## AMP 109 BWR REACTOR PRESSURE Vessel Internals (Version 2020)

## Programme Description

The programme includes inspection, flaw evaluations and repair technologies in conformance with the pertinent governing requirements or guidance documents applicable by the Member States, to provide reasonable assurance of the long-term integrity and safe operation of BWR vessel internal components.

The IAEA-NP-T-3.13 [1], IAEA-TECDOC-1471 [2] and IAEA-NS-G-2.6 [3] provide generic guidelines intended to present the applicable inspection recommendations to assure safety function integrity of the subject safety-related reactor pressure vessel internal components. The IAEA-TECDOC-1471 [2] provides information on:

* Component description and function;
* Evaluation of susceptible locations and safety consequences of failure;
* Provide recommendations for methods, extent, and frequency of inspection;
* Discuss acceptable methods for evaluating the structural integrity significance of flaws detected during these examinations.

The IAEA-NP-T-3.2 [4] recommends repair and replacement procedures. Moreover, specific industrial codes and guidelines exist for various Member States:

* Japan: JSME S NA1 [5], NISA-161a-03-01 [6], JANTI-VIP-06 [7];
* Germany: KTA 3204 [8];
* USA and international: BWRVIP Reports [9-49];
* USA only: GALL Revision 2 [50].

In addition, this programme addresses ageing management of cast austenitic stainless steels (CASS) reactor internal components for BWRs. For CASS components, the screening criteria of IGALL AMP 112 or BWRVIP-234 [48] are used to identify potentially susceptibility CASS reactor internal components for BWRs when fluence exceeds 6x1020 n/cm2. For “potentially susceptible” components, the programme considers loss of fracture toughness due to neutron embrittlement or thermal ageing embrittlement.

This AMP also addresses ageing degradation of X-750 alloy, and precipitation-hardened (PH) martensitic stainless steel (SS) (e.g., 15-5 and 17-4 PH steel) materials and martensitic SS (e.g., 403, 410, 431 steel) that are used in BWR vessel internal components. When exposed to high energy neutron fluence, these materials can experience neutron embrittlement and a decrease in fracture toughness. PH-martensitic SSs and martensitic SSs are also susceptible to thermal embrittlement. Effects of thermal and neutron embrittlement can cause failure of these materials in vessel internal components. In addition, X-750 alloy in a BWR environment is susceptible to intergranular stress corrosion cracking (IGSCC).

## Evaluation and Technical Basis

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

The programme is focused on managing the effects of cracking due to stress corrosion cracking (SCC), including IGSCC, or irradiation-assisted stress corrosion cracking (IASCC) and cracking due to fatigue and loss of material due to wear. This programme also includes loss of toughness due to neutron and thermal embrittlement. The programme applies to wrought and cast reactor vessel internal components. The programme contains inservice inspection (ISI) to monitor the effects of cracking on the intended function of the components, uses specific guidelines as the basis for inspection, evaluation, repair and/or replacement, as needed, and evaluates the susceptibility of CASS, X-750 alloy, PH martensitic SS (e.g., 15-5 and 17-4 PH steel), and martensitic SS (e.g., 403, 410, 431 steel) components to neutron and/or thermal embrittlement.

Criteria of inspection, evaluation, repair and re-inspection are given for example in BWRVIP documents [9-49], KTA 3204 [8] and JSME S NA1 [5] for the following components

* Core shroud;
* Core plate;
* Core spray;
* Shroud support;
* Jet pump assembly;
* Low-pressure coolant injection (LPCI) coupling;
* Top guide;
* Control rod drive (CRD) housing;
* Lower plenum components;
* Steam dryer;
* Access hole cover plate.

For repairs, ageing management strategies are provided by the repair designer, not the guidelines.

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

The BWR Vessel Internals programme is a condition monitoring programme and has no preventive actions. Maintaining high water purity reduces susceptibility to SCC or IGSCC. Reactor coolant water chemistry is monitored and maintained in accordance with the Water Chemistry Programme (e.g., [33, 47]). The programme description, evaluation and technical basis of water chemistry are presented in AMP 103. In addition, for core shroud repairs or other IGSCC repairs, the programme maintains operating tensile stresses below a threshold limit that precludes IGSCC of X-750 material. And, it is possible to apply preventive actions in accordance with IAEA-NP-T-3.13 [3] and IAEA TECDOC-1471 [2].

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

The programme monitors the effects of cracking on the intended function of the component by detection and sizing of cracks by inspection in accordance with the Section XI of the ASME Code [51], BWRVIP guidelines [9-49] or according to corresponding national standards, such as KTA 3204 in Germany [8] or JSME S NA1 in Japan [5].

Loss of fracture toughness due to neutron embrittlement in CASS materials can occur. Loss of fracture toughness by CASS material due to thermal embrittlement is dependent on the material’s casting method, molybdenum content, and ferrite content. The programme does not directly monitor for loss of fracture toughness that is induced by thermal ageing or neutron irradiation embrittlement. 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.

Loss of fracture toughness of X-750 alloys, PH-martensitic SSs, and martensitic SSs, either from neutron or thermal embrittlement as applicable, cannot be identified by typical ISI activities. However, by performing visual or other inspections, applicants can identify cracks that could lead to failure of a potentially embrittled component prior to component failure. Applicants can thus indirectly manage the effects of embrittlement in the PH steels, martensitic SSs, and X-750 components by identifying ageing degradation (i.e., cracks), implementing early corrective actions, and monitoring and trending ageing degradation.

The extent and schedule of the inspection and test techniques prescribed by the applicable guidelines are designed to maintain structural integrity and ensure that ageing effects will be discovered and repaired before the loss of intended function of BWR vessel internals. Inspection can reveal cracking. Vessel internal components are inspected in accordance with the requirements of the applicable codes that specify visual VT-1 examination to detect discontinuities and imperfections, such as cracks, corrosion, wear, or erosion, on the surfaces of components. This inspection also specifies visual VT‑3 examination to determine the general mechanical and structural condition of the component supports by (a) verifying parameters, such as clearances, settings, and physical displacements, and (b) detecting discontinuities and imperfections, such as loss of integrity at bolted or welded connections, loose or missing parts, debris, corrosion, wear, or erosion. The guidelines also provide for inspection of BWR vessel internals to manage loss of material and cracking using appropriate examination techniques such as visual examinations (e.g., EVT-1, VT-1) and volumetric examinations (e.g., UT).

The applicable guidelines recommend more stringent inspections, in accordance with the national regulatory requirements, such as EVT‑1 examinations or ultrasonic methods of volumetric inspection, for certain selected components and locations. The nondestructive examination (NDE) techniques appropriate for inspection of BWR vessel internals, including the uncertainties inherent in delivering and executing NDE techniques in a BWR, are included in Vessel Internals guidelines.

Thermal and/or neutron embrittlement in susceptible CASS, PH-martensitic steels, martensitic SSs, and X-750 components are indirectly managed by performing periodic visual inspections capable of detecting cracks in the component. The inspection technique is capable of detecting the critical flaw size with adequate margin. The critical flaw size is determined based on the service loading condition and service-degraded material properties. If cracking is detected after the initial inspection, the frequency of reinspection is justified by the applicant based on crack growth rates and fracture toughness properties appropriate for the condition of the component. The sample size is generally 100% of the accessible component population, excluding components that may be in compression during normal operations or have sufficient redundancy to justify a sampling programme.

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

Inspections that are scheduled in accordance with the applicable Codes and approved guidelines, and reliable examination methods provide timely detection of potential degradation. Each guideline recommends baseline inspections that are used as part of data collection towards trending. The guidelines provide recommendations for expanding the sample scope and reinspecting the components if flaws are detected, and, for evaluation of crack growth in SSs, nickel alloys, and low-alloy steels.

The fracture toughness of PH-martensitic steels, martensitic SSs, and X-750 alloys susceptible to thermal and/or neutron embrittlement need to be assessed as required.

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

This programme is a condition monitoring programme and does not include specific provisions to mitigate degradation of reactor vessel internal components. Mitigation of ageing effects for RPV internals are considered in other AMPs. For example, in AMP 103 on Water Chemistry, as well as [33, 47].

1. ***Acceptance criteria:***

Acceptance criteria are given in the pertinent governing requirements or guidance documents for the plant. Flaws detected in CASS components are evaluated in accordance with the applicable procedures of the pertinent governing requirements or guidance documents. Additional information for crack growth rates to use in evaluating cracking can be found in [11, 30, 31, 38, 39].

Acceptance criteria for the assessment of CASS materials, PH-martensitic steels, martensitic stainless steels, and X-750 alloys susceptible to thermal ageing and/or neutron embrittlement are assessed on a case-by-case basis.

1. ***Corrective actions:***

Repair and replacement are performed in conformance with the applicable guidelines listed above and the pertinent governing requirements or guidance documents for the plant. For top guides where cracking is observed, sample size and inspection frequencies are increased.

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.

IAEA-NP-T-3.13 [1] and IAEA-TECDOC-1471 [2] provides information on current inspection, monitoring and mitigation practices for managing ageing of BWR vessel internals. Additionally, there is documentation of cracking in both the circumferential and axial core shroud welds, and in shroud supports. Cracking in vertical core shroud welds have also been documented [35, 52]. It has affected shrouds fabricated from Type 304 and Type 304L SS, which is generally considered to be more resistant to SCC. Weld regions are most susceptible to IGSCC, although it is not clear whether this is due to sensitization and/or impurities associated with the welds or the high residual stresses in the weld regions [52-55].

Both circumferential and radial cracking have been observed in the shroud support access hole covers that are made from Alloy 600 [56].

Cracking of the core plate has not been reported, but the creviced regions beneath the plate are difficult to inspect. Specific guidelines [15] address the safety significance and inspection requirements for the core plate assembly. Only inspection of core plate bolts (for plants without retaining wedges) or inspection of the retaining wedges is required. Cracking has also been observed in the top guide of Swedish and U.S. BWRs [50].

Instances of cracking have occurred in the jet pump assembly [57], hold-down beam [58], and jet pump riser pipe elbows [59].

Cracking of dry tubes has been observed at 14 or more BWRs. The cracking is intergranular and has been observed in dry tubes without apparent sensitization, suggesting that IASCC may also play a role in the cracking [50].

IGSCC in the X-750 materials of a tie rod coupling and jet pump hold-down beam was observed in an American plant [50].

Additional operating experience events are described in Section 5 "Events" of reference [60].

Relevant research and development results are produced by the Halden BWR (HBWR) Project in Norway and the EPRI in US.

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 [61]).

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