Rulemaking for Appendix H to 10 CFR Part 50—Reactor Vessel Material Surveillance Program Requirements—Regulatory Basis

RIN Number: 3150-AK07
NRC Docket ID: NRC-2017-0151

[ENTER DATE HERE]

UNITED STATES NUCLEAR REGULATORY COMMISSION

Executive Summary

Appendix H, "Reactor Vessel Material Surveillance Program Requirements" (Appendix H), to Title 10 of the *Code of Federal Regulations* (10 CFR) Part 50, "Domestic Licensing of Production and Utilization Facilities," requires licensees of commercial light-water nuclear power reactors with a peak neutron fluence at the end of the design life of the reactor vessel (RV) exceeding $1x10^{17}$ neutrons per centimeter-squared (n/cm^2) (with energy greater than 1 million electron volts (E > 1 MeV)) to maintain an RV material surveillance program. This program monitors the changes in mechanical properties of the RV materials. These surveillance programs include a number of capsules that contain test specimens (e.g., Charpy and tensile) and monitoring materials (temperature and dosimetry), that are located inside the RV and placed closer to the core than the inside wall of the RV. Based on their location, the amount of neutron fluence received by these capsules typically exceeds that received by the RV wall itself. Therefore, the test results from the specimens within the surveillance capsule experience operating conditions identical to the vessel wall, but at higher levels of neutron irradiation. This practice allows for the collection of bounding test data regarding the change in material properties of the RV following irradiation, which informs the U.S. Nuclear Regulatory Commission's (NRC) regulatory decisions and operational assessments of the RV material at operating plants.

The NRC has not modified the regulatory requirements for the design and implementation of an RV material surveillance program since 1995. The requirements in Appendix H to 10 CFR Part 50 are based, in part, on the information contained within the American Society for Testing and Materials (ASTM) E 185-73, "Standard Recommended Practice for Surveillance Tests for Nuclear Reactor Vessels"; ASTM E 185-79, "Standard Practice for Conducting Surveillance Tests for Light-Water Cooled Nuclear Power Reactor Vessels"; and ASTM E 185-82, "Standard Practice for Conducting Surveillance Tests for Light-Water Cooled Nuclear Power Reactor Vessels," which are incorporated by reference.

The material data obtained from the RV material surveillance program, established under Appendix H to 10 CFR Part 50, are used by the fracture toughness analyses required by Appendix G, "Fracture Toughness Requirements" (Appendix G), to 10 CFR Part 50; 10 CFR 50.61, "Fracture Toughness Requirements for Protection Against Pressurized Thermal Shock Events"; and 10 CFR 50.61a, "Alternate Fracture Toughness Requirements for Protection Against Pressurized Thermal Shock Events."

In 2008, the NRC broadened the scope of its ongoing rulemaking effort for Appendix G to 10 CFR Part 50 to incorporate revisions to Appendix H to 10 CFR Part 50. Six years later, in June 2014, the NRC staff requested Commission approval in COMSECY-14-0027, "Rulemaking to Revise Title 10, *Code of Federal Regulations*, Part 50, Appendix H, 'Reactor Vessel Material Surveillance Program Requirements,'" (NRC, 2014a, not publicly available), to separate the rulemaking activities of Appendix G from Appendix H to 10 CFR Part 50. The NRC staff requested this separation because the complex technical basis for revising Appendix G to 10 CFR Part 50 was not complete. The Commission, in its staff requirements memorandum (SRM) to COMSECY-14-0027, dated August 8, 2014 (NRC, 2014b, not publicly available), approved the NRC staff's request to begin rulemaking activities on Appendix H to 10 CFR Part 50, independent of the completion date or conclusions related to the technical basis development activities for Appendix G to 10 CFR Part 50.

The purpose of this rulemaking effort is to amend the requirements of Appendix H to 10 CFR Part 50 and thus reduce the regulatory burden on reactor licensees and the NRC for a

non-safety-significant issue. This document provides the regulatory basis for revising the regulations in Appendix H to 10 CFR Part 50. It describes the regulatory framework for RV material surveillance programs, provides summary information on the background of these surveillance programs, outlines the regulatory topics that have motivated this rulemaking effort, and presents options to address these topics. Finally, it assesses the relative efficiency of two typical rulemaking processes: standard notice-and-comment rulemaking and the direct final rule process. The NRC staff analysis shows that this rulemaking can be conducted with no impact to public health and safety and the environment; staff recommends that NRC conduct this rulemaking effort using the direct final rule process. This abbreviated process would minimize the use of agency resources and potentially allow the revised requirements to become effective sooner, thus providing licensees the benefit of the rule change sooner.

Table of Contents

List of Figures

List of Tables

Abbreviations and Acronyms

Δ	change or delta
ADAMS	Agencywide Documents Access and Management System
AEC	Atomic Energy Commission
ASME	American Society of Mechanical Engineers
ASME Code	ASME Boiler and Pressure Vessel Code
ASTM	ASTM International (formerly American Society for Testing and Materials)
B&W	Babcock & Wilcox
BWR	boiling-water reactor
BWRVIP	Boiling Water Reactor Vessels and Internals Program
°C	Celsius
CFR	Code of Federal Regulations
cm	centimeter(s)
CMM	correlation monitor material
CER	cumulative effects of regulation
E	energy
EPRI	Electric Power Research Institute
ETC	embrittlement trend curve
°F	Fahrenheit
FA	fuel assembly
FR	*Federal Register*
GALL	Generic Aging Lessons Learned
HAZ	heat-affected zone
ISP	integrated surveillance program
LR	license renewal
MeV	million electron-volts
MIRVSP	Master Integrated Reactor Vessel Surveillance Program
n	neutron
NEI	Nuclear Energy Institute
NPV	net present value
NRC	U.S. Nuclear Regulatory Commission
PERT	program evaluation and review technique
PTS	pressurized thermal shock
PWR	pressurized-water reactor

RG	regulatory guide
RPV	reactor pressure vessel
RT_{NDT}	reference temperature for nil-ductility transition
RT_{PTS}	reference temperature for pressurized thermal shock
RV	reactor vessel
SECY	Office of the Secretary
SLR	subsequent license renewal
SRM	staff requirements memorandum
T_0	master curve reference temperature
U.S.	United States of America
USE	upper-shelf energy
WGOPC	Working Group on Operating Plant Criteria
YS	yield strength

1.0 Introduction

1.1 Scope of Document

The scope of this document encompasses commercial light-water nuclear power reactors required to have a reactor vessel (RV) material surveillance program under Appendix H, "Reactor Vessel Material Surveillance Program Requirements" (Appendix H), to Title 10 of the *Code of Federal Regulations* (10 CFR) Part 50, "Domestic Licensing of Production and Utilization Facilities."

This document provides the regulatory basis for the Appendix H to 10 CFR Part 50 rulemaking effort. It also explains the existing framework for RV material surveillance programs, summarizes background information, describes regulatory topics that have motivated this rulemaking effort, and presents options to address this effort.

Section 1.0 of this regulatory basis summarizes the background associated with an RV material surveillance program and developments leading to this rulemaking effort. Section 2.0 details the existing regulatory framework for Appendix H to 10 CFR Part 50 and the way in which surveillance data obtained from an RV material surveillance program are used to demonstrate compliance with certain requirements of 10 CFR Part 50. Section 3.0 describes the regulatory topics associated with Appendix H to 10 CFR Part 50 that this rulemaking effort will address and the basis for doing so. Section 4.0 provides an assessment of the options considered during this rulemaking effort. Section 5.0 discusses the other regulatory considerations related to this rulemaking effort for Appendix H to 10 CFR Part 50. Section 6.0 discusses stakeholder involvement. Section 7.0 contains the references that appear in this document.

1.2 Background

1.2.1 Description of a Reactor Vessel Material Surveillance Program

The RV and its internal components support and align the fuel assemblies that make up the reactor core and provide a flow path to ensure adequate heat removal from the fuel assemblies. It also provides containment and a floodable volume to maintain core cooling in the event of an accident causing loss of the primary coolant. The RV is comprised of a cylindrical shell with a welded hemispherical bottom head and a removable hemispherical upper head. Some vessel shells were fabricated from curved plates that were joined by longitudinal and circumferential welds. Others were manufactured using forged rings and, therefore, only have circumferential welds that join the rings. These plate and forging materials are referred to as base metals. Maintenance of the structural integrity of the RV is essential in ensuring plant safety, because there is no redundant system to maintain core cooling in the event of a vessel failure.

One characteristic of RV steels is that their material properties change as a function of temperature and neutron irradiation. The primary material property of interest for the purposes of RV integrity is the fracture toughness of the RV material. Extensive experimental work determined that Charpy impact energy tests, which measure the amount of energy required to fail a small material specimen, can be correlated to change in fracture toughness of a material.

Thus, the Charpy impact specimen[1] became the standard to assess the change in fracture toughness in ferritic steels.

The fracture toughness of RV materials decreases with decreasing temperature and decreases with increasing irradiation from the reactor. The decrease in fracture toughness due to neutron irradiation is referred to as "neutron embrittlement." The fracture toughness of RV materials is determined by using fracture toughness curves in the American Society of Mechanical Engineers (ASME) Code, which are indexed to the reference temperature for nil-ductility transition (RT_{NDT}), as specified in ASME Code Section II. To account for the effects of neutron irradiation, the increase in RT_{NDT} is equated to the increase in the 30 ft-lb index temperature from tests of Charpy-V notch impact specimens irradiated in capsules as a part of the surveillance program. The surveillance program includes Charpy impact specimens of the base and weld metals for the RV in each surveillance capsule. These surveillance capsules are exposed to the same operating conditions as the RV, and because the capsules are located closer to the reactor core than the RV inner diameter, the surveillance specimens are generally exposed to higher neutron irradiation levels than those experienced by the RV at any given time.

As a result, the test specimens generally reflect changes in fracture toughness due to neutron embrittlement in advance of what the RV experiences and provide insight to the future condition of the RV. Therefore, the NRC instituted RV material surveillance programs as a requirement of Appendix H to 10 CFR Part 50, so that the placement and testing of Charpy impact specimens in capsules between the inner diameter vessel wall and the core can provide data for assessing and projecting the change in fracture toughness of the RV.

For those RVs that require a material surveillance program,[2] its purpose is to monitor changes in the fracture toughness properties of materials in the beltline region[3] of the RV and to use this information to analyze the RV integrity. Surveillance programs are designed not only to examine the current status of RV material properties but also to predict the changes in these properties resulting from the cumulative effects of irradiation.

The determination as to whether a commercial nuclear power RV requires a material surveillance program under Appendix H to 10 CFR Part 50 was made at the time of plant licensing. If this program was required, the surveillance program was designed and

Commented [A1]: Revise to cover New Reactors.

---

1 A bar of metal, or other material, having a V-groove notch machined across the 10mm thickness dimension.

2 Appendix H to 10 CFR Part 50 requires a material surveillance program for reactor vessels in which the peak neutron fluence at the end of the design life will exceed 1 x 10^{17} neutrons/centimeter-squared (n/cm^2) with energy greater than one million electron volts (E > 1 MeV). The test data obtained from this material surveillance program is used to demonstrate compliance with Appendix G to 10 CFR Part 50, for the reactor vessel beltline materials.

3 Appendix G to 10 CFR Part 50 defines the beltline region as the region of the reactor vessel (shell material including welds, heat-affected zones (HAZs), and plates or forgings) that directly surround the effective height of the active core and adjacent regions of the reactor vessel that are predicted to experience sufficient neutron radiation damage to be considered in the selection of the most limiting material with regard to radiation damage. This definition in Appendix G to 10 CFR Part 50 is applicable to all RV vessel ferritic materials with projected neutron fluence values greater than 1 x 10^{17} n/cm^2 (E > 1 MeV), and this fluence threshold remains applicable for the design life as well as throughout the licensed operating period.

implemented at that time using the existing requirements. Certain aspects of the program, such as the specific materials to be monitored, the number of required surveillance capsules to be inserted in the RV, and the initial capsule withdrawal schedule were designed for the original licensed period of operation (i.e., 40-years). Appendix H to 10 CFR Part 50 required three, four, or five surveillance capsules to be included in the design of reactor material surveillance programs for the original licensed period of operation, based on the irradiation sensitivity of the material used to fabricate the RV. Most plants have included several additional surveillance capsules beyond the number required by Appendix H to 10 CFR Part 50~~,~~. These capsules~~which~~ are referred to as standby capsules. The surveillance program for each RV provides assurance that the plant's operating limits (e.g., the pressure-temperature limits) continue to meet the provisions in Appendix G of Section XI of the ASME Code, as required by Appendix G to 10 CFR Part 50. The program also provides assurance that the RV material upper shelf energy meets the requirements of Appendix G to 10 CFR Part 50. These assesments are used to ensure the integrity of the RV.

Commented [A2]: Verify that this is accurate. The number of capsules is in the same table in ASTM E185-82 that the staff is characterizing as providing only a recommended withdrawal schedule; why does the staff not consider the minimum number of capsules from that table a recommendation rather than a requirement?

To assess the integrity of each RV, the material properties of the RV materials must be determined. The properties of these materials in the unirradiated condition are assessed by using the ASME Section III provisions, and changes in the properties due to irradiation are monitored using the surveillance program. As a result, the unirradiated material properties of the RV materials are necessary to measure the irradiation shift of the tested surveillance materials. This measurement is important, because it provides an indication of the embrittlement in the RV itself and generally provides the ability to assess future projections of RV integrity, because the surveillance capsules and test specimens typically experience a higher neutron fluence level than the RV.

The changes in material properties due to irradiation are a function of the initial chemistry of the RV base metal, weld wire, and weld flux that were used in the fabrication of the RV, particularly the copper and nickel contents of the material, as well as the effect of neutron exposure on these same materials. These properties become the input data that are used in the assessment of the RV's structural integrity to meet the requirements of Appendix G to 10 CFR Part 50,~~;~~ 10 CFR 50.61, "Fracture Toughness Requirements for Protection Against Pressurized Thermal Shock Events,"~~;~~ and 10 CFR 50.61a, "Alternate Fracture Toughness Requirements for Protection Against Pressurized Thermal Shock Events." Under Appendix G to 10 CFR Part 50, limits[4] are placed on the operation of nuclear power plants to ensure that brittle failure of the RV does not occur. The surveillance capsules, which contain these Charpy impact specimens, are periodically withdrawn and tested during the licensed period of operation of a reactor and evaluated to determine the effect of radiation on the RV steel. Based on these test results, adjustments to the technical specifications—either in the pressure-temperature operating limits for the plant or in the operating procedures required to meet the limits—are made as necessary.

In addition to the Charpy impact specimens ~~Beyond~~ for determining the embrittlement in the RV ~~using Charpy impact specimens~~, the surveillance capsules typically contain neutron dosimeters, thermal monitors, and tension specimens.[5]~~.~~ Surveillance capsules may also contain correlation monitor material (CMM), which is a material with composition, properties, and response to

4 The Appendix G to 10 CFR Part 50 limits include the Charpy upper shelf energy requirement, the pressure-temperature limits, and the minimum temperature requirement.

5 Tension specimens have a standardized sample cross-section, with two shoulders and a gage (section) in between.

radiation that have been well-characterized. The overall accuracy of neutron fluence measurements is dependent upon knowledge of the neutron spectrum. Therefore, a variety of neutron detector materials (dosimetry wires) are included in each surveillance capsule and used in the determination of neutron fluence for the vessel. The thermal monitors that are placed in the capsules (e.g., low melting point elements or eutectic alloys) are used to identify the irradiated specimen temperature.

Reactor material surveillance programs and capsule withdrawal schedules were initially designed based on the original 40-year operating license. However, as a means to comply with 10 CFR Part 54, “Requirements for Renewal of Operating Licenses for Nuclear Power Plants,” and demonstrate that neutron embrittlement of the RV will be adequately managed during extended operation, licensees have maintained their surveillance programs required by Appendix H to 10 CFR Part 50 as supplemented by additional guidance. The NRC documented this guidance in the original NUREG-1801, “Generic Aging Lessons Learned (GALL) Report,” issued 2001 (NRC, 2001); NUREG-1801, Revision 1, issued 2005 (NRC, 2005); and Revision 2, issued 2010 (NRC, 2010),” for plants operating for 60 years; and in NUREG-2191, “Generic Aging Lessons Learned for Subsequent License Renewal (GALL-SLR) Report,” issued 2017 (NRC, 2017d), for plants operating for 80 years. Therefore, the RV material surveillance programs are ongoing programs that extend beyond the original license of a nuclear power plant (i.e., license renewal to operate for 60 years and for subsequent license renewal (SLR) to operate for 80 years). The objective of the surveillance program during the license renewal and SLR periods is to continue monitoring changes in fracture toughness properties of the RV materials through the operating life of the plant to ensure the integrity of the RV. As such, there are no aspects of the surveillance program that are uniquely affected by license renewal or SLR.

Since the withdrawal schedule of surveillance capsules was based on plants operating during the original 40-year license term, it may be necessary for standby capsules or capsules containing reconstituted specimens (i.e., specimens of previously tested capsules) to be incorporated into the RV material surveillance program to provide monitoring during plant operation beyond the original 40-year license term. As an additional alternative, NUREG-1801 (original and Revisions 1 and 2) and NUREG-2191 indicated that applicants may join an integrated surveillance program (ISP), which is further discussed in Section 1.2.2. of this document. Because of the maturity of RV material surveillance programs in the existing operating fleet, the vast majority of the surveillance capsules that were inserted into the RV for the original licensed period of operation have already been withdrawn and tested. In addition, a portion of the existing operating fleet has also withdrawn and tested surveillance capsules that account for the license renewal period ~~o~~from 40 to 60 years of plant operation.

1.2.2 Types of Reactor Vessel Material Surveillance Programs

Plant-Specific Programs

In plant-specific programs, the surveillance capsules located within the RV of a plant contain specimens taken from materials used in fabricating the beltline of the RV ~~that are located within the RV of that plant~~. These capsules are then periodically withdrawn according to ~~an~~ NRC-approved withdrawal schedules and the specimens are tested to monitor the reduction in fracture toughness caused by neutron irradiation that has occurred during the operation of that specific plant~~RV~~. Under Appendix H to 10 CFR Part 50, the testing procedures and reporting requirements must meet the American Society for Testing and Materials International (ASTM) E 185-82, “Standard Practice for Conducting Surveillance Tests for Light-Water Cooled

Nuclear Power Reactor Vessels," to the extent practicable for the configuration of the specimens in the capsule. The design of the surveillance program and the withdrawal schedule must meet the requirements of the ASTM E 185 that is current on the issue date of the ASME Code to which the RV was purchased. Later editions of ASTM E 185, up to and including those editions through 1982, may be used. In sum, the surveillance program must comply with ASTM E 185, as modified by Appendix H to 10 CFR Part 50.

Commented [A3]: How will this work for a new power reactor purchasing an RV after the effective date of ASTM E185-16? That is the edition of E185 that is current now, but it is not incorporated by reference in 10 CFR Part 50, Appendix H. It is not eliminated by the clause regarding "later editions of ASTM E 185 may be used, but including only those editions through 1982" because it isn't a "later edition" for a new reactor, it's the current version.

Based upon the Vogtle 3 & 4 UFSAR and FSER, it appears that their surveillance programs are based upon ASTM E185-82, though there seem to be more than the 5 capsules recommended in ASTM E185-82, Table 1.

Integrated Surveillance Programs (ISP)

As an alternative to a plant-specific program, Appendix H to 10 CFR Part 50 permits the use of an ISP that requires review and approval by the NRC before implementation. In an ISP, the representative materials chosen for surveillance for a reactor are irradiated in one or more other reactors that have similar design and operating features. The data obtained from these test specimens may then be used in the analysis of other plants participating in this program. Under Appendix H to 10 CFR Part 50, the testing procedures and reporting requirements must meet ASTM E 185-82, to the extent practicable for the configuration of the specimens in the capsule.

Currently, the NRC has approved the following ISPs for use in the United States:

- Boiling Water Reactor Vessels and Internals Program (BWRVIP) Integrated Surveillance Program

- Master Integrated Reactor Vessel Surveillance Program (MIRVSP)

BWRVIP ISP

Before the implementation of the BWRVIP ISP, many of the boiling-water reactor (BWR) plants did not have surveillance material that represented the limiting plate or weld material of the subject RV. Given these limitations, the Supplemental Surveillance Program was introduced in the late 1980s to obtain additional BWR surveillance data on well-characterized BWR vessel materials. This program successfully filled in gaps in the existing plant-specific surveillance programs to match the BWR fleet limiting beltline materials. The BWRVIP utilities concluded that an ISP would provide significant benefits over the current individual surveillance programs. The BWRVIP utilities identified two primary benefits of the ISP: (1) the quality of BWR surveillance data would be improved, and (2) the overall costs to the BWR fleet would be reduced. In 1998, the BWRVIP developed an ISP that combined all the separate U.S. BWR plant-specific surveillance programs into a single integrated program, using host reactor capsules containing select representative materials and added data from the ongoing Supplemental Surveillance Program. The ISP resulted in a better representation of the limiting beltline materials for each plant, while reducing the number of capsules to be tested.

The NRC approved the implementation of the BWRVIP ISP by letter dated February 1, 2002, for the original license of applicable~~the~~ plants in BWRVIP-86-A, ~~by letter dated February 1, 2002~~ (BWRVIP, 2002; includes the NRC approval letter), and for the period of extended operation (i.e., license renewal) by letter dated February 24, 2006, in BWRVIP-116-A, ~~by letter dated February 24, 2006~~ (BWRVIP, 2006—proprietary).

MIRVSP

In 1976, the capsule holders in a number of Babcock & Wilcox (B&W) 177-Fuel Assembly (FA) plants were found to be damaged, and subsequent inspections revealed that all of the capsule holders were damaged to some extent from cracking caused by flow-induced vibration. Furthermore, all of the early vintage B&W designed RVs were fabricated using the submerged arc welding process and welding consumables that resulted in welds that were sensitive to fast neutron exposures (i.e., the Linde 80 class of materials).

The MIRVSP was developed in 1977 for the B&W 177-FA plants as the result of the two conditions described above to augment the existing plant-specific RV material surveillance programs and share information among plants. Following its development, the program was modified in 1988 to include Westinghouse Nuclear Steam Supply System plants with RVs manufactured by B&W, because they have essentially identical welds (i.e., the Linde 80 class of materials) as the B&W 177-FA plants. The MIRVSP is involved in continuing the plant-specific surveillance programs to monitor the long-term effects of neutron irradiation on the RV materials and uses specially designed higher fluence and supplementary weld metal surveillance capsules to study the effects of irradiation on specially selected weld metals.

The NRC approved the implementation of the MIRVSP by letter dated June 11, 1991, ~~which~~ ~~is~~as detailed in BAW-1543, Revision 3~~, by letter dated June 11, 1991~~. BAW-1543, Revision 4 (MIRVSP, 1993), was essentially the same as Revision 3, with the exception of an update to some of the units' withdrawal schedules. Seven supplements have been issued since BAW-1543, Revision 4; in general, the supplements included updates to fluence values and to the surveillance capsule insertion and withdrawal schedules, deleted certain plants from the program, and incorporated the disposal plan for stored surveillance capsules.

1.2.3 Appendix H to 10 CFR Part 50 Rulemaking Effort

In 2001, the NRC began a rulemaking to revise Appendix G to 10 CFR Part 50 (RIN 3150-AG98; NRC Docket ID: NRC-2008-0582) to eliminate the pressure-temperature limits related to the metal temperature of the RV closure head flange and vessel flange areas. The NRC expanded the rulemaking scope in 2008 to include revisions to Appendix H to 10 CFR Part 50, because the fracture toughness analysis required by Appendix G to 10 CFR Part 50 relies on data obtained from the RV material surveillance program established under Appendix H to 10 CFR Part 50.

In COMSECY-14-0027, "Rulemaking to Revise Title 10, *Code of Federal Regulations*, Part 50, Appendix H, 'Reactor Vessel Material Surveillance Program Requirements,'" issued on June 25, 2014 (NRC, 2014a, not publicly available), the NRC staff requested Commission approval to separate the rulemaking activities to revise both Appendices G and H to 10 CFR Part 50, and to proceed separately with rulemaking for Appendix H to 10 CFR Part 50.

The Commission in its staff requirements memorandum (SRM) to COMSECY-14-0027, dated August 8, 2014 (NRC, 2014b, not publicly available), approved the staff's recommendation to proceed with a separate rulemaking for Appendix H to 10 CFR Part 50. The SRM to COMSECY-14-0027 directed the staff to begin the Appendix H to 10 CFR Part 50 rulemaking independent of the completion date or conclusions of the Appendix G to 10 CFR Part 50 technical basis development activities. Subsequently, the Commission directed the staff in SRM-SECY-16-0009, "Recommendations Resulting from the Integrated Prioritization and Re-Baselining of Agency Activities," dated April 13, 2016 (NRC, 2016), to stop all work on the development of the technical basis for a potential change to Appendix G to 10 CFR Part 50.

1.3 Problem Statement

Since the issuance of Appendix H to 10 CFR Part 50 in 1973, substantial material data analyses, knowledge, and experience have been attained through the many years of conducting RV material surveillance programs. Thus, this rulemaking effort is being undertaken to reduce the regulatory burden on both reactor licensees and the NRC by reducing testing and reporting requirements, which will not impact public health and safety and the environment. Section 3.0 discusses the areas that are being considered during this rulemaking effort.

2.0 Existing Regulatory Framework

2.1 Appendix H to 10 CFR Part 50

2.1.1 Current Requirements under Appendix H to 10 CFR Part 50

Light-water RVs are fabricated from low-alloy steel, which can become less ductile, and thereby more susceptible to unstable fracture because of the cumulative effects of neutron irradiation. Under Appendix H to 10 CFR Part 50, an RV material surveillance program is required for RVs for which the peak neutron fluence at the end of the design life of the vessel will exceed 10^{17} n/cm^2 (E > 1.0 MeV). The purpose of the material surveillance program required by Appendix H to 10 CFR Part 50 is to monitor changes in the fracture toughness properties of ferritic materials in the RV beltline region of light-water nuclear power reactors that result from exposure of these materials to neutron irradiation and the thermal environment. Under this material surveillance program, fracture toughness test data are obtained from irradiated material specimens exposed in surveillance capsules, which are withdrawn periodically from the RV.

The activities addressed as part of designing an RV material surveillance program include selecting materials to be monitored by the surveillance program, selecting appropriate test specimen types and numbers of specimens, establishing the number of capsules and their placement in the RV; and developing the surveillance capsule withdrawal schedule. The activities addressed as part of the conduct of an RV material surveillance program include maintaining a surveillance capsule withdrawal schedule, periodically withdrawing capsules, performing tests on the specimens contained in the capsules, and reporting the test results.

The design of this material surveillance program and the withdrawal schedule must meet the requirements of the edition of ASTM E 185 that is current on the issue date of the ASME Code when the RV was purchased. Later editions of ASTM E 185, up to and including those editons through 1982 (ASTM E 185-82), may be used. Appendix H to 10 CFR Part 50 specifically incorporates by reference ASTM E 185-73, “Standard Recommended Practice for Surveillance Tests for Nuclear Reactor Vessels”; ASTM E 185-79, “Standard Practice for Conducting Surveillance Tests for Light-Water Cooled Nuclear Power Reactor Vessels”; and ASTM E 185-82, “Standard Practice for Conducting Surveillance Tests for Light-Water Cooled Nuclear Power Reactor Vessels.” In sum, the surveillance program must comply with ASTM E 185, as modified by Appendix H to 10 CFR Part 50. The proposed withdrawal schedule, including any changes to the withdrawal schedule, must be submitted to and approved by the NRC, before implementation.

Commented [A4]: This does accurately reflect the current wording of Appendix H, but doesn’t address any limitation to ASTM E185-82 for the current ASME code when the RV was purchased.

Appendix H to 10 CFR Part 50 requires that surveillance specimen capsules be located near the inside RV wall in the beltline region so that the specimen irradiation history duplicates, to the extent practicable, the neutron spectrum, temperature history, and maximum neutron fluence experienced by the RV inner surface. Furthermore, the design and location of the surveillance capsule holders must permit insertion of replacement capsules.

For each capsule withdrawal, the test procedures and reporting requirements must meet the requirements of ASTM E 185-82, to the extent practicable for the configuration of the specimens in the capsule. This is to ensure that the changes in mechanical properties of the ferritic RV materials can be evaluated and to provide experimental data to benchmark against dosimetry calculations.

As an alternative to a plant-specific material surveillance program, Appendix H to 10 CFR Part 50 permits the development of an ISP, which requires approval by the NRC, on a case-by-case basis. An ISP involves representative materials chosen for surveillance for a reactor being irradiated in one or more other reactors that have similar design and operating features. Appendix H to 10 CFR Part 50 requires that an ISP incorporate the following criteria:

- The reactor in which the materials will be irradiated and the reactor for which the materials are being irradiated must have sufficiently similar design and operating features to permit accurate comparisons of the predicted amount of radiation damage.
- Each reactor must have an adequate dosimetry program.
- There must be adequate arrangements for data sharing among plants.
- There must be a contingency plan to ensure that the surveillance program for each reactor will not be jeopardized by operating at a reduced power level or by an extended outage of another reactor from which data are expected.
- There must be substantial advantages to be gained, such as reduced power outages or reduced personnel exposure to radiation, as a direct result of not requiring surveillance capsules in all reactors in the set.

For an ISP, Appendix H to 10 CFR Part 50 does not permit a reduction in the requirements for the number of materials to be irradiated, the specimen types, or the number of specimens per reactor, nor is a reduction in the amount of testing permitted unless previously authorized by the Director, Office of Nuclear Reactor Regulation, or the Director, Office of New Reactors, as appropriate.

Following each withdrawal and testing of a surveillance capsule, the test results must be the subject of a technical report, which must include the data required by ASTM E 185 and the results of all fracture toughness tests conducted on the beltline materials in the irradiated and unirradiated conditions. The report must be submitted to the NRC within one year of the date of capsule withdrawal, unless an extension is granted by the Director, Office of Nuclear Reactor.

2.1.2 Current Regulatory Guidance for Appendix H to 10 CFR Part 50

Initial ~~40-Year Operating License~~Period of Operation

Appendix H to 10 CFR Part 50 requires that RVs have their beltline materials monitored by a surveillance program complying with ASTM E 185. Specifically, the design of the surveillance program and the withdrawal schedule must meet the requirements of the edition of the ASTM E 185 that is current on the issue date of the ASME Code to which the RV was purchased. Later editions of ASTM E 185, up to and including those editions through 1982, may be used. In sum, the surveillance program must comply with ASTM E 185, as modified by Appendix H to 10 CFR Part 50. Furthermore, the test procedures and reporting requirements must meet the requirements of ASTM E 185-82 to the extent practicable for the configuration of the specimens in the capsule for each capsule withdrawal.

ASTM E 185 contains the necessary procedures and guidelines for the design of a surveillance program. Specifically, this includes the selection of RV materials to be monitored and the contents within the surveillance capsule, the means to encapsulate these contents and the location of the surveillance capsules within the RV. ASTM E 185 also contains the necessary procedures and guidelines for measuring and testing the contents of the surveillance capsule, and for reporting the results to the NRC; specifically, measuring the mechanical properties and radiation exposure conditions, and determining the irradiation effects. Under Appendix H to 10 CFR Part 50 and ASTM E 185, the surveillance program and the withdrawal schedule were originally established and designed for the initial 40-year operating license of a nuclear power plant (see Section 7.6.2 of ASTM E 185-79 and ASTM E 185-82).

Commented [A5]: Revise to cover combined license holders.

~~Renewal of Operating License~~ License Renewal and Subsequent License Renewal

To renew its operating license or combined license for plant operation beyond 40-years, a licensee~~s~~ must comply with the regulations in 10 CFR Part 54 and demonstrate that the effects of aging will be adequately managed so that the intended function of systems, structures and components within the scope of 10 CFR Part 54 will be maintained consistent with the current licensing basis. Thus, licensees have continued to use their surveillance programs ~~required by~~under Appendix H to 10 CFR Part 50 as supplemented by additional guidance, to demonstrate that embrittlement on the RV will be adequately managed during extended operation.

Therefore, RV material surveillance programs are ~~an~~ ongoing programs that extend~~s~~ beyond the original license of a nuclear power plant (i.e., during license renewal to operate for 60 years and potentially ~~for~~ during SLR to operate for 80 years). The objective of the surveillance program during extended plant operations remains the same as it was during the initial 40-year operating license, ~~which is~~ to continue monitoring changes in fracture toughness of the RV materials to ensure the integrity of the RV. As such, there are no aspects of the surveillance program that are uniquely affected by license renewal and SLR.

Because the withdrawal schedule of surveillance capsules was initially based on plant operation during the original 40-year license term, it may be necessary for standby capsules or capsules containing reconstituted specimens (i.e., specimens from previously tested capsules) to be incorporated into the RV material surveillance program to provide monitoring during plant operation beyond the original 40-year license term. As an additional alternative, applicants may join an ISP. NUREG-1801, Revision 2 (NRC, 2010), contains guidance for licensees seeking plant operation for 60 years, while guidance for licensees seeking plant operation for 80 years is in NUREG-2191 (NRC, 2017d).

2.1.3 History of Appendix H to 10 CFR Part 50

As published in the *Federal Register* on July 3, 1971 (36 FR 12697), the Atomic Energy Commission (AEC) issued for public comment a proposed rulemaking to add to 10 CFR Part 50 a new Appendix G, "Fracture Toughness Requirements," and new Appendix H, "Reactor Vessel Material Surveillance Program Requirements." The AEC stated that the purpose of the proposed amendments was to specify minimum fracture toughness requirements for ferritic materials of pressure-retaining components of the reactor coolant pressure boundary for boiling and pressurized-water power reactors and to require surveillance of the fracture toughness specimens of the RV material by periodic tests. ~~These amendments to 10 CFR Part 50 only applied to boiling- and pressurized-water power reactors.~~

The AEC indicated that the proposed amendments to add Appendices G and H to 10 CFR Part 50 would specify minimum fracture toughness requirements needed to ensure that

General Design Criterion (GDC) 31, "Fracture Prevention of Reactor Coolant Pressure Boundary," of Appendix A, "General Design Criteria for Nuclear Power Plants," to 10 CFR Part 50 is satisfied and describe methods by which the fracture toughness of reactor coolant pressure boundary materials should be determined. Because of the special importance to safety of the RV and because the fracture toughness properties of the RV beltline region may change as a result of neutron irradiation, special requirements for periodic testing of irradiated specimens of RV beltline materials would be specified.

GDC 31 states the following:

> The reactor coolant pressure boundary shall be designed with sufficient margin to assure that when stressed under operating, maintenance, testing, and postulated accident conditions (1) the boundary behaves in a non-brittle manner and (2) the probability of rapidly propagating fracture is minimized. The design shall reflect consideration of service temperatures and other conditions of the boundary material under operating, maintenance, testing, and postulated accident conditions and the uncertainties in determining (1) material properties, (2) the effects of irradiation on material properties, (3) residual, steady-state and transient stresses, and (4) size of flaws.

As published in the *Federal Register* on July 17, 1973 (38 FR 19012), the AEC issued the final rule to amend 10 CFR Part 50, to include Appendices G and H. The AEC explained that Appendix H to 10 CFR Part 50 differs from the amendments published for public comment in the following ways:

- Terminology was changed to be consistent with that of Appendix G to 10 CFR Part 50 and the ASME Code. In particular, the adjustment for irradiation effects is described in these amendments as an adjustment of the reference temperature for nil ductility transition, RT_{NDT}, and the amount of temperature shift is determined by a slightly different treatment of the Charpy data than that given in the proposed amendment.

- Provision was made for accelerated irradiation capsules and for modification of capsule withdrawal schedules based on the results of tests of specimens that received the accelerated irradiation.

- A general provision for an ISP was substituted for the specific requirements given in the proposed rule. It appeared from comments that it would be impractical to meet the requirements of the proposed rule for a commonality of multiple reactors.

The AEC reiterated that Appendices G and H to 10 CFR Part 50 are intended to implement GDC 31. The AEC further explained that the margin of safety against brittle fracture would be controlled more quantitatively by these amendments than by the proposed rule, particularly with regard to specific guidelines for the treatment of heat-up and cooldown conditions. Appendices G and H to 10 CFR Part 50 use language consistent with the ASME Code and have adopted certain of its requirements but also include several key supplemental requirements. For the vessel beltline, inservice requirements were based on the reference temperature, as adjusted, to account for irradiation damage, and there was an additional fracture toughness requirement in the form of upper shelf energy values from the Charpy curve for the material in its unirradiated condition.

Appendix H to 10 CFR Part 50 has undergone several revisions following the issuance of the 1973 final rule. The significance of these amendments has varied from strictly administrative changes to the revision of surveillance program requirements. Further details about the substantive changes are described below.

As published in the *Federal Register* on September 26, 1979 (44 FR 55328), the Commission amended Appendix H to 10 CFR Part 50 to permit greater flexibility in meeting the surveillance program requirements and to simplify requirements by substituting references to national standards that had already been incorporated by reference into the NRC's regulations. The Commission revised Appendix H to 10 CFR Part 50, paragraph II.C.2, to no longer prohibit attachment of surveillance capsules to the RV wall, because, for some vessel designs, the advantages of attachment to the wall (fewer problems in achieving the desired lead factor and the structural integrity of the capsule holder) outweighed the disadvantage of concern for RV integrity. Furthermore, the Commission added requirements to state that, if capsule holders are attached to the vessel wall, the attachments must meet ASME Code requirements for construction and inspection of permanent structural attachments to RVs. Additionally, the Commission revised Appendix H to 10 CFR Part 50 to remove the fixed limits on lead factor (i.e., the ratio of neutron flux at the capsule to the maximum flux at the RV inner wall) of greater than one but less than three. The Commission explained that enforcement of the then-present requirement would require modification of certain designs that had satisfactorily met all surveillance and structural requirements in service. Furthermore, safety concerns were satisfied by retention of the general requirement on the lead factor.

As published in the *Federal Register* on May 27, 1983 (48 FR 24008), the Commission amended 10 CFR Part 50 to clarify the applicability of the requirements to all plants, modify certain requirements, and shorten and simplify these regulations by more extensively incorporating by reference appropriate national standards. Specifically, Appendix H to 10 CFR Part 50 was revised to incorporate ASTM E 185-73, E 185-79, and E 185-82 by reference. The Commission also revised the proposed requirement that surveillance reports be submitted within 90 days after completion of testing to require submittal of these reports within one year of capsule withdrawal, unless an extension is granted by the Director, Office of Nuclear Reactor Regulation. This revision still accomplished the primary purposes of this requirement for timely reporting of test results and notification of any problems.

As published in the *Federal Register* on December 19, 1995 (60 FR 654~~7~~56), the Commission amended Appendix H to 10 CFR Part 50 to remove the provision for ISPs that permitted the reduction in the amount of testing if the initial results agreed with the predictions. The Commission described the other principal change as a clarification of the editions of ASTM E 185 that apply to the various portions of the material surveillance programs. The Commission explained that a surveillance program consists of two essential parts: (1) the design of the program and (2) the subsequent testing and reporting of results from the surveillance capsules. Once the NRC approves the design of a surveillance program, it cannot be changed without prior approval. However, the testing and reporting requirements are updated, along with technical improvements made to ASTM E 185. The Commission revised Appendix H to 10 CFR Part 50 so that, for each capsule withdrawal, the test procedures and reporting requirements must meet the requirements of ASTM E 185-82 to the extent practicable for the configuration of the specimens in the capsule.

Appendix H to 10 CFR Part 50 has had several other amendments; however, these changes were administrative in nature. Further details regarding these changes appear in 41 FR 6256, 41 FR 16445, 51 FR 40303~~6~~, 53 FR 43419, 57 FR 61785, 59 FR 50688, 68 FR 753~~90~~88, and 73 FR 57~~23~~09.

2.2 ASTM Standards for Reactor Vessel Material Surveillance Programs

Appendix H to 10 CFR Part 50 incorporates by reference ASTM E 185-73, ASTM E 185-79, and ASTM E 185-82. These standards provide procedures for monitoring the radiation-induced changes in the mechanical properties of ferritic materials in the beltline of light-water cooled nuclear power RVs and include guidelines for designing a minimum surveillance program, selecting materials, and evaluating test results. The purpose of this surveillance program is 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 RV.

The aspects of ASTM E 185 on designing an RV material surveillance program can be grouped into the following four categories:

(1) test material
(2) test specimens
(3) irradiation conditions
(4) capsules and withdrawal schedule

Since its incorporation into Appendix H to 10 CFR Part 50, ASTM E 185 was revised in 2002 to divide the contents of the standard so that ASTM E 185 provided the details on RV material surveillance program design, while ASTM E 2215, "Standard Practice for Evaluation of Surveillance Capsules from Light-Water Moderated Nuclear Power Reactor Vessels," contained details on surveillance capsule testing and evaluation. The aspects for surveillance capsule testing and evaluation specified in ASTM E 185 and, ultimately, in ASTM E 2215, can be grouped into the following five categories:

(1) characterization of the reactor environment
(2) materials to test and specimen testing
(3) test data evaluation
(4) adjustment of the capsule withdrawal schedule
(5) retention of tested specimens

2.2.1 Changes to the ASTM Standards

The operation of commercial light-water nuclear power plants since the 1970s provided empirical evidence of the effects of irradiation embrittlement on RV steels. This, combined with a better scientific understanding of irradiation embrittlement, prompted revisions and updates to the ASTM requirements for surveillance monitoring programs. The 2016 edition of ASTM E 185 and ASTM E 2215 are the most up-to-date versions for these standards.

During this rulemaking effort, the NRC staff assessed incorporating by reference the 2016 editions of ASTM E 185 and ASTM E 2215 into Appendix H to 10 CFR Part 50. Section 4.2 includes this assessment.

2.2.2 Differences in ASTM Standards Related to Aspects Required by Appendix H to 10 CFR Part 50

The NRC staff reviewed the 1973, 1979, and 1982 editions of ASTM E 185 to determine whether there were any differences in requirements that would affect the regulatory topics addressed during this rulemaking effort. These aspects are related to the inclusion and testing of heat-affected zone (HAZ) specimens, tension specimens, CMM, and thermal monitors in surveillance capsules.

Test Materials and Test Specimens

The 1973, 1979, and 1982 editions of ASTM E 185 consistently specify that the surveillance test materials shall be prepared from samples taken from the actual materials used in fabricating the beltline of the RV and that these surveillance test materials shall include the base metal, butt weld, and weld HAZ. Furthermore, these three editions of ASTM E 185 consistently require 12 Charpy impact specimens for base metal, weld metal, and weld HAZ, per capsule, in the irradiated condition; and 15 Charpy impact specimens for base metal, weld metal, and weld HAZ in the unirradiated condition.

The 1973 edition of ASTM E 185 only required tension specimens if the predicted increase in transition temperature of the RV steel is greater than 37.8 degrees Celsius (C) (100 degrees Fahrenheit (F)) or where the calculated peak neutron fluence (E > 1 MeV) of the RV is greater than $5x10^{18}$ n/cm^2. Specifically, ASTM E 185-73 required two tension specimens for base metal and weld metal, per capsule, in the irradiated condition and three tension specimens for base metal and weld metal in the unirradiated condition. On the other hand, ASTM E 185-79 and ASTM E 185-82 required three tension specimens for base metal and weld metal, per capsule, in the irradiated condition and three tension specimens for base metal and weld metal in the unirradiated condition, regardless of the predicted increase in transition temperature of the RV steel.

Because Appendix H to 10 CFR Part 50 incorporates, by reference, the 1973, 1979, and 1982 editions of ASTM E 185, it is likely that there is a variation between the contents of surveillance capsules (i.e., presence of tension specimens and number of tension specimens) in the current operating fleet. This is because the test material requirements in the current operating fleet were established during the design of the plant’s surveillance programs, which may have occurred before the issuance of the 1973 final rule that incorporated the 1973 edition of ASTM E 185 and its subsequent amendment in 1995 that incorporated the 1979 and 1982 versions of ASTM E 185.

As published in the *Federal Register* on December 19, 1995 (60 FR 6547~~6~~5), the Commission revised Appendix H to 10 CFR Part 50 such that, for each capsule withdrawal, the test procedures and reporting requirements must meet the requirements of ASTM E 185-82 to the extent practicable for the configuration of the specimens in the capsule. Thus, any variations in requirements and recommendations for testing specimens in the 1973, 1979, and 1982 editions of ASTM E 185 are not significant.

Correlation and Thermal Monitors

The 1973 edition of ASTM E 185 specified that the testing of specimens should be modified as outlined in ASTM E 184, “Recommended Practice for Effect of High-Energy Radiation on the Mechanical Properties of Metallic Materials,” which recommends that a metal specimen from a standard reference material be used to correlate one irradiation experiment with another. This is done so that the mechanical property changes of the reference material may serve as a relative standard for estimating exposure. In the 1979 and 1982 editions of ASTM E 185, correlation monitors are explicitly categorized as optional for inclusion in surveillance capsules and are discussed within the ASTM standard instead of being cited in a secondary reference. Consistently, these three editions of ASTM E 185 only recommend the inclusion of CMMs in surveillance capsules.

The 1973, 1979, and 1982 editions of ASTM E 185 consistently specify the insertion of thermal monitors within surveillance capsules. These three editions of ASTM E 185 proposed the use of low melting point elements or eutectic alloys, instead of instrument monitors, to detect significant variations in exposure temperature to provide evidence of the maximum exposure temperature of the specimens. These monitor materials should be selected to indicate unforeseen capsule temperatures.

2.3 Material Surveillance Data Required by Appendix H to 10 CFR Part 50

The material surveillance data required to be submitted to the NRC under Appendix H to 10 CFR Part 50 is used for the purposes listed below.

2.3.1 10 CFR 50.60, "Acceptance Criteria for Fracture Prevention Measures for Light-Water Nuclear Power Reactors for Normal Operation"

In 10 CFR 50.60, the NRC requires licensees of light-water nuclear power reactors to meet the fracture toughness requirements of Appendix G to 10 CFR Part 50 and the material surveillance program requirements in Appendix H to 10 CFR Part 50. The regulations permit these licensees to use alternatives to the requirements, as described in Appendices G and H to 10 CFR Part 50, when the NRC grants an exemption under 10 CFR 50.12, "Specific Exemptions," ~~and~~ or 10 CFR 52.7, "Specific Exemptions."

2.3.2 10 CFR 50.61, "Fracture Toughness Requirements for Protection Against Pressurized Thermal Shock Events," and 10 CFR 50.61a, "Alternate Fracture Toughness Requirements for Protection Against Pressurized Thermal Shock Events"

The operational characteristics of PWRs makes them susceptible to a severe transient identified as pressurized thermal shock (PTS). PTS events are characterized by a small break loss of coolant accident as an initiating event, followed by rapid cooling (i.e., thermal shock) of the internal vessel surface from safety injection, which is then coupled with repressurization of the reactor coolant system. With a sufficiently embrittled RV, the combination of cold vessel surface, high thermal stresses and high pressure can cause the brittle propagation of small cracks in the RV, potentially resulting in propagation of a through-wall crack and possible failure of the vessel. As a condition of their license, PWRs must demonstrate compliance with 10 CFR 50.61 or 10 CFR 50.61a to ensure that they do not approach the levels of embrittlement that make them susceptible to failure due to PTS.

In 10 CFR 50.61, the NRC requires the estimation of the reference temperature for PTS (i.e., RT_{PTS}) of the steels in the RV beltline using the end of license neutron fluence levels, and demonstration that the RV RT_{PTS} values are below the screening criteria specified in the rule.

This estimation is determined by using surveillance program results[6] in conjunction with formulae and tables provided in 10 CFR 50.61.
The screening criteria provided in 10 CFR 50.61 restrict the maximum values of RT_{PTS} permitted during the plant's operational life to 132 degrees C (+270 degrees F) for axial welds, plates, and forgings, and 149 degrees C (+300 degrees F) for circumferential welds. Should RT_{PTS} exceed these screening criteria, 10 CFR 50.61 requires the licensee to either take actions to keep RT_{PTS} below the screening criteria, or perform plant-specific analyses to demonstrate operating the plant beyond the 10 CFR 50.61 screening limits.

10 CFR 50.61a provides an alternate approach to demonstrating adequate toughness, including less restrictive screening criteria than those included in 10 CFR 50.61. 10 CFR 50.61a includes (1) an alternate embrittlement trend correlation (ETC) for use in predicting irradiation induced shifts in the RT_{NDT}, (2) new requirements for the evaluation of plant and heat-specific surveillance data to ensure the applicability of the alternate ETC, and (3) new requirements for the evaluation of RV inservice inspection data. 10 CFR 50.61a also defines generic procedures and criteria to ensure compliance with the revised PTS evaluation requirements. If these generic criteria cannot be met, this alternate PTS rule allows licensees to perform additional plant-specific evaluations to demonstrate that the RV has adequate resistance to fracture during PTS events and submit them to the NRC for approval.

2.3.3 10 CFR 50.66, "Requirements for Thermal Annealing of the Reactor Pressure Vessel"

This regulation is intended for use by those light-water nuclear power reactors where neutron radiation has reduced the fracture toughness of the RV materials. A thermal annealing treatment may be applied to the RV to recover the fracture toughness of the material, as subject to the requirements in 10 CFR 50.66. A report describing the plan for conducting the thermal annealing must be submitted at least three years before the date at which the limiting fracture toughness criteria in 10 CFR 50.61 or Appendix G to 10 CFR Part 50 would be exceeded.

In 10 CFR 50.66(b)(3)(ii)(B), the NRC states that the post-anneal re-embrittlement trend of both RT_{NDT} and Charpy upper-shelf energy must be estimated, and must be monitored using a surveillance program defined in the Thermal Annealing Report and which conforms to the intent of Appendix H to 10 CFR Part 50.

2.3.4 Appendix G to 10 CFR Part 50, "Fracture Toughness Requirements"

Appendix G to 10 CFR Part 50 specifies requirements for ferritic materials of pressure-retaining components of the reactor coolant pressure boundary of light-water nuclear power reactors. These requirements are needed so that there are adequate margins of safety during any condition of normal operation to which the pressure boundary may be subjected over its operating life.

Specifically, RV materials are required to meet the fracture toughness requirements of the ASME Code. In addition, the RV beltline materials must have an unirradiated Charpy upper

[6] Surveillance program results are any data that demonstrate the embrittlement trends for the limiting beltline material, including but not limited to data from test reactors or from surveillance programs at other plants, with or without a surveillance program integrated under Appendix H to 10 CFR Part 50.

shelf energy (USE) of no less than 102 joules (75 ft-lb) and maintain an USE throughout the life of the RV of no less than 68 joules (50 ft-lb). Lower values of USE must be approved by the NRC and the licensee must demonstrate that such low USE values will provide margins of safety against fracture equivalent to those required by Appendix G of Section XI of the ASME Code. One approach to demonstrate equivalent margins for upper shelf energy is provided in Appendix K of Section XI of the ASME Code. Furthermore, ASTM 185-79 and E 185-82 define the methodology to determine the Charpy USE.
Appendix G to 10 CFR Part 50 also includes pressure-temperature limits and minimum temperature requirements for the RV that must be followed to ensure that fracture toughness requirements for the reactor coolant pressure boundary are maintained.

2.4 Capsule Withdrawal Schedule

Appendix H to 10 CFR Part 50 requires light-water nuclear power reactor licensees to have an RV material surveillance program to monitor changes in the fracture toughness properties of the RV materials adjacent to the reactor core. The NRC requires licensees to periodically test irradiated material specimens from test capsules in their RVs to evaluate changes in material fracture toughness to assess the integrity of the RV. The program must meet the design, test procedures, and reporting requirements of ASTM E 185-82, or earlier editions. The number, design, and location of these surveillance capsules within the RV are established during the design of the program before initial plant operation. A majority of reactor licensees have already completed the withdrawal and testing of their capsules for plant operation through 40 years, while some reactor licensees have also completed the withdrawal and testing of their capsules for plant operation through 60 years.

The NRC staff has determined that the remaining 35 capsule withdrawals would occur between the years 2020 and 2041. The NRC staff assumed that the industry would withdraw the remaining capsules on the schedule, as defined in Table 1~~Table 1~~.

Table 1 Capsule Withdrawal Schedule

Year	**No. of Capsules Scheduled for Withdrawal** [1, 2]
2020	2
2021	2
2022	2
2023	1
2024	1
2025	5
2026	1
2027	3
2028	4
2029	3
2030	3
2031	2
2032	1
2033	1
2034	2
2036	1

2039	1
Total	**35**

[1] The capsule withdrawal schedule is based on proprietary information contained in a 2011 report for PWRs, a 2012 report for BWRs, Watts Bar Unit 2 information, and supplemented by NRC staff engineering judgment. The schedule includes scheduled withdrawals for all operating units except for those that have announced early cessation of operation as identified in Section 5.1 of this document.

[2] The NRC staff did not list years 2035, 2037, 2038, 2040, and 2041 because the NRC staff assumed that these years would not have any capsule withdrawals based on the references listed in the above footnote.

3.0 Regulatory Topics

This section describes the regulatory topics that were investigated to determine whether it is necessary to amend the requirements of Appendix H to 10 CFR Part 50. The primary purpose of this rulemaking effort is to reduce the regulatory burden on reactor licensees and the NRC that is associated with test specimens contained within surveillance capsules and the reporting of surveillance test results, while still ensuring protection of public health and safety and the environment. The NRC staff investigated the following regulatory topics:

- HAZ specimens
  - Eliminate the requirement for inclusion of weld HAZ specimens.
  - Eliminate the requirement for testing weld HAZ specimens.
- Tension Specimens
  - Reduce the number of tension specimens included in surveillance capsules (new or reconstituted).
  - Reduce the requirement for testing tension specimens.
  - Specify the required test temperatures for irradiated materials (i.e., at room temperature and service temperature).
- CMM
  - Specify that CMM testing is not required.
- Thermal Monitors
  - Eliminate the requirement for inclusion of thermal monitors.
  - Eliminate the requirement for examining thermal monitors.
- Surveillance Test Results Reporting
  - Extend licensee's submittal of surveillance capsule reports from 1 year to 18 months after the withdrawal of the capsule.

3.1 Heat-Affected Zone Specimens

The first regulatory topic investigated during this rulemaking effort eliminates the requirements for (1) including HAZ specimens in new and reconstituted surveillance capsules and (2) testing of HAZ specimens in existing surveillance capsules.

The editions of ASTM E 185 incorporated by reference in Appendix H to 10 CFR Part 50 specify that the surveillance test specimens shall include base metal, weld metal, and HAZ materials. HAZ specimens were first required in RV material surveillance programs in 1966 (ASTM E 185-66). Cracks in HAZ materials had been observed to cause the failure of components in non-nuclear applications, and from early research, these failures were in HAZ materials with high hardness measurements, which is associated with low fracture toughness.

HAZ test results from surveillance specimens have revealed the inhomogeneous nature of the HAZ material, which also resulted in significant scatter of the HAZ Charpy test data. This was the basis for eliminating the requirement for HAZ specimens after the 1994 edition of ASTM E 185, as discussed in “Irradiation Embrittlement of Reactor Pressure Vessels (RPVs) in Nuclear Power Plants” (Soneda, N. ed., 2015): “Since the weld HAZ has been shown to exhibit superior fracture toughness compared to the plate or forging and does not provide relevant embrittlement data with respect to the non-HAZ weld metal, it is prudent to no longer require the inclusion or testing of HAZ specimens.”

The continued need to include HAZ material in RV material surveillance programs was more recently investigated in a paper written by Koichi Masaki, Jinya Katsuyama, and Kunio Onizawa, "Study on the Structural Integrity of RPV Using PFM Analysis Concerning Inhomogeneity of the Heat-Affected Zone" (Masaki, K, et al., 2013). This paper investigated the features of HAZ inhomogeneity in RV steels to determine the need for surveillance test specimens of HAZ materials in Japan. The authors performed a structural integrity assessment of the inhomogeneous distribution of fracture toughness for HAZ materials using a probabilistic fracture mechanics analysis code and determined the following:

- The HAZ region close to the weld metal has coarse grain HAZ that has high toughness, causing arrest of postulated cracks.

- The HAZ region close to base metal has fine grain HAZ that is continuously distributed along the fusion line such that if crack initiation occurs in the region, crack arrest may not occur.

This outcome is expected metallurgically, because the HAZ is a tempered version of the plate or forging and, as such, it should exhibit superior fracture toughness compared to the plate or forging. This was also demonstrated by T.U. Marston and W. Server in "Assessment of Weld Heat-Affected Zones in a Reactor Vessel Material" (Marston, T.U. and W. Server, 1978), which determined that for the conditions evaluated in the paper, the HAZs of the nuclear quality welds have higher fracture toughness than those of the parent base material.

For these reasons, the NRC staff is proposing to pursue rulemaking that would result in (1) current RV material surveillance programs not being required to test and report results for HAZ specimens and include HAZ specimens in reconstituted or new surveillance capsules, and (2) new RV material surveillance programs not being required to include HAZ specimens during the design of the program.

3.2 Tension Specimens

The second regulatory topic investigated during this rulemaking effort reduces the number of tensions specimens required (1) in new and reconstituted surveillance capsules and (2) for testing in existing surveillance capsules.

The editions of ASTM E 185 currently incorporated by reference in Appendix H to 10 CFR Part 50 specify the following with respect to tensile testing:

- For unirradiated material, tension specimens shall be tested for both the base and weld material at specified temperatures.

- For irradiated material, tension specimens shall be included for both the base and weld material and tested at specified temperatures.

- Tensile testing shall be conducted in accordance with ASTM Method E8 and recommended practice ASTM E21.

The variation of tensile properties (e.g., yield strength, tensile strength, and elongation) with test temperatures is established by testing tension specimens over a range of temperatures. Performing tensile tests both before and after irradiation permits quantification of the hardening effect of irradiation using the increase in yield strength, or ΔYS. NRC regulations have no requirements related to strength properties. Furthermore, the NRC regulations do not specify an approach to directly assess RV integrity from strength properties. Tensile data provides an indication of the radiation-induced strength property changes in the RV material and serves as a consistency check relative to Charpy data; in particular for cases where the Charpy data show unexpected or inconsistent trends with prior data.

For example, general correlations between shifts in fracture transition temperature and ΔYS have been identified (McElroy, R.J., and A.L. Lowe, Jr., 1996). If the data from the Charpy tests are inconsistent, the trends described in the cited paper make it possible to predict the shift in transition temperature from the change in yield strength due to embrittlement. In this case, a comparison of the change in yield strength with the Charpy data could provide additional information to gain an understanding of the causes for inconsistent results.

Furthermore, in the event that optional fracture toughness testing is conducted, tensile data is needed for the calculation of relevant fracture parameters (e.g., J-integral). However, the inclusion of fracture toughness specimens in surveillance capsules is optional per ASTM E 185-82. For instance, ASME Section XI Code Case N-629 provides an alternative to the methods in Appendix G to 10 CFR Part 50 to allow the use of fracture toughness data in developing a master curve reference temperature (T_0) for ferritic materials in place of RT_{NDT}. Regulatory Guide 1.147, “Inservice Inspection Code Case Acceptability, ASME Section XI, Division 1,” incorporates this code case by reference into 10 CFR 50.55a. To use this alternative, the yield strength of the material, which is determined from tests of tensile specimens, is required at the proper embrittlement level.

Past experience (Westinghouse 2015—proprietary) has demonstrated that the differences in the test temperatures specified in ASTM E 185 can be small, which could yield small differences in tensile properties (e.g., the irradiated mid-range transition temperature and the upper end Charpy transition temperature can be close in value). Therefore, the requirement to test three specimens per material at the specified temperatures could produce redundant tensile information. However, eliminating one test temperature and testing at room temperature and service temperature at all irradiation levels allows for the comparison of the change in strength properties from both irradiation and temperature.

Based on its evaluation the NRC staff is proposing to pursue rulemaking that would result in a reduction to the number of required tensile tests and tension specimens in surveillance capsules. Specifically, current RV material surveillance programs would only be required to test one tension specimen at room temperature and one tension specimen at service temperature for all materials and irradiation levels. The disposition of the remaining tension specimens in existing surveillance capsules, if any, would be at the discretion of the licensee. Furthermore, the number of tension specimens required for reconstituted and new surveillance capsules would align with the two test temperatures described above for current RV material surveillance programs and new RV material surveillance programs.

3.3 Correlation Monitor Material

The third regulatory topic investigated during this rulemaking effort is to specify that testing of CMM is optional if this material is included in existing, new, and reconstituted surveillance capsules.

A CMM is a prototypical RV material that has been fabricated to maximize homogeneous behavior, has been used in many surveillance capsules and has an established trend from extensive testing (ASTM DS 54; IAEA, 2001; Stallman, 1987). The purpose of a CMM in a surveillance capsule is to provide reference data for comparison to the established trends for the CMM. The intent of the CMM reference data is to demonstrate that the irradiation conditions of the surveillance capsule have provided embrittlement in the CMM comparable to the established trend for the CMM. Thus, this provides additional information to understand the results from the RV materials in the surveillance capsule. The CMM is selected so that it has a comparable composition and processing history to the RV material. The editions of ASTM E 185 currently incorporated by reference in Appendix H to 10 CFR Part 50 specify that it is optional to include CMM in surveillance capsules. These editions of ASTM E 185 do not explicitly indicate whether or not CMMs shall be tested if they were optionally included in a surveillance capsule. However, ASTM E 185 contains reporting requirements for supplemental or additional specimens (which include the CMM specimen) if testing is performed. Therefore, it is ambiguous whether CMM testing is required even though they are optional to include in surveillance capsules.

In practice, the testing of CMM has demonstrated variability in the measured material properties of the CMM, which has limited the practical use of the data. Several references (Stallman, 1987; Wang, 1996; and Wallin, 1999) have shown that the fitted CMM data are in general agreement with the predictions of NRC Regulatory Guide 1.99, “Radiation Embrittlement of Reactor Vessel Materials,” Revision 2, issued May 1988 (NRC, 1988); however, the raw CMM data exhibit significant scatter.

Based on its evaluation, the NRC staff is proposing that this rulemaking effort would not affect the design of RV material surveillance programs nor the optional inclusion of CMM in surveillance capsules. Furthermore, the proposed rule would specify that testing of CMM is optional even if it is included in surveillance capsules.

3.4 Thermal Monitors

The fourth regulatory topic investigated during this rulemaking effort eliminates the requirements for (1) including temperature monitors in new and reconstituted surveillance capsules and (2) examining temperature monitors in existing surveillance capsules.

ASTM E 185 specifies that the surveillance capsules shall include one set of temperature monitors that are located within the capsule where the specimen temperature is predicted to be the maximum~~,~~ and additional sets of temperature monitors may be placed at other locations to characterize the temperature profile. ASTM E 185 further specifies that the maximum exposure temperature of the surveillance capsule materials shall be determined, and, if a discrepancy greater than 14 degrees C or 25 degrees F occurs between the observed and the expected capsule exposure temperatures, an analysis of the operating conditions shall be conducted to determine the magnitude and duration of these differences. The standard specifies reporting of the temperature monitor results and an estimate of the maximum capsule exposure temperature.

Irradiation temperature is one of the parameters that is closely correlated with the effects of neutron embrittlement of RV steels, with lower embrittlement measured at higher irradiation temperatures within a range close to the standard operating temperature of 288 degrees C (550 degrees F). Therefore, knowledge of the irradiation temperature history of surveillance capsules is important to ensure that the surveillance data are properly interpreted and do not portray a non-conservative estimate of the RV neutron embrittlement.

Typically, the temperature monitors used in surveillance capsules are high purity, low melting point elements, or eutectic alloys. They are targeted to melt at specific temperatures, normally somewhat in excess of the planned operating temperature, to identify the highest temperature seen by the surveillance capsule. Some of these temperature monitors are housed in glass tubes (Westinghouse, 2011); others are in tubular aluminum alloy crucibles, which are stacked in a stainless-steel holder tube and inserted into machined locations within the aluminum spacer blocks inside the capsule (Lowe, 1999). The latter are evaluated using radiography (Lowe, 1999). These temperature monitors provide an indication of whether the melt temperature was observed but do not provide a time-based exposure history of the monitor; thus, they are a "'go/no-go" indication of the maximum surveillance capsule temperature.

Use of temperature melt wire monitors to identify the peak capsule temperature does not provide information on the actual time-based temperature exposure conditions of the surveillance capsule, which is important to properly interpret the surveillance data. This merely indicates the highest temperature experienced by the surveillance capsule, not the duration of the exposure at that temperature. As described in Lowe's paper (Lowe, 1999), several things can complicate the interpretation of the information from temperature melt wire monitors. The first complication results when the surveillance capsule experiences a short duration thermal transient that increases the coolant inlet temperature. This could result in a positive indication from the temperature melt wire monitors, which is insignificant to the overall exposure conditions of the surveillance capsule, and not to the radiation response of the test specimens located within the surveillance capsule. A second complication is caused by possible interpretation issues, where apparent "melting" of the temperature melt wire monitors is actually caused by long-term exposure of the monitor to temperatures near, but below, its melting point, and a resulting creep mechanism, which causes slumping of the monitor in its crucible (Lowe, 1999).

Commented [A6]: Missing word here; should this be "and not important to" or something like that?

As an alternative to temperature melt wire monitors, an estimate of the average capsule temperature during full power operation for each reactor fuel cycle would provide the irradiation temperature history of the surveillance capsule. In a typical pressurized-water reactor and boiling-water reactor, the coolant inlet temperature and the recirculation temperature, respectively, provides a reasonable estimate of the capsule irradiation temperature history. To date, licensees have been able to deteremine the irradiation temperature history of surveillance capsules to properly interpret the data based on the plant paramenters that are already being montioried.

Based on its evaluation, the NRC staff proposing to pursue rulemaking that would result in (1) current RV material surveillance programs not being required to test and report results for thermal monitors and include thermal monitors in reconstituted or new surveillance capsules, and (2) new RV material surveillance programs not being required to include thermal monitors during the design of the program.

3.5 Surveillance Test Results Reporting

The fifth regulatory topic investigated during this rulemaking effort extends the time period given to a licensee following each capsule withdrawal to submit the technical report containing the test results required by ASTM E 185 and Appendix H to 10 CFR Part 50.

Appendix H to 10 CFR Part 50 currently requires that within one year of the date of the surveillance capsule withdrawal, a summary technical report be submitted to the NRC that contains the data required by ASTM E 185, and the results of all fracture toughness tests conducted on the beltline materials in the irradiated and unirradiated conditions, unless an extension is granted by the Director, Office of Nuclear Reactor Regulation.

This one-year limit was adopted in Appendix H to 10 CFR Part 50 on July 26, 1983, and is described in the *Federal Register* (48 FR 24008). The primary purpose of this requirement when it was first implemented was the timely reporting of test results and notification of any problems determined from surveillance tests. At that time, timely reporting of surveillance data was crucial, because there was a limited amount of available data from irradiated materials from which to estimate embrittlement trends. The number of commercial light-water reactors operating in the United States and the associated number of years of operation since this requirement was first adopted have increased significantly. This has led to an extensive amount of embrittlement data and knowledge of the mechanisms associated with embrittlement of the RV; thus, there is a reduced need for prompt reporting of the test results.

The one-year requirement to submit a report following each capsule withdrawal is a challenge for some licensees, particularly those participating in the BWRVIP ISP. Implementation of this ISP requires significant coordination among the multiple licensees participating in the program. In general, these licensees are continuing to request a six-month extension to the one-year reporting requirement and to date, the Director, Office of Nuclear Reactor Regulation, has approved these requests. In addition, as surveillance capsules remain in the RV to achieve higher neutron fluence levels to support plant operation through 60 years and 80 years, longer periods of radioactive decay may be necessary before the capsule can be shipped to hot-cell laboratories to perform testing.

The purpose of proposing a rulemaking change to the reporting requirement is to reduce the regulatory burden for licensees to submit and for the NRC to review these routine extension requests, while still ensuring adequate protection of public health and safety ~~and the environment~~. Furthermore, increasing the time given to licensees to submit a summary report following each capsule withdrawal from 1 year to 18 months is appropriate~~,~~ because (1) sufficient embrittlement data currently exists and the mechanisms associated with embrittlement of the RV are well understood, and (2) this is a reasonable accommodation of the extension period requested previously by licensees.

Based on its evaluation, the NRC staff proposes to pursue rulemaking that would result in reactor licensees being afforded 18 months following the withdrawal of a surveillance capsule to submit ~~its~~the capsule report to the NRC. Thus, reactor licensees participating in the BWRVIP ISP would no longer need to routinely request extensions to the reporting requirements due to administrative challenges, and the NRC would review fewer requests.

4.0 Description of Options

This section considers three options to amend the requirements of Appendix H to 10 CFR Part 50 that the NRC staff is proposing associated with test specimens contained within surveillance capsules and the reporting of surveillance test results. These three options include (1) the no action (status quo), (2) rulemaking to incorporate by reference the latest editions of ASTM E 185 and ASTM E 2215 into Appendix H to 10 CFR Part 50, and (3) rulemaking to revise Appendix H to 10 CFR Part 50, and are described below. In order to reduce the regulatory burden on the reactor licensees and to the NRC, as described in Section 3.0, the NRC staff is proposing these changes to the regulations while still ensuring protection of public health and safety and the environment.

4.1 Option 1: No Action (Status Quo)

This option would maintain the current requirements in Appendix H to 10 CFR Part 50 (i.e., status quo) and the specimens and testing required by ASTM E 185-73, E 185-79, and E 185-82, as applicable. Licensees would continue to (1) test Charpy impact specimens for the weld HAZ; (2) test tension specimens for the weld metal and base metal at various temperatures; (3) test correlation monitors, if they were included; and (4) examine thermal monitors in each surveillance capsule in accordance with ASTM E 185-82, to the extent practicable. Licensees needing additional time to submit their surveillance capsule reports would continue to submit extension requests for NRC review and approval.

4.2 Option 2: Rulemaking To Incorporate by Reference the Latest Editions of ASTM E 185 and ASTM E 2215 into Appendix H to 10 CFR Part 50

The latest edition of ASTM E 185 referenced by Appendix H to 10 CFR Part 50 is the 1982 edition that contains guidelines for designing an RV materials surveillance program and evaluating test results. Subsequently, in 2002, these guidelines were separated so that ASTM E 185 provides the guidelines for designing an RV materials surveillance program while a new standard, ASTM E 2215, contains guidelines on evaluating the RV material surveillance program test results. The NRC staff explored the possibility of incorporating by reference the latest edition of both ASTM E 185 and E 2215 (i.e., the 2016 editions) into Appendix H to 10 CFR Part 50. Reactor license applicants seeking approval for the design of their RV material surveillance program before plant operation would be required to use the 2016 edition of these ASTM standards.

The NRC staff reviewed ASTM E 185-82, ASTM E 185-16, and ASTM E 2215-16 to compare the standards and distinguish the aspects that are constituted as requirements and recommendations. The purpose of this review was to determine the additional requirements associated with the 2016 edition of these ASTM standards when compared to the requirements currently in Appendix H to 10 CFR Part 50 to determine whether these additional requirements were necessary to ensure adequate protection of public health and safety ~~and the environment~~. This review identified the following significant aspects required by the 2016 edition of ASTM E 185 and ASTM E 2215 that are not requirements in the current regulations:

- ASTM E 185-16 may require the inclusion of additional surveillance capsules (i.e., program and standby capsules) in the RV material surveillance program.

- ASTM E 185-16 requires the testing of one additional surveillance capsule during the first 40 years of reactor operation.

- ASTM E 185-16 requires the inclusion and testing of two additional RV materials (i.e., limiting base and weld metal materials from the geometric beltline) within each surveillance capsule.

- ASTM E 185-16 requires the inclusion and testing of fracture toughness specimens from the limiting RV materials.

- ASTM E 2215-16 permits the use of ASTM E 900, "Guide for Predicting Radiation-Induced Transition Temperature Shift in Reactor Vessel Materials," and other neutron-fluence-related references, which contain calculational methods that the NRC has not assessed.

Based on its review of the requirements established in ASTM E 185-16 and ASTM E 2215-16, the NRC staff determined that adopting and implementing these ASTM Standards would create a significant and unnecessary burden for reactor applicants and licensees without a corresponding benefit to public health and safety ~~and the environment~~. To require inclusion and testing of additional surveillance capsules, RV materials from the beltline, and fracture toughness specimens from the limiting RV materials would be an overly conservative approach to monitor the change in material properties of the RV. Furthemore, the additional requirements in these ASTM standards are beyond the NRC's current regulatory framework and approved methods to assess RV integrity. Based on the significant quantity of data from surveillance programs required by Appendix H to 10 CFR Part 50, extensive research programs conducted on neutron embrittlement and RV integrity, and the adequacy of the existing surveillance programs, there is no technical basis to require additional surveillance capsules, surveillance materials and surveillance specimens beyond the current requirements. The addition of these requirements would not have a corresponding benefit to public health and safety and the environment. A minimum of 13 possible conditions on the use of these ASTM standards were identified to offset the unnecessary burden from the additional required guidelines without a cost-justified increase in protection. Thus, the NRC staff could not justify imposing such requirements from ASTM E 185-16 and ASTM E2215-16 on reactor license applicants seeking approval for the design of their RV material surveillance program before plant operation.

Significant NRC resources would have been necessary to quantify the exact cost burden to licensees associated with the use of ASTM E 185-16 and ASTM E 2215-16. This activity was not performed because of the considerable unnecessary burden to reactor applicants, as outlined above, without a benefit to public health and safety, and they are not necessary to adequately assess the RV integrity under the NRC's regulatory framework and currently approved methods.

At a public meeting on June 1, 2017 (NRC, 2017a), the NRC staff presented the impacts of incorporating ASTM E 185-16 and ASTM E 2215-16 into Appendix H to 10 CFR Part 50, as compared to the current regulations. The NRC staff presented order-of-magnitude estimates on the cost burden to licensees associated with using ASTM E 185-16 and ASTM E 2215-16, which included the required inclusion and testing of (1) additional surveillance capsules, (2) RV materials from the beltline and limiting non-beltline materials, and (3) fracture toughness specimens from the limiting RV materials. The NRC staff also described aspects of the 2016 edition of the ASTM E 185 and E 2215 that would be considered for conditions if this rulemaking effort pursued incorporating these standards into Appendix H to 10 CFR Part 50. These conditions would be needed to ensure that reactor applicants are not unnecessarily burdened to implement aspects of ASTM E 185-16 and ASTM E 2215-16 that do not have a direct correlation with the requirements in 10 CFR Part 50 for assessing RV integrity. The NRC staff explained that there was no technical basis to require additional surveillance capsules and surveillance specimens beyond the current requirements based on the currently available data from extensive research programs, and existing surveillance programs. External stakeholders participating in the meeting agreed with the NRC staff's assessment.

In summary, the NRC staff identified that a minimum of 13 possible conditions on the use of ASTM E 185-16 and ASTM E2215-16 would be necessary to offset the unnecessary burden without a corresponding benefit to public health and safety and the environment. Thus, the NRC staff determined that this approach was suboptimal to the approach described in Option 3. As a result, this option is not deemed viable and was not considered further in this regulatory basis.

4.3 Option 3: Rulemaking To Revise Appendix H to 10 CFR Part 50

Under this option, the NRC staff would undertake a rulemaking effort to revise the underlying regulations to alleviate the regulatory burden to existing licensees and future applicants as follows:

- HAZ specimens
  - Eliminate the requirement for inclusion of weld HAZ specimens.
  - Eliminate the requirement for testing weld HAZ specimens.
- Tension Specimens
  - Reduce the number of tension specimens included in surveillance capsules (new or reconstituted).
  - Reduce the requirement for testing tension specimens.
  - Specify the required test temperatures for irradiated materials (i.e., at room temperature and service temperature).
- CMM
  - Specify that CMM testing is not required.
- Thermal Monitors
  - Eliminate the requirement for inclusion of thermal monitors.
  - Eliminate the requirement for examining thermal monitors.
- Surveillance Test Results Reporting
  - Extend submittal of surveillance capsule reports to 18 months after the withdrawal of the capsule.

Table 2~~Table 2~~ summarizes the applicability of these changes to power reactor applicants and licensees.

Table 2 Applicability of Proposed Changes to Applicants and Licensees

Description of Change	Current and Future Power Reactor Applicants	Power Reactor Licensees
HAZ specimens	Eliminate HAZ specimen inclusion in capsules.	Eliminate HAZ inclusion in new and reconstituted capsules. Eliminate testing HAZ specimens for existing capsules.
Tension specimens	Reduce tensile specimens in capsules. Specify the required test temperatures for irradiated materials.	Reduce tensile specimens in new and reconstituted capsules. Reduce tensile testing. Specify the required test temperatures for irradiated materials.
Correlation monitor materials	Eliminate correlation monitor testing.	Eliminate correlation monitor testing for existing capsules.
Thermal monitors	Eliminate thermal monitor inclusion in capsules.	Eliminate thermal monitor inclusion in new and reconstituted capsules. Eliminate examination of thermal monitor in existing capsules.
Surveillance test results reporting	Extend reporting requirements from 1 year to 18 months following each capsule withdrawal.	Extend reporting requirements from 1 year to 18 months following each capsule withdrawal.

In conducting its cost-benefit analysis associated with the proposed rulemaking, the NRC staff evaluated using the standard notice-and-comment rule process against the direct final rule process. Details of both approaches and the NRC staff's assessment are provided below.

4.3.1 Option 3A: Standard Notice-and-Comment Rule Process

Under this option, the NRC staff would use the standard notice-and-comment rule process[7] to revise the underlying regulations to alleviate the regulatory burden to existing licensees and to future applicants as described above. The NRC staff assumes that the effective date of the final rule for the standard notice-and-comment rule process is late 2021 and industry would incur benefits beginning in year 2022.

4.3.2 Option 3B: Direct Final Rule Process

Under this option, the NRC staff would use the direct final rule process[8] to revise the underlying regulations to alleviate the regulatory burden to existing licensees and to future applicants as described above. The NRC staff assumes that the effective date of the final rule for the direct final rule process is 2020.

---

7 During the standard notice-and-comment rule process, the public is usually given 75 to 90 days to provide comments after publication of the proposed rule.
8 The public is usually given 30 days to provide comments after publication of the direct final rule.

5.0 Other Regulatory Considerations

5.1 Cost and Benefit Considerations

The potential costs and benefits of the options must be considered for light-water power reactor licensees and the NRC. The analyses in this section are based on the NRC staff's assessment and input, as well as on limited input from external stakeholders. The NRC will make a more detailed evaluation of costs and benefits if it decides to pursue the rulemaking option.

Analysis Baseline

The analyses in this section present the incremental costs and benefits that the licensees and the NRC would realize from the rulemaking action. Incremental costs and benefits are calculated values that are above the status quo condition (Option 1). The status quo condition for this rulemaking action includes the benefits and costs to comply with the current requirements in Appendix H to 10 CFR Part 50.

The NRC staff examined two processes to perform rulemaking—the standard notice-and-comment rule process and the direct final rule process. Table 3~~Table 3~~ compares the rulemaking activities for these two processes.

Table 3 Comparison of Option 3A and 3B Rulemaking Processes

Rulemaking Phase	Option 3A: Standard Notice-and-Comment Rule	Option 3B: Direct Final Rule
Rulemaking	Develop the proposed rule.	Develop the direct final rule and companion proposed rule.
	Publish the proposed rule for public comment.	Publish the direct final rule with the companion proposed rule for public comment.
	Consider and resolve public comments.	Verify there are no significant adverse comments,[1] resolve public comments, withdraw proposed rule.
	Prepare and publish final rule.	Prepare and publish a notice to confirm the effective date for the direct final rule.

1 If significant adverse comments are received, the NRC staff would withdraw the final rule and could proceed either using the standard notice-and-comment rule process or recommend to the Commission that rulemaking activities should cease because the activity would no longer be cost-justified.

The cost estimate compares Option 1 (no action) to Option 3A (standard notice-and-comment rule) and Option 3B (direct final rule). The most significant advantages of Option 3B are the lower NRC costs to complete the direct final rule activities and the earlier effective date of the rule, which provides an additional burden reduction to the licensees, with no impact to public health and safety and the environment. The NRC staff recognizes that the costs and benefits described in this draft analysis are order-of-magnitude estimates that are subject to further refinement and input from stakeholders. However, these estimates are useful to eliminate unviable solutions, to establish feasibility and to identify potential tradeoffs early in the process.

Affected Facilities

The NRC staff estimates that the final rule will cover all U.S. commercial light-water reactor operating units and units under construction.[9] However as of April 2018, the following plants have announced plans to permanently shut down before their license expiration:

- Oyster Creek Nuclear Generating Station plans to shut down by October 31, 2018.
- Pilgrim Nuclear Power Station plans to shut down by June 1, 2019.
- Three Mile Island Nuclear Station Unit 1 plans to shut down on or about September 30, 2019.
- Davis-Besse Nuclear Power Station Unit 1 plans to shut down by May 31, 2020.
- Indian Point Nuclear Generating Units 2 and 3 plan to shut down by April 30, 2021.
- Perry Nuclear Power Plant Unit 1 plans to shut down by May 31, 2021.
- Beaver Valley Power Station Units 1 and 2 plan to shut down by October 31, 2021.
- Palisades Nuclear Plant plans to shut down by spring of 2022.
- Diablo Canyon Power Plant Units 1 and 2 plan to shut down in 2025.

The analysis evaluates the incremental costs and benefits on a per-unit basis for all operating units with the exception of those facilities that have announced early cessation of operations. Additionally, some units have completed their capsule withdrawals under their RV material surveillance program and would not experience any burden reduction.

Identification of Affected Attributes

The NRC staff evaluated the following attributes in support of this regulatory basis.

- NRC implementation
- Industry implementation
- Industry operation
- NRC operation

5.1.1 NRC Implementation

The NRC's development and implementation of proposed changes to Appendix H to 10 CFR Part 50, through a rulemaking would result in incremental costs to the NRC. These costs include the activities listed in Table 3~~Table 3~~.

5.1.1.1 Option 1 – No Action: NRC Implementation Costs

This option would have no incremental impact on the NRC. However, the NRC staff would continue to review test results from capsule specimens that do not provide beneficial surveillance data or support direct regulatory needs to assess and monitor embrittlement on the RV. Furthermore, the NRC staff would continue to review extension requests for submittal of test results within one year of the capsule withdrawal that have generally been associated with licensees participating in the ISPs.

---

9 This analysis does not include reactor units that have received a construction permit or a combined license that are not currently under construction.

5.1.1.2 Option 3A – Standard Notice-and-Comment Rule Process: NRC Implementation Costs

Table 4~~Table 4~~ shows that the NRC has implementation costs pertaining to rulemaking costs that comprise completing the regulatory basis, preparing and publishing the proposed rule, and preparing and issuing the final rule. The NRC implementation cost for Option 3A is estimated to range from ($417,966) at a 7-percent discount rate to ($441,276) at a 3-percent discount rate.

Table 4 Option 3A: NRC Implementation Costs (Standard Notice-and-Comment Rule Process)

Year	Activity	Hours	NRC hourly rate	One Time Cost		
				Undiscounted	**7% NPV**	**3% NPV**
2018	Prepare and publish proposed rule for public comment	463	$131	($60,588)	($60,588)	($60,588)
2019		1,388	$131	($181,763)	($169,871)	($176,468)
2020	Resolve public comments and prepare and issue final rule	1,250	$131	($163,685)	($142,968)	($154,288)
2021		417	$131	($54,562)	($44,538)	($49,932)
			Total:	**($460,596)**	**($417,966)**	**($441,276)**

5.1.1.3 Option 3B – Direct Final Rule Process: NRC Implementation Costs

Table 5~~Table 5~~ shows that the NRC has implementation costs for preparing the final and companion rules to revise the testing and reporting requirements in Appendix H to 10 CFR Part 50. The NRC implementation cost for Option 3B is estimated to range from ($282,593) at a 7-percent discount rate to ($288,998) at a 3-percent discount rate.

Table 5 Option 3B: NRC Implementation Costs (Direct Final Rule)

Year	Activity	Hours	NRC hourly rate	Total Cost		
				Undiscounted	**7% NPV**	**3% NPV**
2018	Develop direct final rule (Alternative)	898	$131	($117,655)	($117,655)	($117,655)
2019		1,347	$131	($176,483)	($164,938)	($171,343)
			Total:	**($294,139)**	**($282,593)**	**($288,998)**

5.1.2 Industry Implementation

5.1.2.1 Option 1 – No Action: Industry Implementation Costs

This option would maintain the current requirements in Appendix H to 10 CFR Part 50 (i.e., status quo) and as such, this option would have no incremental impact on the industry.

Although there is no incremental impact on licensees, this option would result in continued expenditures by licensees or future applicants that are associated with testing or examining capsule specimens that do not provide beneficial surveillance data or support direct regulatory needs to assess and monitor embrittlement of the RV. Furthermore, licensees or future applicants that participate in an ISP will likely continue to submit extension requests for submittal of test results within the one year requirement of the capsule withdrawal because of the significant coordination needed among multiple licensees participating in the ISP and with hot-cell laboratories.

5.1.2.2 Option 3A – Standard Notice-and-Comment Rule Process: Industry Implementation Costs

The NRC staff assumes that there are little to no industry implementation costs for rulemaking material review and comment because of the noncontroversial nature of the proposed changes.

5.1.2.3 Option 3B – Direct Final Rule Process: Industry Implementation Costs

The NRC staff assumes that there are little to no industry implementation costs for rulemaking material review and comment because of the noncontroversial nature of the proposed changes.

5.1.3 Industry Operations Cost

The industry would avert costs in Options 3A and 3B resulting from the following and as further described below:

- HAZ specimens
  - Eliminate the requirement for inclusion of weld HAZ specimens.
  - Eliminate the requirement for testing weld HAZ specimens.
- Tension Specimens
  - Reduce the number of tension specimens included in surveillance capsules (new or reconstituted).
  - Reduce the requirement for testing tension specimens.
  - Specify the required test temperatures for irradiated materials (i.e., at room temperature and service temperature).
- CMM
  - Specify that CMM testing is not required.
- Thermal Monitors
  - Eliminate the requirement for inclusion of thermal monitors.
  - Eliminate the requirement for examining thermal monitors.
- Surveillance Test Results Reporting
  - Extend submittal of surveillance capsule reports to 18 months after the withdrawal of the capsule.

Heat-Affected Zone Specimens

Licensees of operating reactor units would realize incremental savings if they are no longer required to test HAZ test specimens upon the withdrawal of each surveillance capsule and if they are no longer required to include HAZ test specimens in reconstituted or new surveillance capsules.

Applicants for a reactor license that will seek NRC review and approval for an RV material surveillance program would realize incremental savings if they are not required to include HAZ test specimens in new surveillance capsules.

Based on industry input, the NRC staff estimates that the cost for HAZ specimen testing is $7,500 per withdrawn capsule.

Tension Specimens

Licensees of operating reactor units and applicants for a reactor license that will seek NRC review and approval for an RV material surveillance program would realize incremental savings, resulting from the reduction in the number of required tensile tests and tension specimens in surveillance capsules. The disposition of the remaining tension specimens in existing surveillance capsules, if any, would be at the discretion of the licensee.

Specifically, licensees of operating reactor units would only be required to test one tension specimen at room temperature and one tension specimen at service temperature for all materials and irradiation levels. The disposition of the remaining tension specimens in existing surveillance capsules, if any as mentioned above, would be at the discretion of the licensee. Furthermore, the number of tension specimens required for reconstituted and new surveillance capsules would align with the two test temperatures described above for licensees of operating reactor units and applicants for a reactor license that will seek NRC review and approval for an RV material surveillance program.

Based on ASTM E 185-82, each capsule is required to contain three tension specimens for each material (i.e., base and weld). The proposed rule would eliminate testing of one of these three specimens for each material. The remaining two specimens for each material would still require testing at the test temperatures specified above. The NRC staff assumed that the cost to test two tension specimens is two-thirds of the cost to test the three required specimens, for each material (e.g., one-third of the current tensile test cost would be averted).

Based on industry input, the NRC staff estimates that the cost for tension specimen test averted cost is $2,500 per withdrawn capsule, based on the assumption that one-third of the current tensile test would no longer require testing and that the cost for tensile testing is $7,500 per withdrawn capsule.

Correlation Monitor Materials

Licensees of operating reactor units and applicants for a reactor license that will seek NRC review and approval for an RV material surveillance program would realize incremental savings. This would result from explicitly specifying that testing of CMM specimens, if they are included in existing, reconstituted or new surveillance capsules, is optional upon the withdrawal of a surveillance capsule.

Based on industry input, the NRC staff estimates that the cost for CMM specimen testing is $7,500 per withdrawn capsule. However, since CMM specimens are optionally included in surveillance capsules, the NRC staff assumed that only 40 percent of the remaining surveillance capsules contain CMM specimens. The NRC staff's assumption is based on a sampling of surveillance capsule reports submitted by the licensees.

Thermal Monitors

Licensees of operating reactor units would realize incremental savings if they are no longer required to (1) examine thermal monitors upon the withdrawal of each surveillance capsule and (2) include thermal monitors in reconstituted or new surveillance capsules.

Applicants for a reactor license that will seek NRC review and approval for an RV material surveillance program would realize incremental savings if they are not required to include thermal monitors in new surveillance capsules.

Based on industry input, the NRC staff estimates that the cost for thermal monitor testing is $2,500 per withdrawn capsule.

Surveillance Test Results Reporting

Appendix H to 10 CFR Part 50 requires light-water nuclear power reactor licensees to have an RV material surveillance program to monitor changes in the fracture toughness properties of the RV materials adjacent to the reactor core. The NRC requires licensees to periodically test irradiated material specimens from test capsules in their RVs to evaluate changes in material fracture toughness properties to assess the integrity of the RV. The program must meet the design, test procedures, and reporting requirements of ASTM E 185-82, or earlier editions. The number, design, and location of these surveillance capsules within the RV are established during the design of the program before initial plant operation.

As part of this rulemaking effort, the NRC staff is proposing that reactor licensees having an NRC-approved RV material surveillance program would be permitted an additional 6 months to submit their report of surveillance testing following the withdrawal of each surveillance capsule, compared to the current Appendix H to 10 CFR Part 50 requirements.

Those licensees that participate in an ISP; specifically, operating BWRs, would no longer need to submit routine extension requests for the report on surveillance testing following each capsule withdrawal to accommodate internal processes established by the BWRVIP (i.e., committee review process). These licensees would be relieved of the administrative and financial burden associated with submitting the usual extension requests.

Applicants for a reactor license that will seek NRC review and approval for an RV material surveillance program will have 18 months to submit the report of surveillance testing following the withdrawal of each surveillance capsule.

Based on industry input, the NRC staff estimates that the cost for a licensee to prepare and submit a schedule extension request for a surveillance capsule test report is $20,000. Based on a review of previously submitted schedule requests and proprietary industry information, the NRC staff estimates that 16 schedule extension requests will be averted for the years 2020 to 2041 and 15 schedule extension requests will be averted for the years 2022 to 2041.

5.1.3.1 Option 1 – No Action: Industry Operation Costs

This option would have no incremental impact on the industry. However, some reactor licensees would continue to be required to prepare and submit extension requests for submittal of test results within one year of the capsule withdrawal that have generally been associated with licensees participating in ISPs.

5.1.3.2 Option 3A – Standard Notice-and-Comment Rule Process: Industry Operation Costs

Under this option, the operating reactor units with remaining capsules would begin to realize the averted cost savings in year 2022, after the final rule becomes effective in late 2021. Based on

Table 1Table 1, 31 capsules would be withdrawn beginning in year 2022 and continuing through year 2041. Table 6Table 6 shows the resulting industry cost savings, beginning in 2022.

Table 6 Option 3A: Industry Operation Costs—(Standard Notice-and-Comment Rule)

Years	Description	No. of Capsules	Net Unit Cost	Undiscounted	Net Present Value	
					7% Discount Rate	3% Discount Rate
2022 – 2041	Industry HAZ tests	31	$7,500	$232,500	$118,638	$171,863
	Industry tension specimen tests	31	$2,500	$77,500	$39,546	$57,288
	Industry CMM tests	12.4	$7,500	$93,000	$47,455	$68,745
	Industry thermal monitor tests	31	$2,500	$77,500	$39,546	$57,288
	Industry report submittal extension	15	$20,000	$300,000	$143,487	$215,377
			Total	**$780,500**	**$388,673**	**$570,561**

5.1.3.3 Option 3B – Direct Final Rule Process: Industry Operations Costs

Under this option, the operating reactor units with remaining capsules would begin to realize the averted cost savings in 2020, when the direct final rule becomes effective. Based on Table 1Table 1, 35 capsules would be withdrawn beginning in 2020 and continuing through 2041. Table 7Table 7 shows the resulting averted cost savings.

Table 7 Option 3B: Industry Operation Costs (Direct Final Rule)

Years	Description	No. of Capsules	Net Unit Cost	Undiscounted	Net Present Value	
					7% Discount Rate	3% Discount Rate
2020—2041	Industry HAZ tests	35	$7,500	$262,500	$143,984	$199,729
	Industry tension specimen tests	35	$2,500	$87,500	$47,995	$66,576
	Industry CMM tests	14	$7,500	$105,000	$57,594	$79,892
	Industry thermal monitor tests	35	$2,500	$87,500	$47,995	$66,576
	Industry report submittal extension	16	$20,000	$320,000	$160,956	$234,229
			Total	**$862,500**	**$458,523**	**$647,003**

5.1.4 NRC Operation Costs

The following proposed changes to Appendix H to 10 CFR Part 50 through a rulemaking would result in changes in incremental operation costs to the NRC:

- Eliminate the NRC review of HAZ specimen test results.

- Reduce the NRC review of tension specimen test results, except at room temperature and service temperature.
- Eliminate the NRC review of CMM test results.
- Eliminate the NRC review of thermal monitor test results.
- Reduce the need for the NRC to review routine licensee schedule extension requests related to the submittal of the surveillance capsule reports.

Heat-Affected Zone Specimens

Because the HAZ testing is eliminated, the NRC would realize averted costs. The NRC staff estimates that the NRC would save 2 hours per capsule by eliminating the review of HAZ test result submittals.

Tension Specimens

Because the tensile testing is reduced, the NRC would realize averted costs. The NRC staff estimates that it would save 2 hours per eliminated tension test.

Correlation Monitor Material

Because CMM testing is eliminated, the NRC would realize averted costs. The NRC staff estimates that it would save 2 hours per eliminated CMM test.

Thermal Monitors

Because the requirement to examine thermal monitors is reduced, the NRC would realize averted costs. The NRC staff estimates that it would save 2 hours per eliminated thermal monitor examination.

Surveillance Test Results Reporting

Because the need for licensees to request extensions is reduced by extending the allowable time to submit the test results from 1 year to 18 months, the NRC would realize averted costs to review and approve these requests. The NRC staff estimates that it would save 60 hours by reducing the number of hours to review and approve a schedule extension request.

5.1.4.1 Option 1 – No Action: NRC Operation Costs

This option would have no incremental impact on the NRC. However, the NRC would continue to be required to review extension requests for submittal of test results within one year of the capsule withdrawal that have generally been associated with licensees participating in ISPs.

5.1.4.2 Option 3A – Standard Notice-and-Comment Rule Process: NRC Operation Costs

Under this option, the operating reactor units with remaining capsules would begin to realize the averted cost savings in year 2022, after the final rule becomes effective in late 2021. Table 8~~Table 8~~ shows the resulting NRC cost savings, beginning in 2022.

Table 8 Option 3A: NRC Operation Costs (Standard Notice-and-Comment Rule)

Years	Description	No. of Submissions	No. of Review Hours	Hourly Rate	Undiscounted	Net Present Value	
						7% Discount Rate	3% Discount Rate
2022 – 2041	NRC HAZ tests	31	2	$131	$8,122	$4,144	$6,004
	NRC tension specimen tests	31	2	$131	$8,122	$4,144	$6,004
	NRC CMM tests	12.4	2	$131	$3,249	$1,658	$2,402
	NRC thermal monitor tests	31	2	$131	$8,122	$4,144	$6,004
	NRC report submittal extension	15	60	$131	$117,900	$56,390	$84,643
				Total	**$145,515**	**$70,482**	**$105,056**

5.1.4.3 Option 3B – Direct Final Rule Process: NRC Operation Costs

Under this option, the operating reactor units with remaining capsules would begin to realize the averted cost savings in the year 2020, when the direct final rule becomes effective. The resulting NRC cost savings are shown in Table 9~~Table 9~~.

Table 9 Option 3B: NRC Operation Costs (Direct Final Rule)

Years	Description	No. of Submissions	No. of Review Hours	Hourly Rate	Undiscounted	Net Present Value	
						7% Discount Rate	3% Discount Rate
2020—2041	NRC HAZ tests	35	2	$131	$9,170	$5,030	$6,977
	NRC tension specimen tests	35	2	$131	$9,170	$5,030	$6,977
	NRC CMM tests	14	2	$131	$3,668	$2,012	$2,791
	NRC thermal monitor tests	35	2	$131	$9,170	$5,030	$6,977
	NRC report submittal extension	16	60	$131	$125,760	$63,256	$92,052
				Total	**$156,938**	**$80,357**	**$115,774**

5.1.5 Presentation of Results

This section presents the analytical results, including a discussion of supplemental considerations and uncertainties in estimates on the overall benefits.

5.1.5.1 Summary Table

Table 10~~Table 10~~ summarizes the quantified incremental net benefits for Options 3A and 3B, as compared to the no-action option.

Table 10 Summary Table

Description	Option 3A—Standard Notice-and-Comment[1]			Option 3B—Direct Final Rule[2]		
	Undiscounted	7% NPV	3% NPV	Undiscounted	7% NPV	3% NPV
Industry Implementation	$0	$0	$0	$0	$0	$0
Industry Operation	$780,500	$388,673	$570,561	$862,500	$458,523	$647,003
Industry Total	***$780,500***	***$388,673***	***$570,561***	***$862,500***	***$458,523***	***$647,003***
NRC Implementation	($460,596)	($417,966)	($441,276)	($294,139)	($282,593)	($288,998)
NRC Operation	$145,515	$70,482	$105,056	$156,938	$80,357	$115,774
NRC Total	***($315,081)***	***($347,484)***	***($336,220)***	***($137,201)***	***($202,236)***	***($173,224)***
Total	**$465,419**	**$41,188**	**$234,341**	**$725,299**	**$256,288**	**$473,779**
Difference in Benefits between Option 3B and Option 3A				**$259,881**	**$215,099**	**$239,438**

1 Standard notice-and-comment rule process credit for averted costs begin in 2022.

2 Direct final rule process credit for averted costs begin in 2020.

As shown in Table 10, both Options 3A and 3B reduce the burden on the industry, although the net benefits estimated for Option 3B are greater because the NRC staff estimated that the direct final rule would become effective in 2020, two years sooner than for Option 3A. The difference in undiscounted benefits between Option 3B and Option 3A is $259,881.

Based on this estimate, the Option 3A rule process results in estimated averted costs to the industry that range from $388,673 using a 7-percent discount rate to $570,561 using a 3-percent discount rate. The Option 3B rule process slightly exceeds the averted costs for Option 3A with estimated averted costs to the industry that range from $458,523 using a 7-percent discount rate to $647,003 using a 3-percent discount rate, which is approximately $70,000 ($458,523 versus $388,673) more than Option 3A.

Likewise, the NRC would realize burden reduction in operations by eliminating certain testing requirements and reducing the need to review and approve schedule extensions for submitting RV specimen test results. However, the NRC costs to complete the rulemaking exceed these benefits. Based on this estimate, the Option 3A (standard notice-and-comment rule process) results in NRC estimated costs between ($347,484) using a 7-percent discount rate and ($336,220) using a 3-percent discount rate. Option 3B (direct final rule process) results in estimated costs to the NRC that range from ($202,236) using a 7-percent discount rate to ($173,224) using a 3-percent discount rate.

Because the direct final rule process would use fewer agency resources, the NRC costs using a 7-percent discount factor are approximately $145,000 less for Option 3B when compared to Option 3A.

5.1.5.2 Uncertainty Analysis

The NRC staff completed a Monte Carlo sensitivity analysis for this regulatory basis using the specialty software @Risk®.[10] The Monte Carlo approach answers the question, "What distribution of net benefits results from multiple draws of the probability distribution assigned to key variables?"

As this regulatory basis uses estimates of values that are sensitive to plant-specific cost drivers and plant dissimilarities, the NRC staff provides the following analysis of the variables that have the greatest amount of uncertainty.

Monte Carlo simulations involve introducing uncertainty into the analysis by replacing the point estimates of the variables used to estimate base case costs and benefits with probability distributions. By defining input variables as probability distributions instead of point estimates, the influence of uncertainty on the results of the analysis (in other words, the net benefits) can be effectively modeled.

The probability distributions chosen to represent the different variables in the analysis were bounded by the range-referenced input and the NRC staff's professional judgment. When defining the probability distributions for use in a Monte Carlo simulation, summary statistics are needed to characterize the distributions. These summary statistics include the minimum, most likely, and maximum values of a program evaluation and review technique (PERT) distribution,[11] the minimum and maximum values of a uniform distribution, and the specified integer values of a discrete population. The NRC staff used the PERT distribution to reflect the relative spread and skewness of the distribution defined by the three estimates.

The NRC performed the Monte Carlo simulation by repeatedly recalculating the results, 5,000 times. For each iteration, the values were chosen randomly from the probability distributions that define the input variables. The values of the output variables were recorded for each iteration, and these resulting output variable values were used to define the resultant probability distribution. Figures 1 through 3 display the probability distribution function and the descriptive statistics of the incremental benefits and costs of the two rulemaking options (Options 3A and 3B), compared to the no-action option (Option 1). The analysis shows that both the industry (i.e., Figure 1 shows that Option 3B has greater averted cost savings) and the NRC (i.e., Figure 2 shows that Option 3B has a lower implementation cost) would benefit if Option 3B, the direct final rule process is selected. Furthermore, the uncertainty analysis of Figure 3 shows that while Option 3A is slightly cost beneficial, Option 3B is more cost beneficial than Option 3A based on the uncertainty of the analysis inputs.

---

10 Information about this software is available at http://www.palisade.com.

11 A PERT distribution is a special form of the beta distribution with specified minimum and maximum values. The shape parameter is calculated from the defined *most likely* value. The PERT distribution is similar to a triangular distribution, in that it has the same set of three parameters. Technically, it is a special case of a scaled beta (or beta general) distribution. The PERT distribution is generally considered superior to the triangular distribution when the parameters result in a skewed distribution, as the smooth shape of the curve places less emphasis in the direction of skew. Similar to the triangular distribution, the PERT distribution is bounded on both sides and therefore, may not be adequate for some modeling purposes if it is desired to capture tail or extreme events.

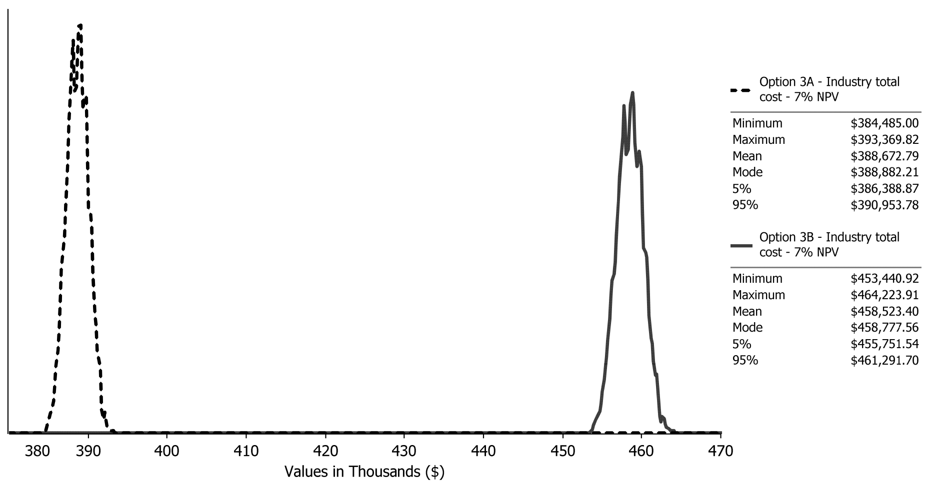

Figure 1 Industry Total Averted Costs—7-Percent Net Present Value (NPV)

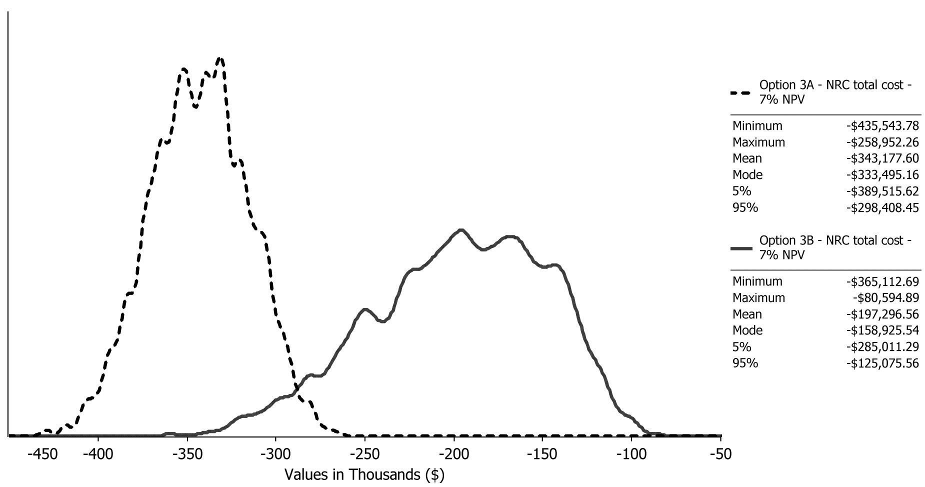

Figure 2 NRC Total Costs—7-Percent NPV

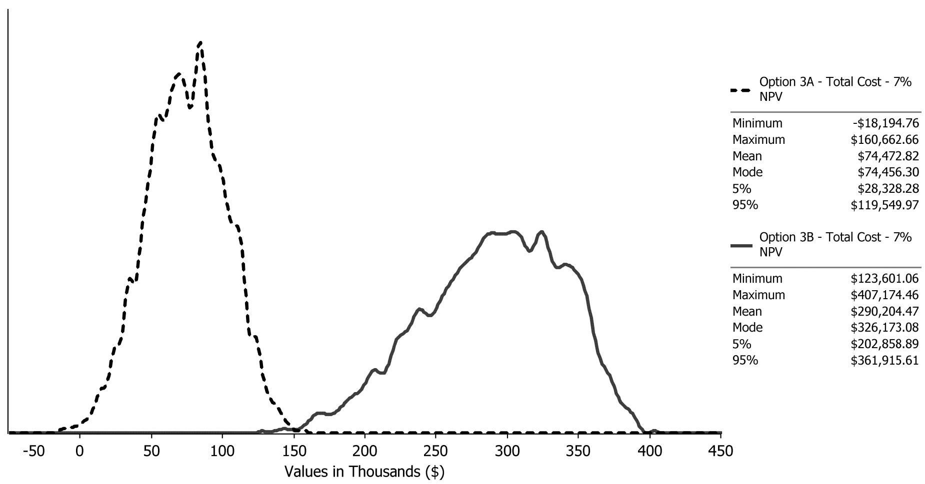

Figure 3 Total Averted Cost—7-Percent NPV

Figure 4 provides a direct comparison that shows Option 3B provides $216 thousand greater net benefits than those achieved by Option 3A with a 90-percent confidence interval in which the net benefits would fall between $123 thousand and $300 thousand.

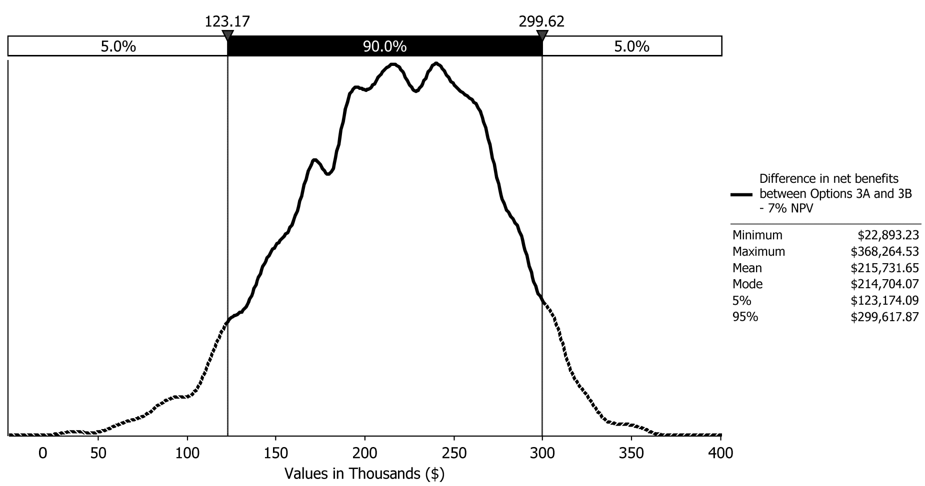

Figure 4 Difference in Net Benefits between Option 3A and Option 3B

Figure 5 shows a tornado diagram that identifies the key variables whose uncertainty drives the largest impact on total costs (and averted costs). This figure ranks the variables based on their contribution to cost uncertainty on the mean value. Three variables—the NRC costs to develop the direct final rule, the NRC costs to review the licensee requests for extensions, and the NRC costs to review CMM test results—cause the greatest uncertainty in the costs. The remaining key variables show diminishing variation.

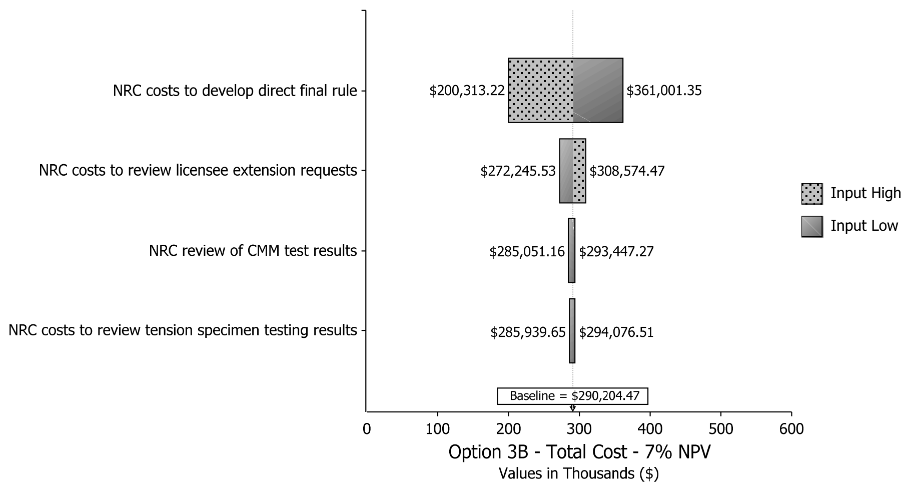

Figure 5 Tornado Diagram—Total Averted Costs—7-Percent NPV

This uncertainty analysis shows Option 3B is the preferred option, because it provides $216 thousand greater net benefits than those achieved by Option 3A with a 90-percent confidence interval, in which the net benefits would fall between $123 thousand and $300 thousand using a 7-percent discount factor.

5.1.6 Decision Rationale

The cost-benefit analysis evaluated three options. Option 1, the no-action alternative, would maintain the current requirements in Appendix H to 10 CFR Part 50 (i.e., status quo) and as such, the specimens and testing required by ASTM E 185-73, E 185-79, and E 185-82, as applicable. Option 1 avoids the costs that the proposed rule would impose; however, licensees will continue to be required to (1) test Charpy impact specimens for the weld HAZ, (2) test tension specimens for the weld metal and base metal at various temperatures, (3) test CMMs, if they were included, and (4) examine thermal monitors in each surveillance capsule in accordance with ASTM E 185-82, to the extent practicable. Furthermore, licensees that need additional time to submit their surveillance capsule reports would continue to submit extension requests for NRC review and approval.

Option 2 is a rulemaking option to incorporate by reference the latest editions of ASTM E 185 and ASTM E 2215 into Appendix H of 10 CFR Part 50. Based on the NRC staff's review of the requirements established in ASTM E 185-16 and ASTM E 2215-16, the NRC staff determined that the burden associated with implementing these ASTM standards would be significant without a corresponding benefit to public health and safety. Significant NRC resources would have been necessary to (1) to develop a minimum of 13 conditions that would be imposed on the 2016 edition of the ASTM E 185 and E 2215 standards, if the rulemaking effort incorporated these standards into Appendix H of 10 CFR Part 50; and (2) quantify the cost burden to licensees associated with their use. Because of this estimated high level of effort, without a corresponding benefit to public health and safety, this option was not considered viable.

Under Option 3, the NRC would undertake a rulemaking effort to revise the underlying regulations to alleviate the burden to existing licensees and to future applicants with no adverse impact to public health and safety and the environment, as follows:

- HAZ specimens
  - Eliminate the requirement for inclusion of weld HAZ specimens.
  - Eliminate the requirement for testing weld HAZ specimens.
- Tension Specimens
  - Reduce the number of tension specimens included in surveillance capsules (new or reconstituted).
  - Reduce the requirement for testing tension specimens.
  - Specify the required test temperatures for irradiated materials (i.e., at room temperature and service temperature).
- CMM
  - Specify that CMM testing is not required.
- Thermal Monitors
  - Eliminate the requirement for inclusion of thermal monitors.
  - Eliminate the requirement for examining thermal monitors.
- Surveillance Test Results Reporting
  - Extend submittal of surveillance capsule reports to 18 months after the withdrawal of the capsule.

This option achieves the objective of maximizing the burden reduction for the RV material surveillance program, while maintaining a comparable level of safety. This option also has the advantage of relative simplicity to implement. The NRC staff considered two rulemaking processes for its implementation. Option 3A is the standard notice-and-comment rule process, in which the NRC would prepare and issue a regulatory basis and proposed rule for public comment before preparing and issuing a final rule. Option 3B is the direct final rule process, in which the NRC would prepare the final and companion rules to revise the testing and reporting requirements in Appendix H to 10 CFR Part 50.

Table 10~~Table 10~~ shows that under Option 3A, the NRC implementation costs under the standard notice-and-comment rule process when compared to the savings associated with the burden reduction to the licensees and the NRC would be slightly cost beneficial. Based on this estimate, Option 3A (standard notice-and-comment rule process) results in estimated NRC implementation costs between ($347,484) using a 7-percent discount rate and ($336,220) using a 3-percent discount rate. Option 3B (direct final rule process) results in estimated costs to the NRC that range from ($202,236) using a 7-percent discount rate to ($173,224) using a 3-percent discount rate. Because the direct final rule process would use less agency resources, the NRC costs for Option 3B are approximately $145,000 less than that required for Option 3A when using a 7-percent discount rate.

The NRC staff also observed that the remaining number of surveillance capsules in the existing fleet of commercial nuclear power reactors is only a small fraction of the total number that have already been withdrawn and tested because of the maturity of RV material surveillance programs. Therefore, the opportunity to reduce licensee burdens associated with the RV material surveillance test program can only be maximized if the rulemaking effort is completed under the direct final rule process; thus, Option 3B preferred.

5.2 Backfitting and Issue Finality

The NRC's backfitting provisions for holders of construction permits, and applicants and holders of operating licenses, appear in 10 CFR 50.109, "Backfitting" (the Backfit Rule). Issue finality provisions, which are analogous to the backfitting provisions in 10 CFR 50.109, appear in 10 CFR 52.63, "Finality of Standard Design Certifications"; 10 CFR 52.83, "Finality of Referenced NRC Approvals; Partial Initial Decision on Site Suitability"; 10 CFR 52.98, "Finality of Combined Licenses; Information Requests"; 10 CFR 52.145, "Finality of Standard Design Approvals, Information Request"; and 10 CFR 52.171, "Finality of Manufacturing Licenses; Information Requests." The backfitting and issue finality considerations, as applied to these entities and regulatory approvals, are considered below.

Neither of the options presented would constitute backfitting under 10 CFR 50.109, "Backfitting," or violate any issue finality provision in 10 CFR Part 52, "Licenses, Certifications, and Approvals for Nuclear Power Plants." Option 1 would maintain the status quo of the requirements for a Reactor Vessel Material Surveillance Program under Appendix H to 10 CFR Part 50, thereby imposing no change in requirements or NRC positions. Options 3A and 3B would (1) provide licensees with a non-mandatory relaxation from the current 1 year following a capsule withdrawal to 18-months to submit surveillance capsule test results, and (2) reduce testing requirements by amending the NRC's regulations. Because this change is non-mandatory, licensees would not be required to comply with the regulations that eliminate or reduce testing requirements for specified surveillance capsule specimens or that extend the allowable period for submitting surveillance test results to the NRC (i.e., licensees can continue to submit surveillance capsule test results 12-months following a capsule withdrawal), the rulemaking for Options 3A and 3B would not constitute backfitting or violate issue finality.

5.3 Regulatory Flexibility Analysis

The Regulatory Flexibility Act, enacted in September 1980, requires agencies to consider the effect of their regulatory proposals on small entities, analyze alternatives that minimize effects on small entities, and make their analyses available for public comment.

This rulemaking effort affects primarily the utilities that own light-water nuclear power reactors, and the vendors of those reactors, none of which meet the definition of "small entities" set forth in the size standards established by the NRC in 10 CFR 2.810, "NRC Size Standards." Therefore, a proposed rulemaking would not have a significant economic effect on a substantial number of small entities.

5.4 Compliance with National Environmental Policy Act

A rulemaking to revise Appendix H to 10 CFR Part 50 would not be a major Federal action significantly affecting the quality of the human environment; therefore, an environmental impact statement would not be required. An environmental assessment developed along with the rulemaking likely would conclude that the regulatory action would not increase the probability of accidents and would not increase any radioactive effluents or the resultant doses above the regulatory limits, adversely affect any endangered or threatened species, or entail an NRC undertaking involving historic sites. This is because the rulemaking would not change the process for handling, transporting, or storing the surveillance capsule and its contents from the licensee's site to the hot cell laboratory, where testing of specimens is performed. Although the rulemaking would remove requirements for testing certain specimens after the capsules are transported to the hot cell laboratory, this change would have no environmental impact. The environmental impacts associated with licensing of any future commercial nuclear power reactor will be considered in the process for individual license applications.

5.5 NRC Strategic Plan

This rulemaking effort supports the NRC's 2018–2022 Strategic Plan (NUREG-1614; NRC, 2018) in relation to the five principles of good regulation: independence, openness, efficiency, clarity, and reliability.

Independence. The rulemaking effort would consider all facts and opinions from licensees and other interested members of the public. Final decisions would be based on objective, unbiased assessments of all information and would be documented with reasons explicitly stated.

Openness. The rulemaking effort would be transacted publicly and candidly. The public would be informed about and have the opportunity to participate in the regulatory process. Open channels of communication would be maintained with Congress, other government agencies (i.e., federal, state and local), non-govenmental organizations, licensees, and the public, as well as with the international nuclear community. Thus far, the NRC staff has engaged the regulated community, the public, and other interested stakeholders via public meetings during the early development of the regulatory basis and rulemaking to ensure that diverse views were considered in the regulatory decision-making process.

Efficiency. The rulemaking effort would reduce the regulatory burden on reactor licensees and the NRC that are associated with test specimens contained within surveillance capsules and the reporting of surveillance test results. It would eliminate the testing of certain specimen types that were found not to contribute to the results of safety analyses and assessments of the integrity of the RV. The proposed revisions to the requirements in Appendix H to 10 CFR Part 50 would have no adverse effect on public health and safety. Furthermore, the direct final rule process is the most effective and efficient approach to conduct this rulemaking effort because it would (1) minimize the use of agency resources and (2) potentially allow the revised requirements to become effective sooner, thus providing licensees the benfit of the rule change sooner. The direct final rule would continue to ensure protection of public health and safety and the environment.

Clarity. The rulemaking effort to revise Appendix H to 10 CFR Part 50 would result in coherent, logical, and practical regulations. A clear nexus between the revised regulations and agency goals and objectives would be established. The revised requirements would be readily understood and easily applied.

Reliability. The rulemaking effort would result in regulations that are based on the best available knowledge from research and operational experience. Since the issuance of Appendix H to 10 CFR Part 50 in 1973, substantial material data analyses, knowledge, and experience have been attained through the many years of conducting RV material surveillance programs. This information would be used to revise the requirements in Appendix H to 10 CFR Part 50 to lend stability for the design and implementation of an RV material surveillance program.

5.6 Peer Review of Regulatory Basis

The Office of Management and Budget's "Final Information Quality Bulletin for Peer Review," dated December 16, 2004, requires each Federal agency to subject "influential scientific information" to peer review before dissemination. The Office defines "influential scientific information" as "scientific information the agency reasonably can determine will have or does have a clear and substantial impact on important public policies or private sector decisions." This regulatory basis document does not contain "influential scientific information." Therefore, the NRC staff has determined that there is no need for a peer review of the regulatory basis.

5.7 Cumulative Effects of Regulation

The NRC has implemented a program to address the possible cumulative effects of regulation (CER) in the development of regulatory bases for rulemakings. The consideration of CER is an organizational effectiveness challenge that results from a licensee or other affected entity, implementing several complex positions, programs, or requirements within a prescribed implementation period and with limited available resources, including the ability to access technical expertise to address a specific issue. This interaction will occur during a public meeting.

The preferred option (i.e., Option 3B) would provide licensees with a non-mandatory relaxation from the current surveillance capsule testing and reporting requirements. Licensees would not be required to (1) eliminate or reduce testing requirements for specified surveillance capsule specimens or (2) extend the allowable period for submitting surveillance test results to the NRC (i.e., licensees can continue to submit surveillance capsule test results one year following a capsule withdrawal). The preferred option would reduce the regulatory burden on reactor licensees and the NRC for a non-safety-significant issue. Consequently, there would be no associated CER for this rulemaking.

5.8 Information Collection Requirements

The proposed rulemaking would involve changes to existing information collection and reporting requirements. These proposed changes would reduce the burden on licensees by decreasing the amount of information that is required to be collected and then submitted to the NRC in technical reports following the withdrawal of each surveillance capsule.

With respect to the revisions discussed in this regulatory basis, ASTM E 185 requires testing irradiated Charpy impact specimens for the weld HAZ, testing tension specimens for the applicable test materials (i.e., base metal and weld metal), and examining temperature monitors, which are contained in the surveillance capsules. CMM is also tested, if included in the surveillance capsule. Furthermore, Appendix H to 10 CFR Part 50 requires that, following each capsule withdrawal, the test results be the subject of a summary technical report to be submitted to the NRC. The report must include the data required by ASTM E 185-82, to the extent practicable, for the configuration of the specimens in the capsule.

As a result of the potential changes to Appendix H to 10 CFR Part 50, licensees would no longer be required to perform (1) test irradiated Charpy impact specimens for the weld HAZ, (2) test CMM, and (3) examine temperature monitors. Also, the required number of tension specimens tested would be reduced for the applicable test materials (i.e., base metal and weld metal). Thus, the results of these tests and exams would also no longer be required to be reported.

5.9 Relevant Legal and Policy Issues

The NRC staff has not identified any potential legal or policy issues resulting from the evaluated options.

5.10 Safety Goal Evaluation

Safety goal evaluations are applicable to regulatory initiatives that are considered to be generic safety enhancement backfits subject to the substantial additional protection standard in 10 CFR 50.109(a)(3). This regulatory basis describes potential regulatory changes that would not qualify as generic safety enhancement backfits because the changes under consideration would be as follows:

- Revise requirements to eliminate and reduce the need to test certain surveillance capsule specimens.

- Extend the required submittal period of 1 year to 18 months for reporting surveillance test results.

Therefore, no safety goal evaluation is needed because the potential revisions do not affect one's ability to monitor changes in the fracture toughness properties of the RV materials and to analyze the integrity of the RV. These material surveillance programs would continue to be effective at predicting, in advance, the changes in RV material properties resulting from the cumulative effects of radiation.

6.0 Stakeholder Involvement

Since 2013, activities related to the Appendix H to 10 CFR Part 50 rulemaking have been discussed at many public meetings and other interactions between the NRC and stakeholders, as detailed below.

American Society of Mechanical Engineers (ASME) Code Committee Meetings

The NRC staff regularly attend and participate in quarterly ASME Code committee meetings. These committees are responsible for developing, revising, and maintaining ASME codes and standards. The NRC staff provides regular status updates of NRC activities related to the Appendix H to 10 CFR Part 50 proposed rulemaking to attendees of the ASME Section XI, Working Group on Operating Plant Criteria. The ASME meetings are open to the public, and status updates of the Appendix H to 10 CFR Part 50 proposed rulemaking appear on the meeting agenda, thereby allowing any interested parties to participate.

NRC Public Meetings Involving Reactor Vessel Material Surveillance Program for Subsequent License Renewal

Following the issuance of SLR guidance documents (i.e., the GALL-SLR Report and the SRP-SLR) for public comment, the NRC staff held several public meetings (Category 2 and Category 3) to discuss the NRC staff's resolution of public comments. Several of the meetings discussed the Reactor Vessel Material Surveillance Programs for Subsequent License Renewal, as it relates to this rulemaking. Table 11~~Table 11~~ provides the meeting dates at which the public comments related to Reactor Vessel Material Surveillance Programs were discussed and the Agencywide Documents Access and Management System (ADAMS) accession numbers for the meeting-related documents.

Table 11 NRC Public Meetings Involving Reactor Vessel Material Surveillance Programs for Subsequent License Renewal

Date	Meeting	Reference (ADAMS Accession No.)
4/26/2016	Public Meeting To Discuss Comments on the Mechanical Sections of the Draft Subsequent License Renewal Guidance Documents	ML16119A236
6/1/2016	Public Meeting To Discuss Comments on the Electrical and Mechanical Sections of the Draft Subsequent License Renewal Guidance Documents	ML16180A027
6/23/2016	Public Meeting To Discuss Potential Optimization of the Subsequent License Renewal Application Review Process and Guidance Documents	ML16204A137
7/28/2016	Public Meeting To Discuss Comments on the Mechanical Sections of the Draft Subsequent License Renewal Guidance Document	ML16218A432
9/15/2016	Public Teleconference with the Nuclear Energy Institute To Discuss Current and Subsequent License Renewal Topics	ML16267A068

NRC Public Meetings Involving Appendix H to 10 CFR Part 50 Rulemaking

Each year, the NRC staff holds a Category 2 public meeting to discuss reactor pressure vessel issues and the materials programs. Also held annually is a Category 2 public meeting to exchange technical information on materials programs. The Appendix H to 10 CFR Part 50 proposed rulemaking has been one of the ongoing topics addressed at these meetings. Stakeholder feedback provided at these meetings has helped to inform the NRC staff's development of this rulemaking. Table 12~~Table 12~~ provides the meeting dates at which the Appendix H to 10 CFR Part 50 proposed rulemaking was discussed and the ADAMS accession numbers for the meeting-related documents.

Table 12 NRC Public Meetings Involving the Appendix H to 10 CFR Part 50 Rulemaking

Date	Meeting	Reference (ADAMS Accession No.)
12/05/2013	Public Meeting To Discuss Reactor Pressure Vessel Issues	ML13339A971
02/19/2015	Public Meeting To Discuss Reactor Pressure Vessel Issues	ML15061A072
01/19/2016	Public Meeting To Discuss Reactor Pressure Vessel Issues and 10 CFR Part 50 Appendix H Proposed Rulemaking	ML16021A001
05/23–25/2017	Annual Materials Programs Technical Information Exchange Public Meeting	ML17132A164

NRC Public Meeting on Appendix H to 10 CFR Part 50 Regulatory Basis Development

On June 1, 2016, the NRC staff held a Category 3 public meeting to exchange information needed to develop the draft regulatory basis for revising the regulations in Appendix H to 10 CFR Part 50. The discussion focused on the rulemaking scope, the options being considered to revise Appendix H to 10 CFR Part 50, and preliminary cost-benefit information. Meeting participants included representatives from the nuclear industry (e.g., Nuclear Energy Institute, Electric Power Research Institute, and American Nuclear Insurers), nuclear power licensees (e.g., Duke Energy, Florida Power and Light, and Dominion Energy), a foreign nuclear regulatory organization, and a private citizen. The NRC staff acknowledged that feedback obtained at the meeting would be considered as the NRC staff develops the regulatory basis and preliminary cost-benefit information in support of the proposed rulemaking effort. The meeting was transcribed (NRC, 2017b), and the NRC staff detailed the results of this public meeting in a meeting summary (NRC, 2017c).

The NRC staff presented two options for the Appendix H to 10 CFR Part 50 proposed rulemaking. The first option would retain ASTM E 185-82 and make limited revisions to Appendix H to 10 CFR Part 50. The second option would incorporate the more recent ASTM E 185-16 and E 2215-16 and revise Appendix H to 10 CFR Part 50. Of these two, the utility members expressed support for the first option. The reasons given were the potential to maximize the burden reduction and its relative simplicity. This option also addressed most of the utility members' concerns for data reporting by extending the reporting period for surveillance capsules and eliminating certain test specimens, such as HAZ specimens. The NRC staff notes that these proposed changes would still ensure protection of public health and safety and the environment.

Industry and licensee representatives confirmed the NRC staff's cost estimates, and provided feedback reflecting cost variations within their operational experiences. The NRC staff also asked stakeholders whether it was necessary to develop a regulatory guide to support the rulemaking. Currently, the agency has no regulatory guide specific to Appendix H to

10 CFR Part 50. The general reaction of the industry representatives was to not develop guidance.

7.0 References

American Society for Testing and Materials (ASTM) DS 54, "Radiation Effects Information Generated on the ASTM Reference Correlation-Monitor Steels."

ASTM E 184, "Recommended Practice for Effect of High-Energy Radiation on the Mechanical Properties of Metallic Materials."

ASTM E 185-73, "Standard Recommended Practice for Surveillance Tests for Nuclear Reactor Vessels."

ASTM E 185-79, "Standard Practice for Conducting Surveillance Tests for Light-Water Cooled Nuclear Power Reactor Vessels."

ASTM E 185-82, "Standard Practice for Conducting Surveillance Tests for Light-Water Cooled Nuclear Power Reactor Vessels."

ASTM E 185-16, "Standard Practice for Design of Surveillance Programs for Light-Water Moderated Nuclear Power Reactor Vessels."

ASTM E 900, "Guide for Predicting Radiation-Induced Transition Temperature Shift in Reactor Vessel Materials."

ASTM E 2215-16, "Standard Practice for Evaluation of Surveillance Capsules from Light-Water Moderated Nuclear Power Reactor Vessels."

Boiling Water Reactor Vessel and Internals Program (BWVIP), "Updated BWR Integrated Surveillance Program Implementation Plan," BWRVIP-86-A, February 1, 2002, Agencywide Documents Access and Management System (ADAMS) Accession No. ML020380691.

BWRVIP, "BWR Vessel and Internals Project Predictions of Neutron Irradiation Embrittlement in Boiling Water Reactor Pressure Vessel Steels, Final Report," BWRVIP-147, December 2005.

BWRVIP, "BWR Vessel and Internals Project, Integrated Surveillance Program (ISP) Implementation for License Renewal," BWRVIP-116, February 24, 2006, ADAMS Accession No. ML060750016 (proprietary).

BWRVIP, "Updated BWR Integrated Surveillance Program (ISP) Implementation Plan," BWRVIP-86, Rev. 1-A, June 2013.

Electric Power Research Institute (EPRI), "Review of Dose Rate Effects on RPV Embrittlement: Joint Electric Power Research Institute (EPRI)-CRIEPI RPV Embrittlement Studies (1999–2004)," EPRI, Palo Alto, CA: 2002, 1003529 and CRIEPI, Tokyo, Japan: T980204.

International Atomic Energy Agency (IAEA), "Reference manual on the IAEA JRQ correlation monitor steel for irradiation damage studies," IAEA-TECDOC-1230, July 2001.

Lowe, A.L., Jr., "Role and Experience with Thermal Monitors in Reactor Vessel Surveillance Capsules," Effects of Radiation on Materials: 18th International Symposium, ASTM STP 1325, R.K. Nanstad, M.L. Hamilton, F.A. Garner, and A.S. Kumar, Eds., American Society for Testing and Materials, 1999.

Marston, T.U. and W. Server, “Assessment of Weld Heat-Affected Zones in a Reactor Vessel Material,” *Journal of Engineering Materials and Technology*, Volume 100, pp. 267–271, July 1978.

Masaki, K. et al, “Study on the Structural Integrity of RPV Using PFM Analysis Concerning Inhomogeneity of the Heat-Affected Zone,” *E-Journal of Advanced Maintenance*, Vol. 5-2, pp. 85–92, Japan Society of Maintenology, 2013.

McElroy, R.J., and Lowe, Jr., A.L., “Irradiation Embrittlement Modelling of Linde 80 Weld Metals,” Effect of Radiation on Materials: 17th International Symposium, ASTM STP 1270, David S. Gelles, Randy K. Nanstad, Arvind S. Kumar, and Edward A. Little, Eds., American Society for Testing and Materials,1996.

Master Integrated Reactor Vessel Surveillance Program, “The B&W Owners Group Materials Committee Master Integrated Reactor Vessel Surveillance Program,” BAW-1543, Rev. 4, February 1993.

U.S. Nuclear Regulatory Commission (NRC), “Radiation Embrittlement of Reactor Vessel Materials,” Regulatory Guide 1.99, Rev. 2, May 1988.

NRC, “Generic Aging Lessons Learned (GALL) Report,” NUREG-1801, July 2001.

NRC, “Generic Aging Lessons Learned (GALL) Report,” NUREG-1801, Rev. 1, September 2005.

NRC, “Generic Aging Lessons Learned (GALL) Report—Final Report,” NUREG-1801, Rev. 2, December 2010.

NRC, “Rulemaking to Revise Title 10, *Code of Federal Regulations*, Part 50, Appendix H, ‘Reactor Vessel Material Surveillance Program Requirements,’” COMSECY-14-0027, June 25, 2014a (not publicly available).

NRC, “Rulemaking to Revise Title 10, *Code of Federal Regulations*, Part 50, Appendix H, ‘Reactor Vessel Material Surveillance Program Requirements,’” SRM-COMSECY-14-0027, August 8, 2014b (not publicly available).

NRC, “Recommendations Resulting from the Integrated Prioritization and Re-Baselining of Agency Activities,” SRM-SECY-16-0009, April 13, 2016, ADAMS Accession No. ML16104A158.

NRC, Slides for Public Meeting related to “10 CFR 50 Appendix H Rulemaking,” June 1, 2017a, ADAMS Accession No. ML17145A239.

NRC, Meeting Transcript for Public Meeting related to “10 CFR 50 Appendix H Rulemaking,” June 1, 2017b, ADAMS Accession No. ML17173A074.

NRC, Meeting Summary for Public Meeting related to “10 CFR 50 Appendix H Rulemaking,” June 28, 2017c, ADAMS Accession No. ML17173A081.

NRC, “Generic Aging Lessons Learned for Subsequent License Renewal (GALL-SLR) Report,” NUREG-2191, Vol. 1 and 2, July 2017d.

NRC, “Strategic Plan: Fiscal Years 2018–2022,” NUREG-1614, Vol. 7, February 2018.

Office of Management and Budget, “Final Information Quality Bulletin for Peer Review,” December 16, 2004.

Soneda, N. ed., “Irradiation Embrittlement of Reactor Pressure Vessels (RPVs) in Nuclear Power Plants,” Woodhead Publishing, 2015.

Stallmann, F.W., “Analysis of the A302B and A533B Standard Reference Materials in Surveillance Capsules of Commercial Power Reactors,” NUREG/CR-4947, November 1987.

U.S. Code of Federal Regulations, “Domestic Licensing of Production and Utilization Facilities,” Part 50, Chapter I, Title 10, “Energy.”

Wallin, K., “Application of the master curve method to crack initiation and crack arrest,” ASME PVP-Vol. 393, *Fracture, Fatigue and Weld Residual Stress*, 1999, pp. 3–9.

Wang, J.A., “Analysis of the Irradiation Data for A302B and A533B Correlation Monitor Materials,” NUREG/CR-6413, April 1996.

Westinghouse, “Analysis of Capsule 2840 from the Calvert Cliffs Unit No. 1 Reactor Vessel Radiation Surveillance Program,” WCAP-17365-NP, Rev. 0, March 2011.

Westinghouse, “Results of Analysis of Capsule W from the Ameren Missouri Callaway Unit 1 Reactor Vessel Radiation Surveillance Program,” WCAP-18001-NP, Rev. 0, September 2015, ADAMS Accession No. ML15288A518.