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POLICY ISSUE
(Notation Vote)

March 8, 2022 SECY-22-0019

FOR: The Commissioners

FROM: Daniel H. Dorman
Executive Director for Operations

SUBJECT: RULEMAKING PLAN FOR THE REVISION OF EMBRITTLEMENT AND SURVEILLANCE REQUIREMENTS FOR HIGH-FLUENCE NUCLEAR POWER PLANTS IN LONG-TERM OPERATION

PURPOSE:

To request Commission approval to conduct rulemaking to amend the reactor pressure vessel (RPV) embrittlement and surveillance requirements in Title 10 of the *Code of Federal Regulations* (10 CFR) Part 50, "Domestic Licensing of Production and Utilization Facilities," for high-fluence plants in long-term operation.

SUMMARY:

This paper provides the U.S. Nuclear Regulatory Commission (NRC) staff's request to initiate a rulemaking to revise the RPV embrittlement and surveillance requirements in 10 CFR Part 50. The rulemaking would revise Appendix H, "Reactor Vessel Material Surveillance Program Requirements," to 10 CFR Part 50 to include additional surveillance testing requirements for long-term operation and a revised fluence function fit (either a new embrittlement trend curve (ETC) or an update to existing trend curves) in the applicable regulations and implementing

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guidance for all materials that will experience high neutron fluence[1] levels. This revision is necessary because of an underprediction of RPV material neutron embrittlement with the high fluences that will be reached at some pressurized-water reactor (PWR) plants in long-term operation (e.g., beyond 60 years of operation). The amount of underprediction will increase with increased neutron fluence, thus the safety margins associated with protection against brittle fracture will continue to decrease. Under current regulatory practice, licensees can defer, and some have deferred, surveillance capsule testing required by Appendix H to 10 CFR Part 50 that is intended to confirm embrittlement predictions from the ETC model. Using a risk-informed approach, the staff has determined that the combined effect of the underprediction and testing deferral practice could impact the staff's long-term confidence in the integrity of the RPV for certain plants—that is, about 10 years from now. These circumstances recommend change to the current regulations to ensure the safety margins and performance monitoring necessary to provide reasonable assurance that RPV integrity will be maintained over the extended operating lifetime of each plant. The staff's analysis confirms that reactors operating today provide reasonable assurance of adequate protection of public health and safety. This issue is a potential long-term concern that may only affect certain plants and does not compromise the current integrity of the RPVs.

BACKGROUND:

In the event of an accident at a nuclear power plant, the three principal barriers to fission product release are the reactor coolant system, which includes the RPV; the reactor fuel cladding; and the containment vessel(s). These barriers are intended to be independent and to provide defense in depth against fission product release. The NRC regulations provide reasonable assurance that the RPV will independently fulfill its intended functions over the lifetime of the plant during both normal operation and design-basis accidents scenarios. The main focus of these regulations is ensuring that the fracture toughness of the vessel is sufficient to prevent catastrophic failure of the vessel during operation or accident conditions. The failure of the RPV would not only impact the barriers to fission release but would also have a direct impact on the core damage frequency.

Within these regulations, the material fracture toughness predicted by the ETC model in 10 CFR 50.61, "Fracture toughness requirements against pressurized thermal shock events," and Regulatory Guide (RG) 1.99, Revision 2, "Radiation Embrittlement of Reactor Vessel Materials," issued May 1988, is used to demonstrate that the margin to prevent brittle fracture of the RPV is maintained during both normal operation, as defined in 10 CFR Part 50, Appendix G, "Fracture Toughness Requirements," and by 10 CFR 50.61 for pressurized thermal shock (PTS) events. In conjunction, Appendix H to 10 CFR Part 50 contains requirements for performance monitoring through surveillance programs to demonstrate that the generic ETC model predictions adequately describe the properties of critical plant-specific RPV materials over the entire reactor operating lifetime.

The existing ETC model in 10 CFR 50.61 and RG 1.99, was developed in the mid-1980s using data available at the time and presuming an operating lifetime of 40 years for the RPV. This model has several nonconservative characteristics, the most significant being the underprediction of RPV material neutron embrittlement under the high neutron fluences that will be reached at many PWR plants in long-term operation. The amount of underprediction will

[1] Neutron fluence is the cumulative number of neutrons passing through a given area over time and is typically measured in units of neutrons per square centimeter (n/cm^2). Neutron fluence is a parameter used to evaluate the cumulative damage to the material by neutron irradiation.

increase with increased neutron fluence. In parallel, licensees are allowed to defer, and many have deferred, surveillance capsule testing required by Appendix H to 10 CFR Part 50 that is intended to confirm embrittlement predictions from the ETC model.

Embrittlement Trend Curve

The ETC in 10 CFR 50.61 and RG 1.99 was issued in 1988 and was based on the surveillance test data available at that time. The ETC is part of the fabric of 10 CFR 50.61 and Appendix G to 10 CFR Part 50, as both provisions require that the fracture toughness values used in the pressure-temperature limits and PTS analyses account for the effects of neutron irradiation. The requirements in 10 CFR 50.61 include the ETC model and require its use. As such, any updates to the ETC model would necessitate rulemaking. While Appendix G to 10 CFR Part 50 does not require a specific ETC model, RG 1.99 provides guidance that includes the ETC model to account for embrittlement effects. In Generic Letter 88-11, "NRC Position on Radiation Embrittlement of Reactor Vessel Materials and Its Impact on Plant Operations," issued July 1988, the NRC stated that licensees should use RG 1.99 in all pressure-temperature (P-T) limit and PTS analyses unless licensees can justify an alternative method. Hence, most licensees use this RG to determine their plant-specific P-T limits.

The staff performed a comprehensive review of RG 1.99 to evaluate its continued adequacy for the operating power reactor fleet and new light-water-reactor designs (TLR-RES/DE/CIB-2019-2, "Assessment of the Continued Adequacy of Revision 2 of Regulatory Guide 1.99—Technical Letter Report," issued July 2019, Agencywide Documents Access and Management System [ADAMS] Accession No. ML19203A089). This review found potential safety-significant deficiencies in the prediction of embrittlement at high neutron fluences (such as those experienced in long-term operation), the potential for noncredible surveillance data (i.e., data that does not meet the credibility criteria in Section B of RG 1.99), and continued licensee reliance on the RG 1.99 ETC model trend prediction, even when surveillance data indicate a different trend. The staff concluded that the estimates of embrittlement provided by the ETC in RG 1.99 appear to become nonconservative (by a maximum of 150 degrees Fahrenheit (F)) at neutron fluence levels greater than 3 to 6×10^{19} neutrons per centimeter squared (n/cm^2) (fast neutron flux [i.e., E > 1 mega electronvolt MeV]). This is evident for base metals from the U.S. data and corroborated by the international data referenced in the staff's review. No conclusion can be drawn at this time for weld metals because the available data is too sparse; however, the existing data strongly suggests that base metals will manifest this nonconservatism before weld metals.

Surveillance Testing

Appendix H to 10 CFR Part 50 requires licensees to implement a material surveillance program to monitor changes in the fracture toughness properties of ferritic materials in the RPV beltline region due to neutron irradiation. This program must comply with ASTM International (formerly American Society for Testing and Materials) E 185-82, "Standard Practice for Conducting Surveillance Tests for Light-Water Cooled Nuclear Power Reactor Vessels." This standard was developed "to monitor changes in the properties of actual vessel materials caused by long-term exposure to the neutron radiation and temperature environment of the given reactor vessel" because of the variability in the behavior of RPV steels. Under the program required by Appendix H to 10 CFR Part 50, fracture toughness test data are obtained from material specimens exposed in surveillance capsules that are withdrawn periodically from the RPV. Table 1 of the ASTM standard provides a recommended withdrawal schedule for an RPV with a design life of 32 effective full-power years (EFPYs). The last capsule in Table 1 of the ASTM standard is specified for withdrawal when the capsule fluence is “not less than once or greater than twice the peak EOL vessel fluence,” where EOL is defined in the standard as “end-of-life; the design lifetime in terms of years; effective full power years; or neutron fluence.” The standard further notes, “This capsule may be held without testing following withdrawal.” Appendix H to 10 CFR Part 50 further states that “a proposed withdrawal schedule must be submitted with a technical justification” and “must be approved prior to implementation.”

In 1996, the Commission issued a decision that determined that licensees may make changes to the withdrawal schedule without prior approval if the changes are in conformance with the ASTM standard. Changes that are not in conformance with the ASTM standard require a license amendment.[2] This decision was further communicated in NRC Administrative Letter 97-04, “NRC Staff Approval for Changes to 10 CFR Part 50, Appendix H, Reactor Vessel Surveillance Specimen Withdrawal Schedules,” dated September 30, 1997, which states:

> The Commission found that while 10 CFR Part 50, Appendix H, II.B.3 requires prior NRC approval for all withdrawal schedule changes, only certain changes require license amendments as the process to be followed for such approval. Specifically, those changes that do not conform to the ASTM standard referenced in Appendix H (ASTM E 185, Standard Practice for Conducting Surveillance Tests for Light-Water Cooled Nuclear Power Reactor Vessels) will require approval by the license amendment process, whereas changes that conform to the ASTM standard require only staff verification of such conformance.

The NRC addresses plant-specific surveillance programs in three guidance documents: two that are related to license renewal (for plant operation to 60 years) and one for subsequent license renewal (for plant operation to 80 years):

(1) NUREG-0800, “Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants: LWR Edition,” Revision 2, issued March 2007, Section 5.3.1 (SRP), Subsection II (“Acceptance Criteria”), states:

> The material surveillance program criteria of ASTM E 185 cited in 10 CFR Part 50, Appendix H, is predicated on an assumed 40-year reactor vessel design life. For those applicants proposing a facility with greater than a 40-year design life, the criteria of ASTM E 185 must be supplemented to provide for monitoring of the reactor vessel materials for the entire reactor vessel design life.

(2) NUREG-1801, “Generic Aging Lessons Learned (GALL) Report,” Revision 2, issued December 2010, Section XI.M31, “Reactor Vessel Surveillance,” states:

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[2] The Commission’s decision was in response to an appeal of an Atomic Safety and Licensing Board (ASLB) decision. In 1995, in response to a contention that challenged the procedural consequences of removing the material surveillance specimen withdrawal schedule from the Perry Nuclear Power Plant technical specifications, the ASLB held that any change to the Perry surveillance withdrawal schedule for RPV material specimens must be treated as a license amendment (Memorandum and Order LBP-95-17, 42 NRC 137 (1995)). On appeal, the Commission reversed and vacated LBP-95-17 in 1996, holding that not all changes to a withdrawal schedule required a license amendment (Memorandum and Order CLI-96-13, 44 NRC 315 (1996)).

> However, the surveillance program in ASTM E 185 is based on plant operation during the current license term, and additional surveillance capsules may be needed for the period of extended operation.

(3) NUREG-2191, Volume 2, "Generic Aging Lessons Learned for Subsequent License Renewal (GALL-SLR) Report," issued July 2017, Section XI.M31, "Reactor Vessel Material Surveillance," states:

> Parameters Monitored or Inspected: … If a surveillance capsule was previously identified for withdrawal and testing to address the initial period of extended operation, it is not acceptable to redirect or postpone the withdrawal and testing of that capsule to achieve a higher neutron fluence that meets the neutron fluence criterion for the subsequent period of extended operation.
>
> Detection of Aging Effects: … Because the withdrawal schedule in Table 1 of ASTM E 185-82 is based on plant operation during the original 40-year license term, standby capsules may need to be incorporated into the program as capsules to be tested within a withdrawal schedule that covers the subsequent period of extended operation. Alternatively, this program can propose implementation of in-vessel irradiation of capsule(s) with reconstituted specimens from previously tested capsules and appropriate neutron fluence monitoring.

The guidance in these documents is consistent in that the development of ASTM E 185-82 was predicated on a 40-year RPV design life and that surveillance programs for a design life beyond 40 years should be supplemented with additional surveillance capsules to provide for adequate monitoring of the RPV for the entire design life.

<u>DISCUSSION</u>:

<u>Title</u>

Embrittlement and Surveillance Requirements for High-Fluence Nuclear Power Plants

<u>Regulation</u>

Rulemaking to amend the embrittlement and surveillance requirements for high-fluence plants in long-term operation primarily would affect:

- Appendix H to 10 CFR Part 50
- 10 CFR 50.61

<u>Regulatory Issues</u>

<u>Insufficient RPV material surveillance in long-term operation</u>

Appendix H to 10 CFR Part 50 requires licensees to implement a material surveillance program to monitor changes in the fracture toughness properties of ferritic materials in the RPV beltline region due to neutron irradiation. This program must comply with ASTM E 185-82. Table 1 of the ASTM standard provides a recommended withdrawal schedule for an RPV with a design life of 32 EFPYs. Through guidance in the SRP, the GALL Report, and the GALL-SLR, the staff recommended that plant-specific surveillance programs be supplemented to provide monitoring for the plant’s entire design and operating life to address a design life beyond 40 years, a period of extended operation, or a subsequent period of extended operation.

Even with these requirements and guidance, many plants have delayed the withdrawal and testing of the same capsule originally scheduled for the initial 40-year operating license, rescheduled to address the initial period of extended operation, and rescheduled again to address the subsequent period of extended operation. For example, during the review of two subsequent license renewal applications, the staff found that the withdrawal of a capsule intended for the original 40-year surveillance program and credited for aging management under their 60-year renewed operating license had been extended, in some cases several times, until the capsule achieved the 80-year projected peak neutron fluence of interest for the RPV. Some licensees have adopted this practice of repeatedly extending the withdrawal of the same capsule - without the withdrawal and testing of any surveillance capsules in the intervening time to verify the current embrittlement status of the RPVs - with the last available surveillance data in some cases representing less than 30 years of plant operation.

One licensee, under its subsequently renewed license issued in 2019, extended the withdrawal schedule of a particular capsule until approximately 2026; based on this schedule, the RPVs at the site will have been in service for approximately 53 years, and approximately 25 years would have elapsed since the last time the licensee withdrew and tested a capsule (i.e., 2001). Another licensee, under its subsequently renewed license issued in 2021, adopted a similar practice. The schedules approved by the NRC allow the licensee to withdraw a capsule from one unit in 2027 and from the other unit in 2032. Based on these approved schedules, approximately 41 and 30 years will have elapsed since the last capsule with relevant information was withdrawn and tested (1986 and 2002, respectively).

In the review of these subsequent license renewal applications, the staff verified that each licensee’s aging management program contained a sufficient plan to obtain plant-specific surveillance data for the proposed subsequent period of extended operation by withdrawing and testing a capsule with neutron fluence equivalent to the peak RPV fluence at 80 years. Therefore, even with the previous delay in withdrawing some capsules, the surveillance data generated by the aging management program would provide reasonable assurance that embrittlement of the RPV would be adequately managed during the subsequent period of extended operation. However, at any time following issuance of the renewed license, these licensees may elect to modify their surveillance withdrawal schedules per ASTM E185-82, and therefore would further delay the scheduled withdrawal and testing of the capsule credited with monitoring embrittlement at the 80-year equivalent fluence with only a conformance review by the staff.

Licensees are able to delay their final capsule from their original 40-year program because the ASTM E 182-82 standard was not developed to explicitly account for design lives beyond 40 years. ASTM E 185-82 states that the last capsule can be withdrawn when the capsule fluence is “not less than once or greater than twice the peak end-of-life vessel fluence.” Therefore, delaying the final capsule from the original 40-year program to the initial period of extended operation, and then again to the subsequent period of extended operation is still in conformance with the ASTM standard. Further, licensees can also delay the withdrawal and testing of capsules within their licensed period of operation with only a check of conformance of the schedule to ASTM E 185-82 in accordance with Administrative Letter 97-04, allowing plants to continually delay the withdrawal of capsules. These delays can cause a large gap (possibly up to 60 years) in the time between capsule withdrawals, which is in conflict with the periodic monitoring of embrittlement required by Appendix H to 10 CFR Part 50 and described in ASTM E 185-82. In addition, even if these licensees decide to withdraw their last capsules, Appendix H to 10 CFR Part 50 and ASTM E 185-82 do not require that these specimens be tested to confirm the embrittlement status of the RPV. Based on the current regulations and experience, it has been demonstrated that there exists (1) an increasing gap in plant-specific surveillance data, (2) a lack of knowledge of the current embrittlement status of RPV material properties based on surveillance data, and (3) an increased uncertainty in the embrittlement projections of the RPV in the intervening time.

Underprediction of embrittlement in long-term operation

Appendix G to 10 CFR Part 50 specifies fracture toughness requirements for ferritic materials of pressure-retaining components of the reactor coolant pressure boundary to provide adequate margins of safety during any condition of normal operation over the boundary's service lifetime. Appendix G, Section IV.A., states, in part, the following:

> For the reactor vessel beltline materials, including welds, plates and forgings, the values of RT_{NDT}[3] and Charpy upper-shelf energy must account for the effects of neutron radiation, including the results of the surveillance program of Appendix H of this part. The effects of neutron radiation must consider the radiation conditions (i.e., the fluence) at the deepest point on the crack front of the flaw assumed in the analysis.

While Appendix G to 10 CFR Part 50 does not require a specific ETC model, RG 1.99 is the implementing guidance to account for embrittlement effects. In Generic Letter 88-11, "NRC Position on Radiation Embrittlement of Reactor Vessel Materials and Its Impact on Plant Operations," dated July 12, 1988 (ADAMS Accession No. ML031150357), the NRC stated that licensees should use RG 1.99 in all P-T limit and PTS analyses unless licensees can justify an alternative method.

The fracture toughness requirements for protection against PTS events for PWRs are set forth in 10 CFR 50.61, which specifies use of the same ETC as in RG 1.99 to calculate the shift in transition temperature (ΔRT_{PTS}) due to embrittlement at the end-of-life fluence for each of the RPV beltline materials. This shift is used to determine the reference temperature for PTS (RT_{PTS}). RT_{PTS} is then compared to screening criteria (270 degrees F for axial welds and 300 degrees F for circumferential welds), which are based on deterministic fracture mechanics and relevant operating history at the time that the NRC developed 10 CFR 50.61 in the 1980s. If a plant projects that it will surpass these limits in its operating life, the rule specifies mitigative measures to address the issue (e.g., flux reduction, a fracture mechanics analysis, or a thermal annealing treatment of the RPV). The assessment required by 10 CFR 50.61 must be updated whenever there is a significant change[4] in projected values of RT_{PTS}, or upon request for a change in the expiration date for operation of the facility.

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3 RT_{NDT} is defined in 10 CFR Part 50, Appendix G, as the reference temperature of the material, for all conditions. RT_{NDT} is a key input in the calculation of P-T limits.

4 In accordance with 10 CFR 50.61, changes to RT_{PTS} values are considered significant if either the previous value or the current value, or both values, exceed the screening criterion before the expiration of the operating license or the combined license under 10 CFR Part 52, "Licenses, Certifications, and Approvals for Nuclear Power Plants," including any renewed term, if applicable for the plant.

Since both Appendix G to 10 CFR Part 50 and 10 CFR 50.61 require licensees to account for the plant-specific embrittlement behavior of their RPV materials in assuring the RPV integrity during normal operation and accident conditions, an underprediction in embrittlement may result in a reduction in the margin to brittle fracture of the RPV during both normal operations and a PTS event.

Safety Impact on Operating Reactors

The staff conducted a holistic, risk-informed evaluation of RPV structural integrity ("Impacts of Embrittlement on Reactor Pressure Vessel Integrity from a Risk-Informed Perspective," Final Report (ADAMS Accession No. ML21314A228)). In this evaluation, the staff investigated the safety impact of the underpredictions in the ETC from 10 CFR 50.61 and RG 1.99 and the decreased performance monitoring that results from delaying surveillance capsule withdrawals. The staff also investigated the risk significance of these combined issues through both quantitative and qualitative analyses using a targeted sample of approximately 200 individual materials from 21 plants. The staff conducted generic probabilistic fracture mechanics analyses that suggested that, for normal operation, the underprediction in embrittlement can increase the conditional probability of failure by several orders of magnitude for certain transients, but the expected frequency for these transients is low, resulting in a through-wall crack frequency that is typically less than $1x10^{-6}$ per year. However, there is significant uncertainty in extending these generic findings to individual plants, due, for example, to plant-specific material differences, fluence maps (e.g., axial and azimuthal variations), and transient frequencies.

Because of the large uncertainties in the risk calculations, the staff also assessed the impact of these issues on the safety margin associated with normal operations and performance monitoring requirements. Using qualitative analyses, the staff demonstrated that the underprediction in the ETC can decrease the margin in the P-T limits that prevent brittle fracture of the RPV. In addition, uncertainties in the analyses are amplified without the intended periodic performance monitoring in long-term operation.

The staff's evaluation suggests that the embrittlement predictions from this ETC become nonconservative (by a maximum of 150 degrees F) at neutron fluence levels approaching greater than 3 to $6x10^{19}$ n/cm^2 ($E > 1$ MeV). Using peak fluence values from the Electric Power Research Institute (EPRI) Materials Reliability Program MRP-326, "Materials Reliability Program: Coordinated PWR Reactor Vessel Surveillance Program Guidelines (MRP-326)," dated December 19, 2011, an estimated 34 percent of the PWRs will reach a neutron fluence level at the RPV inside surface of $6x10^{19}$ n/cm^2 by 80 years of operation. However, the number of PWRs impacted is heavily based on plant-specific circumstances (i.e., accumulated neutron fluence, plant-specific materials, and available surveillance data); therefore, further work is needed to determine which plants are impacted by this nonconservative prediction. Boiling-water reactors are not expected to approach this neutron fluence threshold because neutron fluence levels are projected to be generally one to two orders of magnitude lower than PWRs at 80 years of operation.

Through this evaluation, the staff demonstrated that underpredicting the embrittlement of the RPV, coupled with a lack of surveillance testing in long-term operation, may eventually (about 10 years from now for PTS; about 23 years from now for P-T limits and upper shelf energy [i.e., the temperature regime where failure occurs in a ductile manner]), impact the staff's confidence in the integrity of the RPV for certain plants. These findings demonstrate that the current regulations may not be adequate to ensure the long-term safety margins and performance monitoring necessary to provide reasonable assurance that RPV integrity will be maintained over the extended operating lifetime of each plant. The staff views this issue as a long-term concern that does not compromise the current integrity of the RPVs.

Impacts on New and Advanced Reactors

In addition to the current operating fleet, the NRC staff investigated the impacts of the ETC in RG 1.99 on new light-water reactors. It is expected that all new known light-water-reactor designs will use modern RPV material chemistries having a low copper content. The staff has demonstrated in TLR-RES/DE/CIB-2019-2 that significant mispredictions of embrittlement may occur for these low-copper-content RPV material chemistries. While it is possible that the ETC in RG 1.99 produces mispredictions of embrittlement for low copper materials, the actual embrittlement of new reactor materials is likely to be low and will not result in a safety issue due to selection of low-copper materials. In addition, some small modular light-water reactor designs operate at temperatures outside of the temperature range for the data used in the development of the current ETC in RG 1.99, thus increasing the uncertainty in the embrittlement prediction. Since the current database used in the development of the ETC in RG 1.99 has no surveillance data for these non-light-water reactor designs, this ETC, and any other that is based on the current surveillance data from light-water reactors, is not applicable to those designs. However, a conservative correction factor may be used to compensate for the misprediction in embrittlement due to temperature, but like chemistry, the expected embrittlement of these new materials is also expected to be low and not a safety issue.

Public Interactions

On May 19, 2020, the NRC staff held a public meeting (ADAMS Accession No. ML20168A008) to present its findings on the evaluation of a potential alternative to RG 1.99 based on the ETC in ASTM E 900-15, "Standard Guide for Predicting Radiation-Induced Transition Temperature Shift in Reactor Vessel Materials," including the technical elements of the potential alternative RG, safety/risk analysis results, and fleet impact. The staff requested industry and public feedback on the technical elements of the proposed alternative RG, on the interest of the industry in the potential for burden reduction with the alternative RG, and on the staff's safety/risk analysis. Participants at this meeting also discussed recent experiences in subsequent license renewal applications with the implementation of reactor vessel material surveillance programs during extended plant operation, relative to Appendix H to 10 CFR Part 50. Feedback from the industry and public stakeholders recommended that the NRC consider:

- Use of a lower minimum temperature limit for an updated ETC, which could allow a power increase for some plants.
- Use of a reduced margin for well-behaved surveillance data (i.e., data that meets the associated credibility criteria).
- Whether updating the ETC to ASTM E 900-15 would improve safety or decrease costs.
- Use of sister plant data when updating the RG.
- Use of forensic harvesting to help with the risk analyses.

On October 18, 2021, the staff held a follow-on public meeting (ADAMS Accession No. ML21309A034) to present results from a holistic, risk-informed analysis related to the safety impact of the underpredictions in the ETC from 10 CFR 50.61 and RG 1.99 and the decreased performance monitoring that results from delaying surveillance capsule withdrawals (ADAMS Accession No. ML21314A228). The staff also requested feedback on potential alternatives to address these issues.

Three external organizations also presented information at the October 18, 2021, public meeting. First, EPRI discussed industry initiatives that will help generate high-fluence data. Second, Duke Energy provided prepared remarks related to the delays in the capsule withdrawal schedule of the RPV material surveillance program at H.B. Robinson Steam Electric Plant. Finally, Beyond Nuclear expressed its concern for the limited amount of time the public has to participate in the NRC staff's review process for subsequent license renewal applications, especially when considering the issues identified by the NRC staff in its presentation. Additional feedback from the public and industry stakeholders recommended the NRC consider:

- ASTM E 900-15 as the preferred ETC model.
- Only one plant will surpass a neutron fluence of $6x10^{19}$ n/cm^2 at a location one-quarter of the wall thickness[5] from the inner diameter before 80 years of operation. The P-T limit calculations in Appendix G to 10 CFR Part 50 use this location at one-quarter of the wall thickness.
- The recent embrittlement prediction issues related to a plant in Japan.
- The effects of neutrons reflected from the concrete on the reactor wall fluence values.
- The implications of data taken from similar materials removed from decommissioned plants.

Existing Regulatory Framework

As described above, Appendix H to 10 CFR Part 50 requires that licensees implement a material surveillance program to monitor changes in the fracture toughness properties of ferritic materials in the RPV beltline region due to neutron irradiation; this program must comply with ASTM E 185-82.

Appendix G to 10 CFR Part 50 specifies the fracture toughness requirements for the RPV materials during normal operation and requires including effects of neutron radiation in the determination of fracture toughness. While Appendix G to 10 CFR Part 50 does not explicitly specify a particular ETC, the NRC indicated its position on an acceptable ETC in Generic Letter 88-11, which recommends using RG 1.99 in all P-T limit evaluations unless licensees can justify an alternative method.

In addition, 10 CFR 50.61 incorporates the ETC in RG 1.99 as a methodology to calculate the shift in transition temperature due to embrittlement at the end-of-life fluence for each of the RPV

5 Due to attenuation, the fluence at the inner diameter location is higher than at a location one-quarter of the wall thickness from the inner diameter.

beltline materials. These estimates are compared to a screening criterion that allows an assessment of the risk of brittle failure due to PTS.

Why Rulemaking Is the Preferred Solution

In its evaluation of the embrittlement issue, the staff considered maintaining the status quo and two rulemaking alternatives, as discussed below.

Alternative 1, Status Quo: Make no changes to Appendix H to 10 CFR Part 50, 10 CFR 50.61, or RG 1.99. To address plant-specific circumstances, the staff would evaluate proposed plant-specific actions in accordance with Management Directive 8.4, "Management of Backfitting, Forward Fitting, Issue Finality, and Information Requests," dated September 20, 2019. In addition, the staff would consider generic communications, such as bulletins and generic letters, to address the issue. Bulletins are intended for significant issues that have great urgency, and generic letters are intended for emergent or routine technical issues with generic applicability or risk-significant compliance matters that should be brought to the attention of licensees promptly.

Pros:

- This is the only alternative that would not require resources for a rulemaking and developing or updating the related guidance documents within the current planning horizon. A rulemaking to address the varying plant-specific circumstances that can affect embrittlement of the RPV could be complex. The staff could continue to use existing guidance and procedures, to the extent applicable. Thus, agency resources would be spent on a plant-specific basis to determine appropriate action, including consideration of backfitting implications. This alternative would be an advantage only if a limited number of licensees continue to pursue long-term operation.

- Existing NRC licensing processes would continue to be used to address this issue on a case-by-case basis in instances where an affected licensee applies for long-term operation.

Cons:

- This alternative may require pursuing multiple plant-specific backfitting actions.

- This alternative could lead to inconsistent approaches between plants. Using a variety of different approaches to correcting this issue may not have a direct impact on plant safety but will impact the reliability and efficiency of NRC regulatory decision making.

- In about 10 years from now, these issues have the potential to affect staff confidence in the integrity of the RPV in long-term operation, and additional work is needed to determine which plants are impacted by these issues and the degree to which they would be impacted. Neither a bulletin nor a generic letter would be sufficient to address the long-term aspects of these issues as additional plants consider extended operation, given the additional work needed to determine the full scope of plants impacted.

Alternative 2, Focused Solution: Revise Appendix H to 10 CFR Part 50 to include additional surveillance testing requirements for long-term operation. A revised fluence function fit (e.g., a new ETC or an update to existing ETCs) would be developed for only RPV materials that will experience high neutron fluence levels and would be appropriately implemented in a manner to be determined in the applicable regulations and guidance.

Pros:

- This alternative is a long-term solution that would focus on a generic basis on the conditions of concern, balance the impact on the plants while regaining confidence in adequate margin and performance monitoring, and provide assurance of adequate protection against RPV failure.

- This alternative would ensure, on a generic basis, that changes in fracture toughness properties of the RPV would be monitored in long-term operation. Furthermore, this alternative would require that licensees withdraw and test surveillance capsules on a schedule consistent with demonstrating adequate aging management in long-term operation, thereby providing confidence in adequate margins of safety for protection against brittle fracture of the RPV.

- This alternative efficiently provides a stable and predictable risk-informed regulatory framework for NRC decision-making and licensee compliance.

- Addressing this issue via rulemaking would provide for stakeholder input.

- Rulemaking would involve a single backfitting action (as compared to Alternative 1) through a revised ETC and new surveillance requirements for licensees that continue to pursue long-term operation and exceed the neutron fluence threshold of $6x10^{19}$ n/cm^2.

Cons:

- Accounting for the various plant-specific scenarios in the existing fleet (i.e., limiting materials, plants with or without surveillance data) in developing a focused solution that does not adversely impact plants at a lower neutron fluence, would require significant agency resources for both rulemaking and guidance development.

Alternative 3, Comprehensive Solution: Revise Appendix H to 10 CFR Part 50 to include additional surveillance testing requirements for long-term operation, update the applicable regulations (e.g., 10 CFR 50.61) to require all licensees to use an NRC-approved ETC that properly accounts for radiation effects, update RG 1.99 to contain an ETC (and associated technical requirements) that appropriately accounts for radiation effects, and update implementing guidance.

Pros:

- This alternative provides all of the pros from Alternative 2 and represents a comprehensive long-term solution to the issue.

- This alternative provides a single, consistent ETC throughout all fluence ranges and removes ambiguity regarding which ETC licensees should use.
- A rulemaking would involve a single backfitting action (as compared to Alternative 1) by revising the regulations to expand the recommended withdrawal schedule contained in

ASTM E 185, modify licensees' ability to hold the last capsule without testing following its withdrawal from the RPV, and add a modified ETC.

Cons:

- This alternative would expend the most NRC resources (i.e., rulemaking and guidance development) because it would revise all applicable regulations and guidance.

- This alternative may have unintended consequences (e.g., unnecessary changes to P-T curves) for plants that are currently at a neutron fluence level that is properly represented by the current ETC in RG 1.99.

Description of Rulemaking: Scope

The staff recommends Alternative 2, a long-term solution which would address the issues presented in this paper in a focused, risk-informed manner. The rulemaking would modify the current surveillance testing requirements in Appendix H to 10 CFR Part 50 to include the withdrawal and testing of at least one capsule with a neutron fluence between one and two times the peak neutron fluence of interest at the end of the licensed life. Additional requirements would ensure that if a surveillance capsule were previously identified for withdrawal and testing to address a certain period of operation (i.e., initial or extended), then it is not acceptable to redirect or postpone the withdrawal and testing of that capsule to a later period of operation.

In addition, the staff would correct the underprediction issue with the current ETC in 10 CFR 50.61 and RG 1.99 with either a new ETC or an update to the existing ETC for all materials that will experience high neutron fluence levels. The decision on how to correct and implement an updated ETC would occur during the development of the regulatory basis if the Commission approves the initiation of this rulemaking. This update would affect those plants with materials that are impacted by the underprediction issue, and the staff would determine its implementation so as not to impact plants where these issues are not relevant.

The staff could modify 10 CFR 50.61 to make the embrittlement requirement similar to that in Appendix G to 10 CFR Part 50. Appendix G requirements are focused on normal operating conditions, and state that the reference temperature of the material "must account for the effects of neutron radiation." The NRC stated in Generic Letter 88-11 that RG 1.99 is to be used to account for neutron radiation in all P-T analyses (Appendix G) unless licensees can justify an alternative method. During the development of the regulatory basis, the staff would determine whether modifying 10 CFR 50.61 in a similar fashion (with an update to RG 1.99) would provide an appropriate solution.

Description of Rulemaking: Preliminary Backfitting and Issue Finality Assessment

The current regulations in Appendix H to 10 CFR Part 50, including the ASTM standard that is incorporated by reference, do not explicitly address the longer reactor lifetimes now being licensed that are beyond the original 40-year license. The staff will evaluate the increased uncertainty at high fluence in determining RPV embrittlement, which comes from a lack of supporting data and a need to adjust the supporting correlations and analyses. The NRC must justify any rulemaking or plant-specific action (i.e., order) in accordance with the NRC's backfitting requirements in 10 CFR 50.109, "Backfitting," and the Commission's policy in MD 8.4. The staff would determine the 10 CFR 50.109 provision that could apply to a rulemaking or plant-specific action. There currently is not a safety issue involving the topic of this rulemaking plan warranting immediate action.

Description of Rulemaking: Estimated Schedule

The following is the estimated schedule for Alternative 2:

- Deliver regulatory basis to the Commission—14 months after receipt of the Commission staff requirements memorandum (SRM) approving rulemaking.

- Deliver proposed rule to the Commission—15 months after the regulatory basis public comment period closes.

- Deliver final rule to the Commission—15 months after the proposed rule public comment period closes.

Implementation of Alternative 3 would take an additional 4 months to complete due to the more comprehensive rule. In addition, Alternative 3 would require additional staff resources to complete the comprehensive long-term solution to the issue, versus the focused solution offered by Alternative 2.

The schedule includes time to coordinate reviews with the Advisory Committee on Reactor Safeguards (ACRS) and the Committee to Review Generic Requirements (CRGR).

The staff will develop a detailed schedule if the Commission approves this rulemaking plan. Further, as the rulemaking progresses, the staff may identify opportunities and efficiencies that allow completing the rulemaking and related guidance sooner.

Description of Rulemaking: Preliminary Recommendation on Priority

Based on the Common Prioritization of Rulemaking (CPR) methodology (ADAMS Accession No. ML18263A070), the preliminary priority for this rulemaking activity is high. Based on the CPR method, the staff has determined that this activity would be a high-priority rulemaking because it would be (1) a significant contributor to the NRC Strategic Plan's safety goal, and it would implement a majority of the Plan's safety strategies, (2) a significant contributor to the efficient and reliability principles of good regulation, (3) a moderate contributor to the governmental priority as it supports the continued operation of high fluence plants in long-term operation, and (4) significant contributor to increasing public awareness and confidence by reducing regulatory uncertainty in RPV integrity in long-term operation from a risk-informed perspective. The priority for a rulemaking activity can change over time. Common reasons for a change in priority are new Commission or senior management direction or changes in the rulemaking scope.

Description of Rulemaking: Estimate of Resources

The enclosure presents an estimate of the resources needed to complete this rulemaking. While this rulemaking is not budgeted in fiscal year 2022, the staff can use the planning, budgeting, and performance management process to reapportion resources within the rulemaking product line under the operating reactor business line to conduct this rulemaking.

Cumulative Effects of Regulation

The staff will follow its cumulative effects of regulation process by engaging with external stakeholders throughout the rulemaking. In consideration of this process during the pre-rulemaking phase, the staff held a public meeting on October 18, 2021. The staff provided potential alternatives (including rulemaking) to address RPV embrittlement in long-term operation but received no feedback as to the effects of these alternatives on licensees.

Additionally, the staff recognizes that the NRC's other rulemaking projects affecting RPV embrittlement that involve increased fuel enrichment and higher fuel burnup may cause plants to reach the fluence limit of concern earlier. The staff will coordinate with these other rulemaking activities to limit overlapping attributes and requirements to minimize the cumulative effects of regulation on licensees.

Agreement State Considerations

The staff identified no Agreement State considerations for this rulemaking because the requirements in Appendix H to 10 CFR Part 50 and 10 CFR 50.61 are not subject to regulation by Agreement States.

Guidance

The staff estimates that the following guidance documents may be updated in parallel with the rulemaking to support the review of licensing actions related to RPV integrity: RG 1.99, Revision 2; the SRP (NUREG-0800); the GALL Report (NUREG-1801, Revision 2); and the GALL-SLR (NUREG-2191).

Advisory Committee on Reactor Safeguards Review

The staff has had several interactions with ACRS members before the development of this rulemaking plan on the separate technical issues (ADAMS Accession No. ML19331A231). The staff briefed the ACRS Subcommittee on Metallurgy and Reactor Fuels on November 15, 2021 (ADAMS Accession No. ML21323A021), on the results of the risk-informed analyses and possible alternatives to address the issues with the ETC underprediction of embrittlement and the delaying of surveillance capsule testing. The ACRS subcommittee requested a full committee brief, currently scheduled for April 2022. They expect to write a letter regarding this effort.

Committee to Review Generic Requirements Review

On June 30, 2021, the staff provided an informational briefing to the CRGR on the issues, the safety impact, and the backfitting and issue finality implications of the proposed regulatory activity. The CRGR agreed that the staff was proceeding correctly, and the Committee is prepared to review the rulemaking activity at the appropriate time. The staff will work with the CRGR to address any backfitting and issue finality subjects that the staff, the CRGR, or interested stakeholders may identify.

Advisory Committee on the Medical Use of Isotopes Review

The staff finds that review by the Advisory Committee on the Medical Use of Isotopes is not necessary because the proposed rulemaking would not affect NRC regulation or licensing of medical uses of byproduct material.

Analysis of Legal Matters

The Office of the General Counsel has reviewed this rulemaking plan and has not identified any issues necessitating a separate legal analysis at this time.

COMMITMENT:

If the Commission approves initiation of the rulemaking, in accordance with SECY-16-0042, "Recommended Improvements for Rulemaking Tracking and Reporting," dated April 4, 2016 (ADAMS Accession No. ML16075A070), the staff will allocate resources in accordance with the CPR process.

RECOMMENDATION:

The staff recommends the Commission take the following action:

- Approve Alternative 2 and proceed with the initiation of a rulemaking to revise Appendix H to 10 CFR Part 50 to include additional surveillance testing requirements for long-term operation and revise applicable regulations and guidance to include a revised fluence function fit for all materials that will experience high fluence levels (e.g., a new ETC or an update to existing ETCs).

RESOURCES:

The enclosure to this plan presents an estimate of the resources needed to complete this rulemaking. The resource estimates in the enclosure are not publicly available.

COORDINATION:

The Office of the General Counsel has no legal objection to this action. The Office of the Chief Financial Officer has reviewed this paper and has no concerns with the estimated resources in the enclosure.

Daniel H. Dorman

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Date: 2022.03.08 15:37:25 -05'00'

Daniel H. Dorman
Executive Director
for Operations

Enclosure:
Estimated Resources (Nonpublic)

SUBJECT: RULEMAKING PLAN FOR THE REVISION TO EMBRITTLEMENT AND SURVEILLANCE REQUIREMENTS FOR HIGH FLUENCE NUCLEAR POWER PLANTS IN LONG-TERM OPERATION, March 8, 2022

ADAMS Accession Nos.: ML21314A194 (pkg); SECY: ML21314A215; Enclosure : ML21314A235
SECY-012

OFFICE	NRR/DNRL: TL	NMSS/REFS/RRPB: PM	QTE	NMSS/REFS/RRPB: RS
NAME	DRudland	SSchneider	JDougherty	GLappert
DATE	11/18/2021	11/18/2021	11/22/2021	11/29/2021
OFFICE	NMSS/REFS/RRPB:	NMSS/REFS/RASB: BC	NRR/DNRL/NVIB: BC	NRR/DORL/LPL4: BC
NAME	IBerrios	CBladey	ABuford	JDixon-Herrity
DATE	12/02/2021	12/03/2021	12/03/2021	12/02/2021
OFFICE	RES/DE/CIB: BC	OCIO/GEMSD/FLICB/ICT: CO	NMSS/REFS: D	NRR/DNRL: D
NAME	RIyengar (BLin for)	DCullison	JTappert (KCoyne for)	BSmith
DATE	12/02/2021	01/12/2022	12/10/2021	12/10/2021
OFFICE	NRR/DORL: D	RES/DE: D	OCFO	RES: D
NAME	BPham (CCarusone for)	LLund	RAllwein (STitherington for)	RFurstenau (SCoffin for)
DATE	12/10/2021	12/09/2021	12/15/2021	12/14/2021
OFFICE	OGC (NLO)	NRR: D	EDO	
NAME	HBenowitz	AVeil (RTaylor for)	DDorman	
DATE	01/26/2022	02/16/2022	03/08/22	

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