**AMP 113 PWR REACTOR PRESSURE VESSEL INTERNALS (Version 2021)**

**Programme Description**

This programme manages the effects of age-related degradation mechanisms that are applicable to the reactor vessel internals (RVI) components of PWRs, including WWERs. These ageing effects include (a) various forms of cracking, including stress corrosion cracking (SCC), which also encompasses primary water stress corrosion cracking (PWSCC), irradiation-assisted stress corrosion cracking (IASCC), or cracking due to fatigue/cyclical loading; (b) loss of material induced by wear; (c) loss of fracture toughness due to either thermal ageing or neutron irradiation embrittlement; (d) changes in dimension due to void swelling; and (e) loss of preload due to thermal and irradiation-enhanced stress relaxation, creep and (f) mechanical damage due to general operation.

The programme includes activities for inspecting, detecting, monitoring, mitigating, evaluating, and, if applicable, dispositioning non-conforming RVI components at the facility. The programme is a sampling-based condition monitoring programme with periodic examinations and other inspections of highly affected internals locations. These examinations provide reasonable assurance that the effects of age-related degradation mechanisms will be managed during operation.

The programme includes the selection of baseline components identified as precursors of the expected degradation and specifies their inspection methods. Expansion of the inspection to additional components is required in case of degradation detected in the baseline components. Several components are identified for which the existing programmes are adequate.

### Evaluation and Technical Basis

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

The scope of the program includes all PWR RVI components based on the plant’s applicable nuclear steam supply system design and that require ageing management. Components are listed in detail in [5], [6], [19]. The scope of the programme does not include welded attachments to the internal surface of the reactor vessel because these components are assigned to the reactor vessel and can be adequately managed in accordance with AMP102. If the programme is based on a generic evaluation of RVIs, the applicability of this generic evaluation is demonstrated, and plant-specific changes made to the generic programme as necessary. Examples of generic evaluations of PWR RVIs are provided in [1]-[12]. Example for national requirements for scope and attributes of PWR RVI AMP is provided in [13].

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

This programme relies on PWR water chemistry control to prevent or mitigate ageing effects that can be induced by corrosion mechanisms (e.g., stress corrosion cracking or any of its forms as PWSCC, IASCC), or loss of material induced by general, pitting or crevice corrosion). Reactor coolant water chemistry is monitored and maintained in accordance with AMP 103.

This programme may also rely on minimization of neutron irradiation of RVI material using fuel management approaches such as low leakage zone configurations or dummy fuel elements. (Information on fuel management is given in [2].)

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

Detection of ageing effects typically occurs before there is a loss of the structure and component intended function(s). The parameters to be monitored or inspected are appropriate to ensure that the structure and component intended function(s) will be adequately maintained for the period of operation under all design conditions.

The programme manages the following ageing effects and degradation mechanisms that are applicable in general to the RVI components at the facility:

1. Cracking induced by SCC including PWSCC, IASCC, or fatigue/cyclical loading - For the detection of cracking, the programme monitors for evidence of surface breaking linear discontinuities if a visual inspection technique is used as the non-destruction examination (NDE) methods, or for relevant flaw presentation signals if a volumetric ultrasonic testing (UT) method is used as the NDE method. The degradation mechanisms mentioned above are specific for a baffle to former assembly (e.g. bolts), a control element assembly, a control rod guide tube, core barrel assembly, a core shroud assembly, a core support barrel assembly, core support shield and lower grid assemblies, a lower support structure.
2. Loss of material induced by wear - For detection of loss of material, the programme monitors for gross or abnormal surface conditions that may indicate loss of material occurring in the components. The loss of the material could result in mechanical binding between parts of RVI, or RVI and RPV. The detection of the material loss could be indicated by changes in vibration condition of RVI induced by flow velocities and its directions that can be monitored and evaluated. Measurement of reactor internals vibration most often is performed using mechanical sensors mounted on the reactor vessel or other primary system components, or by analyzing the noise content of the signals generated by ex-core or in-core neutron flux detection [27]- [46]. The elements susceptible to wear are a flux thimble tube, control rod guide tubes, baffle to former bolts, internals hold down spring, an upper core plate alignment pin, a core barrel assembly, a core shroud assembly, a core support barrel assembly, core support shield and lower internals assemblies.
3. Loss of fracture toughness induced by either thermal ageing or neutron irradiation embrittlement - The programme does not directly monitor loss of fracture toughness induced by thermal ageing or neutron irradiation embrittlement, or by void swelling and irradiation growth; instead, the impact of loss of fracture toughness on component integrity is indirectly managed by using visual or volumetric examination techniques to monitor for cracking in the components and by applying applicable reduced fracture toughness properties in the flaw evaluations if cracking is detected in the components. All RVIs materials are to some degree sensitive to thermal ageing or neutron irradiation embrittlement especially such elements as a core shroud assembly, core barrel and core baffle assemblies, a core support shield, lower internals and lower support structures and a core basket.
4. Changes in dimension due to void swelling and irradiation growth, distortion, or deflection - The programme uses physical measurements to monitor for dimensional changes due to void swelling, irradiation growth, distortion, or deflection (an example model is given in [4]). Changes in dimension could have potential negative impact on, e.g., a core basket, a core baffle, a core shroud, a baffle plate and bolts, a guide tube support.
5. Loss of preload caused by thermal and irradiation-enhanced stress relaxation or creep - For the detection of loss of preload, the programme monitors for gross surface conditions that may indicate loosening in applicable bolted, fastened, keyed, or pinned connections. For the detection of loss of pre-load the programme can monitor changes in vibration condition of RVI.
6. Mechanical damage caused during operation (manipulation during outages) - For the detection of mechanical damage, the programme monitors for evidence of surface breaking, impact traces, distortion of geometry if a visual inspection technique is used as the non-destruction examination (NDE) methods.

Standards for examination methods, procedures, and personnel are provided in the programme, with preference to well-established examination methods. These methods include volumetric UT examination methods for detecting flaws in bolting, physical measurements for detecting changes in dimension, and various visual (e.g. VT-1 or with regard to [2] EVT-1, and VT-3 [14]) examinations for detection of general surface conditions and detection and sizing of surface-breaking discontinuities. Surface examinations, i.e. ET [2], may also be used as an alternative to visual examinations for detection and sizing of surface-breaking discontinuities.

For IAEA Member States which apply former Soviet, Russian or national procedures, a description of the visual examination is given in corresponding documents [15], [16].

For IAEA Member States applying national normative documents, the description is given in corresponding standards, e.g. [17].

Cracking caused by SCC, IASCC, and fatigue is monitored/inspected by either visual examination (for internals other than bolting) or by volumetric UT examination. Visual methods can be used if the component/material has been shown, even with reduced fracture toughness, to withstand flaws large enough to see visually and not to undergo unstable brittle fracture. In addition, visual examinations are used to monitor/inspect for loss of material induced by wear and for general ageing conditions, such as gross distortion caused by void swelling and irradiation growth or by gross effects of loss of preload caused by thermal and irradiation-enhanced stress relaxation and creep.

Detection of ageing in the RVI can be implemented through inspections that focus on critical locations of the RVI [10], e.g. where the development of degradation is most likely to occur and/or the consequences of failure are the highest. Determination, though measurements and calculations, of the neutron flux distribution can provide information to aid in the assessment of critical locations of the RVI.

Another approach that can provide means for detection of ageing effects is the measurement and tracking of the vibration condition of the RVI on a long-time basis in order to provide sufficient data for trending.

To aid in the identification of void swelling, the baseline geometry presented in the design documentation of the RVI can be a starting point for further trending and evaluation (prior the effects of swelling and irradiation creep could take place). In case of lack of the RVI dimensions they could be measured prior to the expected development of degradation and considered a starting point for further trending as well.

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

The methods for monitoring, recording, evaluating, and trending the data that result from the programme´s inspections shall provide for identification of adverse ageing trends such that corrective action can be performed as necessary in a timely manner.

Monitoring and trending the RVI operational history, i.e. the sequence of operational transients characterised by pressure and temperature time courses, can enable the periodical fatigue evaluation in critical locations of the RVI, as discussed in AMP 101.

The methods for monitoring and trending neutron swelling through combination of measurements and calculations are described in TLAA 109.

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

This programme is a condition monitoring programme that will detect the ageing effects of concern such that, should ageing effects be identified, remediation of the condition can be accomplished, as necessary. Water chemistry control during operation and shutdown is important to avoid corrosion problems. Water chemistry control is maintained in accordance with AMP 103.

1. ***Acceptance criteria:***

The programme provides specific acceptance criteria for the examinations. For components addressed by examinations referenced in the AMP 102, the acceptance criteria in that programme apply. For other components covered by existing programmes, the examination acceptance criteria are described within the existing programme reference document.

The programme contains the following types of examination acceptance criteria:

* Components whose visual examination (and surface examination as an alternative to visual examination) confirms the absence of the relevant conditions shall be considered acceptable for continued service. In addition, there are requirements to record and disposition surface breaking indications that are detected and sized by visual examinations (e.g. VT-1/EVT-1);
* For volumetric examination, the examination acceptance criterion is the capability for reliable detection of acceptable indications in bolting; in addition, there are requirements for assessment of the system-level/ bolted or pinned assemblies that can accomplish its intended function even with unacceptable volumetric (UT) examination indications that exceed specified limits;
* For physical measurements, the examination acceptance criterion for the acceptable tolerances in the measurements shall be specified with justification to ensure the component can accomplish its intended function even with the dimensional changes;
* For monitoring of vibration conditions, the acceptance criteria shall be specified on the basis of changes in vibration conditions or on the basis of general operational experience of other units of the same technical type (with respect to plant specific condition).

1. ***Corrective actions:***

Detected conditions that do not satisfy the examination acceptance criteria are required to be dispositioned through the plant corrective action programme, which may require repair, replacement, or analytical evaluation for continued service until the next inspection. The disposition will ensure that design basis functions of the reactor internals components will continue to be fulfilled for all licensing basis loads and events during intended period of operation. Examples of methodologies that can be used to analytically disposition unacceptable conditions include engineering evaluation methods, for example [18], as well as supplementary examinations to further characterize the detected condition, or, alternatively, component repair and replacement procedures.

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.

Incidents of PWR internals ageing degradation are identified in IAEA-TECDOC-1557 [19] as well as in [1], [2]. Examples of reports for PWR internals inspection findings are also included in [20] - [22].

Within past and the current Euroatom framework programme (EP) of the European Commission (EC) a number of research projects were and are currently performed, which address ageing degradation of PWR internals. In the project INTERWELD [23], organized within the 5th Euroatom EP (1999-2002), the irradiation effects on microstructure, properties and residual stresses in the heat effected zone of stainless steel (i.e. 304 and 347) welds in core shrouds were investigated. The objective of the project PERFECT [24] , organized within the 6th Euroatom FP (2003-2006), and its follow-up project PERFORM60 [25], organized within the 7th Euroatom FP (2009-2013), was the development of the numerical multi-scale models for the prediction of the degradation of reactor pressure vessels and reactor internals under LTO. One more a 4-year (2015-2019) European research project SOTERIA in the field of nuclear safety concentrated on the ageing phenomena occurring in reactor pressure vessel (RPV) steels and in the internal steels (internals) in order to provide crucial information to regulators and operators to ensure safe long-term operation (LTO) of existing European nuclear power plants (NPPs).

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 [26]).

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