SLR Document Changes: Add FE Section 3.5.2.2.2.7 and AMR Items for Irradiation Embrittlement of Reactor Vessel (RV) Steel Supports and Other Steel Structural Support Components near RV

Overview of purpose of change: Add new SRP-SLR further evaluation (FE) sections 3.5.2.2.2.7 and 3.5.3..2.2.7 and associated new SRP-SLR Table 3.5.1 and GALL-SLR aging management review (AMR) line items to address loss of fracture toughness due to irradiation embrittlement for steel structural support components, and other related non-metallic components other than concrete, located in the vicinity of the Reactor Vessel (RV) (e.g., RV steel supports, Lubrite® lubricant, etc).

Irradiation neutron fluence and gamma dose experienced through the subsequent period of extended operation (80 years) by steel structural support components (e.g., RV steel supports, neutron shield tank, shield walls, tc.) located in the vicinity of the reactor pressure vessel could be significant to cause aging effects. For subsequent license renewal (SLR), potential aging effects due to irradiation are applicable to these components and should be evaluated to determine the need for a plant-specific program or plant-specific enhancement to applicable GALL-SLR program(s) to manage these irradiation aging effects. The purpose of this change is to provide further evaluation guidance and AMR line items in the SLR guidance documents to address irradiation aging effects for steel and related non-concrete structural components. This new guidance is based on the experience gained from the staff review of the first three SLR applications and is analogous to the guidance for concrete irradiation effects in SRP-SLR Section 3.5.2.2.2.6.

Basis Document Input: Revise NUREG-2221 as follows.

Add the following rows to Table 2-2.

Table 2-2 New AMR Items Added in GALL-SLR Report, Chapter III, Structures and Component Supports

New AMR Item No.	Technical Bases for Changes
III.A4.T-36 (PM to Confirm)	This new item addresses irradiation aging effects on non-ASME steel structural support components located in the vicinity of the reactor vessel which could occur at fluence/dose levels that may be reached during the subsequent period of extended operation. To account for the possible effects applicants should complete a plant-specific further evaluation recommended in new SRP-SLR Section 3.5.2.2.2.7 described in Table 3-7.
III.B1.3.T-37 (PM to Confirm)	This new item addresses irradiation aging effects on ASME (Class MC) steel structural support components located in the vicinity of the reactor vessel which could occur at fluence/dose levels that may be reached during the subsequent period of extended operation. To account for the possible

	effects applicants should complete a plant-specific further evaluation recommended in new SRP-SLR Section 3.5.2.2.2.7 described in Table 3-7.
III.B1.3.T-38 (PM to Confirm)	This new item addresses irradiation aging effects on non-steel (except concrete) components associated with structural support components located in the vicinity of the reactor vessel which could occur at fluence/dose levels that may be reached during the subsequent period of extended operation. To account for the possible effects applicants should complete a plant-specific further evaluation recommended in new SRP-SLR Section 3.5.2.2.2.7 described in Table 3-7.

Add the following row to Table 2-25.

Table 2-25 Chapter IX.E – Aging Effects - Differences from Chapter IX, GALL Report, Rev. 2 and Their Technical Bases

Defined Term	Summary of Significant Changes	Technical Bases for Change
Loss of fracture toughness	The existing description was supplemented to add the following text at the end of the description: In reactor vessel steel supports and other steel structural support components, loss of fracture toughness is caused by irradiation embrittlement and neutrons from the complete energy spectrum (E > 0.1 MeV in contrast to E > 1 MeV used for reactor vessel neutron fluence) should be considered for embrittlement predictions.	The description was supplemented to clarify that neutrons from the complete energy spectrum (E > 0.1 MeV in contrast to E > 1 MeV used for reactor vessel neutron fluence) should be considered for embrittlement predictions for steel structural support components (e.g. reactor vessel steel supports) and related non-steel components located in the vicinity of the reactor vessel. This relates to the further evaluation recommended in the new SRP-SLR Section 3.5.2.2.2.7 (refer to description in Table 3-7) to address loss of fracture toughness due to irradiation embrittlement for these components.

SLR Document Changes: Add FE Section 3.5.2.2.2.7 and AMR Items for Irradiation Embrittlement of Reactor Vessel (RV) Steel Supports and Other Steel Structural Support Components near RV

Add the following text to Table 3-7.

Table 3-7 SRP-SLR Chapter 3.5, Containments, Structures, and Component Supports, Differences from SRP-LR, Revision 2 and Their Technical Bases

Location of Change	Summary of the Change	Technical Bases for Change
Sections 3.5.2.2.2.7 and 3.5.3.2.2.7	Added new Further Evaluation acceptance criteria Section 3.5.2.2.2.7 (and corresponding review procedure Section 3.5.3.2.2.7) to address loss of fracture toughness and reduction of strength of steel structural support components (e.g., reactor vessel supports) located in the vicinity of the reactor vessel due to irradiation embrittlement. New AMR line items 101 and 102, associated with the new further evaluation and providing references to corresponding new GALL-SLR AMR line items, are also added to SRP-SLR Table 3.5-1.	Loss of fracture toughness due to irradiation embrittlement from accumulated neutron fluence and gamma dose, through the subsequent period of extended operation, could occur in BWR and PWR steel structural support components located in the vicinity of the Reactor Vessel (RV) (e.g., RV steel supports, neutron shield tank, shield wall, etc). The irradiation aging effect could result in reducing or compromising the structural integrity of the above steel structural components as well as could cause loss of function in related non-steel components (e.g., Lubrite in RV support sliding feet). lubricant To address the above concern, new further evaluation Section 3.5.2.2.2.7 (and corresponding review procedure Section 3.5.3.2.2.7) is added to determine if a plant-specific aging management program (AMP) or plant-specific enhancements to selected GALL-SLR AMPs is needed to manage the aging effects due to irradiation in these steel and related non-steel (other than concrete) structural support components located in the vicinity of the RV for the subsequent period of extended operation. New AMR line items 101 and 102 associated with the further evaluation are also added to SRP-SLR Table 3.5-1. The criteria and technical reevaluation procedures (with exception of the structural consequence analysis) of the engineering

		approach in NUREG-1509 "Radiation Effects on Reactor Pressure Vessel Supports, May 1996" provides one acceptable approach for performing the further evaluation for irradiation embrittlement of steel structural support components. The conclusions in NUREG-1509 were based on analyses and limited to neutron fluences relevant to 40 years of operation. Since the neutron fluences for the subsequent period of extended operation to 80 years often exceed the neutron fluence values used in the analyses of NUREG-1509, the analytical methodologies (except the structural consequence analysis approach in Section 4.5) in NUREG-1509 remain applicable but the conclusions are no longer supported.
3.5.6 References	Added the following references. 21. NUREG-1509, "Radiation Effects on Reactor Pressure Vessel Supports," US Nuclear Regulatory Commission, Washington DC, May 1996. 22. ASME. ASME Code, Section XI, "Rules for Inservice Inspection of Nuclear Power Plant Components," Nonmandatory Appendix A, "Analytical Evaluation of Flaws," New York, New York: The American Society of Mechanical Engineers. 2013.	The new references added are referenced in the new further evaluation Sections 3.5.2.2.2.7 and 3.5.3.2.2.7 in SRP-SLR to address irradiation aging effects on steel structural support components located in the vicinity of the reactor vessel.

SLR Document Changes: Add FE Section 3.5.2.2.2.7 and AMR Items for Irradiation Embrittlement of Reactor Vessel (RV) Steel Supports and Other Steel Structural Support Components near RV

Document Changes:

SRP-SLR (NUREG-2192): Add the following sections to SRP-SLR Section 3.5.

3.5.2.2.2.7 Loss of Fracture Toughness Due to Irradiation Embrittlement of Steel Structural Support Components Located in the Vicinity of the Reactor Vessel

Loss of fracture toughness due to irradiation embrittlement from accumulated neutron fluence and gamma dose could occur in BWR and PWR structural support components (including associated weldments and bolted connections), located in the vicinity of the Reactor Vessel (RV), made of steel material exposed to low-temperature, low-flux radiation in an air-indoor uncontrolled environment. These components include the RV steel supports, neutron shield tank, steel structural support components of reactor shield wall and sacrificial shield wall, or other steel structural support components located in the vicinity of the RV. The irradiation aging effect could result in reducing or compromising the structural integrity of the above steel structural components. Further evaluation is recommended to determine if a plant-specific aging management program (AMP) or plant-specific enhancements to selected GALL-SLR AMPs is needed to manage the aging effects due to irradiation embrittlement in these steel structural support components located in the vicinity of the RV for the subsequent period of extended operation. Loss of function due to radiation exposure (neutron and/or gamma) of related non-steel (except concrete) components (e.g., Lubrite® or other lubricant/coating in support sliding feet) that may have been used in RV supports and are important to capability to perform its function should also be evaluated and dispositioned, with supporting technical information, on a plant-specific basis for the subsequent period of extended operation. The acceptance criteria for a plant-specific program or program enhancements are described in BTP RLSB-1 {Appendix A.1 of NUREG-2192 (SRP-SLR)}.

The irradiation aging effects may be addressed by analysis, testing, aging management inspections (e.g., one-time, periodic), or a combination of these methods and the evaluation should be supported by an adequate technical basis that also accounts for uncertainties and limitations of available technical data and knowledge. NUREG-1509, “Radiation Effects on Reactor Pressure Vessel Supports,” (Ref. 21) provides general guidance and an acceptable approach (with exception of structural consequence analysis approach in Section 4.5) to evaluate loss of fracture toughness via a screening evaluation, a fracture mechanics analysis or a transition temperature analysis (relative to the lowest operating temperature). A plant-specific AMP or plant-specific enhancements to selected GALL-SLR AMPs may not be necessary for the steel structural support components if (i) the screening criteria or criteria for reevaluation in Chapter 4, “RPV Support Reevaluation Criteria,” of NUREG-1509, with exception of the structural consequence analysis approach in Section 4.5, are satisfied on a plant-specific basis using the engineering approach and technical evaluation

procedures described therein; other applicant-proposed demonstrated technical reevaluation approach may be used if supported by adequate technical justification; and (ii) there is no plant-specific operating experience of irradiation embrittlement observed to date. For non-steel, non-concrete structural support components, the applicant should provide supporting technical information and data to justify its determination regarding the need for a plant-specific program or program enhancements to manage irradiation aging effects.

In its technical evaluation the applicant should estimate the neutron and gamma fluence incident on the RV steel supports and other applicable steel structural support components for the subsequent period of extended operation. The fluence estimation should use appropriate methodologies and suitably conservative assumptions to estimate the levels of neutron and gamma fluence for the subsequent period of extended operation. Fluence methodologies that have previously been reviewed and approved by the NRC may be used, but justification should be provided for the applicability of the methodologies beyond the basis for validation and approval of the methodology (e.g., differences in location(s) between the region being analyzed and the location(s) that the methodology was benchmarked against). If analysis methodologies are utilized that have not been reviewed by the NRC, the staff may need more detail in the description of the analysis model and how it was validated to make a finding on its adequacy for its intended purpose. The scope for the justification should be scaled consistently with the amount of margin to key damage thresholds (i.e., the uncertainty in the fluence estimation should not exceed the margin).

Based on the results of the fluence estimation, the applicant should evaluate the susceptibility of components to loss of fracture toughness. The evaluation should demonstrate that the RV steel supports and other steel structural support components noted above will remain capable of performing their intended function consistent with the current licensing basis through the subsequent period of extended operation. The applicant should include description of the methodologies and assumptions used in sufficient technical detail. The evaluation should include the complete neutron energy spectrum (based on E > 0.1 MeV) in embrittlement predictions, and should consider influence of alloying elements, such as copper, on radiation embrittlement. The structural evaluation should account for current observed and potential future degradations from applicable susceptible aging effects (e.g., loss of material, etc.) and/or address how these susceptible aging effects will be managed consistent with the assumptions made in the evaluation.

3.5.3.2.2.7 Loss of Fracture Toughness Due to Irradiation Embrittlement of Steel Structural Support Components Located in the Vicinity of the Reactor Vessel

Further evaluation is recommended of a plant-specific program (or plant-specific enhancements to selected GALL-SLR AMPs) to manage loss of fracture toughness due to irradiation embrittlement from accumulated neutron fluence and gamma dose, which could occur in BWR and PWR steel structural support components (including associated weldments and bolted connections) located in the

vicinity of the Reactor Vessel (RV) during the subsequent period of extended operation. These components include the RV steel supports, neutron shield tank, steel structural support components of reactor shield wall and sacrificial shield wall, or other steel structural support components located in the vicinity of the RV. Further, loss of function due to radiation exposure (neutron and/or gamma) for non-steel, non-concrete materials (e.g., Lubrite® or other lubricant/coating in support sliding feet) that are used in these structural support components should also be evaluated and dispositioned, with supporting technical information, on a plant-specific basis for the subsequent period of extended operation. If a plant-specific program or program enhancements are determined to be necessary, the reviewer confirms that the acceptance criteria for AMP program elements described in BTP RLSB-1 {Appendix A.1 of NUREG-2192 (SRP-SLR)}. Otherwise, the reviewer confirms the adequacy of the justification provided for the aging effects not requiring management such that intended function(s) are maintained consistent with the CLB for the subsequent period of extended operation.

The applicant may address irradiation aging effects by analysis, testing, aging management inspections (e.g., one-time, periodic), or a combination of these methods; the reviewer confirms the evaluation is supported by an adequate technical basis that also accounts for uncertainties and limitations of available technical data and knowledge. NUREG-1509, “Radiation Effects on Reactor Pressure Vessel Supports,” (Ref. 21) provides general guidance and an acceptable approach (with exception of structural consequence analysis approach) to evaluate loss of fracture toughness via a screening evaluation, a fracture mechanics analysis or a transition temperature analysis (relative to the lowest operating temperature). A plant-specific AMP or plant-specific enhancements to selected GALL-SLR AMPs may not be necessary for the steel structural support components if (i) the screening criteria or criteria for reevaluation in Chapter 4, “RPV Support Reevaluation Criteria,” of NUREG-1509 (with exception of the structural consequence analysis approach in Section 4.5) are satisfied on a plant-specific basis using the technical evaluation procedures described therein; (note that adequacy of technical justification provided for other applicant-proposed demonstrated technical evaluation approachused will be reviewed on a case-by-case basis) and (ii) there is no plant-specific operating experience of irradiation embrittlement observed to date. The methodology in Nonmandatory Appendix A of the ASME Code, Section XI (Ref. 22) may be used for analytical evaluation of postulated flaws in a fracture mechanics analysis. For related non-steel, non-concrete structural support components, the applicant should provide supporting technical information and data to justify its determination regarding the need for a plant-specific program to manage irradiation aging effects; the reviewer evaluates this on a case-by-case basis.

It should be noted that the conclusions in NUREG-1509 (Ref. 21) were based on analyses and limited to neutron fluences relevant to 40 years of operation. Since the neutron fluences for the subsequent period of extended operation to 80 years often exceed the neutron fluence values used in the analyses of NUREG-1509, the analytical methodologies (except the structural consequence analysis approach in Section 4.5) in NUREG-1509 remain applicable but the conclusions are no longer supported.

The reviewer confirms that the applicant’s technical evaluation estimated the neutron and gamma fluence incident on the RV steel supports and other applicable steel structural support components for the subsequent period of extended operation and evaluated

the susceptibility of components to loss of fracture toughness. The evaluation should demonstrate that the RV steel supports and other steel structural support components noted above will remain capable of performing their intended function consistent with the current licensing basis through the subsequent period of extended operation. The reviewer confirms that the evaluation included sufficient description that demonstrate that appropriate methodologies and conservative assumptions were implemented to estimate the levels of neutron fluence and gamma dose for the subsequent period of extended operation. The damage parameter "displacements per atom (dpa)" should include neutrons of all energies (high and low) rather than only those with E > 1 MeV (i.e., embrittlement predictions should include damage from the entire neutron energy spectrum based on E > 0.1 MeV). Alloying elements, such as copper, can increase the rate of radiation embrittlement. Therefore, the evaluation should take into consideration the material properties and chemical composition of the steel (e.g., initial nil ductility temperature (NDT), type of steel, copper content, weld material) and the lowest service (operating) temperature to which the components are exposed.

A structural integrity evaluation of the RV steel supports and other steel structural support components should include all design basis loading combinations referenced in the current licensing basis (CLB). It is essential that the evaluation account for: (1) plant specific operating experience of RV steel supports and other structural components degradation due irradiation embrittlement and other susceptible aging effects; (2) the current as-found physical condition of the supports and structural components; and (3) account for the effects of observed signs of degradation (including but not limited to corrosion, cracks, or permanent deformation) and potential future degradations reasonably projected to the end of the subsequent period of extended operation (i.e., 80 years). This should typically be based on a detailed physical examination (to the extent possible) of the RV supports that is documented in an inspection report that serves as the basis for the evaluation and decisions regarding further actions. Where a detailed physical examination is not feasible, adequately justified assumptions of potential degradations through the end of the subsequent period of extended operation (i.e., 80 years) should be made, or appropriate monitoring actions proposed to manage the susceptible aging effects consistent with the assumptions made in the evaluation.

3.5.6 References: Add the following references.

21. NUREG-1509, "Radiation Effects on Reactor Pressure Vessel Supports," US Nuclear Regulatory Commission, Washington DC, May 1996.

22. ASME. ASME Code, Section XI, "Rules for Inservice Inspection of Nuclear Power Plant Components," Nonmandatory Appendix A, "Analytical Evaluation of Flaws," New York, New York: The American Society of Mechanical Engineers. 2013.

Revise Table 3.5-1 of NUREG-2192 (SRP-SLR) to add the following AMR line items:

SLR Document Changes: Add FE Section 3.5.2.2.2.7 and AMR Items for Irradiation Embrittlement of Reactor Vessel (RV) Steel Supports and Other Steel Structural Support Components near RV

Table 3.5-1 Summary of Aging Management Programs for Containments, Structures and Component Supports Evaluated in Chapters II and III of the GALL-SLR Report							
New, Modified, Deleted, Edited Item	**ID**	**Type**	**Component**	**Aging Effect/Mechanism**	**Aging Management Program (AMP)/TLAA**	**Further Evaluation Recommended**	**GALL-SLR Item**
N	101 (PM to Confirm)	BWR/PWR	Steel structural support components (reactor cavity area proximate to the reactor vessel): reactor vessel support/pedestal/skirt structure; shield wall; sacrificial shield wall; neutron shield tank; reactor vessel support sliding feet assembly; reactor vessel seismic restraints; welds; bolted connections; support anchorage to building structure	Loss of fracture toughness due to irradiation embrittlement	Plant-specific aging management program and/or plant-specific enhancements to selected GALL-SLR AMPs	Yes (SRP-SLR Section 3.5.2.2.2.7)	III.A4.T-36 III.B1.3.T-37 (PM to Confirm)
N	102 (PM to Confirm)	BWR/PWR	Reactor vessel support sliding surfaces, other special components (e.g., special coatings)	Loss of mechanical or other function due to irradiation	Plant-specific aging management program and/or plant-specific enhancement to selected GALL-SLR AMPs	Yes (SRP-SLR Section 3.5.2.2.2.7)	III.B1.3.T-38 (PM to Confirm)

SLR Document Changes: Add FE Section 3.5.2.2.2.7 and AMR Items for Irradiation Embrittlement of Reactor Vessel (RV) Steel Supports and Other Steel Structural Support Components near RV

GALL-SLR (NUREG-2191): Revise the following Tables as indicated below.

Revise Table A4 in Chapter III of NUREG-2191 Volume 1 to add the following:

III STRUCTURES AND COMPONENT SUPPORTS **Table A4 Group 4 Structures (Containment Internal Structures, Excluding Refueling Canal)**								
New, Modified, Deleted, Edited Item	**Item**	**SRP Item (Table, ID)**	**Structure and/or Component**	**Material**	**Environment**	**Aging Effect/Mechanism**	**Aging Management Program (AMP)/TLAA**	**Further Evaluation**
N	III.A4.T-36 (PM to confirm)	3.5-1, 101 (PM to confirm)	Steel structural support components (reactor cavity area proximate to the reactor vessel): reactor vessel support/pedestal/skirt structure; shield wall; sacrificial shield wall; neutron shield tank;	Steel	Air – indoor uncontrolled	Loss of fracture toughness due to irradiation embrittlement	Plant-specific aging management program and/or plant-specific enhancements to selected GALL-SLR AMPs	Yes

Revise Table A4 in Chapter III of NUREG-2191 Volume 1 to add the following:

III STRUCTURES AND COMPONENT SUPPORTS **Table B1.3 Class MC**								
New, Modified, Deleted, Edited Item	**Item**	**SRP Item (Table, ID)**	**Structure and/or Component**	**Material**	**Environment**	**Aging Effect/Mechanism**	**Aging Management Program (AMP)/TLAA**	**Further Evaluation**
N	III.B1.3.T-37 (PM to Confirm)	3.5-1, 101 (PM to confirm)	Reactor vessel support/ skirt: support members; sliding feet assembly; seismic restraints; neutron	Steel	Air – indoor uncontrolled	Loss of fracture toughness due to irradiation embrittlement	Plant-specific aging management program and/or plant-specific	Yes

			shield tank; welds; bolted connections; support anchorage to building structure				enhancements to selected GALL-SLR AMPs	
N	III.B1.3.T-38 (PM to Confirm)	3.5-1, 102 (PM to confirm)	Reactor vessel support sliding feet surfaces, other special components (e.g., special coating)	Lubrite®; Graphitic material; Fluorogold; Lubroflour; special coatings	Air – indoor uncontrolled	Loss of mechanical function due to irradiation	Plant-specific aging management program and/or plant-specific enhancements to selected GALL-SLR AMPs	Yes

Revise the following row in Table IX.E of NUREG-2191 Volume 2 to add the following text indicated in red:

IX.E Use of Terms for Aging Effects	
Term	**Usage in this document**
Loss of fracture toughness	Loss of fracture toughness can result from various aging mechanisms, including thermal aging embrittlement and neutron irradiation embrittlement. In reactor vessel steel supports and other steel structural support components, loss of fracture toughness is caused by irradiation embrittlement and neutrons from the complete energy spectrum (E > 0.1 MeV in contrast to E > 1 MeV used for reactor vessel neutron fluence) should be considered for embrittlement predictions.