NDS are not replaceable, but ÚJV Řež, a. s. is working on a project to compensate for this by installing a measurement system on surface of concrete. As part of this project, new optical fiber sensors were installed and tested. As a result of this experience, optical fiber sensors will be used for future containment monitoring systems.

Monitoring devices can fail in service and are replaced, where possible. Areas with a very aggressive coastal environment can accelerate the degradation of invar wires such that they may need to be changed as often as every 3 to 5 years. EPRI and ESKOM have installed a system based on long gauge fiber optic sensors to replace invar wires. The sensors were tested during an ILRT test and showed very good correlation with existing invar wires [11].

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 Part 50, Appendix B [12]).

**References:**

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[12] UNITED STATES NUCLEAR REGULATORY COMMISION, 10 CFR Part 50, Appendix B, Quality Assurance Criteria for Nuclear Power Plants, Office of the Federal Register, National Archives and Records Administration, USNRC, Latest Edition.