**AMP 160 NEUTRON FLUENCE MONITORING (VERSION 2020)**

**Programme Description**This AMP monitors neutron fluence for reactor pressure vessel (RPV) components and reactor vessel internal (RVI) components as necessary to evaluate relevant time limited ageing analyses (TLAAs) and to ensure adequate ageing management of certain neutron fluence related ageing effects. This programme is used in conjunction with AMP 118 and AMP 152. Neutron fluence is a time-dependent input parameter for evaluating the loss of fracture toughness due to neutron irradiation embrittlement. Accurate neutron fluence values are also necessary to identify the location of the RPV beltline region for which neutron fluence is projected to exceed levels such that neutron embrittlement effects need to be evaluated.

The assessment of neutron fluence is an input to RPV irradiation embrittlement analyses that are mandated by national regulatory requirements or plant technical specifications. As described in Section 4 of SRS 82, the neutron irradiation embrittlement TLAAs that are managed by this AMP can include, but are not limited to: (a) pressurized thermal shock (PTS) analyses for PWRs; (b) RPV upper-shelf energy (USE) analyses, (c) changes in RTNDT (ΔRTNDT) for BWR and PWR plants and TK0 (ΔTKF) for WWER plants, and (d) pressure-temperature (P-T) limit analyses. Additional information is provided in [1-7].

The calculations of neutron fluence also factor into other analyses or technical report methodologies that assess irradiation-related ageing effects. Examples include, but are not limited to: (a) evaluation of the susceptibility of RVI components to neutron radiation damage mechanisms, including irradiation embrittlement (IE), irradiation assisted stress corrosion cracking (IASCC), irradiation-enhanced stress relaxation or creep (IESRC), and void swelling or neutron induced component distortion; and (b) evaluating the dosimetry data obtained from an RPV surveillance programme.

Guidance on acceptable methods and assumptions for determining reactor vessel neutron fluence is consistent with national regulatory requirements. An example is provided in [8], which is used in conjunction with regulatory requirements [9-13].

This programme monitors in-vessel or ex-vessel dosimetry capsules and evaluates the dosimetry data, as needed. The implementation of such dosimetry capsules may be needed if the reactor surveillance programme in accordance with AMP 118 and AMP 152 has exhausted the available capsules for in-vessel exposure.

**Evaluation and Technical Basis**

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

The scope of the programme includes RPV and RVI components that are subject to a neutron embrittlement TLAA or other analysis involving time-dependent neutron irradiation. The programme monitors neutron fluence for determination of the susceptibility of the components to IE, IASCC, IESRC, and void swelling or distortion. The programme also continues to ensure the adequacy of the neutron fluence estimates by: (a) monitoring plant and core operating conditions relative to the assumptions used in the neutron fluence calculations, and (b) continuously updating the qualification database associated with the neutron fluence method as new calculational and measurement data become available for benchmarking. This programme is used in conjunction with AMP 118 and AMP 152.

Updated neutron fluence calculations, plant modifications, and RPV surveillance programme data are used to identify component locations within the scope of this programme, including the beltline region of the RPV. This programme provides a means to comply with national regulatory requirements, and if appropriate, plant Technical Specifications (TSs), related to calculating neutron fluence estimates and incorporating those calculations into neutron irradiation analyses for the RPVs and RVIs.

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

This programme is a condition monitoring programme through calculation of neutron fluence values, and thus there are no specific preventive actions. Because this programme can be used to ensure that the inputs and assumptions associated with neutron fluence in the irradiation embrittlement TLAAs (described in Section 4 of SRS 82) remain within their respective limits, this programme can prevent those TLAAs from being outside of the acceptance criteria that are set as regulatory or design limits in the analyses. Since the programme is used to ensure that the inputs and assumptions associated with neutron fluence in irradiation embrittlement TLAAs will remain within their respective limits, this programme does have some preventative aspects to it.

***3. Detection of ageing effects:***

The programme monitors component neutron fluence as determined by the neutron fluence analyses, and appropriate plant and core operating parameters that affect the calculated neutron fluence. The calculational methods, benchmarking, qualification, and surveillance data are monitored to ensure the adequacy of neutron fluence calculations. Neutron fluence levels in specific components are monitored to ensure component locations within the scope of this programme are identified.

Neutron fluence is estimated using a computational method that incorporates the following major elements: (1) determination of the geometrical and material input data for the reactor core, vessel and internals, and cavity; (2) determination of the characteristics of the neutron flux emitting from the core; (3) transport of the neutrons from the core to the vessel, and into the cavity; and (4) qualification of the calculational procedure.

Guidance on acceptable methods and assumptions for determining RPV neutron fluence is described in national regulatory requirements. If the national regulatory requirements address neutron fluence calculations within the effective height of the core, then methods to estimate neutron fluence for the RPV regions significantly above and below the active field region of the core and for RVI components may require additional justification.

The programme uses applicant-defined activities or methods to track the RPV and RVI component neutron fluence levels, as required. The neutron fluence levels estimated in this programme are used as input to the evaluation for determining applicable ageing effects for RPV and RVI components, including evaluation of TLAAs as described in Section 4 of SRS 82.

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

Monitoring and trending of neutron fluence is needed to ensure the continued adequacy of various neutron fluence analyses as identified as TLAAs by the plant. When applied to RVI components and to components significantly above and below the active fuel region of the core, the programme also assesses and justifies whether the current neutron fluence methodology is acceptable for monitoring and projecting the neutron fluence values for these components during the planned operating period, or else appropriately enhances (with justification) the programme’s monitoring and trending element activities accordingly on an as-needed basis. Trending is performed to ensure that plant and core operating conditions remain consistent with the assumptions used in the neutron fluence analyses and that the analyses are updated as necessary.

Neutron fluence estimates are typically determined using a combination of plant and core operating history data that address past plant operating conditions, and projections that are intended to address future operation. Although projections for future operation may conservatively over-estimate the core neutron flux to cover potential variations in plant and core operation and increases in neutron flux at any given time, there is no explicit requirement to do so. Therefore, projections for future plant and core operation is periodically verified to ensure that any projections used in the neutron fluence calculations remain bounding with respect to actual plant operating conditions.

This programme monitors in-vessel or ex-vessel dosimetry capsules and evaluates the dosimetry data, as needed. Additional dosimetry capsules may be needed if the reactor surveillance programme in accordance with AMP 118 and AMP 152 has exhausted the available capsules for in-vessel exposure.

***5. Mitigating ageing effects:***

This programme does not mitigate ageing effects.

***6. Acceptance criteria:***

There are no specified acceptance values for neutron fluence; the acceptance criteria relate to the different parameters that are evaluated using neutron fluence, such as evaluation of TLAAs as described in Section 4 of SRS 82.

National regulatory requirements may provide guidance for acceptable methods to determine neutron fluence, in particular for the RPV beltline region, e.g. [8]. It is noted that applying the guidance of [8] to determine neutron fluence for locations other than those close to the active fuel region of the core may require additional justification regarding, for example, the level of detail used to represent the core neutron source, the methods to synthesize the three-dimensional flux field, and the order of angular quadrature used in the neutron transport calculations. The applicability of existing qualification data may also require additional justification.

***7. Corrective actions:***

The programme provides for corrective actions by updating the analyses for the RPV components or assessing the need for revising the augmented inspection bases for RVI components, if the neutron fluence assumptions in RPV analyses or augmented inspection bases for RVI components are projected to be exceeded. Acceptable corrective actions include revisions to the neutron fluence calculations to incorporate additional operating history data, if such data become available; use of improved modelling approaches to obtain more accurate neutron fluence estimates; and rescreening of RPV and RVI components when the estimated neutron fluence exceeds threshold values for specific ageing mechanisms.

When the fluence monitoring activities are used to confirm the validity of existing RPV neutron irradiation embrittlement analyses and result in the need for an update of an analysis that is mandated by a specific national regulatory requirement, the corrective actions to be taken follow those prescribed in the applicable regulation.

***8. 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.

There is no specific operating experience related to this AMP.

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

***9. Quality management:***

Site quality assurance procedures, review and approval processes, and administrative controls are implemented in accordance with the different national requirements (e.g., [14]).

**References**

[1] INTERNATIONAL ATOMIC ENERGY AGENCY, Pressurized Thermal Shock in Nuclear Power Plants: Good Practices for Assessment Deterministic Evaluation for the Integrity of Reactor Pressure Vessel, IAEA-TECDOC-1627, IAEA, Vienna, December 2010.

[2] INTERNATIONAL ATOMIC ENERGY AGENCY, Integrity of Reactor Pressure Vessels in Nuclear Power Plants: Assessment of Irradiation Embrittlement Effects in Reactor Pressure Vessel Steels, IAEA Nuclear Energy Series No. NP-T-3.11, IAEA, Vienna, April 2009.

[3] INTERNATIONAL ATOMIC ENERGY AGENCY, Assessment and management of ageing of major nuclear power plant components important to safety: BWR pressure vessels, IAEA-TECDOC-1470, IAEA, Vienna, October 2005.

[4] INTERNATIONAL ATOMIC ENERGY AGENCY, Assessment and management of ageing of major nuclear power plant components important to safety: BWR pressure vessel internals, IAEA-TECDOC-1471, IAEA, Vienna, October 2005.

[5] INTERNATIONAL ATOMIC ENERGY AGENCY, Assessment and Management of Ageing of Major Nuclear Power Plant Components Important to Safety: PWR pressure vessels(Update), IAEA-TECDOC-1556, IAEA, Vienna, June 2007.

[6] INTERNATIONAL ATOMIC ENERGY AGENCY, Assessment and Management of Ageing of Major Nuclear Power Plant Components Important to Safety: PWR pressure vessel internals (Update), IAEA-TECDOC-1557, IAEA, Vienna, June 2007.

[7] INTERNATIONAL ATOMIC ENERGY AGENCY, Guidelines for prediction of irradiation embrittlement of operating WWER-440 reactor pressure vessels Report prepared within the framework of the coordinated research project, IAEA-TECDOC-1442, IAEA, Vienna, June 2005.

[8] UNITED STATES NUCLEAR REGULATORY COMMISSION, Regulatory Guide 1.190, Calculational and Dosimetry Methods for Determining Pressure Vessel Neutron Fluence, USNRC, Washington, March 2001.

[9] UNITED STATES NUCLEAR REGULATORY COMMISSION, 10 CFR 50.60, Acceptance Criteria for Fracture Prevention Measures for Lightwater Nuclear Power Reactor for Normal Operation, USNRC, Washington, Latest Edition.

[10] UNITED STATES NUCLEAR REGULATORY COMMISSION, 10 CFR 50.61, Fracture Toughness Requirements for Protection Against Pressurized Thermal Shock Events, USNRC, Washington, Latest Edition.

[11] UNITED STATES NUCLEAR REGULATORY COMMISSION, 10 CFR 50.61a, Alternate Fracture Toughness Requirements for Protection Against Pressurized Thermal Shock Events, USNRC, Washington, Latest Edition.

[12] UNITED STATES NUCLEAR REGULATORY COMMISSION, 10 CFR Part 50, Appendix G, Fracture Toughness Requirements, USNRC, Washington, Latest Edition.

[13] UNITED STATES NUCLEAR REGULATORY COMMISSION, 10 CFR Part 50, Appendix H, Reactor Vessel Material Surveillance Program Requirements, USNRC, Washington, Latest Edition.

[14] 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, Washington, Latest Edition.