
Regulatory Analysis for Emergency Core Cooling System Performance during Loss-of-Coolant Accidents Final Rule (10 CFR 50.46c)

U.S. Nuclear Regulatory Commission
Office of Nuclear Reactor Regulation





[Page intentionally left blank.]

Table of Contents

Table of Contents.....	1
List of Figures	4
List of Tables.....	5
Abbreviations and Acronyms	7
Executive Summary	9
1 Introduction	13
1.1 Background	13
1.2 Statement of the Problem.....	16
1.3 Objectives.....	17
2 Identification and Preliminary Analysis of Alternative Approaches	19
2.1 Alternative 1: Maintain the Existing ECCS Requirements	19
2.2 Alternative 2: Case-by-Case Approach	20
2.3 Alternative 3: Amend the Regulation to Modify ECCS Acceptance Criteria	21
3 Safety Goal Evaluation	23
4 Estimation and Evaluation of Values and Impacts.....	25
4.1 Identification of Affected Attributes	25
4.2 Overview of Major Changes	27
4.3 Methodology for Evaluation of Benefits and Costs	28
4.3.1 Overview of the Approach	28
4.3.2 Assumptions and Considerations.....	29
4.3.3 Affected Entities	30
4.3.4 Sign Conventions	31
4.3.5 Analysis Horizon.....	31
4.3.6 Base Year.....	32
4.3.7 Data.....	32
5 Evaluation of Alternatives	36
5.1 Industry Implementation	36
5.1.1 Cladding Embrittlement–Alternative 2	36
5.1.2 Cladding Embrittlement–Alternative 3	37
5.1.3 Risk-Informed	40
5.2 Industry Operation	46
5.2.1 Cladding Embrittlement–Alternative 2	46

5.2.2	Cladding Embrittlement–Alternative 3	46
5.2.3	Risk-Informed	48
5.3	Total Industry Costs.....	48
5.3.1	Cladding Embrittlement–Alternative 2	48
5.3.2	Cladding Embrittlement–Alternative 3	50
5.3.3	Risk-Informed	52
5.4	NRC Implementation	53
5.4.1	Cladding Embrittlement Alternative 2	53
5.4.2	Cladding Embrittlement–Alternative 3	55
5.4.3	Risk-Informed	58
5.5	NRC Operation	59
5.5.1	Cladding Embrittlement	59
5.5.2	Risk-Informed	59
5.6	Total NRC Costs.....	59
5.6.1	Cladding Embrittlement–Alternative 2	59
5.6.2	Cladding Embrittlement–Alternative 3	60
5.6.3	Risk-Informed	60
5.7	Improvements in Knowledge	60
5.8	Regulatory Efficiency.....	60
5.9	Public Health (Accident)	60
5.10	Occupational Health (Accident).....	61
5.11	Onsite Property.....	61
5.11.1	Cladding Embrittlement	61
5.11.2	Risk-Informed	61
5.12	Offsite Property.....	61
5.13	Other Considerations.....	61
5.14	Uncertainty Analysis	62
5.14.1	Uncertainty Analysis Assumptions	62
5.14.2	Uncertainty Analysis Results.....	62
5.14.3	Summary of Uncertainty Analysis	68

5.15	Disaggregation	68
5.16	Future Design Certifications	69
5.17	Hypothetical Future Operating Reactors	70
6	Presentation of Results.....	71
6.1	Summary of Benefits and Costs	71
6.2	Nonquantified Benefits and Costs	74
6.3	Changes from the Proposed Rule to the Final Rule Regulatory Analysis	74
7	Decision Rationale.....	79
7.1	Technology Neutral	79
7.2	Research Findings.....	79
7.3	Crud Effects.....	80
7.4	Risk-Informed	80
7.5	Results of Comparison of Alternatives 2 and 3 against the Alternative 1 Baseline	80
7.6	Staff Recommendation	82
8	Rule Implementation.....	84
9	References	86
	Appendix A—Supplementary Tables	89

List of Figures

Figure 1	Total Annual Industry Cost for Operating Reactors (Alternative 2)	50
Figure 2	Annual Industry Cost per Unit for Operating Reactors (Alternative 2)	50
Figure 3	Total Annual Industry Cost for Operating Reactors (Alternative 3)	52
Figure 4	Annual Industry Cost per Unit for Operating Reactors (Alternative 3)	52
Figure 5	Cladding embrittlement: Total industry costs (7% NPV)	63
Figure 6	Cladding embrittlement: Total NRC costs (7% NPV)	63
Figure 7	Cladding embrittlement: Net benefit (7% NPV)	64
Figure 8	Top ten variables where uncertainty drives the largest impact on cladding embrittlement costs (7% NPV)	65
Figure 9	Risk-Informed: Total industry costs (7% NPV)	66
Figure 10	Risk-Informed: Total NRC costs (7% NPV)	66
Figure 11	Risk-Informed: Net benefit (7% NPV)	67
Figure 12	Top ten variables where uncertainty drives the largest impact on risk-informed costs (7% NPV)	67
Figure 13	Cladding embrittlement: Total industry costs (7% NPV)	101
Figure 14	Cladding embrittlement: Total NRC costs (7% NPV)	102
Figure 15	Cladding embrittlement: Net Benefit (7% NPV)	103
Figure 16	Top ten variables where uncertainty drives the largest impact on cladding embrittlement costs (7% NPV)	104

List of Tables

Table 1	Total Costs (Cladding Embrittlement)	10
Table 2	Total Benefits (Cladding Embrittlement)	10
Table 3	Total Costs (Risk-Informed)	10
Table 4	Total Benefits (Risk-Informed)	10
Table 5	Cost/Benefit Comparison of Alternatives	11
Table 6	Summary of Significant Benefits Due to 10 CFR 50.46c	28
Table 7	Major Assumptions	29
Table 8	Consumer Price Index—All Urban Consumers, U.S. City Average	33
Table 9	Labor Rates	34
Table 10	Dollar per Person-Rem Conversion Factor	35
Table 11	Industry Implementation Costs for Operating Reactors—Cladding Embrittlement Alternative 2 (Summary)	37
Table 12	Industry Implementation Costs for Operating Reactors—Cladding Embrittlement Alternative 3 (Summary)	39
Table 13	Industry Implementation Costs for Design Certifications and Combined Licenses (Alternative 3)	40
Table 14	Industry Implementation Costs for Future Operating Reactors (Alternative 3)	40
Table 15	Containment CAD Model Inputs	41
Table 16	Industry Implementation: Containment CAD Model	41
Table 17	Industry Implementation: Debris Effects, Break Frequency, and Thermal Hydraulics Model	42
Table 18	Averted Industry Costs for Fibrous Insulation Removal and Replacement	44
Table 19	Exemption Requests Averted by Risk-Informed Alternative	45
Table 20	Industry Operation: Periodic Breakaway Tests (Alternative 2)	46
Table 21	Industry Operation: Periodic Breakaway Tests (Alternative 3)	47
Table 22	Industry Operating Costs for Future Cladding Alloys	48
Table 23	Long Term Cooling Exception Reporting Costs	48
Table 24	Total Industry Costs (Cladding Embrittlement Alternative 2)	49
Table 25	Industry Average Costs per Unit (Cladding Embrittlement Alternative 2)	49
Table 26	Total Industry Costs (Cladding Embrittlement Alternative 3)	51
Table 27	Industry Average Costs per Unit (Cladding Embrittlement Alternative 3)	51
Table 28	Total Industry Costs (Risk-Informed)	53
Table 29	Industry Average Costs per Designated Unit (Risk-Informed)	53
Table 30	NRC Implementation Costs Affecting Operating Reactors, Design Certifications, and Future Operating Reactors (Cladding Embrittlement Alternative 2)	54

Table 31	NRC Implementation Costs for Operating Reactors (Cladding Embrittlement Alternative 2)	54
Table 32	Total NRC Implementation Costs (Cladding Embrittlement Alternative 2)	55
Table 33	NRC Implementation Costs Affecting Operating Reactors, Design Certifications, and Future Operating Reactors (Cladding Embrittlement Alternative 3)	56
Table 34	NRC Implementation Costs for Operating Reactors (Cladding Embrittlement Alternative 3)	56
Table 35	NRC Implementation Costs for Design Certifications and Combined Licensees (Cladding Embrittlement Alternative 3)	57
Table 36	NRC Implementation Costs for Future Operating Reactors (Cladding Embrittlement Alternative 3)	57
Table 37	Total NRC Implementation Costs (Cladding Embrittlement Alternative 3)	57
Table 38	NRC Implementation Costs for Operating Reactors (Risk-Informed)	58
Table 39	NRC Operation: Review of Long-Term Cooling Analysis Changes	59
Table 40	Total NRC Costs (Risk-Informed)	60
Table 41	Disaggregation	68
Table 42	Industry Costs for Future Design Certification	69
Table 43	NRC Costs for Future Design Certification	70
Table 44	Industry Costs for Hypothetical Operating Reactor	70
Table 45	NRC Costs for Hypothetical Future Operating Reactor	70
Table 46	Summary of Net Benefits and Costs (Alternative 2)	71
Table 47	Summary of Net Benefits and Costs (Alternative 3)	72
Table 48	Total Costs (Cladding Embrittlement Alternative 2)	73
Table 49	Total Costs (Cladding Embrittlement Alternative 3)	73
Table 50	Total Costs (Risk-Informed)	74
Table 51	Comments and Responses on Proposed Rule Costs	75
Table 52	Proposed and Final Rule Costs (Cladding Embrittlement)	78
Table 53	Proposed and Final Rule Costs (Risk-Informed)	78
Table 54	Summary of Totals	80
Table 55	Cost/Benefit Comparison of Alternatives	83
Table 56	Uncertainty Analysis Variables	89
Table 57	Industry Implementation Costs (Cladding Embrittlement Alternative 2)	94
Table 58	Industry Implementation Costs (Cladding Embrittlement Alternative 3)	96
Table 59	Industry Operation Costs for Operating Reactors (Cladding Embrittlement)	98

Abbreviations and Acronyms

°C	degree(s) Celsius
°F	degree(s) Fahrenheit
ADAMS	Agencywide Documents Access and Management System
ANL	Argonne National Laboratory
AOR	analysis of record
BLS	U.S. Department of Labor, Bureau of Labor Statistics
BWR	boiling-water reactor
CAD	computer-aided design
CFR	<i>U.S. Code of Federal Regulations</i>
COL	combined license
CPI-U	Consumer Price Index for all urban consumers
DG	draft regulatory guide
ECCS	emergency core cooling system
ER	exemption request
FR	<i>Federal Register</i>
FTE	full-time equivalent
GDC	general design criterion/criteria
GEH	General Electric Hitachi Nuclear Energy
GL	generic letter
GSI	Generic Safety Issue
ISI	inservice inspection
LAR	license amendment request
LOCA	loss-of-coolant accident
LTC	long-term cooling
LWR	light-water reactor
NEI	Nuclear Energy Institute
NINA	Nuclear Innovation North America, LLC
NRC	U.S. Nuclear Regulatory Commission
OMB	Office of Management and Budget
PCT	peak cladding temperature
PERT	program evaluation and review technique
PQD	postquench ductility
PRM	petition(s) for rulemaking
PWR	pressurized-water reactor

RG	final regulatory guide
RIL	research information letter
RIN	regulation identifier number
SRM	staff requirements memorandum/memoranda
TH	thermal-hydraulic
TR	topical report
ZOI	zone of influence

Executive Summary

The U.S. Nuclear Regulatory Commission (NRC) is proposing to amend Title 10 of the *Code of Federal Regulations* (10 CFR) 50.46 to accomplish four objectives: (1) provide technology-neutral performance-based criteria to expand the applicability of the rule to all fuel design and zirconium based fuel cladding materials, as discussed in Petition for Rulemaking (PRM)-50-71, (2) account for new research information into the behavior of fuel cladding under accident conditions, (3) address, in explicit terms, the thermal effects of crud and oxide layers that accumulate on the fuel cladding during plant operation that was raised in PRM-50-84, and (4) provide an alternative approach for addressing the effects of debris on long-term cooling. To achieve these objectives, this rulemaking would amend 10 CFR Part 50 to add the rule language to 10 CFR 50.46c. The analysis presented in this document examines the benefits and costs of the “Emergency Core Cooling System Performance during Loss-of-Coolant Accidents” final rule requirements relative to the baseline case (i.e., the no action alternative).

The key findings are as follows:

The rule encompasses provisions that fall into three groups: (1) technology-neutral changes to the cladding alloys allowed in light-water reactors (LWRs) without licensee exemption to include all zirconium based materials, (2) cladding embrittlement analytical limits, testing, and reporting protocols designed to verify cladding performance, and (3) risk-informed alternatives for dealing with the safety issue of fibrous materials entering the reactor coolant. The NRC has deemed this rulemaking meets the adequate protection exception to the backfit rule. Since the NRC uses a “no action” baseline to estimate incremental costs, the total cost of the proposed rule largely results from imposition of cladding embrittlement protocols. It is important to note, however, that in the absence of 10 CFR 50.46c, the NRC would be forced to, either: (1) determine adequate protection for each plant on a case-by-case basis vs. providing guidance to streamline this process for industry, which would result in costs to industry also detailed in this regulatory analysis under Alternative 3, or (2) establish a “safe harbor” of lower burnup operations for each plant that ensures the degradation mechanisms would not occur, which is not economically viable for the high burnup fuel currently in use.

Because of the cladding embrittlement provisions of this rule, the NRC estimates that the industry as a whole would incur total undiscounted costs of (\$46.3 million), between implementation and operation costs, as documented in this regulatory analysis. For the cladding embrittlement protocols, the NRC expects to incur undiscounted costs of (\$2.3 million), to audit and review the submissions from industry. Some anticipated costs to the industry and the NRC, largely exemption requests and license amendment requests (LARs), would be averted by this rule, estimated at \$1.7 million for industry and \$1.7 million for the NRC, undiscounted. The net present value of these costs and benefits is (\$32.1 million) using a 7-percent discount rate and (\$37.5 million) using a 3-percent discount rate, over a 60-year analysis period. The average unit would incur costs of approximately (\$316,000) to implement this rule.

The risk-informed alternative of this final rule is expected to avert costs to the industry of approximately \$355 million, and to the NRC of approximately \$700,000. These averted costs result from the costly actions of removing the fibrous asbestos insulation from the reactor compartments, and replacing it with metallic insulation. These actions require significant material and labor costs, occupational exposure costs, and radioactive material disposal costs. The averted costs are reduced by the cost that licensees would incur in performing analysis and

testing to verify the plants meet the risk-informed alternative requirements. To review licensees' submittals, the NRC would incur undiscounted costs of approximately (\$5.5 million). The net present value of these costs ranges from (\$3.4 million) using a 7-percent discount rate to (\$4.4 million) using a 3-percent discount rate. Overall, the risk-informed alternative of this rule results in estimated averted costs ranging from \$325 million using a 7-percent discount rate to \$320 million using a 3-percent discount rate.

These costs and benefits are summarized in Table 1 through Table 4 below.

Table 1 Total Costs (Cladding Embrittlement)

Attribute	Total Costs (Cladding Embrittlement)		
	Total	7% NPV	3% NPV
Total Industry Costs:	(\$46,270,000)	(\$33,000,000)	(\$38,480,000)
Total NRC Costs:	(\$2,330,000)	(\$1,870,000)	(\$2,110,000)
Total Costs:	(\$48,600,000)	(\$34,870,000)	(\$40,590,000)

Table 2 Total Benefits (Cladding Embrittlement)

Attribute	Total Benefits (Cladding Embrittlement)		
	Total	7% NPV	3% NPV
Total Industry Benefits:	\$1,710,000	\$1,390,000	\$1,560,000
Total NRC Benefits:	\$1,730,000	\$1,420,000	\$1,580,000
Total Benefits:	\$3,440,000	\$2,810,000	\$3,140,000

Table 3 Total Costs (Risk-Informed)

Attribute	Total Costs (Risk-Informed)		
	Total	7% NPV	3% NPV
Total Industry Costs:	(\$35,670,000)	(\$26,250,000)	(\$30,450,000)
Total NRC Costs:	(\$5,490,000)	(\$3,430,000)	(\$4,360,000)
Total Costs:	(\$41,160,000)	(\$29,680,000)	(\$34,810,000)

Table 4 Total Benefits (Risk-Informed)

Attribute	Total Benefits (Risk-Informed)		
	Total	7% NPV	3% NPV
Total Industry Benefits:	\$319,030,000	\$328,070,000	\$323,900,000
Total NRC Benefits:	(\$4,660,000)	(\$2,730,000)	(\$3,590,000)
Total Benefits:	\$314,370,000	\$325,340,000	\$320,310,000

According to Executive Order 12866, "Regulatory Planning and Overview" (58 FR 51735), an economically significant regulatory action is one that would have an annual effect on the economy of \$100 million or more. This proposed rulemaking does not reach this threshold for the cladding embrittlement protocols because the total costs are far lower than \$100 million. The fibrous insulation replacement that is averted by the risk-informed part of this rule would occur over a period of 5 years or more, therefore at \$320 million to \$325 million total averted costs, it does not meet this threshold.

Benefits. The availability of updated regulatory guides (RGs) and the regulatory requirements in this rule would result in enhanced regulatory efficiency by providing a predictable and stable set of regulations for current LWRs and for future designs and applications, so as to avoid the need for issuance of orders or license conditions and provides for regulatory stability.

Decision Rationale. Based on the research findings discussed in the Background section, the NRC must take action to ensure industry is addressing the embrittlement mechanisms. A case-by-case alternative (Alternative 2) to this final rule was considered in this regulatory analysis, to provide cost estimates without rulemaking to address the new research information into the behavior of fuel cladding under accident conditions and crud effects. Alternative 2 would not achieve either the technology neutral or the risk-informed objectives.

Table 5 Cost/Benefit Comparison of Alternatives

Objective	Alternative 2 – Case-by-Case (7% NPV)	Alternative 3 – The Rule Alternative (7% NPV)	Preferred Alternative
Technology Neutral	\$0	\$2.8 million	Alternative 3
Research Findings	(\$34.2 million)	(\$34.9 million)	Either ¹
Crud Effects	\$0	\$0	Either
Risk-Informed	\$0	\$325 million	Alternative 3
Net Benefit	(\$34.2 million)	\$293 million	Alternative 3

Table 5 shows, from a quantitative standpoint, that the Rule Alternative (Alternative 3) is the most cost-effective way of achieving adequate protection with respect to the four objectives detailed at the beginning of this Executive Summary and displayed in Table 5. The staff notes that Alternative 2 and Alternative 3 do not show a positive net benefit result with respect to the second objective of addressing new cladding embrittlement phenomena. The difference in cost between Alternative 2 and Alternative 3 for this objective is \$0.7 million, or 2.0%. This percentage difference is within the sensitivity of the uncertainty analysis, meaning that effectively the cost of this objective is equivalent between Alternative 2 and Alternative 3. The staff also notes that Alternative 3 shows a positive net benefit result of \$325 million with respect to the fourth objective of providing a Risk-Informed alternative for addressing problematic debris sources, compared to Alternative 2.

When the total benefit/cost results for each of the four objectives are integrated into a single result for each Alternative, Table 5 shows that Alternative 3 is preferable because it meets all four objectives, and is quantitatively the most cost-beneficial alternative as a whole. From a qualitative standpoint, Alternative 3 (the Rule Alternative) provides greater regulatory certainty than Alternative 2 (the Case-by-Case Alternative), meets all four objectives, and is qualitatively the preferred alternative. Because the rulemaking alternative for providing adequate protection is more cost-effective than the case-by-case approach, the rulemaking approach is recommended.

¹ Alternative 2 and 3 are within the sensitivity of the uncertainty analysis and are therefore effectively equal in cost for this objective.

Regarding the no action baseline, which effectively means each plant would have to operate within a safe harbor (i.e., defining the range of applicability of the existing 10 CFR 50.46 requirements), if a future applicant maintains plant operation within this range of applicability then no further demonstration would be required. Considering that current fuels are designed for high burnup operations, this “safe harbor” approach is not economically viable since operating within these “safe harbors” would mean operations at lower burnup levels than are economically practical.

1 Introduction

This document presents a regulatory analysis of the U.S. Nuclear Regulatory Commission's (NRC's) final rule for the emergency core cooling system (ECCS) performance during loss-of-coolant accidents rulemaking and the associated Regulatory Guide (RG) 1.222, "Measuring Breakaway Oxidation Behavior" (Agencywide Documents Access Management System (ADAMS) Accession No. ML15238B044), RG 1.223, "Determining Post Quench Ductility" (ADAMS Accession No. ML15238B079), RG 1.224, "Establishing Analytical Limits for Zirconium-Alloy Cladding Material" (ADAMS Accession No. ML15238B155), and RG 1.229, "Risk-Informed Approach for Addressing the Effects of Debris on Post-Accident Long-Term Cooling," (ADAMS Accession No. ML15252A125). The staff will publish all final guidance concurrent with the final rule. The recommended regulatory action amends Title 10 of the *Code of Federal Regulations* (10 CFR) by establishing new, performance-based requirements for ECCS for light-water nuclear power reactors.

1.1 Background

In SECY-98-300, "Options for Risk-Informed Revisions to 10 CFR Part 50—'Domestic Licensing of Production and Utilization Facilities,'" dated December 23, 1998 (ADAMS Accession No. ML992870048), the NRC began to explore approaches to risk-informing its regulations for nuclear power reactors. One alternative (termed "Option 3" in SECY-98-0300) involved making risk-informed changes to the specific requirements in the body of 10 CFR Part 50. As the NRC developed its approach to risk-informing these requirements, the NRC staff sought stakeholder input in public meetings. Industry representatives identified two regulations that may benefit from risk-informed changes. These were 10 CFR 50.44 and 50.46. In 10 CFR 50.44, the NRC specifies the requirements for combustible gas control inside reactor containment structures, and 10 CFR 50.46 specifies the requirements for light-water power reactor emergency core cooling systems. For 10 CFR 50.46, the potential was identified for making risk-informed changes to requirements for both ECCS cooling performance and ECCS analysis acceptance criteria in 10 CFR 50.46(b).

On March 14, 2000, as amended on April 12, 2000, the Nuclear Energy Institute (NEI) submitted a PRM requesting that the NRC amend its regulations in 10 CFR 50.44 and 50.46 (PRM-50-71) (ADAMS Accession No. ML003723791). The NEI petition noted that these two regulations apply to only two specific zirconium-alloy fuel cladding materials (zircaloy and ZIRLO™). The NEI stated that reactor fuel vendors² had subsequently developed new cladding materials other than zircaloy and ZIRLO™ and that, for licensees to use these new materials under the regulations, licensees had to request NRC approval of exemptions from 10 CFR 50.44 and 50.46.

On May 31, 2000, the NRC published a notice of receipt in the *Federal Register* (65 FR 34599) and requested public comment. The public comment period ended on August 14, 2000, and the NRC received 11 public comment letters from public citizens and the nuclear industry. Although most of the comments generally supported the requests of the PRM, one commenter suggested that the enhanced efficiency of the proposal would be at the expense of public health and safety. The NRC disagrees with that commenter and notes that, while the petition's

² For the purpose of this analysis, the term "vendor" refers to manufacturers of NRC-approved fuel assembly designs. To support implementation of the proposed requirements on individual plant dockets, fuel vendors would submit for NRC review alloy-specific hydrogen uptake models and LOCA model updates.

proposal would remove specific zirconium-alloy names from the regulation, the NRC review and approval of specific zirconium-alloys for use as reactor fuel cladding would be required before their use in reactors (with the exception of lead test assemblies permitted by technical specifications).³

After evaluating the petition and public comments received, the NRC decided that PRM-50-71 should be considered in the rulemaking process. The NRC's determination was published in the *Federal Register* on November 6, 2008 (73 FR 66000). Because most of the issues raised in this PRM pertain to 10 CFR 50.46, the PRM is addressed in this final rule. The PRM also requested changes to 10 CFR 50.44. Those changes were addressed in a rulemaking that revised that section (68 FR 54123; September 16, 2003) to include risk-informed requirements for combustible gas control. The regulation was also modified to be applicable to all boiling- or pressurized-water reactors regardless of the type of fuel cladding material used.

On March 31, 2003, in response to SECY-02-0057, "Update to SECY-01-0133, 'Fourth Status Report on Study of Risk-Informed Changes to the Technical Requirements of 10 CFR Part 50 (Option 3) and Recommendations on Risk-Informed Changes to 10 CFR 50.46 (ECCS Acceptance Criteria)'" (ADAMS Accession No. ML020660607), the Commission issued a staff requirements memorandum (SRM) (ADAMS Accession No. ML030910476) directing the NRC staff to move forward to risk-inform its regulations in specific areas. As one of its requirements, this SRM directed the staff to modify the ECCS acceptance criteria to provide a more performance-based approach to the ECCS requirements in 10 CFR 50.46.

Separate from the effort to modify the regulations to provide a more risk-informed, performance-based regulatory approach, the NRC had also undertaken a fuel cladding research program to investigate the behavior of high-exposure fuel cladding under accident conditions. This research program included an extensive loss-of-coolant accident (LOCA) research and testing program at Argonne National Laboratory (ANL), as well as jointly funded programs at the Kurchatov Institute (supported by the French Institute for Radiological Protection and Nuclear Safety and the NRC) and the Halden Reactor project (a jointly funded program under the auspices of the Organization for Economic Cooperative Development—Nuclear Energy Agency, sponsored by national organizations in 18 countries), to develop the body of technical information needed to support the new regulations.

The effects of both alloy composition and fuel burnup (the extent to which fuel is used in a reactor) on cladding embrittlement (i.e., loss of ductility) under accident conditions were studied in these research programs. The research programs identified new cladding embrittlement mechanisms and expanded the NRC's knowledge of previously identified mechanisms. The research results revealed that alloy composition has a minor effect on embrittlement, but that the cladding corrosion that occurs as fuel burnup increases has a substantial effect on embrittlement. One of the major findings of the NRC's research program was that hydrogen, which is absorbed in the cladding because of zirconium oxidation (i.e., corrosion) under normal operation, has a significant influence on embrittlement during a postulated LOCA. Increased hydrogen content increases both the solubility of oxygen in zirconium and the rate at which it is diffused within the metal, thus increasing the amount of oxygen in the metal during high temperature oxidation in LOCA conditions. Furthermore, the NRC's research program found

³ A detailed discussion of the public comments submitted on PRM-50-71 is contained in a separate document (see Section XIX of the final rule Statement of Considerations (SOC), "Availability of Documents" (ADAMS Accession No. ML15238B016)).

that oxygen from the oxide fuel pellets enters the cladding from the inner surface if a bonding layer exists between the fuel pellet and the cladding, in addition to the oxygen that enters from the oxide layer on the outside of the cladding. Moreover, under some small-break LOCA conditions (such as extended time-at-temperature around 1,000 degrees Celsius (°C) (1,832 degrees Fahrenheit (°F))), the accumulating oxide on the surface of the cladding can break up, allowing large amounts of hydrogen to diffuse into the cladding, exacerbating the embrittlement process.

The research results also confirmed a previous finding that if cladding rupture occurs during a LOCA, large amounts of hydrogen from the steam-cladding reaction can enter the cladding inside surface near the rupture location. These research findings have been summarized in Research Information Letter (RIL)-0801, "Technical Basis for Revision of Embrittlement Criteria in 10 CFR 50.46" (ADAMS Accession No. ML081350225), and the detailed experimental results from the program at ANL are contained in NUREG/CR-6967, "Cladding Embrittlement during Postulated Loss-of-Coolant Accidents" (ADAMS Accession No. ML082130389). Since the publication of NUREG/CR-6967 and RIL-0801, more testing was conducted related to the embrittlement phenomenon, which was documented in supplemental reports. Where the extra testing relates to conclusions and recommendations in RIL-0801, the letter has been supplemented to reference the other reports and incorporate findings (ADAMS Accession No. ML113050484).

The NRC publicly released the technical basis information in RIL-0801 on May 30, 2008, and NUREG/CR-6967 on July 31, 2008. Also on July 31, 2008, the NRC published in the *Federal Register* a notice of availability of the RIL and NUREG/CR-6967, together with a request for comments (73 FR 44778). In that notice, the NRC stated that these documents and comments on the documents would be discussed at a public workshop to be scheduled for September 2008. The public workshop was held on September 24, 2008, and included presentations and open discussion among representatives of the NRC, international regulatory and research agencies, domestic and international commercial power firms, fuel vendors, and the general public. A summary of the workshop, including a list of attendees and presentations, is available (ADAMS Accession No. ML083010496).

Based upon a preliminary safety assessment in response to the research findings in RIL-0801, the NRC determined that immediate regulatory action was not required, and that changes to the ECCS acceptance criteria to account for these new findings could reasonably be addressed through the rulemaking process. Recognizing that finalization and implementation of the new ECCS requirements would take several years, the NRC completed a more detailed safety assessment which confirmed current plant safety for every operating reactor.⁴

On March 15, 2007, Mark Leyse (the petitioner) submitted a PRM to the NRC (ADAMS Accession No. ML070871368) requesting that all holders of operating licenses for nuclear power plants be required to operate such plants at operating conditions (e.g., levels of power production and light-water coolant chemistries) necessary to effectively limit the

⁴ See Section III.A of the final rule SOC for further information (ADAMS Accession No. ML15238B016).

thickness of crud⁵ or oxide layers on fuel rod cladding surfaces. The petitioner requests that the NRC conduct rulemaking in the following three specific areas:

1. Establish regulations that require licensees to operate light-water power reactors under conditions that are effective in limiting the thickness of crud and/or oxide layers on zirconium-clad fuel to ensure compliance with 10 CFR 50.46(b) ECCS acceptance criteria
2. Amend Appendix K to 10 CFR Part 50 to explicitly require that steady-state temperature distribution and stored energy in the reactor fuel at the onset of a postulated LOCA be calculated by factoring in the role that the thermal resistance of crud deposits or oxide layers plays in increasing the stored energy in the fuel (these requirements also need to apply to any NRC-approved, best-estimate ECCS evaluation models used in lieu of Appendix K to 10 CFR Part 50 calculations)
3. Amend 10 CFR 50.46 to specify a maximum allowable percentage of hydrogen content in (fuel rod) cladding

On May 23, 2007, the NRC published a notice of receipt for this petition in the *Federal Register* (72 FR 28902) and requested public comment. The public comment period ended on August 6, 2007. After evaluating the public comments, the NRC resolved PRM-50 84 by deciding that each of the petitioner's issues should be considered in the rulemaking process. The NRC's determination, including the NRC's response to public comments received on the petition, was published in the *Federal Register* on November 25, 2008 (73 FR 71564).

The proposed rule provided a risk-informed approach to address the effects of debris on long-term cooling. This approach could be used to close actions related to Generic Safety Issue (GSI)-191, "Experimental Studies of Loss-of-Coolant-Accident-Generated Debris Accumulation and Head Loss with Emphasis on the Effects of Calcium Silicate Insulation," which concluded that debris could clog the containment sump strainers in pressurized-water reactors (PWRs) leading to the loss of net positive suction head for the ECCS and containment spray system pumps. It is acceptable for closing GSI-191 as applied to Long Term Cooling, and could be extended to address debris during a LOCA. The NRC issued Generic Letter (GL) 2004-02, "Potential Impact of Debris Blockage on Emergency Recirculation during Design Basis Accidents at Pressurized-Water Reactors," dated September 13, 2004 (ADAMS Accession No. ML042360586), requesting that licensees address the issues raised by GSI-191. The staff also prepared several Commission papers on GSI-191 and had numerous public interactions on the same subject.⁶

1.2 Statement of the Problem

The action is needed to provide technology-neutral performance-based criteria, to address new research findings, to clarify how the NRC regulates with respect to crud considerations, and to

⁵ For the purpose of this regulatory analysis, the NRC defines "crud" as any foreign substance deposited on the surface of the fuel cladding before the initiation of a LOCA. It is known that this layer can impede the transfer of heat.

⁶ For additional background information, please see SECY-12-0093, "Closure Options for Generic Safety Issue-191, Assessment of Debris Accumulation on Pressurized-Water Reactor Sump Performance," dated July 9, 2012 (ADAMS Accession No. ML121320270).

provide voluntary risk-informed criteria to evaluate the effects of debris on long-term cooling. The action is in response to recent research by ANL, the Kurchatov Institute, and the Halden Reactor project into the behavior of fuel cladding under accident conditions, in particular under LOCA conditions. This research indicated that the current combination of peak cladding temperature (PCT) (1,204°C (2,200°F)) and local cladding oxidation criteria (17 percent) do not always ensure postquench ductility (PQD) after a postulated LOCA. The final rule will replace the limits on PCT and local oxidation with specific cladding performance requirements and acceptance criteria that ensure that an adequate level of cladding ductility is maintained throughout the postulated LOCA. The NRC developed three regulatory guides (RGs) that provide acceptable means of meeting the final rule performance requirements. The three RGs are: RG 1.222, "Measuring for Breakaway Oxidation Behavior" (ADAMS Accession No. ML15238B044); RG 1.223, "Determining Post-Quench Ductility" (ADAMS Accession No. ML15238B079); and RG 1.224, "Establishing Analytical Limits for Zirconium-Alloy Cladding Material" (ADAMS Accession No. ML15238B155).

The final rule will expand applicability to all light-water nuclear power reactors, regardless of fuel design or cladding material used, to account for the development of new fuel designs and cladding materials other than zircaloy and ZIRLO™. Under the current rule, licensees that use different types of cladding material are required to request NRC approval for an exemption from the rule.

The final rule will also require licensees to evaluate thermal effects of crud and oxide layers that accumulate on fuel cladding. This amendment addresses one of the requests of PRM-50-84. Lastly, the NRC identified the need for an approach that would allow entities to address the effects of debris on long-term cooling in a manner that would be more timely and cost-effective for some licensees than the current use of deterministic methods. The revised rule will contain a provision to allow licensees to use an alternative risk-informed approach to evaluate the effects of debris for long-term cooling (LTC). As guidance for this provision, the NRC developed RG 1.229, "Risk-Informed Approach for Addressing the Effects of Debris on Post-Accident Long-Term Core Cooling" (ADAMS Accession No. ML15252A125).

1.3 Objectives

The principal objectives of the revision to the requirements for ECCS performance for light-water nuclear power reactors are to: (1) provide technology-neutral performance-based criteria, (2) account for the new research information, (3) address the issues raised in PRM-50-84, and (4) provide an alternative approach for addressing the effects of debris on long-term cooling. These objectives are necessary to ensure adequate protection, as determined by the NRC, in different ways: (1) the technology-neutral portion of the rule enables use of all zirconium-based cladding alloys, without requiring an exemption and provides for greater regulatory certainty; (2) testing that addresses the research findings supports current, high efficiency, high burnup core loading patterns and operating cycles, and verifies cladding performance without interfering with manufacturing flexibility; (3) the final rule clarifies the ongoing NRC actions to ensure crud issues are addressed; and (4) the risk-informed alternative supports closure of many issues in GSI-191 while removing need for costly fiber replacement.

This regulatory analysis was developed following the “Regulatory Analysis Guidelines of the U.S. Nuclear Regulatory Commission”⁷ (Guidelines). In particular, with regard to adequate protection, the Guidelines state that, “The level of protection constituting ‘adequate protection’ is that level which must be assured *without regard to cost*” (emphasis added). The Guidelines also state that “ ... a proposed backfit to one or more of the facilities regulated under 10 CFR Part 50 does not require a regulatory analysis if the resulting safety benefit is required for purposes of compliance or adequate protection under 10 CFR 50.109(a)(4).” In addition, the applicability and implementation approach as applied to 10 CFR Part 52 licenses and regulatory approvals is such that there is no violation or inconsistency with any issue finality provision in 10 CFR Part 52. However, the Guidelines note that if there is more than one way to achieve compliance or reach a level of adequate protection, costs may be a factor in that decision. With respect to the regulatory guides, the NRC believes that the development of such guidance for 10 CFR 50.46c is desirable to ensure a consistent means of generating and using experimental data to establish regulatory limits and for establishing an alternative approach for addressing the effects of debris on long-term cooling.

⁷ NUREG/BR-0058, Revision 4, “Regulatory Analysis Guidelines of the U.S. Nuclear Regulatory Commission,” Office of Nuclear Regulatory Research, September 2004 (<http://www.nrc.gov/reading-rm/doc-collections/nuregs/brochures/br0058/#pub-info>).

2 Identification and Preliminary Analysis of Alternative Approaches

Based on the new research data and information, the NRC staff concluded that the no-action alternative (described below as addressing the embrittlement and risk-informed alternative by use of a “safe harbor” approach), the alternative to amend the current regulation to modify ECCS acceptance criteria, and the alternative to address Industry on a case-by-case basis are the only credible regulatory actions available to maintain adequate protection. These three alternatives are discussed in the following subsections.

2.1 Alternative 1: Maintain the Existing ECCS Requirements

Under Alternative 1, the “no-action” alternative (or regulatory baseline) would not revise the regulations and the regulatory objectives discussed above would instead be handled as follows: (1) continuing with current prescriptive, technology-specific requirements that will require NRC approval of new fuel types by exemption; (2) addressing the technical issues raised by the new research findings through periodic NRC review; (3) addressing crud concerns through NRC oversight; and (4) addressing debris considerations during long-term cooling through NRC oversight and by exemption.

The current rule requires that the embrittlement issue and the risk-informed approach to evaluating the effects of debris on long-term cooling be resolved on a unit-by-unit basis (e.g., through exemptions, license amendments, and orders). For industry, this has already required preparing and submitting exemption requests for 20 operating units for using fuel that is not identified in 10 CFR 50.46, and an estimated 25 more exemption requests would be required over the next five years if no action is taken.

If the rule language of § 50.46c is not added to 10 CFR according to Alternative 3, there are two other possible courses of action to address the research findings detailed above. One option is Alternative 2, a case-by-case approach to verifying each operating reactor is operating with acceptable margins, and that is described below. The other alternative would be to define a “safe harbor” on plant operations relative to these burnup-related and corrosion-related degradation mechanisms. The fabrication-related degradation mechanism would need to be addressed by other means (e.g., testing, restricted manufacturing), which would mean defining the range of applicability of the existing 10 CFR 50.46 requirements. If a future applicant maintains plant operation within this range of applicability, then no further demonstration would be required. Based upon a review of fuel operating and cladding corrosion characteristics, the NRC staff has determined that a significant reduction in allowable fuel rod burnup would be necessary to demonstrate continued applicability of existing regulations. As a result of these fuel rod burnup restrictions, fuel cycle costs would likely increase millions of dollars per reload cycle for every reactor. This alternative is clearly not economically viable and will not be discussed further.

Also, under this “no-action” alternative, 10 sites using fibrous insulation would require exemption requests to use a risk-informed approach to address GSI-191. The removal and replacement of fibrous insulation inside containment would constitute a significant industry cost.

The NRC would need to review the above exemption requests for fuel not identified in 10 CFR 50.46 and for analyzing long-term cooling using a risk-informed approach. The avoidance of these exemption requests and other costs are shown quantitatively in the

attributes as averted costs (i.e., savings) for the final rule. However, as discussed above, the continued regulatory uncertainty of Alternative 1 and the economic impacts of each plant operating within its “safe harbor” would almost certainly result in further increased costs to industry, as the NRC required industry to ensure adequate protection without the benefit of the guidance provided by 10 CFR 50.46c.

In light of recent research findings that indicate that the current regulations do not always ensure PQD after a LOCA, this final rule is necessary to ensure adequate protection to the public health and safety by maintaining that level of protection (i.e., reasonable assurance of adequate protection) that the NRC thought would be achieved (throughout the entire term of licensed operation). However, based upon a preliminary safety assessment in response to the research findings in RIL-0801, the NRC determined that immediate regulatory action was not required, and that changes to the ECCS acceptance criteria to account for these new findings could be addressed through the rulemaking process. Recognizing that finalization and implementation of new ECCS requirements would take several years, the NRC completed a more detailed safety assessment that confirmed current plant safety for every operating reactor.⁸

The baseline would be maintained if the Commission decides not to issue the final rule, decides to instruct NRC staff not to evaluate each unit on a case-by-case basis, and decides to continue with the existing fuel requirements and the use of a deterministic approach or a risk-informed approach by exemption on a unit-by-unit basis to evaluate the effects of debris on long-term cooling.

2.2 Alternative 2: Case-by-Case Approach

An alternative to amending 10 CFR 50.46 would be for the NRC to address the research findings detailed above, and their impact on the nuclear industry, on a case-by-case basis. Per the Atomic Energy Act of 1954, the NRC is required to verify adequate protection in order to allow continued operation of a nuclear reactor. As a result of the research findings, adding 50.46c rule language was intended to fulfill this requirement by causing industry to demonstrate adequate protection through the cladding embrittlement protocol. The nuclear industry has been allowed to continue operation without taking into consideration the research findings, as discussed above, while NRC developed this rule language. However, an alternative would be to address the adequate protection concerns stemming from the research findings using a “case-by-case” regulatory approach. The case-by-case approach is designated as Alternative 2 in this regulatory analysis.

Under the “case-by-case” alternative, the NRC would require that future license amendment requests (LARs) involving changes in fuel design (e.g., cladding alloy, fuel vendor), fuel utilization (e.g., power uprate, boiling-water reactor (BWR) extended operating regimes), or ECCS performance address the phenomena mentioned above in the statement of the problem. Similar burden exists for future 10 CFR 50.46 exemption requests involving transition to a zirconium alloy not covered by the existing regulation. The NRC would also have to address, on a continuing basis, the safety basis for allowing continued operation of those licensees who do *not* need a license amendment to implement changes in fuel design, fuel utilization or ECCS design and operation. It is likely that most of the existing reactors will eventually trigger an assessment of the new degradation mechanisms. In addition, due to the technical basis behind

⁸ See Section II.A of the final rule SOC for further information (ADAMS Accession No. ML15238B016).

this rulemaking, and the public attention and interest, it is likely that without rulemaking, some external stakeholders would avail themselves of opportunities to have their concerns addressed. This could be in the form of requests for hearing and associated waivers of the applicability of NRC regulations under 10 CFR 2.335, petitions for modification, suspension or revocation of licenses under 10 CFR 2.206, requests for rulemaking under 10 CFR 2.802, submission of allegations to the NRC, and perhaps subsequent appeals of licensing decisions to the various U.S. Circuit Courts of Appeal. This regulatory analysis assumes 60 instances where licensees would have to assess the new degradation mechanisms mentioned above, over the next 10 years. In addition, vendors would have to establish methods to verify that fuel provided to reactors was not at risk of exhibiting the new degradation methods as a result of manufacturing processes.

The NRC would have to issue Generic Communication and Orders expressing this to Industry, and would have to review all of the Industry submissions which are expected to verify the adequate protection of each unit as mentioned above.⁹

The expected result of this “case-by-case” alternative is that vendors would decide to adopt similar protocol to what is delineated by this regulatory analysis and the regulatory guides for § 50.46c. The LARs, topical reports, and testing would occur by issuing orders instead of a final rule. While significant work has been done on § 50.46c that would inform these orders and reduce uncertainty, the lack of final regulatory guides and the lack of public involvement in the development and issuance of these orders would add to the regulatory uncertainty. Additionally, as orders are typically followed by rulemaking to make the requirements generically applicable, the NRC would incur additional costs to turn the orders and the lessons learned from their implementation into a future rulemaking with applicable guidance.

This regulatory analysis provides cost estimates for a case-by-case approach that approximates what would have to occur if the proposed § 50.46c rule language is not adopted under Alternative 3. A further discussion of the need for a case-by-case approach, in the event Alternative 3 is not accepted by the Commission, is in Section 5.13.

The risk-informed alternative is unavailable in Alternative 1 and Alternative 2, and is therefore treated the same under both alternatives.

2.3 Alternative 3: Amend the Regulation to Modify ECCS Acceptance Criteria

Under this alternative, the NRC would amend the current regulations for ECCS acceptance criteria, found in 10 CFR 50.46(b), by establishing performance-based requirements. The final rule would expand applicability to all light-water reactors (LWRs), regardless of fuel design or cladding materials.¹⁰ This alternative also would incorporate recent research findings that identify previously unknown cladding embrittlement mechanisms and expand the NRC’s knowledge of previously identified mechanisms. Specifically, the research identified that hydrogen, which is absorbed in the cladding during normal operation, has a significant influence

⁹ The case-by-case approach could also be implemented through an appropriately-written regulation (as opposed to an order) requiring each licensee to prepare documentation showing adequate safety at its plant (and possibly requiring NRC review and approval of such documentation). However, this can be viewed as a variation of Alternative 3.

¹⁰ The expansion of the applicability to all LWRs satisfies the request contained in PRM-50-71.

on embrittlement during a postulated accident. Also, the final rule would require licensees to evaluate the thermal effects of crud and oxide layers that may develop on the fuel cladding.¹¹ Furthermore, the final rule alternative would allow licensees to use an alternative risk-informed approach to evaluate the effects of debris on long-term cooling. This risk-informed alternative would alleviate the need for rulemaking related to GSI-191 and decrease the NRC and industry implementation costs that would otherwise be required to develop another rule. Under this alternative, licensees could use risk-informed alternatives without an exemption request to respond to GSI-191.¹²

Three companion RGs were developed to support the technology-neutral, performance-based portion of the rule and to support the new requirements addressing research results on breakaway oxidation effects. The final rule requires the measurement and periodic confirmation of breakaway oxidation behavior for a zirconium-alloy cladding material based on an acceptable experimental technique. The final rule also requires that an analytical time limit is established to preclude breakaway oxidation and requires evaluation of the analytical limit relative to emergency core cooling system performance. RG 1.222 describes an experimental technique acceptable to the NRC staff to measure breakaway oxidation behavior. RG 1.222 also provides guidance on establishing a frequency for confirmatory testing that is sufficient to provide reasonable assurance that the fuel manufacturing process will provide performance consistent with the specified analytical limits. RG 1.224 provides an approach to establish an analytical time limit to prevent breakaway oxidation. The final rule also requires that analytical limits on peak cladding temperature and integral time at temperature be established that correspond to the measured ductile-to-brittle transition for the zirconium-alloy cladding material. RG 1.223 describes an experimental technique that is acceptable to the NRC for measuring the ductile-to-brittle transition for a zirconium-based cladding alloy. RG 1.224 provides a method of using experimental data to establish analytical limits. These RGs will be published concurrent with the final rule.

A companion RG was developed to support a risk-informed voluntary approach for evaluating the effects of debris on long-term cooling. The final rule would allow licensees to address the effects of debris on long-term cooling in a manner that would be more timely and cost-effective for some licensees than the current use of deterministic methods. The NRC will allow partial early implementation of the proposed requirements of 10 CFR 50.46c limited to the alternative risk-informed approach. The final rule will contain a provision allowing NRC licensees to use risk-informed alternatives without an exemption request. This alternative approach, described in RG 1.229, could be used to close all actions related to GSI-191, which concluded that debris could clog the containment sump strainers in pressurized water reactors leading to the loss of net positive suction head for the ECCS and containment spray system pumps.

¹¹ This rule provision satisfies a request of PRM-50-84.

¹² Including the risk-informed alternative responds to the Commission direction provided in SRM-SECY-12-0034, "Proposed Rulemaking – 10 CFR 50.46c: Emergency Core Cooling System Performance During Loss-of-Coolant Accidents (RIN 3150-AH42)," which directed that the final rule should contain a provision allowing NRC licensees, on a case-by-case basis, to use risk-informed alternatives without an exemption request.

3 Safety Goal Evaluation

Safety goal evaluations apply only to regulatory initiatives considered to be generic safety enhancement backfits subject to the substantial additional protection standard at 10 CFR 50.109(a)(3). A safety goal evaluation determines whether a regulatory requirement should not be imposed generically on nuclear power plants because the residual risk is already acceptably low.

The NRC believes that the final rule must be imposed upon nuclear power plant licensees to ensure adequate protection to the public health and safety. The rule would ensure that the level of protection intended to be achieved by the existing rule is maintained. Therefore, the NRC has determined that the rule is necessary to ensure that the facility provides adequate protection to the health and safety of the public.

Imposing the redefinition of fuel cladding acceptance criteria on nuclear power plant licensees is justified under the provisions of the safety goal policy as the requirements of the rule are necessary to ensure adequate protection to the public health and safety by maintaining that level of protection (i.e., reasonable assurance of adequate protection), which the NRC previously thought would be achieved (throughout the entire term of licensed operation) by the existing rule.

Information developed through the NRC's research program into high burnup fuel has identified that the existing criterion for preventing fuel cladding embrittlement might not be adequate in the future to ensure the health and safety of the public. As discussed in Sections I, "Background," and III, "Operating Plant Safety," of the final rule statements of consideration, zirconium-based alloy fuel cladding materials might be subject to embrittlement at a lower combination of temperature and level of oxygen absorption (17 percent) than currently allowed under 10 CFR 50.46(b)(1) because of absorption of hydrogen during normal operation. The final rule corrects those limits initially established to prevent embrittlement of zirconium-based alloy cladding material based on the new research information. In addition, the research work has identified new phenomena, such as breakaway oxidation and oxygen diffusion from the cladding inside surfaces, which are believed to further impair the fuel cladding embrittlement process. Therefore, PQD (which is necessary to ensure coolable core geometry)¹³ is not guaranteed after a postulated LOCA. The final rule (alternative 3) establishes new requirements for zirconium-based alloys to prevent breakaway oxidation and to account for oxygen diffusion from the oxide fuel pellet during the operating life of the fuel. In sum, the NRC believes that imposing the requirements of the final rule is necessary to prevent embrittlement of fuel cladding under LOCA conditions and to ensure that the rule maintains reasonable assurance of adequate protection to public health and safety.

Alternative 3 would replace the limits on PCT and local oxidation with specific cladding performance requirements and acceptance criteria that ensure that an adequate level of cladding ductility is maintained throughout the postulated LOCA. These requirements would qualify as a generic safety enhancement because they might affect the likelihood of core

¹³ The Commission concluded, as part of the 1973 Emergency Core Cooling System rulemaking, that retention of ductility in the zircaloy cladding material was determined to be the best guarantee of its remaining intact during the hypothetical loss-of-coolant accident, thereby maintaining a coolable core geometry. (See "Acceptance Criteria for Emergency Core Cooling Systems for Light-Water-Cooled Nuclear Power Reactors," CLI-73-39, at page 1098 (December 28, 1973).

damage, which generally is the focus of a quantitative safety goal evaluation. However, the magnitude of the proposed change on plant safety is not readily quantifiable for direct comparison to the safety goal criteria.

Alternative 3 would provide for a technology-neutral portion of this rule, enabling use of all currently used zirconium-based cladding alloys, without licensee exemption. This would be a benefit that would reduce costs for industry and the NRC, as it expands authorization for the current operations of the industry.

Alternative 3 would include the option of allowing a nuclear power plant licensee to address the effects of debris on long-term cooling with respect to ECCS performance requirements in 10 CFR 50.46c and General Design Criterion 35 (GDC-35) using a risk-informed approach without requesting an exemption. The rule also would allow licensees who select the option of using the risk-informed approach for addressing the effects of debris on long-term cooling, to also use the same approach in demonstrating compliance with GDC-38 and GDC-41. Because this is a voluntary option with respect to a portion of the existing requirements in GDC-38 and GDC-41, and is intended to provide the same level of safety, a safety goal evaluation is not appropriate for this provision of Alternative 3.

4 Estimation and Evaluation of Values and Impacts

4.1 Identification of Affected Attributes

This section identifies the components of the public and private sectors, commonly referred to as attributes, which this rulemaking is expected to affect. The alternatives would apply to licensees and applicants of nuclear power plants and holders of nuclear power plant design certifications. The NRC believes that nuclear power plant licensees will be the primary beneficiaries. An inventory of the affected attributes was developed using the list provided in Chapter 5 of the NRC's "Regulatory Analysis Technical Evaluation Handbook"¹⁴ (Handbook).

The affected attributes are the following:

- Public Health (Accident). This attribute accounts for expected changes in radiation exposure to the public caused by changes in accident frequencies or accident consequences associated with the alternative (i.e., delta risk). Both Alternatives 2 and 3 relative to the regulatory baseline (Alternative 1) would meet the NRC goal of ensuring the protection of public health and safety and the environment by continuing to ensure that the core remains in a coolable geometry should a loss-of-coolant accident occur and that the ECCS recirculation phase would not be impaired by problematic material clogging the containment sump, containment spray nozzles, or the core cooling channels. This attribute was considered qualitatively.
- Occupational Health (Accident). This attribute measures health effects, immediate and long-term, associated with site workers because of changes in accident frequency or accident consequences associated with the alternative (i.e., delta risk). Both Alternatives 2 and 3 relative to the regulatory baseline (Alternative 1) would ensure that the core remains in a coolable geometry should a loss-of-coolant accident occur and that the ECCS recirculation phase would not be impaired by debris clogging the containment sump, containment spray nozzles, or the core cooling channels and which would result in an incremental decrease in the frequency of an accident resulting in averted worker radiological exposure when compared to the regulatory baseline. This attribute was considered qualitatively.
- Occupational Health (Routine). This attribute accounts for incremental radiological exposures to workers during normal facility operations (i.e., nonaccident situations), from both Alternatives 2 and 3 relative to the regulatory baseline (Alternative 1). The removal of debris sources from containment including the replacement of fibrous insulation with nonfibrous insulation to comply with GSI-191 requirements could result in an increase in worker exposures, which may be avoided if the licensee uses the risk-informed approach to justify retaining the current installed insulation. This attribute was considered qualitatively and included under the industry implementation attribute.
- Onsite Property. This attribute accounts for the expected incremental monetary effects on onsite property, including replacement power costs, decontamination, and refurbishment costs, from both Alternatives 2 and 3 relative to the regulatory baseline

¹⁴ NUREG/BR-0184, "Regulatory Analysis Technical Evaluation Handbook," U.S. Nuclear Regulatory Commission, 1997 (ADAMS Accession No. ML050190193).

(Alternative 1). Both Alternatives 2 and 3 provide additional assurance that the core remains in a coolable geometry should a loss-of-coolant accident occur and that the ECCS recirculation phase would not be impaired by problematic material clogging the containment sump, containment spray nozzles, or the core cooling channels and which would result in an incremental decrease in the frequency of an accident resulting and its severity when compared to the regulatory baseline. These effects are considered qualitatively.

The NRC staff expects that there will be minimal to no short-term power replacement costs because of the replacement of fibrous insulation with reflective metallic insulation. This expectation is based on the industry practice to replace insulation during scheduled refueling outages and without extending the plant outage. If the insulation is not completed during one scheduled refueling outage, the remainder of the insulation replacement will be performed during subsequent scheduled refueling outage(s).

- Offsite Property. This attribute measures the expected incremental monetary effects on offsite property resulting from both Alternatives 2 and 3 relative to the regulatory baseline (Alternative 1). Incremental changes to offsite property can take various forms, both direct, (e.g., land, food, and water) and indirect (e.g., tourism). This attribute is typically estimated as the product of the change in accident frequency and the property consequences resulting from the occurrence of an accident (e.g., costs of interdiction measures such as decontamination, cleanup, and evacuation).

Both Alternatives 2 and 3 relative to the regulatory baseline (Alternative 1) ensure that the core remains in a coolable geometry should a loss-of-coolant accident occur and that the ECCS recirculation phase would not be impaired by problematic material clogging the containment sump, containment spray nozzles, or the core cooling channels. These design features could result in an incremental decrease in the frequency of a radiological release when compared to the regulatory baseline. This attribute was considered qualitatively.

- Industry Implementation. This attribute accounts for the projected net economic effect on the affected licensees of installing or implementing mandated changes. These costs include procedural and administrative activities, equipment, labor, and materials. For this analysis, the basic elements of industry implementation costs are categorized as materials and equipment, engineering design, installation, testing, and licensing. Costs already incurred, including all pre-decisional activities performed by licensed entities and their representatives, are viewed as sunk costs and are not included.
- Industry Operation. This attribute measures the projected net economic effect of routine and recurring activities required by the proposed regulatory action on all affected licensees. In this regulatory analysis, industry operation costs include the cost of recurring administrative activities, equipment, labor, and materials. For this analysis, the basic elements of industry operation costs are categorized as materials and equipment, engineering analysis, testing, and licensing. These costs generally occur annually over the remaining life of the facility.
- NRC Implementation. This attribute measures the projected net economic effect on the NRC of implementing the proposed regulatory action on all affected licensees. These costs include reviewing license documentation to implement the alternative.

Costs already incurred, including all pre-decisional activities performed by the NRC, are viewed as sunk costs and are not included.

- NRC Operation. This attribute measures the projected net economic effect on the NRC after the proposed regulatory action is implemented. Additional inspection, evaluation, and enforcement activities are examples of such costs. As with industry operation costs, NRC operations costs generally occur over long periods of time, such as annually over the remaining life of the licensed facilities.
- Improvements in Knowledge. The revised rule alternative incorporates research findings that identified new cladding embrittlement mechanisms. As a result, future LOCA analyses will improve the predictions of cladding embrittlement. A licensee using the alternative risk-informed approach would identify which pipe break locations inside containment are important to risk and which locations do not contribute to failure of the strainers or core cooling. This information could be fed back into the inservice inspection (ISI) program. Also, this information could be useful in determining where problematic insulation should be replaced if such is necessary to meet the acceptance criteria.
- Regulatory Efficiency. Expanding the applicability of this rule to different fuel designs and additional cladding materials under Alternative 3 would contribute to regulatory efficiency by eliminating the need for licensees to submit exemption requests for different fuel designs or cladding material. Additionally, the rule and regulatory guides would provide a clear, consistent process for Industry submittals to the NRC to demonstrate adequate protection in response to the research findings mentioned above. The regulatory guides also establish regulatory efficiency in this process by providing industry with fuel performance and analysis parameters that are acceptable to the NRC. As a result, the revised rule alternative would improve regulatory efficiency.
- Other Considerations. Without 10 CFR 50.46c, the applicability of 10 CFR 50.46 would need to restrict fuel burnup and residence time limitations. These limitations would not support current, high efficiency fuel loading patterns and fuel utilization. These considerations are discussed in further detail in Section 5.
- Attributes with No Effects. Attributes not expected to be affected under any of the alternatives include the following: other government, general public, antitrust considerations, safeguards and security considerations, and environmental considerations addressing Section 102(2) of the National Environmental Policy Act of 1979.

4.2 Overview of Major Changes

This final rule contains numerous significant changes over 10 CFR 50.46, which are described in detail in the following sections of this document, resulting in benefits. Table 6 offers an overview of these benefits from 10 CFR 50.46c.

Table 6 Summary of Significant Benefits Due to 10 CFR 50.46c

Item	10 CFR 50.46	10 CFR 50.46c	Benefit to Industry
Rule Structure	Prescriptive	Performance-Based	More flexibility
Applicability	Zircaloy or ZIRLO Cladding	All LWR Cladding	Eliminates exemption requests for modern alloys
Burnup-Related Phenomena	None	Cladding Inner Surface Oxygen Ingress	Supports current, high efficiency, high burnup core loading patterns
Corrosion-Related Phenomena	None	Hydrogen-Enhanced Embrittlement	Supports current, high efficiency, extended operating cycles
Fabrication-Related Phenomena	None	Breakaway Oxidation	Confirms cladding performance without interfering with manufacturing flexibility
Debris Consideration	Implicit	Explicit	Regulatory certainty
Debris Treatment	Deterministic	Deterministic or Risk-Informed	Supports closure of GSI-191 and reduces need for costly fiber removal
LTC Regulatory Criteria	General	Explicit	Supports closure of GSI-191 and reduces need for costly fiber removal
Crud Treatment	None	Explicit	Regulatory certainty

4.3 Methodology for Evaluation of Benefits and Costs

4.3.1 Overview of the Approach

This section describes the process used to evaluate costs and benefits associated with the proposed alternatives. The costs include any undesirable changes in affected attributes (e.g., monetary costs, increased exposures) while the benefits include any desirable changes in affected attributes (e.g., monetary savings, improved safety, improved security). The NRC staff developed this regulatory analysis by following the guidance contained in NUREG/BR-0058, “Regulatory Analysis Guidelines of the U.S. Nuclear Regulatory Commission,” Revision 4, issued September 2004 (ADAMS Accession No. ML042820192), and NUREG/BR-0053, Revision 6, “USNRC Regulations Handbook,” September 2005 (ADAMS Accession No. ML052720461) and as supplemented by Commission direction provided in SRM-SECY-14-087.

The analysis evaluates four attributes on a quantitative basis: industry implementation, industry operation, NRC implementation, and NRC operation. Quantitative analysis requires a baseline characterization of the affected universe, including characterization of factors such as the number of affected entities, and the administrative processes and procedures that licensees or applicants would implement, or no longer implement, because of the proposed alternative. The remaining attributes are evaluated qualitatively because the benefits and costs relating to consistent policy application and improvements cannot easily be quantified. Sections 4.3.2 through 4.3.7 describe the analytical method and assumptions used in the quantitative and qualitative analysis of these attributes.

This regulatory analysis measures the incremental effects of the final rule relative to a baseline that reflects anticipated behavior in the event the NRC undertakes no other regulatory action (Alternative 1, the no action alternative). As part of the regulatory baseline used in this analysis, the NRC staff assumes full licensee compliance with existing NRC regulations. Section 5

presents the estimated incremental costs and benefits of the case-by-case approach (Alternative 2) and the final rule (Alternative 3) relative to this baseline.

4.3.2 Assumptions and Considerations

This section provides an overview of the assumptions the staff used in this analysis to estimate the costs and benefits associated with expedited transfer. This section describes:

- assumptions associated with economic modeling, the definition of representative plants and projection of submittals
- assumptions associated with LTC modeling using risk-informed methods and costs associated with the removal of problematic material

Assumptions used are documented throughout this document. For reader convenience, major assumptions are listed in Table 7.

Table 7 Major Assumptions

Topical Area	Major Assumption	Comment
Timing of industry actions, Alternative 2	Industry actions, in terms of year of implementation and number of actions, are assumed to begin in calendar year 2020 following issuance of the order.	Building upon the knowledge gained from rulemaking activities, the NRC staff would prepare and issue an order in calendar year 2019 to address the research findings.
Timing of industry actions, Alternative 3	Industry actions, in terms of year of implementation and number of actions, are calculated based on the information provided in the industry implementation schedule.	The timing of industry actions is based on the schedule discussed during the public Web cast of June 4, 2015 (ADAMS Accession No. ML15169A004), where applicable.
Number of fuel cladding alloys	NRC calculations are based on six alloys.	The number of fuel cladding alloys analyzed is based on input provided by the fuel vendors—one alloy in use by General Electric Hitachi Nuclear Energy (GEH), two alloys in use by AREVA, and three alloys in use by Westinghouse.
Hydrogen uptake model development	Vendors will use RG 1.224 as the basis for acceptable fuel rod cladding hydrogen uptake models for the current commercial zirconium alloys.	The NRC staff cost model is based on the approach described in RG 1.224, which is believed to be the most cost-effective approach.
Industry labor rates	The mean hourly wage rates used in this analysis are: Executives \$ 199.77 Managers \$ 125.44 Technical staff \$ 98.46 Administrative staff \$ 64.25 Licensing staff \$ 126.84 Research staff \$ 143.19	Labor rates are based on the Bureau of Labor Statistics, Occupational Employment Statistics tables (http://www.bls.gov/oes/current/naics4_221100.htm) and informed based on comments provided by GEH in a response to NRC cost inquiries (ADAMS Accession No. ML15273A529).
Crud considerations	No incremental cost to evaluated crud because of this final rule	The NRC's position: The requirement to evaluate crud is a clarification of the existing 10 CFR 50.46 requirement.
No. of sites applying risk-informed method	10 sites, best estimate of 12 units	Based on industry input, the NRC staff estimates that there are 10 sites with a total of 12 power reactor units that would opt to use the risk-informed method to resolve GSI-191 concerns.

Topical Area	Major Assumption	Comment
Risk-informed method	The risk informed method will demonstrate that current plants can resolve GSI-191 concerns without significant removal and replacement of additional containment insulation.	NRC assumption
Replacement power	The NRC staff estimates that there will be minimal or no incremental expense for replacement power because of fibrous insulation replacement.	The NRC staff assumes that licensees would be approved to complete this modification on an implementation schedule that allows for it to be performed as a noncritical path outage activity.
Announced plans for premature reactor shutdown	The NRC staff assumes Pilgrim and Oyster Creek plants will terminate commercial operation by end of calendar year 2019 and before addressing the new embrittlement mechanisms requirements. Therefore, these plants are not included in this analysis.	See Pilgrim Nuclear Power Station announcement, http://www.entergynewsroom.com/latest-news/entergy-close-pilgrim-nuclear-power-station-massachusetts-no-later-than-june2019/) and Oyster Creek Nuclear Power Plant announcement, http://www.exeloncorp.com/PowerPlants/oystercreek/Pages/profile.aspx .

4.3.3 Affected Entities

- Operating reactor units. The NRC staff models units from 58 U.S. light-water nuclear power reactor sites in this analysis.¹⁵
- Future operating reactor units. The NRC staff assumes that there are four future operating light-water nuclear power reactors that would be affected by the final rule and are considered in this analysis. The future nuclear power reactor units are Vogtle Electric Generating Plant, Units 3 and 4 (Vogtle 3 and 4), assumed to begin operations in 2019 and 2020, respectively; and Virgil C. Summer Nuclear Station, Units 2 and 3 (V.C. Summer 2 and 3), also assumed to begin operations in 2019 and 2020, respectively.¹⁶

To account for new nuclear power reactors under construction that are anticipated to begin operation between 2019 and 2020, the NRC modeled a hypothetical nuclear power reactor to analyze the costs and benefits. The NRC assumes that there would be no significant differences between the future operating reactor units listed above and the modelled hypothetical nuclear power reactor. The NRC staff assumes this hypothetical reactor is a PWR design.

- Operating reactor units that are expected to use the risk-informed approach. The NRC staff estimates that there are 12 operating light-water nuclear power reactor units that plan to use the risk-informed approach to respond to GSI-191.

¹⁵ Based on information obtained from NRC, 2015-2016 Information Digest (NUREG-1350, Volume 27), "Appendix H: U.S. Commercial Nuclear Power Reactor Operating Licenses - Expiration by Year, 2013–2049," June 2015. Available at: <http://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr1350/>, last accessed on October 19, 2015.

¹⁶ The timing and certainty for commercial operation of the Bellefonte Nuclear Station, Units 1 and 2, and for other new operating licenses are too speculative to be included in this regulatory analysis.

- New reactors. To account for new nuclear power reactors under construction that are anticipated to begin operation between 2019 and 2020, the NRC modeled a hypothetical nuclear power reactor to analyze the costs and benefits. The NRC assumes that there would be no significant differences between the future operating reactor units listed above and the modelled hypothetical nuclear power reactor. The NRC staff assumes this hypothetical reactor would be a PWR design and would not use the risk-informed approach to address GSI-191.
- Assumptions related to affected entities. Other potential new reactors licensed under 10 CFR Part 52 and small modular reactors, are not explicitly included in this analysis. In the case that additional Part 52 applicants are issued licenses the hypothetical nuclear power reactor is representative of that case.¹⁷

4.3.4 Sign Conventions

The sign conventions used in this analysis are that all favorable consequences for the alternative are positive, and all adverse consequences for the alternative are negative. For example, additional costs above the regulatory baseline are shown as negative values and cost savings and averted costs are shown as positive values. Negative values are shown using parentheses (e.g., negative \$500 is displayed as (\$500)).

4.3.5 Analysis Horizon

4.3.5.1 Current Operating Light-Water Nuclear Power Reactors

Other than for operating reactors that have indicated that they would not seek a license renewal or have opted for early decommissioning,¹⁸ this analysis assumes that the remaining nuclear power plant units will commercially operate through the term of their license, including a 20-year license extension, unless stated otherwise. As a result, on average, the licenses for the current fleet of operating nuclear power plants expire in 2038. Given that the rule is expected to be issued in 2017, the average remaining life for currently operating reactors would be 22 years from rule issuance so that any recurring costs would be discounted over that time.

4.3.5.2 Future Light-Water Nuclear Power Reactors

The NRC staff assumes that there are four future operating light-water nuclear power reactors that would be affected. The nuclear power reactors are Vogtle Electric Generating Plant

¹⁷ The Bellefonte Nuclear Power Station is not included in this analysis because the site does not have any operating units and new construction is indefinitely delayed. Bellefonte Units 1 and 2 are under the Commission Policy Statement on Deferred Plants (52 FR 38077; October 14, 1987). Fermi Unit 3 is not included in this regulatory analysis because as of May 1, 2015, the NRC issued a combined license to DTE Electric Company but DTE Electric Company has no immediate plans to begin construction. South Texas Units 3 and 4 are not included in this regulatory analysis because as of February 12, 2016, the NRC issued a combined license to Nuclear Innovation North America, LLC (NINA) but NINA has no immediate plans to begin construction.

¹⁸ The NRC excluded San Onofre Nuclear Generating Station, Units 2 and 3; Crystal River Nuclear Plant, Unit 3; Kewaunee Nuclear Power Plant; and Vermont Yankee Nuclear Power Station because they have submitted their permanent cessation of power operations per 10 CFR 50.82(a)(1)(i).

(Vogtle), Units 3 and 4, with estimated beginning of operations dates of 2019 and 2020, respectively; and Virgil C. Summer Nuclear Station, Units 2 and 3, also with estimated beginning of operation dates of 2019 and 2020, respectively.

4.3.5.3 Future Combined License Holders

The NRC staff is reviewing six combined license (COL) applications for Levy County, Turkey Point, Lee Station, North Anna, Harris, and Bell Bend. Two of these reviews have been discontinued.¹⁹ The incremental effects of Alternative 2 and 3 on the remaining four COLs are included in this regulatory analysis.

4.3.5.4 Design Certification

One design certification is under review. For this regulatory analysis, the NRC staff assumes that this design certification review is completed and a final NRC safety evaluation report issued by September 2018. Although other design certifications applications could be submitted to the NRC for approval over the period covered by this analysis, the NRC staff is unable to forecast either the number or the timing for when these would occur. The NRC staff decided that evaluating the impact on a design certification under review is sufficient to analyze the costs and benefits of Alternative 2 and 3 on future design certification submittals and on future renewals.

4.3.6 Base Year

The assumed date of implementation of the final rule is in year 2017 so the monetized benefits and costs in this analysis are expressed in year 2017 dollars. One-time implementation costs are assumed to be incurred in year 2017 and ongoing and annual costs of operation related to the alternatives are assumed to begin in year 2018, unless otherwise stated and are then discounted into year 2017 dollars.

4.3.7 Data

To the extent practicable, the regulatory analysis includes quantitative information and qualitative information (e.g., nonquantified information) on attributes affected by the final rule obtained from NRC staff and comments on the regulatory analyses provided with the proposed rule.²⁰ The NRC staff considered the potential differences between the new requirements and the current requirements and has incorporated available, information into this regulatory analysis. The NRC staff used data from subject matter experts, knowledge gained from past rulemakings, and information gained during public meetings and from correspondence to collect data for this analysis.

¹⁹ As of October 2015, the NRC review of the Harris combined license application is suspended and the review of Bell Bend combined license application is on hold.

²⁰ See Section 6.3 for a discussion of changes from the proposed rule regulatory analysis to this regulatory analysis.

4.3.7.1 Discount Rates

In accordance with guidance from the Office of Management and Budget (OMB) Circular No. A-4 and NUREG/BR-0184, net present worth calculations are used to determine how much society would need to invest today to ensure that the designated dollar amount is available in a given year in the future. By using present worth values, costs and benefits, regardless of when the cost or benefit is incurred in time, are valued to a reference year for comparison. Based on NUREG/BR-0184 and consistent with NRC past practice and guidance, present worth calculations are presented using 3-percent and 7-percent real discount rates.²¹ A 3-percent discount rate approximates the real rate of return on long-term government debt, which serves as a proxy for the real rate of return on savings to reflect reliance on a social rate of time preference discounting concept. A 7-percent discount rate approximates the marginal pretax real rate of return on an average investment in the private sector, and is the appropriate discount rate whenever the main effect of a regulation is to displace or alter the use of capital in the private sector. A 7-percent rate is consistent with an opportunity cost of capital²² concept to reflect the time value of resources directed to meet regulatory requirements.

4.3.7.2 Cost/Benefit Inflaters

To evaluate the costs and benefits consistently, the analysis inputs are inflated into 2017 dollars. The most common inflator is the Consumer Price Index for all urban consumers (CPI-U), developed by the U.S. Department of Labor, Bureau of Labor Statistics (BLS). The formula to determine the amount in 2017 dollars is

$$\frac{\text{CPIU}_{2017}}{\text{CPIU}_{\text{Value Year}}} * \text{Value}_{\text{Value Year}} = \text{Value}_{2017}$$

Values of CPI-U used in this cost-benefit analysis are summarized in Table 8.

Table 8 Consumer Price Index—All Urban Consumers, U.S. City Average

Base Year	CPI-U Annual Average ^a	Forecast Percent Change from Previous Year ^b
2000	172.2	
2011	224.939	
2012	229.594	
2013	232.957	
2014	236.736	
2015	239.340	1.10%
2016	244.606	2.20%

²¹ The rates presented in Appendix C to OMB Circular No. A-94 do not apply to regulatory analysis or benefit-cost analysis of public investment. These rates are used for lease-purchase and cost-effectiveness analysis, as specified in the Circular. These discount rates are covered in Appendix B – “Supplemental Information for Value-Impact Analyses” to NUREG/BR-0184.

²² Opportunity cost is the value of the next best alternative to a particular activity or resource. An analyst does not need to assess opportunity cost in monetary terms. Opportunity cost can be assessed in terms of anything that is of value.

Base Year	CPI-U Annual Average ^a	Forecast Percent Change from Previous Year ^b
2017	250.231	2.30%

^a United States Bureau of Labor Statistics, *CPI Detailed Report, December 2014*. “Table 24. Historical Consumer Price Index for All Urban Consumers (CPI-U): U.S. City Average, All-Items,” December, 2014. Web. 27 January 2015. <http://www.bls.gov/cpi/tables.htm>.)

^b United States Congressional Budget Office, *The Budget and Economic Outlook: 2015 to 2025*. “Table 2-1. CBO’s Economic Projections for Calendar Years 2015 to 2025,” January 2015. Web. Sept. 2015. <http://www.cbo.gov/sites/default/files/cbofiles/attachments/49892-Outlook2015.pdf>.

4.3.7.3 Labor Rates

For regulatory analysis purposes, labor rates are developed wherein only variable costs that are directly related to the implementation and operation and maintenance of the proposed requirement are included. This approach is consistent with guidance set forth in NUREG/CR-4627, “Generic Cost Estimates,” and general cost-benefit methodology. The NRC incremental labor rate is \$128 per hour.²³

The NRC staff estimated mean industry incremental labor rates based on data provided by the BLS and supplemented by industry input. The NRC staff used the 2014 Occupational Employment and Wages data, which provided labor categories and the mean hourly wage rate by job type and used the inflator discussed in Section 4.3.7.2 to inflate these rates to 2017 dollars. The labor rates used in the analysis reflect total compensation, which includes health and retirement benefits (using a burden factor of 2.4). The NRC staff used the BLS data tables to select appropriate hourly labor rates for performing the estimated procedural, licensing, and utility related work necessary during and following implementation of the proposed alternative. In establishing this labor rate, wages paid for the individuals performing the work plus the associated fringe benefit component of labor cost (i.e., the time for plant management over and above those directly expensed) are considered incremental expenses and are included. Table 9 provides a breakdown of the labor categories considered that may be required to implement this final rule.

Table 9 Labor Rates

Labor Category	CPI-U Inflator (2014 to 2017)	Labor Multiplier	2017 Dollars			
			BLS Burdened Hourly Mean Wage	BLS Burdened Hourly 25th Percentile Wage	BLS Burdened Hourly 75th Percentile Wage	Mean Hourly Wage
Executive	1.047	2.4	\$203.67	\$142.17	\$246.50	\$199.77
Managers	1.047	2.4	\$126.27	\$96.70	\$151.75	\$125.44
Technical Staff	1.047	2.4	\$98.52	\$81.68	\$115.01	\$98.46
Admin Staff	1.047	2.4	\$64.63	\$47.45	\$79.86	\$64.25
Licensing Staff	1.047	2.4	\$129.47	\$87.68	\$155.87	\$126.84
Research staff	1.047	2.4	\$145.12	\$104.57	\$173.53	\$143.19

²³ The NRC labor rates presented here differ from those developed under the NRC’s license fee recovery program (10 CFR Part 170). The NRC labor rates for fee recovery purposes are set for cost recovery of the services rendered and as such include nonincremental costs (e.g., overhead, administrative, and logistical support costs).

4.3.7.4 Dollar per Person-Rem Conversion Factor

The NRC is revising the dollar-per-person-rem averted conversion factor of \$2,000 per person-rem based on recent information regarding the value of a statistical life and cancer risk factors. The NRC staff used the proposed updated dollar per person-rem values provided in this analysis.

Table 10 Dollar per Person-Rem Conversion Factor

Low Estimate	Base Case	High Estimate
\$2,000	\$3,150	\$5,100

4.3.7.5 Short-Term Replacement Power Costs

Replacement energy costs are the costs for replacing the energy from the nuclear power reactor because of a plant shutdown to install required equipment or due to an accident.²⁴

For the replacement energy cost calculation in this regulatory analysis, the NRC staff expects that there will be minimal to no short-term power replacement costs because of the replacement of fibrous asbestos insulation with reflective metallic insulation. This expectation is based on the industry practice to replace insulation during scheduled refueling outages and without extending the plant outage. If the insulation is not completed during one scheduled refueling outage, the remainder of the insulation replacement will be performed during subsequent scheduled refueling outage(s).

²⁴ The replacement energy cost is the cost to purchase energy required to provide the same level of energy and reliability as would have been available from the affected unit. These estimates do not include transmission or distribution charges.

5 Evaluation of Alternatives

This section presents the quantitative results by attribute separately for the cladding embrittlement and risk-informed requirements. The tables, unless provided within the body of this section, are located in Appendix A.

5.1 Industry Implementation

This attribute is composed of indirect and direct licensee implementation costs for operating reactors, design certifications and future operating reactors.

5.1.1 *Cladding Embrittlement–Alternative 2*

5.1.1.1 *Current Reactor Licensees*

The case-by-case alternative does not provide the regulatory framework of a rule or regulatory guides to detail an approach for verifying adequate protection and addressing the research findings discussed in the introduction of this regulatory analysis. As a result of this lack of regulatory framework, a regulatory uncertainty factor of 10% is applied to all industry costs involving submissions to the NRC. There may be some cost and schedule relief with this alternative because vendors would have two additional years to develop their approaches while the NRC issues generic communication and orders, directing industry to address these findings in future submittals. This is described below in the NRC Implementation section of this regulatory analysis. However, the NRC staff believes that the most likely approach for vendors to address the research findings would be to develop topical reports and breakaway oxidation testing described in Alternative 3. Additionally, the NRC staff expects that licensees will submit LARs to the NRC to demonstrate margin, and meet the adequate protection requirements. Alternative 2 does not present an entirely different set of Industry actions because the NRC staff has concluded that Alternative 3 already consists of the most cost-effective acceptable industry actions. The major difference between Alternative 2 and Alternative 3 is that certain actions under Alternative 2 would be delayed for 2 or more years after expected rule implementation, in 2019, fuel vendors could delay purchasing breakaway oxidation testing equipment until 2019, and certain licensees could make business decisions regarding the continued economic viability of their plant in conforming with these orders.

The implementation schedule allowed by § 50.46c would be applicable to licensees under Alternative 2, and licensees would have to submit LARs to the NRC with their proposed schedules as described below. Under Alternative 2, the NRC staff assumes that 69 LARs will be submitted will be submitted over a 5-year period after the order is issued, divided as follows: 32 Level 1 LARs, 5 Level 2 LARs, and 32 Level 3 LARs.

If Alternative 2 is selected, there is no technology neutral change in 10 CFR 50.46 rule language allowing for the use of advanced zirconium alloys without license exemptions. Therefore, Alternative 2 would not benefit from the 25 averted license exemptions mentioned in Alternative 3.

The industry implementation costs described above would affect operating reactors, design certifications, and future operating reactors. The detailed tables reflecting the industry implementation costs for operating reactors (because of the cladding embrittlement portions of

10 CFR 50.46c) are provided in Appendix A, Table 57. These costs are summarized in Table 11.

As shown in Table 11, the estimated total industry implementation costs for operating reactors, for the cladding embrittlement portions of this final rule under Alternative 2, represent costs ranging from (\$24.9 million) using a 7-percent discount rate to (\$28.4 million) using a 3-percent discount rate.

Table 11 Industry Implementation Costs for Operating Reactors—Cladding Embrittlement Alternative 2 (Summary)

Year	Activity	Cost		
		Undiscounted	7% NPV	3% NPV
2019-2020	Modeling and Topical Reports	(\$4,238,234)	(\$3,610,614)	(\$3,951,112)
2019-2020	Initial Breakaway Testing	(\$11,632,779)	(\$9,307,836)	(\$10,551,545)
2019	Breakaway Testing Equipment	(\$2,301,610)	(\$2,010,315)	(\$2,169,488)
2019-2031	Licensee Amendment Requests	(\$13,298,765)	(\$9,954,655)	(\$11,713,296)
2017-2021	License Exemption Requests	\$0	\$0	\$0
Total:		(\$31,471,388)	(\$24,883,420)	(\$28,385,442)

5.1.1.2 Future Reactors and Design Certifications

The industry implementation costs for both the design certification and COL requests are the same as in Alternative 3, as shown in Table 13. Similarly the submittals for Vogtle and V.C. Summer are the same as in Alternative 3, as shown in Table 14.

5.1.2 Cladding Embrittlement—Alternative 3

5.1.2.1 Current Reactor Licensees

The final rule will require licensees of operating reactors, design certifications, and future operating reactors to make use of revised ECCS analysis models based upon the new required acceptance criteria. The revised ECCS models will be developed by vendors, at the request and expense of the licensees.²⁵ The final rule will require alloy-specific cladding hydrogen uptake models. RG 1.224 provides acceptable fuel rod cladding hydrogen uptake models for the current commercial zirconium alloys. The vendors will also produce licensing topical reports describing the new models for NRC review and approval. The NRC staff estimates that six topical reports, one for each of the six cladding alloys, will be prepared and submitted.

In addition, each vendor will produce a topical report on PQD and breakaway oxidation testing, for a total of three topical reports. For each cladding alloy in use, vendors will produce and submit a topical report on their fuel mechanical design, for a total of six topical reports. Finally, vendors will produce topical reports on their BWR and PWR evaluation models. The NRC staff understands based on vendor input that there will be a total of seven BWR and PWR evaluation models and topical reports submitted. Westinghouse Electric Company (WEC) will produce one BWR and two PWR reports, AREVA will produce one BWR and one PWR report, and GEH

²⁵ The NRC staff did not include a vendor-imposed value-added charge for the licensee purchase of these ECCS models and analyses from the fuel vendor.

will produce two BWR reports. The vendors will also produce test data to characterize alloy performance and develop analytical limits based on this test data to be included within each alloy's topical report. Combined, the NRC staff expects a total of 22 topical reports to be submitted for NRC review because of this rule.

The vendors will also develop and conduct initial breakaway testing on all cladding alloys. Each vendor is expected to perform its own breakaway oxidation testing. These tests require specialized equipment that would need to be procured (i.e., a high-temperature steam oxidation chamber and upgraded test equipment to perform the hydrogen content measurement and hydrogen pre-charging, and ring compression tests). Because the vendors would conduct initial breakaway tests on the licensees' behalf to comply with new requirements, these costs are included with industry implementation costs.

After completing the modeling, reporting, and breakaway oxidation testing, the vendors would prepare input for the LAR for each nuclear power plant unit. This activity is forecast to be completed over several years because of the complexity of this input and the number of LARs. After vendor preparation and submittal of the LAR input to the plant licensee, the licensee would complete preparation of the LAR, coordinate with vendors to resolve issues and seek clarifications, and submit the completed LAR to the NRC. Three levels of effort for the preparation of a LAR are evaluated in this regulatory analysis, Levels 1, 2, and 3. A Level 1 LAR is applicable for situations where no coding is required on the ECCS models, and consists primarily of a reinterpretation of results. A Level 2 LAR is applicable when a few added cases need to be run with the ECCS models, along with sensitivity studies and reinterpretation of results. A Level 3 LAR is applicable when a complete ECCS re-analysis, sensitivity studies, and detailed results analysis are required. Based on industry input, the NRC staff estimates that 69 LARs (for 100 units) will be submitted over a 5-year period after rule implementation, divided as follows: 32 Level 1 LARs, 5 Level 2 LARs, and 32 Level 3 LARs.

The revised rule will require licensees to evaluate the thermal effects of crud and oxide layers that accumulate on the fuel cladding during plant operation. Because licensees were required to account for various thermal parameters under the current regulation, the NRC's position is that the requirement to evaluate crud is a clarification of the previous requirement. As such, there is no incremental cost incurred because of the revised rule.

The industry implementation costs described above would affect operating reactors, design certifications, and future operating reactors. The detailed tables reflecting the industry implementation costs for operating reactors (because of the cladding embrittlement portions of 10 CFR 50.46c) are provided in Appendix A, Table 58. These costs are summarized in Table 12, below.

As shown in Table 12, the estimated total industry implementation costs for operating reactors, for the cladding embrittlement portions of this final rule under Alternative 3, represent costs ranging from (\$24.8 million) using a 7-percent discount rate to (\$26.0 million) using a 3-percent discount rate.

Technology Neutral

The current 10 CFR 50.46 applies to "each boiling or pressurized light-water nuclear power reactor fueled with uranium oxide pellets within cylindrical zircaloy or ZIRLO™ cladding." Licensees must request an exemption to use fuel designs consisting of materials other than those stated for Alternative 1 and Alternative 2. The revised rule will extend applicability to all

LWRs, regardless of fuel design. Additionally, because of the cladding embrittlement research findings, industry would need to submit one topical report per cladding alloy not covered under 10 CFR 50.46, to demonstrate that each of these cladding alloys is designed to adequately protect against the new cladding embrittlement issues. This will eliminate the need for exemption requests, shown in Table 12, and represents a benefit (averted cost). Over the next 5 years after implementation of the final rule, the NRC staff estimates that 25 exemption requests for cladding alloys will be averted because of this rule. It is important to note that, without the cladding embrittlement model changes and testing protocol delineated in this final rule, the technology neutral changes to 10 CFR 50.46 would not be enacted, and therefore these exemption requests would have to be submitted.

**Table 12 Industry Implementation Costs
for Operating Reactors—Cladding Embrittlement Alternative 3 (Summary)**

Year	Activity	Cost		
		Undiscounted	7% NPV	3% NPV
2017-2018	Modeling and Topical Reports	(\$3,852,940)	(\$3,757,993)	(\$3,810,668)
2017-2018	Initial Breakaway Testing	(\$10,575,254)	(\$9,687,765)	(\$10,176,486)
2017	Breakaway Testing Equipment	(\$2,301,610)	(\$2,301,610)	(\$2,301,610)
2017-2021	Licensee Amendment Requests	(\$12,089,786)	(\$10,360,985)	(\$11,296,942)
2017-2021	License Exemption Requests	\$1,689,902	\$1,385,787	\$1,547,852
Total:		(\$27,129,688)	(\$24,722,567)	(\$26,037,854)

5.1.2.2 Future Reactors and Design Certifications

Costs come from the initial submittal activities remaining for the known design certification and combined licenses under review. The NRC is currently reviewing five design certifications, but only one -- Advanced Power Reactor 1400 -- is under active review.²⁶ For this design certification, the estimated 190 hours represent a Level 1 LAR. This design certification has already been docketed and therefore the rule will become applicable to AP1400 at renewal (2032). The estimated costs for this design certification range from (\$27,449) using a 7-percent discount rate to (\$48,611) using a 3-percent discount rate. Additionally the NRC is reviewing four combined license requests (i.e., Levy County, Turkey Point, Lee Station, and North Anna).²⁷ Once they become licensees, the NRC staff estimates that they will expend 921 hours per request. The estimated effect on these COLs is estimated to be equivalent to a Level 2 LAR, and the preparation and submittal of a topical report. These activities result in estimated costs ranging from (\$859,671) using a 7-percent discount rate to (\$1.1 million) using a 3-percent discount rate. The industry implementation costs for both the design certification and COL requests are estimated to range from (\$887,120) using a 7-percent discount rate to (\$1.1 million) using a 3-percent discount rate, as shown in Table 13.

²⁶ Source: NRC Design Certification Applications for New Reactors web page, <http://www.nrc.gov/reactors/new-reactors/design-cert.html>, last updated July 9, 2015.

²⁷ Two combined license applications whose reviews are suspended or on hold (i.e., Harris and Bell Bend) are not included.

Table 13 Industry Implementation Costs for Design Certifications and Combined Licenses (Alternative 3)

Industry Implementation Costs: Design Certification

Year	Activity	Number of Design Certifications*	Per Design Certification		Cost		
			Hours	Weighted Hourly rate	Undiscounted	7% NPV	3% NPV
2032	Initial Submittal	1	593	\$128	(\$75,734)	(\$27,449)	(\$48,611)
Total:					(\$75,734)	(\$27,449)	(\$48,611)

Industry Implementation Costs: COL

Year	Activity	Number of Sites	Per Unit		Cost		
			Hours	Weighted Hourly rate	Undiscounted	7% NPV	3% NPV
2022	COL - Vendor Preparation	4	903	\$128	(\$461,209)	(\$328,836)	(\$397,843)
2023	COL - Industry Processing/Submission	4	356	\$97	(\$138,510)	(\$92,295)	(\$116,000)
2023	COL Topical Report - Vendor Preparation	4	978	\$135	(\$528,681)	(\$352,282)	(\$442,762)
2024	COL Topical Report - Industry Processing/Submission	4	356	\$97	(\$138,510)	(\$86,257)	(\$112,622)
Total:					(\$1,266,911)	(\$859,671)	(\$1,069,227)

Total Industry DCD and COL Cost:					(\$1,342,645)	(\$887,120)	(\$1,117,837)
---	--	--	--	--	----------------------	--------------------	----------------------

Consideration of future operating reactors involves four units, two at Vogtle and two at V.C. Summer. Watts Bar Unit 2 is expected to be in commercial operation in calendar year 2016, and is included in the current operating reactor costs in Table 12. The initial submittals are equivalent to Level 1 LARs, and would occur for Vogtle in 2022 and V.C. Summer in 2023, as the rule allows COL applicants 84 months to comply. Table 14 shows that the V.C. Summer and Vogtle future operating reactors have an estimated cost range of (\$104,462) using a 7-percent discount rate to (\$128,754) using a 3-percent discount rate.

Table 14 Industry Implementation Costs for Future Operating Reactors (Alternative 3)

Year	Activity	No. of Units	Per Model/Cladding Alloy		Cost		
			Hours	Weighted Hourly rate	Undiscounted	7% NPV	3% NPV
2022	COL Submittals (Vogtle and V.C. Summer Units)	2	297	\$128	(\$75,734)	(\$53,997)	(\$65,329)
2023		2	297		(\$75,734)	(\$50,465)	(\$63,426)
Total Future Industry Operating Reactor Implementation Cost:					(\$151,467)	(\$104,462)	(\$128,754)

5.1.3 Risk-Informed

5.1.3.1 Current Reactor Licensees

The NRC staff estimates that 10 sites for a total of 12 nuclear power reactor units will opt for this risk-informed approach based on discussions with industry.²⁸ The NRC will support early implementation of the alternative approach, if desired. A savings from this approach would be

²⁸ Because of the similarity of two set of reactor units, the NRC staff estimates that the 14 units will be analyzed by 12 analyses.

the averted costs for licensees to submit four exemption requests: 10 CFR 50.46c, GDC-35, GDC-38, and GDC-41. This benefit is recognized in the same year that the NRC receives the licensees' submittal.

The NRC expects licensees to use several models, which are discussed below. This is not an exhaustive list as the licensees may decide to use these or comparable models.

A. Containment Computer-Aided Design (CAD) Model

The containment computer-aided design (CAD) model is used to help determine the amount of debris within the zone of influence (ZOI) of each break. Proprietary software programs are available and in use to perform these analyses, reducing the cost uncertainty. These programs account for the time-dependent modeling of the underlying physical phenomena and the propagation of uncertainties in the physical models. The containment CAD model provides a three-dimensional depiction of the containment, containment internals, and large and small bore piping. The model also shows the types and amounts of insulation installed on equipment in areas where it could be damaged by a break jet. The NRC staff made inquiries to establish the basis for NRC cost estimates. Based on cost information received, the NRC staff estimates the costs to develop the containment CAD model are (\$110,000) per unit to collect and load the model inputs shown in Table 15.

Table 15 Containment CAD Model Inputs

Sample CAD Model Inputs	
•	Containment geometry (i.e., concrete walls, piping insulation, weld locations, equipment insulation)
•	Debris quantities (i.e., insulation, coatings, latent debris, miscellaneous debris)

The cost estimate for industry provided in Table 16 is (\$1.3 million) for the development of 12 CAD models. The costs may be lower because some of these licensees (or their contractors) may already have a CAD model available, which could be used for GSI-191 purposes.

Table 16 Industry Implementation: Containment CAD Model

Year	Activity	Number of CAD Models	Per Unit		Cost
			Hours	Weighted Hourly Rate	
2017	Develop Containment CAD model	12	775	\$137	(\$1,278,012)
Total:					(\$1,278,012)

B. Debris Effects Model

The debris effects model is used to determine quantities and characteristics of the debris that reach the ECCS strainers and the reactor core. Its purpose is to determine how much debris transports to the strainer and may also be used to determine the effects of debris on strainer performance and coolant flow to the fuel. Table 17 shows the estimated cost of the debris effects model is (\$9,350,000). This amount is a roll up from the supporting models that feed into this analysis. The major subsidiary models that accrue to the Debris Effects Model are the Sump Clogging Model and the In-Vessel Effects Model. Both the Sump Clogging Model and the

In-Vessel Effects Model have further breakouts, which will be described in the following paragraphs.

The Sump Clogging sub model would include strainer test results to determine if units are the same (e.g., strainer design and size, flow rates, debris types and quantities). The NRC staff estimates that 10 sites would elect to use the risk-informed approach and would perform strainer tests to provide material results. Each site is expected to perform its own test to account for unit-specific design differences. For multiple unit sites, the NRC expects the licensee would confirm that the strainer test results are applicable for both units to use. The NRC staff estimates that the strainer test module hardware is (\$100,000), therefore the total industry cost is (\$1,000,000) for 10 strainer test modules. The NRC staff estimates that the cost of each strainer test is (\$30,000), making the total industry cost (\$300,000) for 10 strainer tests. The NRC staff estimates that the industry cost to analyze the results of a strainer test is (\$10,000) for a total industry cost of (\$100,000) for 10 sites.

The NRC staff estimates the cost to set up and perform the initial head loss test is (\$200,000). The NRC staff estimates that each subsequent test run cost is (\$70,000). Experience indicates that between one and five test runs will most likely be performed based on industry head loss tests performed at St. Lucie (three test runs), South Texas (one test run), and Vogtle (five test runs). The NRC staff estimates, on average, an initial and one additional test run will be performed for a unit total of (\$270,000) times 10 sites for a total of (\$2.7 million). These costs are summarized in Table 17.

Table 17 Industry Implementation: Debris Effects, Break Frequency, and Thermal Hydraulics Model

Year	Item	Number of Units	Item Cost	Cost
2017	Debris Effects Model	12		(\$9,120,000)
2017	<i>Sump Clogging Model</i>	12		<i>(\$4,920,000)</i>
2017	Strainer Test Module Hardware	12	\$100,000	(\$1,200,000)
2017	Strainer Test	12	\$30,000	(\$360,000)
2017	Analysis of Strainer Test(s)	12	\$10,000	(\$120,000)
2017	Head Loss Test	12	\$270,000	(\$3,240,000)
2017	<i>In-Vessel Effects Model</i>	12		<i>(\$4,200,000)</i>
2017	Bypass Test	12	\$175,000	(\$2,100,000)
2017	Debris Generation SubModel	12	\$175,000	(\$2,100,000)
2017	Break Frequency Allocation Model	12		(\$3,840,000)
2017	Thermal Hydraulic Analysis	12	\$50,000	(\$600,000)
2017	Transport Tree Model	12	\$20,000	(\$240,000)
2017	Plant Cleaniness Model	12	\$15,000	(\$180,000)
			Total:	(\$16,380,000)

C. Penetration Testing as a Part of the In-Vessel Effects Model

The In-Vessel Effects model is used to estimate how much debris can reach the reactor core and what its effects will be. Debris penetration tests are used to determine how much debris

passes through the ECCS strainer. The estimated costs for in-vessel effects modeling are summarized in Table 17 and discussed below.

Penetration Testing

Penetration test results are used to calculate mass of fiber that can penetrate the strainer. The test results are used to determine the potential for flow to the core to be interrupted. Penetration testing is expected to cost (\$175,000) per test. The total cost for the 10 sites is expected to be (\$1.75 million).

Bypass Testing

Bypass testing is estimated to range from \$100,000 to \$200,000 per unit depending on how many trials are run. Additional runs are approximately \$25,000 each. The NRC staff estimates the average cost of the bypass test is (\$150,000) plus an additional test costing (\$25,000) at each site for a total of (\$1,750,000).

Debris Generation Submodel

The debris generation sub model calculates the insulation debris amounts and characteristics for each break location. Debris amounts are based on break size, location, and orientation. As part of the model, estimates take into account the relevant ZOI which correlates the estimated location of pipe breaks with the proximate location of debris that will be affected by the high energy line break. This sub model calculates the debris quantities generated for multiple break locations, break sizes, and jet orientations, for each insulation material type impacted. The NRC staff estimates that debris generation testing will cost (\$175,000) per test. The total cost for the 10 sites is expected to cost (\$1.75 million).

D. Break Frequency Allocation Model

In Table 17, the total industry implementation cost of the break and break frequency model for 10 units is (\$3.2 million). The NRC staff expects that the units at each site will have similar pipe weld locations and characteristics. This model has two purposes; to determine pipe break locations, and to determine frequency of each potential break. Pipe welds are postulated as likely failure locations because they can have residual stresses, are subject to degradation mechanisms not generally affecting piping, and are more likely to have defects. Thermal fatigue, stress corrosion cracking, and mechanical fatigue are potential degradation mechanisms for welds. The NRC staff estimates that each of the 10 analyses will cost (\$320,000) for a total of (\$3.2 million).

E. Thermal Hydraulic Model

The NRC staff estimates that the thermal hydraulic model will cost (\$200,000) per site. The total cost of the thermal hydraulic modeling for 10 sites is (\$2 million).

F. Thermal Hydraulic Analysis

The NRC staff estimates that the thermal hydraulic analysis will cost (\$50,000) per site. The total cost of the thermal hydraulic analyses for 10 sites is (\$500,000).

G. Transport Tree Submodel

The transport tree sub-model is a model that calculates the amount of debris that is transported to the sump from each break location. A unit-specific transport tree sub-model is prepared for each licensee using the risk-informed approach. These models are maintained at the licensees' sites and are available for NRC staff review. The NRC staff estimates that the cost of this transport tree sub model is approximately (\$20,000) per site with the total cost amounting to (\$200,000).

The NRC also expects that each licensee will confirm that their plant cleanliness procedure provides sufficient controls to minimize the reintroduction of fibrous insulation material into containment. The NRC staff estimates that the cost to review and revise this procedure, as appropriate, is (\$15,000) per site and (\$150,000) for 10 sites.

H. Averted Insulation Removal and Replacement

The major benefit of the risk-informed approach is the possible elimination of the need to remove fibrous insulation from containment and replace it with materials that are not problematic. The activities averted through this process and the cost components are summarized in Table 18.

Table 18 Averted Industry Costs for Fibrous Insulation Removal and Replacement

Activity	Low Estimate	Best Estimate	High Estimate
Industry Costs for Insulation Removal			
Cost for vendor staff to remove FAI (\$/ft ³)	\$1,860	\$2,200	\$2,850
Amount of insulation to remove (ft ³)	1,600	5,600	9,450
Number of units to remove insulation from	11	12	14
<i>Averted removal of insulation cost</i>	<i>\$32,736,000</i>	<i>\$147,840,000</i>	<i>\$377,055,000</i>
Industry Occupational Exposure during Insulation Removal			
Dollar per person-rem conversion factor	\$2,000	\$3,550	\$5,100
Occupational exposure during insulation removal per unit (person-rem)	13	47	79
Number of units	11	12	14
<i>Averted dose for insulation removal cost</i>	<i>\$294,301</i>	<i>\$1,994,556</i>	<i>\$5,641,292</i>
Industry Costs for Insulation Disposal (Class A hazard)			
Removed insulation (ft ³)	1,600	5,600	9,450
Disposal cost (ft ³)	\$128	\$300	\$600
Number of units to install insulation	11	12	14
Shipping and handling costs to depository	\$100,000	\$300,000	\$450,000
<i>Averted replacement material cost</i>	<i>\$3,352,800</i>	<i>\$23,760,000</i>	<i>\$85,680,000</i>
Industry Costs for Replacement Insulation Installation			
Cost for vendor staff to install replacement insulation (\$/ft ³)	\$2,860	\$4,600	\$6,400
Amount of replacement insulation to install (\$/ft ³)	1,100	2,400	4,000
Number of units to install insulation	11	12	14

Activity	Low Estimate	Best Estimate	High Estimate
<i>Averted replacement insulation installation cost</i>	\$34,606,000	\$132,480,000	\$358,400,000
Industry Occupational Exposure during Insulation Replacement			
Dollar per person-rem conversion factor	\$2,000	\$3,550	\$5,100
Dosage per unit (person-rem)	9	20	33
Number of units to install insulation	11	12	14
<i>Averted dose for insulation installation cost</i>	\$202,332	\$854,810	\$2,387,848
Industry Material Costs for Replacement Insulation			
Replacement insulation (ft ³)	1,100	2,400	4,000
Replacement insulation cost (ft ³)	\$1,200	\$1,400	\$2,050
Number of units to install insulation	11	12	14
<i>Averted replacement material cost</i>	\$14,520,000	\$40,320,000	\$114,800,000
Total Averted Industry Costs	\$85,710,000	\$347,250,000	\$943,960,000

I. Averted Exemption Requests

Another benefit of 10 CFR 50.46c is the expansion of the LTC requirement to allow a debris-induced postquench reheat transient. The current LTC requirement in 10 CFR 50.46(b)(5) does not recognize the potential effects of debris on ECCS coolant delivery to the core. Should 10 CFR 50.46c not be approved by the Commission and not be issued, the industry would be required to request exemptions to 10 CFR 50.46(b)(5) for these debris effects.

Per Table 19, the NRC staff expects savings in the 2017 to 2021 timeframe of foregoing the preparation and submission of exemption requests (ER) by the licensees. The estimated number of exemption requests is 12, which corresponds to the number of units that would use the risk-informed approach. The NRC estimates these submissions to require an average of 558 hours. Using a calculated weighted hourly rate of \$121, the undiscounted savings are approximately \$811,000 with a discounted range between \$425,744 (7-percent discount rate) and \$458,887 (3-percent discount rate).

Table 19 Exemption Requests Averted by Risk-Informed Alternative

Year	Activity	Number of Exemption Requests	Per Exemption Request		Cost		
			Hours	Weighted Hourly rate	Undiscounted	7% NPV	3% NPV
2017-2021	Exemption Request (ER) Preparation and Submission	12	558	\$121	\$811,153	\$425,744	\$458,887
Total:					\$811,153	\$425,744	\$458,887

The estimated total industry implementation costs for operating reactors, for the risk-informed portion of this final rule (the sum of averted costs in Table 18 and Table 19), represents an averted cost from not having to replace fibrous insulation.

5.1.3.2 Future Reactors and Design Certifications

The NRC staff expects that future reactor designs will be cleaner, will not have fibrous insulation in the quantities and percentages as in older reactor designs, and will use the risk-informed alternative methods. As a result, the NRC staff does not expect any incremental costs.

5.2 Industry Operation

5.2.1 Cladding Embrittlement—Alternative 2

In the case-by-case approach to address the research findings, the periodic breakaway testing described in Alternative 3 would be the most effective way for industry to demonstrate adequate protection. However, the NRC expects that this testing would begin in 2020. As this time shift in the incurred costs is the only difference between these two alternatives, a supplemental table is not provided in Appendix A. Additionally, there would not be an averted test during development of a new cladding alloy, which is expected for Alternative 3 (as shown in Table 22), because of the regulatory uncertainty under Alternative 2. The summary costs of the periodic breakaway testing expected under Alternative 2 range from (\$5.1 million) using a 7-percent discount rate to (\$8.8 million) using a 3-percent discount rate, shown below in Table 20.

Table 20 Industry Operation: Periodic Breakaway Tests (Alternative 2)

Year	Activity	No. of Ingots Tested	Per Ingot		Cost per Year		
			Hours	Weighted Hourly Rate	Undiscounted	7% NPV	3% NPV
2020-2078	Periodic Breakaway Tests	40-320	11	\$142	(\$15,056,940)	(\$5,086,901)	(\$8,789,322)

5.2.2 Cladding Embrittlement—Alternative 3

Industry will incur costs associated with periodic confirmation of breakaway oxidation behavior. These costs would be incurred for plants that are both currently operating or will be operating in the future (does not apply to design certifications).

The proposed reporting criteria are structured and written to clarify which items need to be reported, and the timeframe for reporting. The final rule language clarifies the intent of the current regulation. As such, the proposed revision does not constitute a change in burden to the NRC or the industry.

Periodic tests to confirm that fuel is being manufactured consistent with the specified breakaway oxidation analytical time limit are required by the final rule; although the final rule and associated guidance in RG 1.222 and RG 1.224 provides flexibility on the frequency the for these periodic tests with submitted justification. The baseline NRC approved testing frequency is to test each ingot. There is no requirement to submit periodic test results to the NRC, though these results should be retained and available for NRC inspection to verify that the referenced measurement for the onset of breakaway oxidation is valid for fuel loaded in the reactor. The NRC assumes that, once all licensees of operating reactors have put the revised rule into place, 300 to 320 ingots will undergo breakaway tests each year. This estimate is based on published plant

refueling outage frequency, vendor input, the remaining term of nuclear power plant licenses, and is a nominal value based on industry input.

Each periodic breakaway test is expected to take 11 hours per ingot with a weighted labor cost of \$142 per hour. A test will be performed on each ingot produced for nuclear fuel use with testing expected to begin in 2018. Based on the operating license term of existing and planned nuclear power reactors, the number of tests per year will start at 300 increasing to 320 in year 2020 and then will begin to decrease with nuclear power plants decommissioning in year 2040 and onward. From year 2040 to 2078, the number of tests is correlated to the expected number of operating reactors, the last of which is expected to begin decommissioning in year 2078. The total estimated cost range of the periodic breakaway testing for operating reactors is from (\$5.9 million) using a 7-percent discount rate to (\$9.6 million) using a 3-percent discount rate, as summarized in Table 21.²⁹

Table 21 Industry Operation: Periodic Breakaway Tests (Alternative 3)

Year	Activity	No. of Ingots Tested	Per Ingot		Cost per Year		
			Hours	Weighted Hourly Rate	Undiscounted	7% NPV	3% NPV
2018-2078	Periodic Breakaway Tests	40-320	11	\$142	(\$15,952,940)	(\$5,897,104)	(\$9,646,779)

This periodic breakaway testing is one of the larger costs of the cladding embrittlement portions of this final rule, and it is important to note that the NRC allows for adjusting the periodic breakaway testing frequency in the event that breakaway test data demonstrates consistent acceptable alloy performance. Because these reduced test frequencies and respective costs are speculative in nature, the NRC staff did not reduce the estimate in this quantitative cost analysis. However, the future reduction in test frequency is worth acknowledging as it would reduce the total cost of this rule.

As a benefit to future alloys produced, the industry would have greater certainty of the testing required for a new alloy, and therefore would receive the benefit (averted cost) of less testing of any new alloy invented and regulatory certainty.

The NRC staff believes that based on the defined approach and greater certainty provided because of this rule, fuel vendors will be able to develop new fuels through a process that will require at least one fewer test than the current regulatory framework enables. The averted costs for this test are estimated to be equivalent to the initial breakaway oxidation test used in this analysis. The estimated total averted costs for industry operations for future operating reactors range from \$8,121 (7-percent discount rate) to \$13,326 (3-percent discount rate) and are provided in Table 22.

²⁹ The detailed modeling for this calculation is provided in Table 59 of Appendix A.

Table 22 Industry Operating Costs for Future Cladding Alloys

Industry Operation Costs (Indirect - Vendor Operating Costs):							
Year	Activity	Number of Alloys	Per Reload		Cost		
			Hours	Weighted Hourly rate	Undiscounted	7% NPV	3% NPV
2030	Develop new cladding alloy (averted test)	1	138	\$142	\$19,570	\$8,121	\$13,326
Total:					\$19,570	\$8,121	\$13,326

5.2.3 Risk-Informed

Licenseses that elect to use the risk-informed alternative to address the effects of debris in the long-term would be required to periodically update their analyses. Additionally, those licenseses would be required to report errors or changes in their submittals. The NRC assumes that industry would submit one error report per year, and every four years would perform periodic updates of their Long Term Cooling analyses. Because the remaining licensed term of the reactor units using the risk-informed approach is 24 years, the NRC estimates 24 error reports and 60 updates (i.e., 5 updates of 12 analyses) to the long-term cooling analyses. The NRC estimates that these industry operating costs range from (\$8.6 million) using a 7-percent discount factor to (\$12.8 million) using a 3-percent discount factor, as shown in Table 23.

Table 23 Long Term Cooling Exception Reporting Costs

Year	Activity	No. of Reports over Reporting Period	Per report		Cost		
			Hours	Weighted Hourly Rate	Undiscounted	7% NPV	3% NPV
2017-2041	Prepare and submit report detailing changes to or errors in the effects of debris on Long-Term Cooling analysis	24	973	\$106	(\$2,484,206)	(\$1,187,175)	(\$1,752,974)
	Periodic update of Long Term Cooling Debris analysis	60	2,433	\$106	(\$15,526,004)	(\$7,409,362)	(\$11,042,666)
Total:					(\$18,010,495)	(\$8,596,537)	(\$12,795,640)

5.3 Total Industry Costs

5.3.1 Cladding Embrittlement–Alternative 2

Table 24 shows the total industry costs broken down between implementation and operation costs for the cladding embrittlement requirements under Alternative 2, the case-by-case approach. These total industry costs range from (\$31.0 million) using a 7-percent discount rate to (\$38.5 million) using a 3-percent discount rate.

Table 24 Total Industry Costs (Cladding Embrittlement Alternative 2)

Attribute	Undiscounted	7% NPV	3% NPV
Total Industry Implementation Cost:	(\$33,030,000)	(\$25,920,000)	(\$29,690,000)
Total Industry Operation Cost:	(\$15,060,000)	(\$5,090,000)	(\$8,790,000)
Total Industry Cost:	(\$48,090,000)	(\$31,010,000)	(\$38,480,000)

Table 25 provides the estimates of the various average costs per designated unit, for direct and indirect industry costs, and total industry costs for the cladding embrittlement requirements. The estimated total industry implementation costs per unit range from (\$259,000) using a 7-percent discount factor to (\$297,000) using a 3-percent discount factor. Total industry operating costs per unit range from (\$51,000) using a 7-percent discount rate to (\$88,000) using a 3-percent discount rate. The average implementation and operation costs per unit range from (\$310,000) using a 7-percent discount rate to (\$384,000) using a 3-percent discount rate.

Table 25 Industry Average Costs per Unit (Cladding Embrittlement Alternative 2)

Attribute	Total Industry Cost		Average Unit Cost	
	7% NPV	3% NPV	7% NPV	3% NPV
Implementation Costs				
Direct Costs	(\$11,420,000)	(\$16,770,000)	(\$114,200)	(\$167,700)
Indirect Costs	(\$14,500,000)	(\$12,920,000)	(\$145,000)	(\$129,200)
<i>Subtotal</i>	<i>(\$25,920,000)</i>	<i>(\$29,690,000)</i>	<i>(\$259,200)</i>	<i>(\$296,900)</i>
Operating Costs	(\$5,090,000)	(\$8,790,000)	(\$50,900)	(\$87,900)
Total	(\$31,010,000)	(\$38,480,000)	(\$310,100)	(\$384,800)

Annual Costs for Operating Reactors

The following graphs show the Alternative 2 total annual industry costs for operating reactors, and the per unit annual industry costs for operating reactors, for the first 10 years after Industry costs would begin to occur. Figure 1 below shows significant Industry costs for the first 5 years of the rule's implementation, ranging from (\$1.3 million) to (\$12.3 million) per year. Figure 2 demonstrates that these costs result in per unit costs ranging from (\$39,000) to (\$144,000) per year. These per unit costs are higher than the approach of Alternative 3, full implementation of § 50.46c, primarily due to additional costs from regulatory uncertainty. These costs to Industry are delayed by two years as the NRC issues generic communication and orders, which reduces the NPV of these costs, as discussed above.

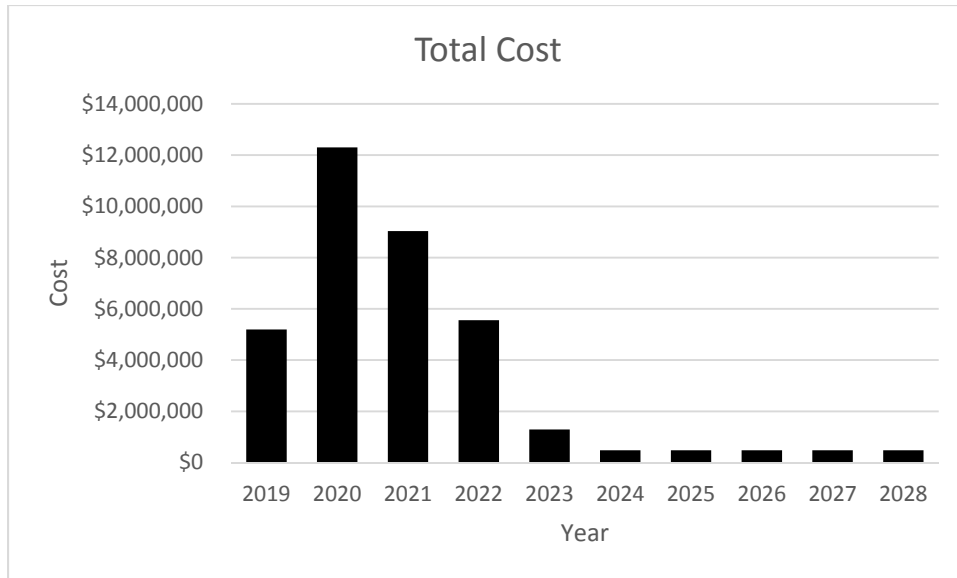


Figure 1 Total Annual Industry Cost for Operating Reactors (Alternative 2)

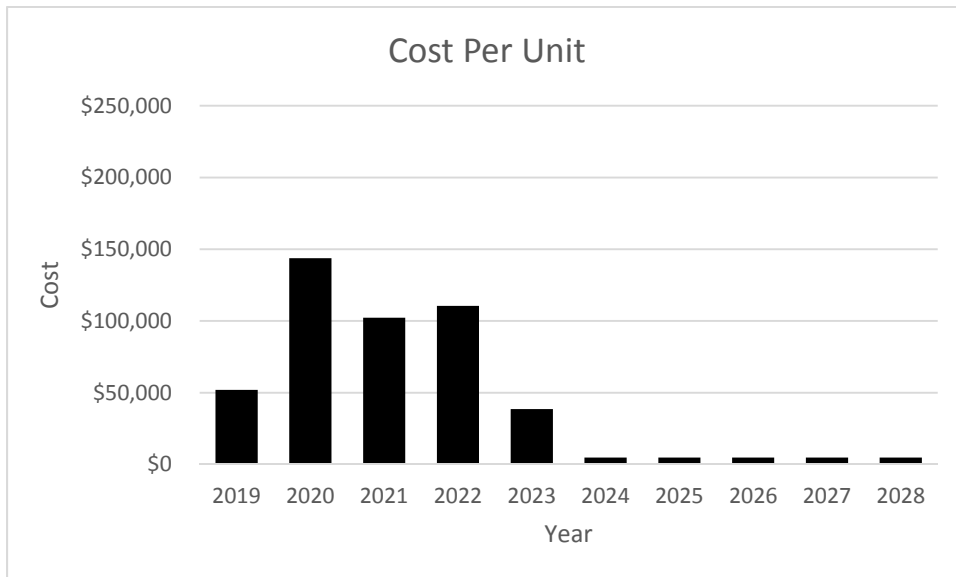


Figure 2 Annual Industry Cost per Unit for Operating Reactors (Alternative 2)

5.3.2 Cladding Embrittlement—Alternative 3

Table 26 shows the total industry costs broken down between implementation and operation costs for the cladding embrittlement requirements under Alternative 3. These total industry costs range from (\$31.6 million) using a 7-percent discount rate to (\$36.9 million) using a 3-percent discount rate.

Table 26 Total Industry Costs (Cladding Embrittlement Alternative 3)

Attribute	Undiscounted	7% NPV	3% NPV
Total Industry Implementation Cost:	(\$28,620,000)	(\$25,710,000)	(\$27,280,000)
Total Industry Operation Cost:	(\$15,930,000)	(\$5,890,000)	(\$9,630,000)
Total Industry Cost:	(\$44,550,000)	(\$31,600,000)	(\$36,910,000)

Table 27 provides the estimates of the various average costs per designated unit, for direct and indirect industry costs, and total industry costs for the cladding embrittlement requirements. The estimated total industry implementation costs per unit range from (\$257,000) using a 7-percent discount rate to (\$273,000) using a 3-percent discount rate. Total industry operating costs per unit range from (\$59,000) using a 7-percent discount rate to (\$96,000) using a 3-percent discount rate. Therefore the average implementation and operation costs per unit range from (\$316,000) using a 7-percent discount rate to (\$369,000) using a 3-percent discount rate.

Table 27 Industry Average Costs per Unit (Cladding Embrittlement Alternative 3)

Attribute	Total Industry Cost		Average Unit Cost	
	7% NPV	3% NPV	7% NPV	3% NPV
Implementation Costs				
Direct Costs	(\$11,720,000)	(\$13,830,000)	(\$117,200)	(\$138,300)
Indirect Costs	(\$13,990,000)	(\$13,450,000)	(\$139,900)	(\$134,500)
<i>Subtotal</i>	<i>(\$25,710,000)</i>	<i>(\$27,280,000)</i>	<i>(\$257,100)</i>	<i>(\$272,800)</i>
Operating Costs				
	(\$5,890,000)	(\$9,630,000)	(\$58,900)	(\$96,300)
Total	(\$31,600,000)	(\$36,910,000)	(\$316,000)	(\$369,100)

Annual Costs for Operating Reactors

Industry costs between Alternative 2 and Alternative 3 differ significantly as explained above. The following graphs show the Alternative 3 total annual industry costs for operating reactors, and the per unit annual industry costs for operating reactors for the first 10 years after expected rule implementation. Figure 3 below shows significant Industry costs for the first 5 years of the rule's implementation, ranging from (\$880,000) to (\$10.9 million) per year. Figure 4 demonstrates that Alternative 3 result in per unit costs ranging from (\$34,000) to (\$130,000) per year. Compared to Figure 2 in the previous section, these per unit costs in Alternative 3 are less than the case-by-case approach of Alternative 2.

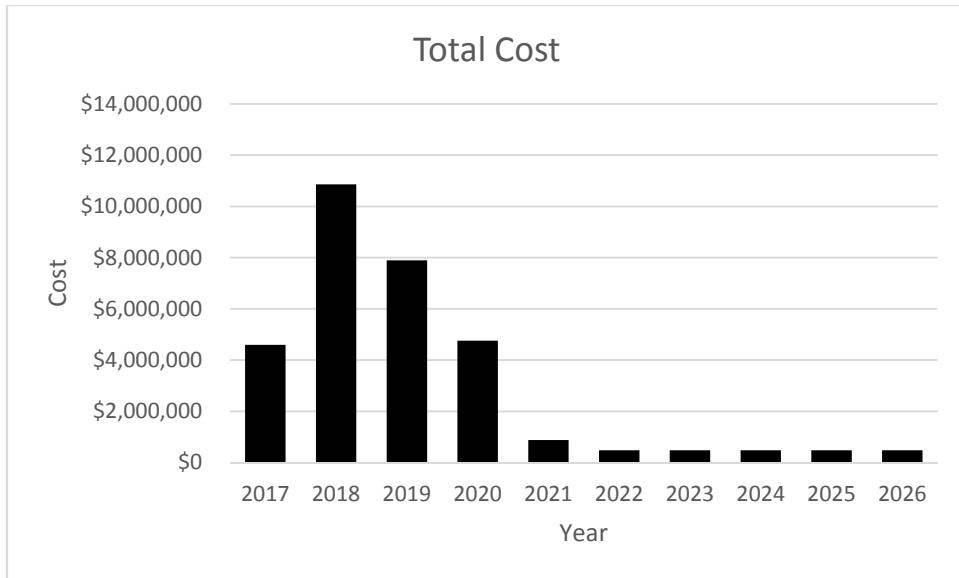


Figure 3 Total Annual Industry Cost for Operating Reactors (Alternative 3)

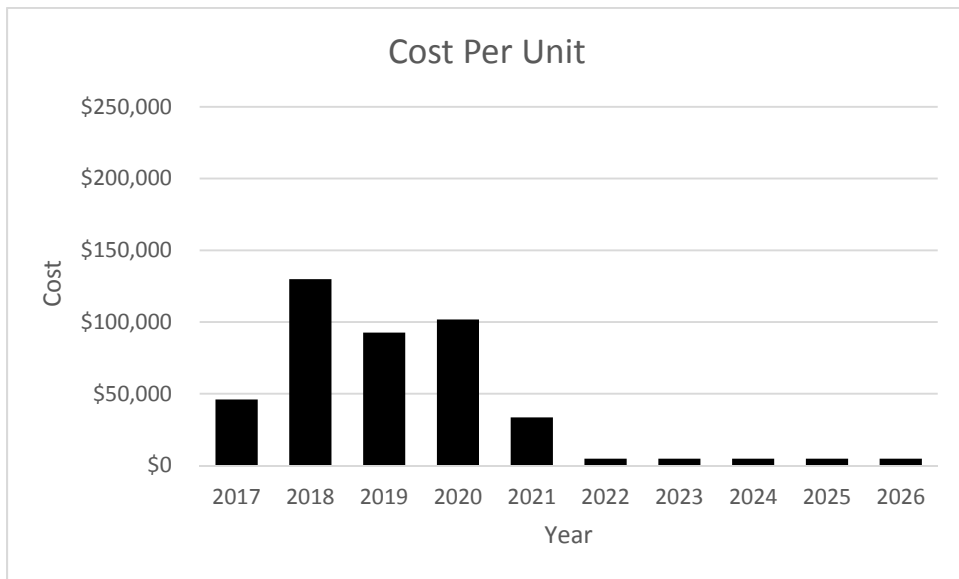


Figure 4 Annual Industry Cost per Unit for Operating Reactors (Alternative 3)

5.3.3 Risk-Informed

Table 28 shows the total industry costs broken down between implementation and operation costs for the risk-informed requirements, which result in overall averted costs. These total industry averted costs are estimated to range from \$328 million using a 7-percent discount to \$324 million using a 3-percent discount.

Table 28 Total Industry Costs (Risk-Informed)

Attribute	Undiscounted	7% NPV	3% NPV
Total Industry Implementation Cost:	\$337,040,000	\$336,660,000	\$336,690,000
Total Industry Operation Cost:	(\$18,010,000)	(\$8,600,000)	(\$12,800,000)
Total Industry Cost:	\$319,030,000	\$328,060,000	\$323,890,000

Table 29 provides the estimates of the average implementation and operation costs per designated unit, and total industry costs for the risk-informed alternative. The estimated total industry implementation costs per unit represent averted costs of approximately \$28.1 million per unit. Total industry operating costs per unit range from (\$159,259) using a 7-percent discount rate to (\$237,037) using a 3-percent discount rate. The average total in averted implementation and operation costs is approximately \$27.9 million per unit.

Table 29 Industry Average Costs per Designated Unit (Risk-Informed)

Attribute	Total Industry Cost		Average Unit Cost	
	7% NPV	3% NPV	7% NPV	3% NPV
Implementation Costs	\$336,660,000	\$336,690,000	\$28,060,000	\$28,060,000
Operation Costs	(\$8,600,000)	(\$12,800,000)	(\$159,259)	(\$237,037)
Total Costs	\$328,060,000	\$323,890,000	\$27,900,741	\$27,822,963

5.4 NRC Implementation

5.4.1 Cladding Embrittlement Alternative 2

5.4.1.1 Current Reactor Licensees

Under the case-by-case alternative, the NRC would incur many similar costs as described under Alternative 3. The timeline of NRC review of submissions from Industry is extended by 2 years, and the reviews of LARs are spread out across a longer timeline based on an expected submission timeline. However, additional costs are incurred as the NRC must issue generic communication and orders instructing industry to address the research findings described above, in their future submissions. NRC best practice following generic orders is to then conduct rule making, and since this rule making concerns adequate protection, this cost estimate assumes that rule making would follow these general orders. This would consist of proposed and final rulemaking, and draft and final regulatory guidance. Because the Technology Neutral changes contained in Alternative 3 are not included in the general orders issued under Alternative 2, the averted exemption request reviews are not applicable to Alternative 2 and industry would have to submit these expected exemption requests.

Table 30 shows the NRC implementation costs that affect operating reactors, design certifications, and future operating reactors. In total, these NRC implementation costs range from (\$2.91 million) using a 7-percent discount rate to (\$3.5 million) using a 3-percent discount rate. Table 31 provides the other estimated costs for the NRC to implement 10 CFR 50.46c for operating reactors. The NRC review of the initial breakaway oxidation testing for all the current cladding alloys is expected to occur in 2021, resulting in costs ranging from (\$86,909) using a 7-percent discount rate to (\$101,216) using a 3-percent discount rate.

Table 30 NRC Implementation Costs Affecting Operating Reactors, Design Certifications, and Future Operating Reactors (Cladding Embrittlement Alternative 2)

Year	Activity	Number of Reviews/Reports	Hours	Weighted Hourly rate	Cost		
					Undiscounted	7% NPV	3% NPV
2017	Issue Generic Communication	1	1040	\$128	(\$133,120)	(\$133,120)	(\$133,120)
2017	Issue Orders	1	1040	\$128	(\$133,120)	(\$133,120)	(\$133,120)
2018	Issue Orders	1	1040	\$128	(\$133,120)	(\$124,411)	(\$129,243)
2023	Proposed rulemaking to make orders generically applicable	1	4160	\$128	(\$532,480)	(\$354,814)	(\$445,944)
2024	Final rulemaking	1	3120	\$128	(\$399,360)	(\$248,701)	(\$324,716)
2023	Draft Regulatory Guides for new rulemaking	3	1040	\$128	(\$399,360)	(\$266,110)	(\$334,458)
2024	Final Regulatory Guides for new rulemaking	3	1040	\$128	(\$399,360)	(\$248,701)	(\$324,716)
2020	NRC Review of Cladding Hydrogen Uptake Models and Topical Reports	6	148	\$128	(\$113,920)	(\$92,993)	(\$104,253)
2020	NRC Review of Topical Reports on PQD, Breakaway	3	148	\$128	(\$56,960)	(\$46,496)	(\$52,126)
2020	NRC Review of BWR / PWR Topical Reports	7	148	\$128	(\$132,907)	(\$108,491)	(\$121,628)
2021			148	\$128	(\$132,907)	(\$101,394)	(\$118,086)
2021	NRC Review of Fuel Mech Design Topical Reports	6	148	\$128	(\$113,920)	(\$86,909)	(\$101,216)
2021	NRC Safety Evaluation Reports on Breakaway Oxidation	6	138	\$128	(\$105,984)	(\$80,855)	(\$94,165)
2022	NRC Review of LARs	37	148	\$128	(\$702,507)	(\$500,878)	(\$605,988)
2023	NRC Review of LARs	16	148	\$128	(\$303,787)	(\$202,426)	(\$254,417)
2024	NRC Review of LARs	16	148	\$128	(\$303,787)	(\$189,183)	(\$247,006)
Total:					(\$4,096,597)	(\$2,918,603)	(\$3,524,203)

Table 31 NRC Implementation Costs for Operating Reactors (Cladding Embrittlement Alternative 2)

Year	Activity	No. of Items	Hours	Hourly rate	Cost		
					Undiscounted	7% NPV	3% NPV
2021	NRC breakaway test review	6	148	\$128	(\$113,920)	(\$86,909)	(\$101,216)
2017-2021	NRC averted exemption request reviews	0	541	\$128	\$0	\$0	\$0
Total:					(\$113,920)	(\$86,909)	(\$101,216)

5.4.1.2 Future Reactors and Design Certifications

The NRC costs for review of the design certification and COLs are the same as in Alternative 3, shown in Table 35. The LAR reviews for future operating reactors are also the same as in Alternative 3, shown in Table 36.

5.4.1.3 Total NRC Cladding Embrittlement Costs

The total cladding embrittlement-based NRC implementation costs for operating reactors (under Alternative 2) are shown in Table 32, including those implementation costs that affect both design certifications and future operating reactors, represent costs estimated to range from (\$3.2 million) using a 7-percent discount rate to (\$3.8 million) using a 3-percent discount rate.

Table 32 Total NRC Implementation Costs (Cladding Embrittlement Alternative 2)

Attribute	NRC Costs		
	Total	7% NPV	3% NPV
Total NRC Implementation Cost	(\$4,270,000)	(\$3,170,000)	(\$3,830,000)

5.4.2 Cladding Embrittlement—Alternative 3

5.4.2.1 Current Reactor Licensees

The NRC will incur several implementation costs. Once the rule is implemented, the NRC will review and approve the approximately 22 vendor licensing topical reports that provide the revised ECCS analysis models. This represents all of the topical reports mentioned in the previous section: on breakaway oxidation, hydrogen modeling, fuel mechanical design, and BWR and PWR evaluation models. For each alloy, the NRC would produce a safety evaluation report on breakaway oxidation. The NRC would also have to review the license amendment requests for each of the plants, as mentioned previously.

Table 33 shows the NRC implementation costs that affect operating reactors, design certifications, and future operating reactors,³⁰ as described above. In total, these NRC implementation costs range from (\$1.6 million) using a 7-percent discount rate to (\$1.8 million) using a 3-percent discount rate.

Table 34 provides other estimated costs for the NRC to implement 10 CFR 50.46c for operating reactors. The NRC review of the initial breakaway oxidation testing for all the current cladding alloys is expected to occur in 2019. Finally, if this final rule were not in effect, the NRC would need to review the aforementioned exemption requests to enable industry to utilize fuels not specifically authorized under § 50.46, also represented as an averted cost in Table 34. The overall averted NRC costs for operating reactors ranges from \$1.3 million using a 7-percent discount rate to \$1.5 million using a 3-percent discount rate.

³⁰ When totaling costs, these costs are part of the operating reactor costs.

Table 33 NRC Implementation Costs Affecting Operating Reactors, Design Certifications, and Future Operating Reactors (Cladding Embrittlement Alternative 3)

Year	Activity	Number of Reviews/Reports	Hours	Weighted Hourly rate	Cost		
					Undiscounted	7% NPV	3% NPV
2018	NRC Review of Cladding Hydrogen Uptake Models and Topical Reports	6	148	\$128	(\$113,920)	(\$106,467)	(\$110,602)
2018	NRC Review of Topical Reports on PQD, Breakaway	3	148	\$128	(\$56,960)	(\$53,234)	(\$55,301)
2018	NRC Review of BWR / PWR Topical Reports	7	148	\$128	(\$132,907)	(\$124,212)	(\$129,036)
2019			148	\$128	(\$132,907)	(\$116,086)	(\$125,277)
2019	NRC Review of Fuel Mech Design Topical Reports	6	148	\$128	(\$113,920)	(\$99,502)	(\$107,381)
2019	NRC Safety Evaluation Reports on Breakaway Oxidation	6	138	\$128	(\$105,984)	(\$92,571)	(\$99,900)
2020	NRC Review of LARs	37	148	\$128	(\$702,507)	(\$573,455)	(\$642,893)
2021	NRC Review of LARs	16	148	\$128	(\$303,787)	(\$231,757)	(\$269,911)
2022	NRC Review of LARs	16	148	\$128	(\$303,787)	(\$216,596)	(\$262,049)
Total:					(\$1,966,677)	(\$1,613,879)	(\$1,802,349)

Table 34 NRC Implementation Costs for Operating Reactors (Cladding Embrittlement Alternative 3)

Year	Activity	No. of Items	Hours	Hourly rate	Cost		
					Undiscounted	7% NPV	3% NPV
2019	NRC breakaway test review	6	148	\$128	(\$113,920)	(\$99,502)	(\$107,381)
2017-2021	NRC averted exemption request reviews	25	541	\$128	\$1,729,600	\$1,418,340	\$1,584,212
Total:					\$1,615,680	\$1,318,838	\$1,476,832

Technology Neutral

As shown above, the final rule would eliminate the need for the NRC to review licensee exemption requests and Topical Reports to use materials other than uranium-oxide fuel pellets within cylindrical zircaloy or ZIRLO™ cladding; this represents a cost savings (averted cost) of \$1.3 million using a 7-percent discount rate and \$1.5 million using a 3-percent discount rate. As discussed previously, the technology neutral changes must be considered along with the cladding embrittlement protocol, for the model changes and tests detailed in this regulatory analysis are required to ensure adequate protection when reactors are operated using these cladding alloys. Without the cladding embrittlement protocol, further regulatory actions would be required, on a case-by-case basis, by NRC staff before approving license renewals. This would lead to regulatory uncertainty, as detailed in this regulatory analysis under Alternative 2, which is averted by the cladding embrittlement protocol in this final rule.

5.4.2.2 Future Reactors and Design Certifications

The NRC assumes that, in 2032, it will conduct a review of the certification amendment analysis for the one aforementioned design certification, and for each of the four COL applicants, the NRC will conduct a review of the application and the topical report in 2023. These activities result in total estimated costs of (\$108,095) using a 7-percent discount rate to (\$139,395) using a 3-percent discount rate. These costs are shown in Table 35.

Table 35 NRC Implementation Costs for Design Certifications and Combined Licensees (Cladding Embrittlement Alternative 3)

Year	Activity	No. of reviews	Per review		Cost		
			Hours	Hourly rate	Undiscounted	7% NPV	3% NPV
2032	NRC design certification submittal review	1	148	\$128	(\$18,987)	(\$6,882)	(\$12,187)
2023	NRC COL submittal review	4	297	\$128	(\$151,893)	(\$101,213)	(\$127,208)
Total:					(\$170,880)	(\$108,095)	(\$139,395)

Table 36 shows the NRC implementation costs for future operating reactors. These costs consist of LAR reviews, and the total NRC implementation costs for future operating reactors range from (\$53,263) using a 7-percent discount rate to (\$65,035) using a 3-percent discount rate.

Table 36 NRC Implementation Costs for Future Operating Reactors (Cladding Embrittlement Alternative 3)

Year	Activity	No. of LARs	Total review hours	Hourly rate	Cost		
					Undiscounted	7% NPV	3% NPV
2022	NRC LAR reviews	3	445	\$128	(\$56,960)	(\$40,612)	(\$49,134)
2023		1	148	\$128	(\$18,987)	(\$12,652)	(\$15,901)
Total:					(\$75,947)	(\$53,263)	(\$65,035)

5.4.2.3 Total NRC Cladding Embrittlement Costs

The total cladding embrittlement-based NRC implementation costs for operating reactors (under Alternative 3) are shown in Table 37, including those implementation costs that affect both design certifications and future operating reactors, represent costs estimated to range from (\$460,000) using a 7-percent discount rate to (\$530,000) using a 3-percent discount rate. These implementation costs are low because of the significant averted cost savings resulting from eliminating the need for exemption request reviews.

Table 37 Total NRC Implementation Costs (Cladding Embrittlement Alternative 3)

Attribute	NRC Costs		
	Total	7% NPV	3% NPV
Total NRC Implementation Cost:	(\$600,000)	(\$460,000)	(\$530,000)

5.4.3 Risk-Informed

5.4.3.1 Current Reactor Licensees

The NRC would incur several implementation costs. The NRC would review licensee submittals of their thermal-hydraulic (TH) analyses that calculate peak cladding temperature (800°F) acceptance criteria or that show adequate flow reaches the core. The PWR Owners Group has submitted a topical report to the NRC for review to increase the debris amounts that can be present and still allow adequate coolant to reach the core.

The NRC implementation costs related to the risk-informed alternative are related to reviewing the risk-informed alternative submittals and the negative costs (savings) from not needing to review exemption requests, reflected in Table 38. The estimated NRC effort includes the review of several models and analyses. These include the Containment CAD Models, the Debris Effects Models, the Break and Break Frequency Models, and Thermal Hydraulic Analyses. The estimated NRC review costs range from (\$1.65 million) using a 7-percent discount rate to (\$1.71 million) using a 3-percent discount rate.

Table 38 NRC Implementation Costs for Operating Reactors (Risk-Informed)

Year	Activity	No. of items	Hours per Item	Weighted Hourly rate	Cost		
					Undiscounted	7% NPV	3% NPV
2018	Review Containment CAD Models	12	230	\$128	(\$353,280)	(\$330,168)	(\$342,990)
2018	Review Debris Effects Models	12			(\$706,560)	(\$660,336)	(\$685,981)
2018	Sump Clogging Models	12			(\$353,280)	(\$330,168)	(\$342,990)
2018	Strainer Tests	12	230	\$128	(\$353,280)	(\$330,168)	(\$342,990)
2018	In-Vessel Effects Models	12			(\$353,280)	(\$330,168)	(\$342,990)
2018	Bypass Test	12	230	\$128	(\$353,280)	(\$330,168)	(\$342,990)
2018	Review Break Frequency Allocation Model	12	230	\$128	(\$353,280)	(\$330,168)	(\$342,990)
2018	Review Thermal Hydraulic Analysis	12	230	\$128	(\$353,280)	(\$330,168)	(\$342,990)
<i>Subtotal:</i>					(\$1,766,400)	(\$1,650,841)	(\$1,714,951)
NRC Implementation Costs: 50.46(b)(5)Exemption Request Savings: Operating Reactors							
2017-2021	Exemption Request (ER) Review	12	541	\$128	\$830,208	\$703,022	\$771,491
<i>Subtotal:</i>					\$830,208	\$703,022	\$771,491
NRC Risk-Informed Implementation Costs for Operating Reactors					(\$936,192)	(\$947,819)	(\$943,460)

The NRC implementation costs related to the risk-informed alternative are incurred by reviewing the risk-informed alternative submittals and models, and there are averted costs (i.e., savings) from not needing to review exemption requests. If this final rule were not in effect, the NRC would have to review the aforementioned exemption requests for long-term cooling based on 10 CFR 50.46(b)(5). Thus, the rule results in averted costs for these exemption requests ranging from \$703,022 (7-percent discount rate) to \$771,491 (3-percent discount rate).

The total risk-informed NRC implementation costs for operating reactors, as shown in Table 38, including those implementation costs that affect both design certifications and future operating reactors, are estimated to range from (\$0.95 million) using a 7-percent discount rate to (\$0.94 million) using a 3-percent discount rate.

5.4.3.2 Future Reactors and Design Certifications

The NRC staff expects that future reactor designs will be cleaner, will not have fibrous insulation in the quantities and percentages as in older reactor designs, and will use the risk-informed alternative methods. As a result, the NRC staff does not expect any incremental costs.

5.5 NRC Operation

5.5.1 Cladding Embrittlement

Although industry will incur operating costs for conducting the periodic breakaway oxidation testing, the NRC will not conduct regularly scheduled reviews of these test results. Instead, the results will be reviewed as part of the existing audit process. Therefore, the NRC will not incur operation costs from periodic breakaway testing and no NRC operation costs are expected from this final rule, with either Alternative 2 or Alternative 3.

5.5.2 Risk-Informed

With respect to the risk-informed alternative, the NRC will review updates to the analysis and errors and changes to the analysis. The NRC expects that it will incur a cost to review the reports that the licensees will submit for staff review. The licensees are expected to submit, on average, one report per year, over the estimated 24 years of the average remaining reactor license term. In addition, industry will update their long-term cooling analyses every 4 years, which is retained on site and available for NRC staff review. Review of these reports represents estimated costs ranging from (\$1.8 million) using a 7-percent discount rate to (\$2.6 million) using a 3-percent discount rate, as shown in Table 39.

Table 39 NRC Operation: Review of Long-Term Cooling Analysis Changes

Year	Activity	No. of report over reporting period	Per report		Cost		
			Hours	Weighted Hourly rate	Undiscounted	7% NPV	3% NPV
2017-2041	NRC review of the Effects of Debris on Long Term Cooling submittals	24	195	\$128	(\$599,040)	(\$286,275)	(\$422,711)
2017-2041	NRC review of the Periodic Updates on Long Term Cooling analysis	60	407	\$128	(\$3,125,760)	(\$1,491,656)	(\$2,223,115)
Total:					(\$3,724,800)	(\$1,777,931)	(\$2,645,826)

5.6 Total NRC Costs

5.6.1 Cladding Embrittlement–Alternative 2

There are no NRC operation costs for the Cladding Embrittlement portion of Alternative 2, the total NRC costs are shown in Table 32, above. These total NRC costs are estimated to range from (\$3.0 million) using a 7-percent discount factor to (\$3.7 million) using a 3-percent discount factor.

5.6.2 Cladding Embrittlement—Alternative 3

There are no NRC operation costs for the Cladding Embrittlement portion for Alternative 3. The total NRC costs are shown in Table 37. These total NRC costs are estimated to range from (\$290,000) using a 7-percent discount factor to (\$350,000) using a 3-percent discount factor.

5.6.3 Risk-Informed

Table 40 shows the total industry costs broken down between implementation and operation costs for the risk-informed alternative. These total NRC costs are estimated to range from (\$2.7 million) using a 7-percent discount rate to (\$3.6 million) using a 3-percent discount rate.

Table 40 Total NRC Costs (Risk-Informed)

Attribute	NRC Costs		
	Total	7% NPV	3% NPV
Total NRC Implementation Cost:	(\$936,192)	(\$947,819)	(\$943,460)
Total NRC Operation Cost:	(\$3,724,800)	(\$1,777,931)	(\$2,645,826)
Total NRC Cost:	(\$4,660,992)	(\$2,725,750)	(\$3,589,286)

5.7 Improvements in Knowledge

The revised rule alternative incorporates research findings that identified new cladding embrittlement mechanisms. As a result, future LOCA analyses will improve the predictions of cladding embrittlement.

An entity using the risk-informed approach identifies which LOCA locations are important to risk and which locations do not contribute to failure of the strainers or core. This information could be fed back into the ISI program. This information could be useful in determining where problematic insulation should be replaced if necessary to meet the acceptance criteria.

5.8 Regulatory Efficiency

Expanding the applicability of this rule to different fuel designs and other cladding materials contributes to regulatory efficiency by eliminating the need for licensees to submit exemption requests for different fuel designs or cladding material. As a result, the revised rule Alternative 3 will improve regulatory efficiency.

In contrast, under Alternative 2 the Industry would not benefit from rule language or regulatory guides but would still be required to address the research findings discussed in detail above. This would result in significant regulatory uncertainty, and is a contributing factor that the NRC staff considered in recommending Alternative 3.

The alternative risk-informed approach allows compliance with the rule and associated GDC without the need for an exemption under 10 CFR 50.12.

5.9 Public Health (Accident)

As noted above, the NRC is initiating these new requirements so that the risk of accidental radiation exposure to the public will remain at the previously assumed level. Therefore, there

will be an insignificant difference in public health (accident) costs or benefits between the regulatory baseline and the revised rule alternative.

5.10 Occupational Health (Accident)

Similarly, the NRC assumes that the risk of an accidental radiation exposure will remain at the level it was assumed to have been before the revised rule. Therefore, there will be an insignificant difference in occupational health (accident) costs or benefits between the regulatory baseline and the revised rule alternative.

5.11 Onsite Property

5.11.1 Cladding Embrittlement

Likewise, the NRC staff assumes that the risk of damage to onsite property would remain at the level it was assumed to have been before the revised rule. Therefore, there will be an insignificant difference in offsite property costs or benefits between the regulatory baseline and the revised rule alternative.

5.11.2 Risk-Informed

The NRC expects that, if required, insulation removal and replacement will be performed by the licensee during an outage. If insulation removal and replacement will take longer than the scheduled outage, the NRC expects that the licensee will replace the remainder of the insulation at the next scheduled outage.

The risk-informed approach allows a small increase in risk over a “clean” (i.e., debris-free) plant. The acceptance criteria for risk (e.g., core damage frequency and large early release frequency) are small and consistent with the Commission’s Safety Goal Policy. Therefore, there will be an insignificant difference in offsite property costs or benefits between the regulatory baseline and the revised rule alternative.

5.12 Offsite Property

The NRC staff assumes that the risk of damage to offsite property would remain at the level it was assumed to have been before the revised rule for both the cladding embrittlement and risk-informed requirements.

5.13 Other Considerations

Another benefit is that 10 CFR 50.46c incorporates new performance-based requirements associated with higher burnup fuel and cladding corrosion. Hence, 10 CFR 50.46c supports the current, high-efficiency fuel-loading patterns and fuel utilization. The existing requirements in 10 CFR 50.46 (circa 1973) were based on separate effects testing on unirradiated zircaloy tubing. The recent LOCA research program identified both fuel burnup and cladding corrosion effects not included in the current regulation. Should 10 CFR 50.46c not be issued, one option would be to define a safe harbor (e.g., operational constraints) where no further action would be required by the licensees. For this approach, the staff would identify fuel rod burnup and cladding corrosion limits where new degradation mechanisms become more limiting than existing 10 CFR 50.46 prescriptive analytical requirements. Hence, if an entity remains within

the safe harbor, then the existing 10 CFR 50.46 analytical requirements continue to remain conservative and appropriate.

The introduction of safe harbor operational constraints could affect fuel and operating costs as follows:

- increased overall fuel cost because of loss of fuel management flexibility
- increased fuel manufacturing cost because of increased number of feed assemblies
- increased fuel storage and disposal cost because of increased number of discharged fuel assemblies
- increased operation and maintenance cost because of shorted reload cycles (i.e., more or longer outages)
- decreased electric production factors because of shorted reload cycles

Based on these considerations, the staff does not view this option as an economically viable alternative to rulemaking.

5.14 Uncertainty Analysis

A Monte Carlo sensitivity analysis was completed for this analysis using @Risk, software specially designed for completing this type of analysis. The Monte Carlo approach provides an answer to the question: What distribution of net benefits results from multiple draws of the probability distribution assigned to key variables?

5.14.1 Uncertainty Analysis Assumptions

As this regulatory analysis is based on estimates of values that are sensitive to plant-specific cost drivers and plant dissimilarities, the NRC staff provides the following analysis of the variables in which there is the greatest amount of uncertainty. To perform this analysis, the NRC staff elected to use a Monte Carlo simulation analysis using the @Risk software.

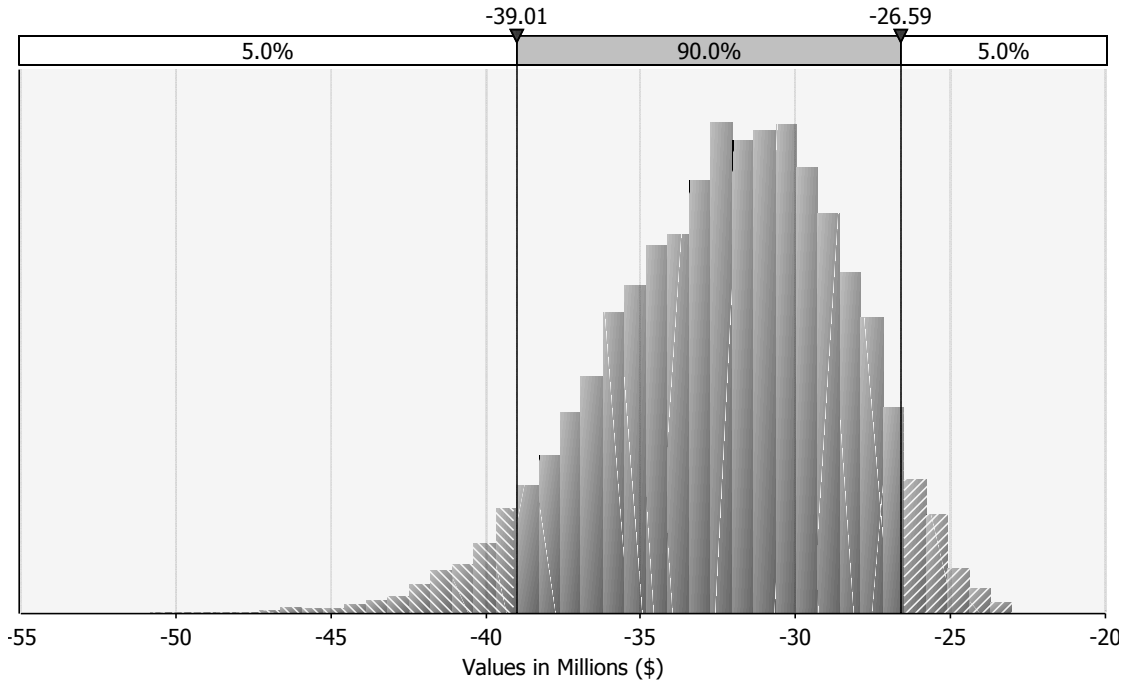
The Monte Carlo approach allows a range of possible inputs to be assigned to a distribution that is sampled in the simulation. The simulation repeatedly generates inputs to its mathematical algorithm that are selected randomly from a distribution of the possible inputs. After 10,000 simulations, the analysis provides a distribution of the results resulting from variations in the values modeled.

The Monte Carlo analysis evaluates the effect on the results because of uncertainty in the analyzed. Table 56, in Appendix A, summarizes the variable distributions considered in this analysis.

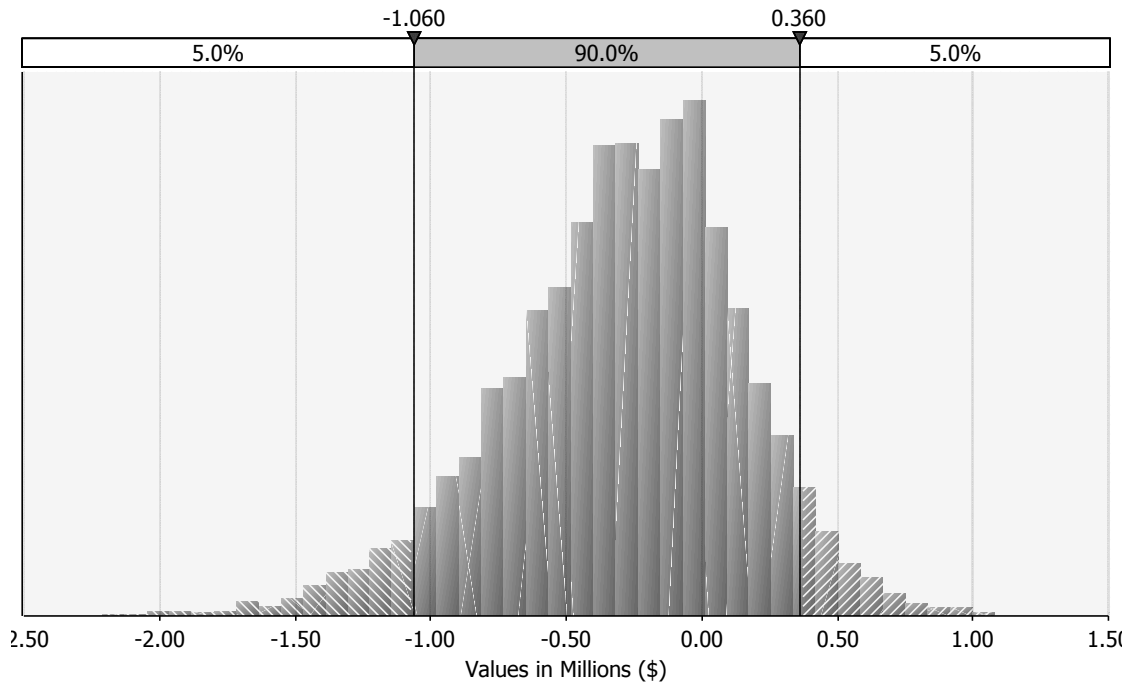
5.14.2 Uncertainty Analysis Results

5.14.2.1 Cladding Embrittlement

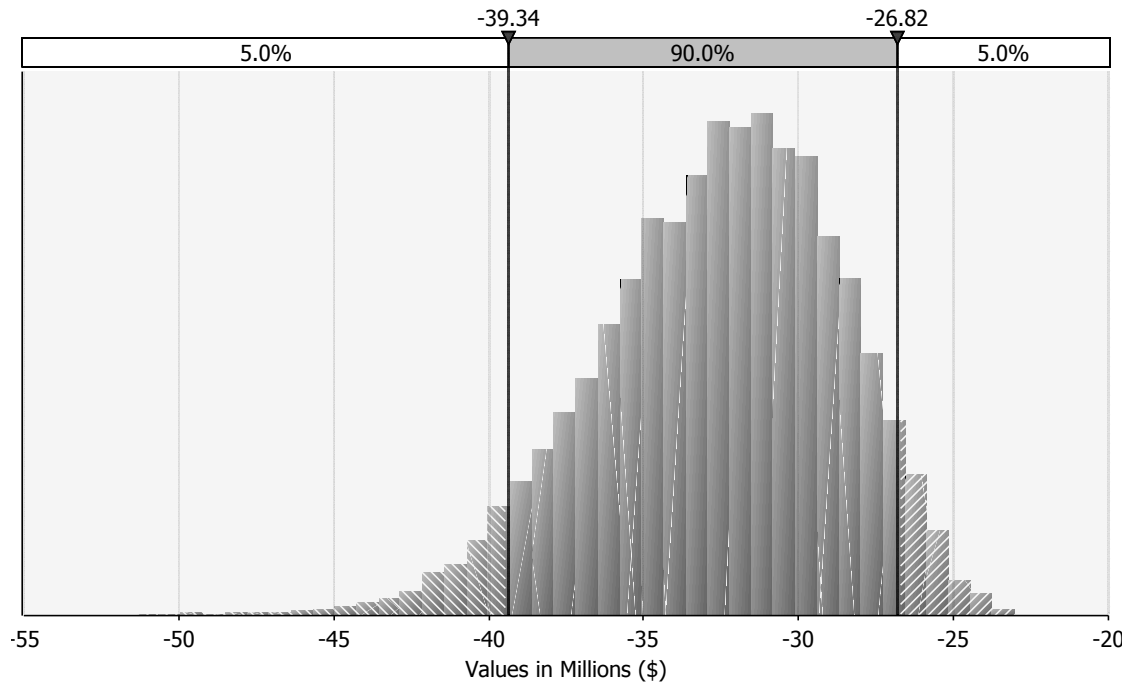
Ten thousand simulations were run. Figure 5 through Figure 7 display the histograms of the realized benefits and costs. The analysis showed that both industry and the NRC will incur additional costs if this rule is issued.



**Figure 5 Cladding embrittlement: Total industry costs (7% NPV)
Alternative 3**



**Figure 6 Cladding embrittlement: Total NRC costs (7% NPV)
Alternative 3**



**Figure 7 Cladding embrittlement: Net benefit (7% NPV)
Alternative 3**

Figure 8 shows a Tornado Diagram, which identifies the factors whose uncertainty drives the largest impact on total costs for the cladding embrittlement portion of this rulemaking. The uncertainty regarding the number of hours to conduct periodic confirmation of breakaway oxidation testing drives the largest amount of uncertainty in the costs of the cladding embrittlement portion of this rulemaking. The rest of the variables in Figure 8 show diminishing variation among other variables.

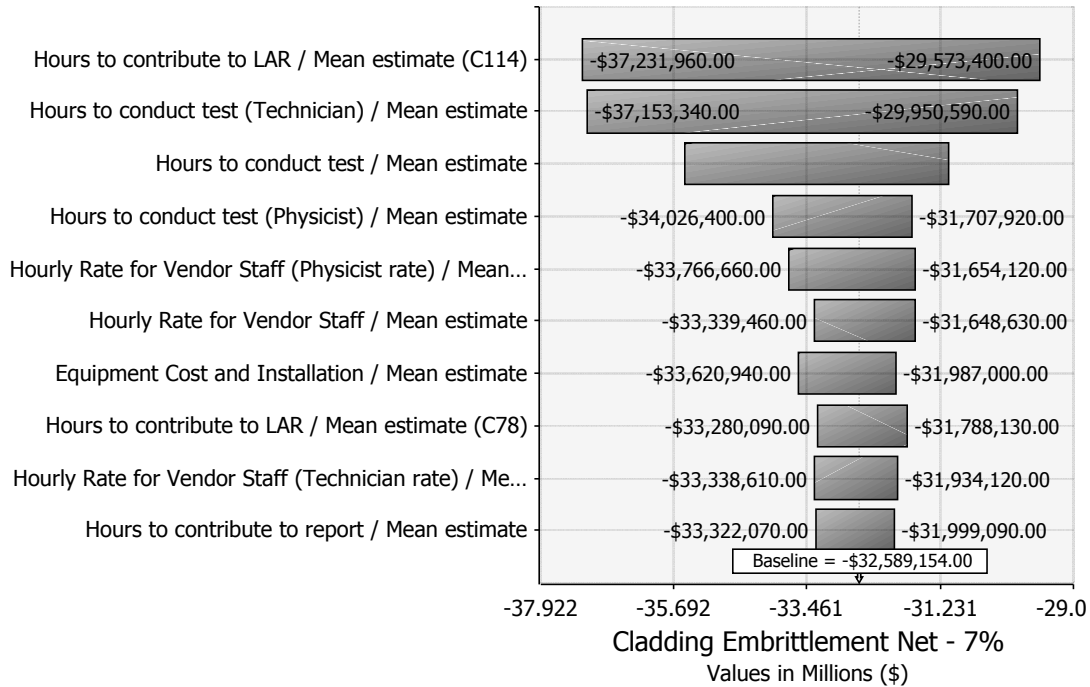


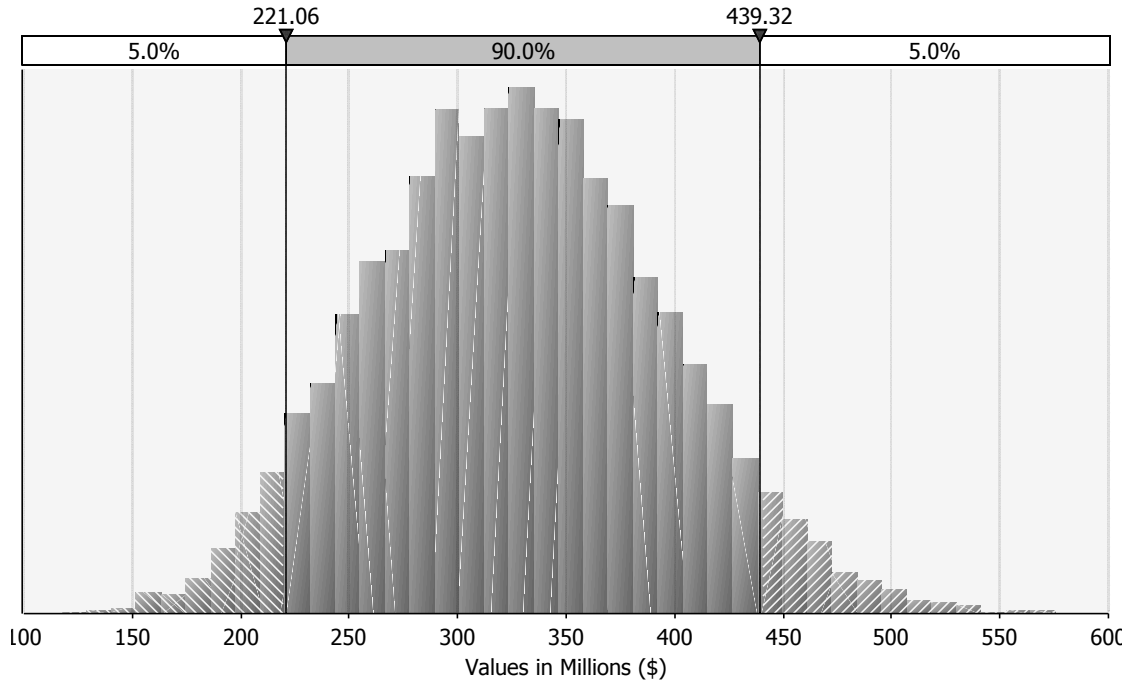
Figure 8 Top ten variables where uncertainty drives the largest impact on cladding embrittlement costs (7% NPV) Alternative 3

* Inputs are ranked by effect on the output mean

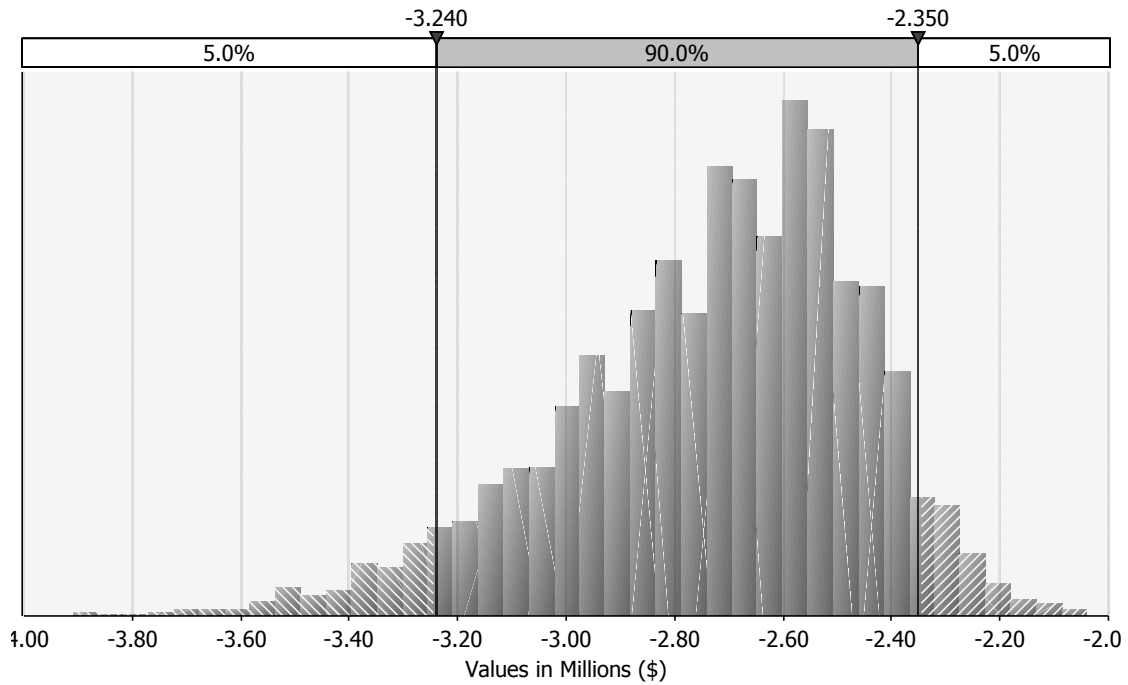
5.14.2.2 Risk-Informed

Ten thousand simulations were run. Figure 9 through Figure 11 display the histograms of the realized benefits and costs. The analysis showed that the industry has large avoided costs compared to the costs for performing the alternative analysis. The NRC will incur additional costs. Overall, the averted costs provided through this approach provide an attractive alternative approach for addressing and resolving the GSI-191 issue.

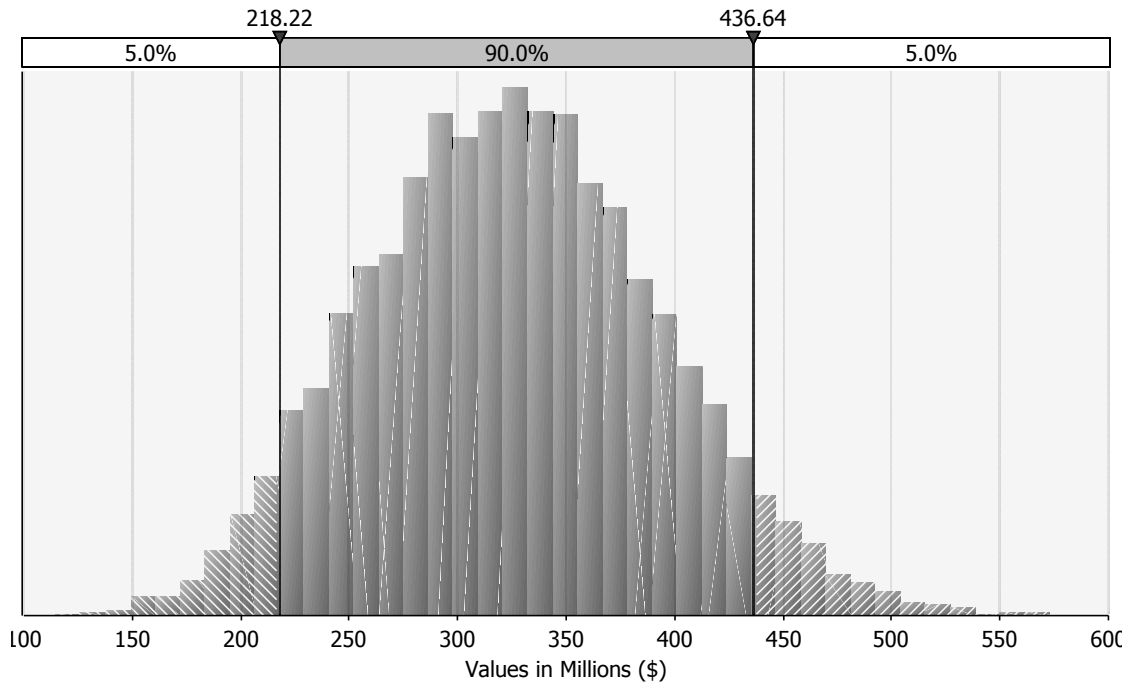
Figure 12 shows a tornado diagram, which identifies the factors whose uncertainty drives the largest impact on total costs for the risk-informed portion of this rulemaking. The uncertainty regarding the amount of installation to remove, and install, drives the largest amount of uncertainty in the costs of the cladding embrittlement portion of this rulemaking. The rest of the variables in Figure 12 show diminishing variation among other variables.



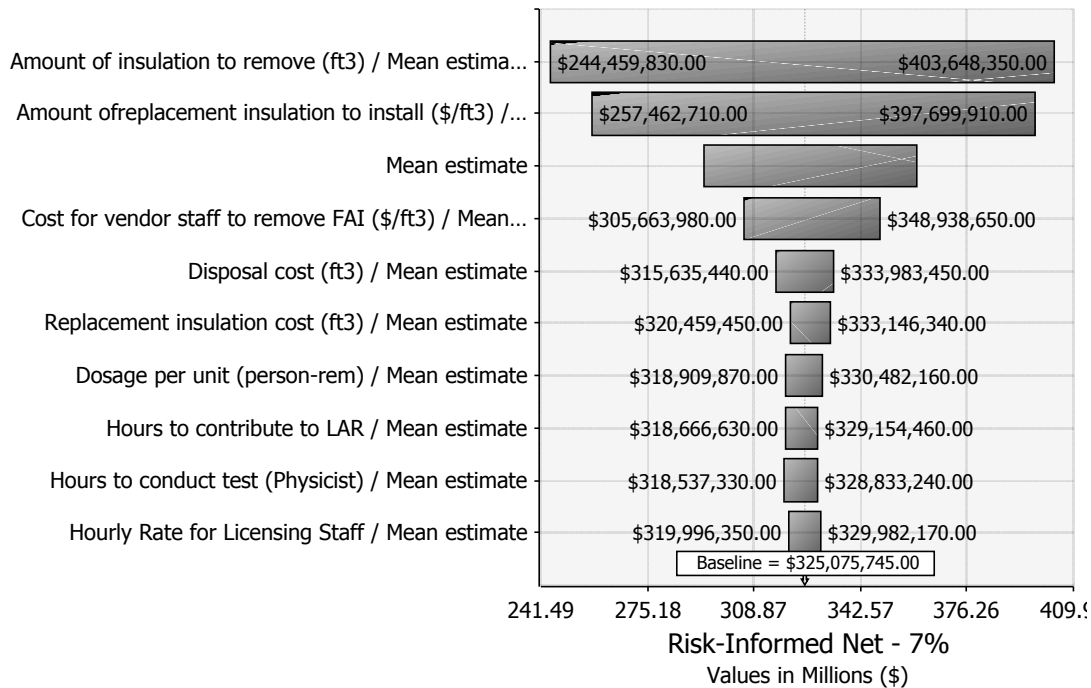
**Figure 9 Risk-Informed: Total industry costs (7% NPV)
Alternative 3**



**Figure 10 Risk-Informed: Total NRC costs (7% NPV)
Alternative 3**



**Figure 11 Risk-Informed: Net benefit (7% NPV)
Alternative 3**



**Figure 12 Top ten variables where uncertainty drives
the largest impact on risk-informed costs (7% NPV)
Alternative 3**

* Inputs are ranked by effect on the output mean

5.14.3 Summary of Uncertainty Analysis

A simulation analysis found that amending the rule would result in positive averted costs (e.g., savings) for all 10,000 simulations for the risk-informed approach. Given the uncertainties involved in obtaining these estimates, a reasonable inference from the analysis is that proceeding with the final rule with the risk-informed alternative provisions represents an efficient use of resources. The cladding embrittlement analysis shows that there is incremental cost to both industry and the NRC if this rule is approved. The uncertainty analysis of the cladding embrittlement portions of the rule shows a standard deviation of \$3.83 million, and the uncertainty analysis of the risk-informed alternative shows a standard deviation of \$66.5 million. The net results of the uncertainty analysis on this final rule shows an overall standard deviation of \$66.4 million. A full uncertainty analysis was also run on Alternative 2, the Case-by-Case Alternative, and the standard deviations were the same as Alternative 3, except for a small difference in the cladding embrittlement analysis where the standard deviation of Alternative 3 is \$3.60 million. The uncertainty analysis for Alternative 2 is included in Appendix A, Figure 13 through Figure 16.

5.15 Disaggregation

To comply with the guidance provided in Section 4.3.2 (“Criteria for the Treatment of Individual Requirements”) of the Guidelines, the NRC conducted a screening review to determine if any of the individual requirements (or set of integrated requirements) of the proposed rule were unnecessary to achieve the objectives of the rulemaking. The NRC disaggregated the rule provisions into five groups: (1) incorporate recent research findings, (2) establish performance-based requirements for ECCS in the event of a LOCA, (3) expand the regulation’s applicability, (4) incorporate the requests of two PRM, and (5) include a provision to allow risk-informed submittals to evaluate the effects of debris on long-term cooling. Furthermore, the NRC concluded that each of the final rule’s requirements is necessary to achieve one or more objectives of the rulemaking. The results of this determination are set forth in Table 41.

Table 41 Disaggregation

10 CFR 50.46c Sections	Regulatory Goals for 10 CFR 50.46c				
	Revise the ECCS Acceptance Criteria to Reflect Recent Research Findings	Establish Performance-Based Requirements	Expand the Applicability of 10 CFR 50.46 to All Fuel Types and Cladding Materials	Incorporate Requests of Two PRM	Allow Risk-Informed Approach for Addressing the Effects of Debris on Long-Term Cooling
Paragraph (a) Applicability.			X	X	
Paragraph (b) Definitions.	X				
Paragraph (d) Emergency core cooling system design.		X	X		
Paragraph (g) Fuel system designs: uranium oxide or mixed uranium-plutonium oxide pellets within cylindrical zirconium-alloy	X	X		X	

10 CFR 50.46c Sections	Regulatory Goals for 10 CFR 50.46c				
	Revise the ECCS Acceptance Criteria to Reflect Recent Research Findings	Establish Performance-Based Requirements	Expand the Applicability of 10 CFR 50.46 to All Fuel Types and Cladding Materials	Incorporate Requests of Two PRM	Allow Risk-Informed Approach for Addressing the Effects of Debris on Long-Term Cooling
cladding.					
Paragraph (k) Use of NRC-approved fuel in reactor.			X	X	
Paragraph (m) Reporting.	X				X
Paragraph (d)(2)(iii) Core Geometry and Coolant Flow.					X
Paragraph (e) Alternate Risk-Informed Approach for Addressing the Effects of Debris on Long-Term Core Cooling.					X

5.16 Future Design Certifications

As there are potential design certifications that may come into the NRC for review, but are too uncertain regarding likelihood and timing to be properly added into the regulatory analysis, the NRC assumes a hypothetical design certification beginning in a hypothetical year (year X), based on 2017 dollars, to determine the cost to the industry and the NRC for the future design certifications.

As shown in Table 42, the Industry would incur costs in relation to implementation costs. These costs derive from the equivalent of a Level 1 LAR submission from both the vendor and industry. The total estimated industry cost for a hypothetical design certification is (\$75,734).

Table 42 Industry Costs for Future Design Certification

Year	Activity	Number of Design Certifications	Per Design Certification		Undiscounted
			Hours	Weighted Hourly rate	
X	Initial Submittal	1	593	\$128	(\$75,734)
Total:					(\$75,734)

As shown in Table 43, the NRC would incur costs in relation to the review of the LAR, which would occur in year X+1. The total estimated NRC cost for a hypothetical design certification is (\$18,987).

Table 43 NRC Costs for Future Design Certification

Year	Activity	Number of Design Certifications	Per Design Certification		Undiscounted
			Hours	Weighted Hourly rate	
X+1	Review Initial Submittal	1	148	\$128	(\$18,987)
Total:					(\$18,987)

5.17 Hypothetical Future Operating Reactors

As there are future operating reactors that are also too uncertain regarding likelihood and timing to be properly added into the regulatory analysis, the NRC assumes a hypothetical future operating reactor (a single reactor at a new site) beginning operation in a hypothetical year (year X), based on 2017 dollars, to determine the cost to the industry and the NRC for the future operating reactor.

As shown in Table 44 the Industry would incur both implementation and operating costs in relation to a hypothetical reactor. The implementation cost would be for Track 1, which would have a total estimated cost of (\$75,734). The industry operating costs for the periodic breakaway test for the hypothetical operating reactor would occur during the first reload and each subsequent reload, and would require approximately 22 hours per year for the expected life of the reactor. The total undiscounted industry estimated cost for the periodic breakaway test is (\$119,828). The total cost for the industry hypothetical future operating reactor is estimated at (\$195,231).

Table 44 Industry Costs for Hypothetical Operating Reactor

Year	Activity (Includes PQD, Breakaway, LTC)	Number of AOR	Per AOR		Cost		
			Hours	Weighted Hourly rate	Undiscounted	7% NPV	3% NPV
X	Track #1	1	593	\$128	(\$75,734)	(\$75,734)	(\$75,734)
Total:					(\$75,734)	(\$75,734)	(\$75,734)

Year	Activity	Per Unit				Number of Years	Cost		
		Average Number of Ingots/Year	Per Ingot		Total Cost		Undiscounted Total	7% NPV	3% NPV
			Hours	Weighted Hourly rate					
X + 1	Periodic Breakaway Tests	2	11	\$142	(\$2,987)	40.00	(\$119,498)	(\$39,828)	(\$69,054)
Total:							(\$119,498)	(\$39,828)	(\$69,054)

As shown in Table 45, the NRC incurs implementation costs because of this rulemaking for a hypothetical future operating reactor. The implementation costs are because of an LAR review. The LAR Review would occur in year X+1, take 148 hours at the NRC hourly rate, for a total NRC hypothetical future operating reactor cost estimated at (\$18,987).

Table 45 NRC Costs for Hypothetical Future Operating Reactor

Year	Activity	Hours	Weighted Hourly rate	Undiscounted
X + 1	LAR Review	148	\$128	(\$18,987)
Total:				(\$18,987)

6 Presentation of Results

This section discusses the incremental benefit and cost estimated for the final rule.

6.1 Summary of Benefits and Costs

Table 46 summarizes the incremental benefits and costs of the final rule as compared to the baseline for Alternative 2, and Table 47 provides the same summary for Alternative 3. The separate total cladding embrittlement (Alternative 2 and 3) and risk-informed costs, along with average implementation costs per unit, are also summarized in Table 48, Table 49, and Table 50, respectively. Appendix A contains the remaining tables not inserted into the body of the regulatory analysis, in cases where the detailed modeling of the costs are expansive enough that placing the tables into the body of the analysis would be too disruptive. These costs are the Industry Implementation and Industry Operation cost tables, and the Uncertainty Analysis Variables.

Table 46 Summary of Net Benefits and Costs (Alternative 2)

Attribute	Total Averted Costs (Costs)		
	Undiscounted	7% NPV	3% NPV
Cladding Embrittlement			
Industry Implementation	(\$33,030,000)	(\$25,920,000)	(\$29,690,000)
Industry Operation	(\$15,060,000)	(\$5,090,000)	(\$8,790,000)
<i>Total Industry Cost</i>	<i>(\$48,090,000)</i>	<i>(\$31,010,000)</i>	<i>(\$38,480,000)</i>
NRC Implementation	(\$4,460,000)	(\$3,170,000)	(\$3,830,000)
NRC Operation	\$0	\$0	\$0
<i>Total NRC Cost</i>	<i>(\$4,460,000)</i>	<i>(\$3,170,000)</i>	<i>(\$3,830,000)</i>
Cladding Embrittlement Net	(\$52,550,000)	(\$34,180,000)	(\$42,310,000)
Risk-Informed			
Industry Implementation	\$0	\$0	\$0
Industry Operation	\$0	\$0	\$0
<i>Total Industry Cost</i>	<i>\$0</i>	<i>\$0</i>	<i>\$0</i>
NRC Implementation	\$0	\$0	\$0
NRC Operation	\$0	\$0	\$0
<i>Total NRC Cost</i>	<i>\$0</i>	<i>\$0</i>	<i>\$0</i>
Risk-Informed Net	\$0	\$0	\$0
Total Net	(\$52,550,000)	(\$34,180,000)	(\$42,310,000)

Table 47 Summary of Net Benefits and Costs (Alternative 3)

Attribute	Total Averted Costs (Costs)		
	Undiscounted	7% NPV	3% NPV
Cladding Embrittlement			
Industry Implementation	(\$28,620,000)	(\$25,710,000)	(\$27,280,000)
Industry Operation	(\$15,930,000)	(\$5,890,000)	(\$9,630,000)
<i>Total Industry Cost</i>	<i>(\$44,550,000)</i>	<i>(\$31,600,000)</i>	<i>(\$36,910,000)</i>
NRC Implementation	(\$600,000)	(\$460,000)	(\$530,000)
NRC Operation	\$0	\$0	\$0
<i>Total NRC Cost</i>	<i>(\$600,000)</i>	<i>(\$460,000)</i>	<i>(\$530,000)</i>
Cladding Embrittlement Net	(\$45,150,000)	(\$32,060,000)	(\$37,440,000)
Risk-Informed			
Industry Implementation	\$337,040,000	\$336,660,000	\$336,690,000
Industry Operation	(\$18,010,000)	(\$8,600,000)	(\$12,800,000)
<i>Total Industry Cost</i>	<i>\$319,030,000</i>	<i>\$328,060,000</i>	<i>\$323,890,000</i>
NRC Implementation	(\$940,000)	(\$950,000)	(\$940,000)
NRC Operation	(\$3,720,000)	(\$1,780,000)	(\$2,650,000)
<i>Total NRC Cost</i>	<i>(\$4,660,000)</i>	<i>(\$2,730,000)</i>	<i>(\$3,590,000)</i>
Risk-Informed Net	\$314,370,000	\$325,330,000	\$320,300,000
Total Net	\$269,220,000	\$293,270,000	\$282,860,000

The final rule (Alternative 3) would result in an estimated averted cost of between \$293 million using a 7-percent discount rate and \$283 million using a 3-percent discount rate, including both cladding embrittlement and risk-informed factors. These costs are associated with four affected attributes: industry implementation and operation, and NRC implementation and operation. Section 5 provides detail on the incremental activities under Alternative 2 and estimates the one-time, recurring and annual costs associated with these activities. In contrast, Alternative 2 would result in an estimated costs of between (\$34.2 million) using a 7-percent discount rate and (\$42.3 million) using a 3-percent discount rate, including both cladding embrittlement and risk-informed factors. This is significantly less cost beneficial than Alternative 3, as detailed in Section 5.

Table 48 Total Costs (Cladding Embrittlement Alternative 2)

	Undiscounted	7% NPV	3% NPV
Implementation Costs			
Total NRC Costs	(\$4,460,000)	(\$3,170,000)	(\$3,830,000)
Total Industry Costs	(\$33,030,000)	(\$25,920,000)	(\$29,690,000)
Total	(\$37,490,000)	(\$29,090,000)	(\$33,520,000)
Operation Costs			
Total NRC Costs	\$0	\$0	\$0
Total Industry Costs	(\$15,060,000)	(\$5,090,000)	(\$8,790,000)
Total	(\$15,060,000)	(\$5,090,000)	(\$8,790,000)
Grand Total 50.46c			
Total NRC Costs	(\$4,460,000)	(\$3,170,000)	(\$3,830,000)
Total Industry Costs	(\$48,090,000)	(\$31,010,000)	(\$38,480,000)
Total	(\$52,550,000)	(\$34,180,000)	(\$42,310,000)
Average Industry Implementation Costs per Unit			
Industry Costs (Direct)		(\$114,200)	(\$167,700)
Industry Costs (Indirect)		(\$145,000)	(\$129,200)
Total		(\$259,200)	(\$296,900)

Table 49 Total Costs (Cladding Embrittlement Alternative 3)

	Undiscounted	7% NPV	3% NPV
Implementation Costs			
Total NRC Costs	(\$600,000)	(\$460,000)	(\$530,000)
Total Industry Costs	(\$28,620,000)	(\$25,710,000)	(\$27,280,000)
Total	(\$29,220,000)	(\$26,170,000)	(\$27,810,000)
Operation Costs			
Total NRC Costs	\$0	\$0	\$0
Total Industry Costs	(\$15,930,000)	(\$5,890,000)	(\$9,630,000)
Total	(\$15,930,000)	(\$5,890,000)	(\$9,630,000)
Grand Total 50.46c			
Total NRC Costs	(\$600,000)	(\$460,000)	(\$530,000)
Total Industry Costs	(\$44,550,000)	(\$31,600,000)	(\$36,910,000)
Total	(\$45,150,000)	(\$32,060,000)	(\$37,440,000)
Average Industry Implementation Costs per Unit			
Industry Costs (Direct)		(\$117,200)	(\$138,300)
Industry Costs (Indirect)		(\$139,900)	(\$134,500)
Total		(\$257,100)	(\$272,800)

Table 50 Total Costs (Risk-Informed)

	Undiscounted	7% NPV	3% NPV
Implementation Costs			
Total NRC Costs	(\$940,000)	(\$950,000)	(\$940,000)
Total Industry Costs	\$337,040,000	\$336,660,000	\$336,690,000
Total	\$336,100,000	\$335,710,000	\$335,750,000
Operation Costs			
Total NRC Costs	(\$3,720,000)	(\$1,780,000)	(\$2,650,000)
Total Industry Costs	(\$18,010,000)	(\$8,600,000)	(\$12,800,000)
Total	(\$21,730,000)	(\$10,380,000)	(\$15,450,000)
Grand Total 50.46c			
Total NRC Costs	(\$4,660,000)	(\$2,730,000)	(\$3,590,000)
Total Industry Costs	\$319,030,000	\$328,060,000	\$323,890,000
Total	\$314,370,000	\$325,330,000	\$320,300,000
Average Industry Implementation Costs per Unit			
Industry Costs (Direct)		\$28,060,000	\$28,060,000
Industry Costs (Indirect)		\$0	\$0
Total		\$28,060,000	\$28,060,000

6.2 Nonquantified Benefits and Costs

There are two primary nonquantified benefits to 10 CFR 50.46c, both of which have been described above. First, the regulatory uncertainty that would exist without this final rule (Alternative 1), regarding the high burnup values currently in use at operating plants, would certainly generate costs to industry and the NRC that are difficult to quantify. Second, the periodic breakaway oxidation testing performed by vendors (under Alternatives 2 and 3) is costed at the maximum expected frequency/quantity based on vendor input. However, as industry has proposed, if the testing results in continuous positive results for several years, the NRC could consider a relaxation in the testing requirements, resulting in fewer annual tests and therefore lower costs. Again, this is difficult to quantify and should be considered in a qualitative manner for this final rule.

6.3 Changes from the Proposed Rule to the Final Rule Regulatory Analysis

When the regulatory analysis for the proposed rule (e.g., draft regulatory analysis) was made public, NRC staff received feedback from industry that the estimates in the draft regulatory analysis were off by significant amounts. The draft regulatory analysis estimated total costs of approximately \$48 million (undiscounted).

Specific public comments on this issue can be found in “NRC Staff Responses to Public Comments on Proposed Rule: ‘Performance-Based Emergency Core Cooling Systems Cladding Acceptance Criteria’ and Three Associated Draft Regulatory Guides, *Federal Register* 79 FR 16106 (March 24, 2014)” (ADAMS Accession No. [ML15281A199](#)), and are summarized in Table 51.

Table 51 Comments and Responses on Proposed Rule Costs

Comment	Response	Reference Number
Industry would like to pursue compliance approach for Track 2 and 3, and the rule does not contain schedule for completion for LOCA analysis or ECCS models.	The NRC agrees. The rule will be modified and Table 1 will be removed and replaced with a requirement for licensees to submit an implementation plan within 180 days.	NEI 1-33, NEI 1-34, NEI 1-35
The NRC's cost estimates for industry activities is substantially below current estimates. Confirmed by industry review and NEI study of previous regulatory issues.	The NRC agrees with the general principle that the NRC must perform regulatory analyses and backfitting analyses which do not deliberately or systematically underestimate the costs of compliance by regulated entities, and which are based upon best available cost data or realistic estimates of costs. The NRC met with industry representatives in public meetings to understand the cost drivers and to collect actual costs and industry estimates associated with implementing rule provisions.	NEI 1-51 part B
Analysis required to evaluate embrittlement and debris effects on LTC have estimated costs exceeding \$1 million/unit, far higher than NRC estimate.		NEI 1-54
NRC review costs of LOCA models are approaching an order of magnitude greater than the \$300,000 estimate in the RA.		WEC 1-28
Costs of setting up, qualifying and then performing the PQD testing exceed \$1,000,000.		WEC 1-29
Track 2 plants could spend over \$1 million/unit for ECCS modeling (short-term cooling) alone, NRC cost estimate for AORs is unclear in scope with respect to Long- and Short-Term Cooling.		NEI 1-56
The number of alloys used for ECCS/LOCA models, and for the various testings (PQD/Breakaway) are different, inconsistent.	The NRC concurs and has worked closely with vendors to obtain accurate information on the number of alloys and models for this final rule.	NEI 1-57
Since development of Appendix B tables used inaccurate information associated with required activities and costs, these tables are incorrect.	Based on numerous public meetings and other vendor interactions, the NRC has revised these cost estimates to the best available information.	NEI 1-58
Work with fuel vendors and licensees to obtain actual cost data.	The NRC concurs and has sought to acquire this information, where available.	All

In preparing this regulatory analysis, the NRC has taken measures to ensure it does not deliberately or systematically underestimate the costs of compliance by regulated entities, and is using the best available cost data, or realistic estimates of costs. The NRC met with industry representatives in several public meetings³¹ to understand the cost drivers and to collect actual costs and industry estimates associated with implementing rule provisions. Additionally, the NRC reiterated the opportunity to provide input on the cost estimates associated with complying with 10 CFR 50.46c via letters to GEH, WEC, and AREVA. Industry cost information received is incorporated into the regulatory analysis consistent with the discussion above and the industry cost information provided during these meetings.

³¹ Public meetings conducted during comment period

- April 29-30, 2014 (Summary: ADAMS Accession No. ML14128A076)
- June 24-26, 2014 (Summary: ADAMS Accession No. ML14177A048)
- July 23, 2014 (Summary: ADAMS Accession No. ML14204A265)

Public meetings after comment period closed

- Implementation and regulatory analysis (March 2015) (Summary: ADAMS Accession No. ML15071A272)
- Regulatory guidance (April 2015) (Summary: ADAMS Accession No. ML15132A743)
- Series of implementation meetings (April, May, June 2015) (Summaries: ADAMS Accession Nos. ML15138A434, ML15156A891, and ML15169A004)
- Long-term cooling (June 2015) (Summary: ADAMS Accession No. ML15174A155)

Regulatory Analysis discussion with AREVA – *closed* (October 2015)

Regulatory Analysis discussion with Westinghouse – *closed* (November 2015)

From these meetings and correspondence, GEH provided written input that was incorporated into the NRC cladding embrittlement cost estimates. The NRC staff also held closed meetings with Westinghouse and AREVA to collect cost data, which these vendors stated are commercially sensitive. The information gained was incorporated into this analysis, within the limits specified by these vendors.

Additionally, because of the comments quoted above and other public comments, the NRC has made several significant changes from the 10 CFR 50.46c draft rule to the final rule. These changes improved the regulatory environment that would result from the final rule, and also reduced industry burden on cost and implementation timeline. The following summarizes the significant changes from the draft to the final 10 CFR 50.46c rule:

- Breakaway oxidation testing and reporting
 - The NRC deleted the vendor annual reporting requirement.
 - The NRC revised confirmatory periodic testing to remove the requirement of a specified testing frequency.
- Long-term cooling fuel performance requirement
 - The NRC deleted the PCT analytical limit and ductility performance metric.
 - The NRC altered the rule to state that if debris prompts a postquench reheat transient, then research must be conducted to demonstrate no further cladding failure.
- Implementation plan
 - The NRC deleted Table 1 plant assignments to provide industry with more flexibility in their implementation schedule.
 - The NRC adopted an NEI proposal that within 6 months each licensee must submit an implementation plan and schedule.
 - LARs must be submitted within 60 months of final rule.
 - Compliance must be achieved within 84 months of final rule.
- PQD Testing Protocol made more flexible, for example with the extent of repeat testing, temperature calibration, and sample preparation
- Numerous changes to RG 1.224:
 - Provides conditions where data in a narrow range of hydrogen content could be “binned” to evaluate the ductile-to-brittle transition.
 - Includes conditions where new cladding alloys could be licensed without testing of irradiated material.
 - Accepts hydrogen-pick up models for all currently approved cladding alloys were added to benefit implementation.

The input from industry and the added detailed cost analysis performed since the draft final rule was made public has had a significant effect on the results of this regulatory analysis. Drawing upon the efforts detailed above, the total estimated costs (i.e., industry plus NRC) of the final rule have been determined to be cost-beneficial, because of the large averted costs resulting from the risk-informed approach.³² However, the NRC staff expects that these large averted

³² The analysis calculated cost for the cladding embrittlement provisions of the final rule, although the analysis is predicated that these provisions are justified under adequate protection as determined by the Commission for the proposed rule. Overall, the final rule is cost beneficial because of the large averted costs for the risk-informed alternative.

costs will only be incurred by a maximum of 14 operating nuclear power units. This section describes the more significant differences between the draft and final regulatory analysis.

First, it is important to note that the regulatory analysis for the proposed rule used order of magnitude cost figures which would certainly change with more detailed final analysis. In performing the regulatory analysis for the final rule, U.S. Government Accountability Office best practices were utilized to depart from the order of magnitude estimates from the proposed rule regulatory analysis and ensure the final costs were well-defined and thorough. Second, the availability of regulatory guidance has given much greater clarity to previously identified costs and benefits, and indicated other costs and benefits that needed to be added to the analysis, or removed, based on new understanding of the impacts of 10 CFR 50.46c. And third, as mentioned above, the NRC has sought industry estimates in the process of preparing the final regulatory analysis, and has been provided with industry responses that have been used to refine the cost estimates as indicated by those industry respondents.

In Table 2 of the draft regulatory analysis compared to Table 58 in this document, the labor estimated for the various models and topical reports was higher (i.e., 0.75 FTE and 0.5 FTE) than the labor estimates made by NRC staff and informed by Industry input. Additionally, nine fewer models and topical reports (i.e., 22 vs. 31) are expected, based on industry input. It is important to note that, in this case and in most others throughout this regulatory analysis, the hourly salary used in the final rule is higher than that used in the draft rule. Based on industry input, the final rule initial breakaway oxidation testing cost estimates are significantly higher than in the draft regulatory analysis. The LAR FTE estimates have changed, specifically for Level 1 LARs, based on further analysis and industry input, as well as the estimated number of these Level 1 LARs, which reduces the cost estimates. The end result of these changes is reflected in Table 58.

Table 4 of the draft regulatory analysis has been significantly refined, as can be seen in Table 14 of this document. The effect of 10 CFR 50.46c upon future operating reactors was overestimated in the draft regulatory analysis, and was determined to consist primarily of the LAR preparation and submission.

The Track 1, 2, and 3 costs for the risk-informed alternative were removed, along with the LTC tests and the operating costs from Table 5 of the draft regulatory analysis, although these costs are replaced with the various models discussed in the risk-informed section of this regulatory analysis, in Table 16 through Table 19 of this document. The main difference, and benefit, of the risk-informed portion of this final regulatory analysis is the estimated costs (averted) of removing fibrous insulation at the 10 sites (estimated 12 units), at an averted cost of approximately \$24 million per unit based on input provided by industry representatives.

In addition to the first part of Table 5 of the draft regulatory analysis being removed and replaced with models for the risk-informed alternative, several changes in the estimates of the periodic breakaway testing in the second part of Table 5 were also made in this document. The time scale has been extended out to represent the current expected reactor life across the industry, the number of ingots tested per year has been adjusted based on Industry input, and the hourly rate and FTE from the draft RA were revised, also partly due to Industry input. The result is approximately a 60-percent increase in undiscounted cost based on the cost estimate summarized in Table 59 of this document.

Table 9 from the draft regulatory analysis, regarding NRC implementation costs, was revised in several significant ways. All of the sunk rulemaking costs were removed, resulting in a

reduction in cost of over \$2.5 million. The total costs associated with NRC review of the various models and topical reports are largely unchanged from the draft RA, however the FTE and hourly rates have been adjusted to values consistent with new information received as discussed above during the process of rule development. The final rule costs mentioned in this paragraph are found in Table 33.

The remainder of NRC cost estimates were updated in a similar degree to the industry cost estimates, between the draft rule and the final rule, with the exception of periodic breakaway testing reviews. Later guidance has determined that the NRC staff will not review the results of periodic breakaway testing, except during scheduled audits, and therefore the estimated costs for periodic breakaway testing review in the draft regulatory analysis of (\$6.1 million) (undiscounted) are removed.

The other significant change from the draft regulatory analysis is the discussion of the implications of continuing to operate under 10 CFR 50.46 as opposed to 10 CFR 50.46c, as discussed in Section 5.13 of this document. There are industry exemption requests indicated in Table 12 and Table 19 of this document and NRC review of these submittals, totaling approximately \$2 million in averted costs to industry which would need to be submitted under 10 CFR 50.46 based on consideration and understanding of the new issues which led to the creation of 10 CFR 50.46c.

There are many other minor changes in the regulatory analysis from the draft 10 CFR 50.46c to this final version, but the changes mentioned above constitute the most significant in terms of changes to the costs and benefit estimates between the draft regulatory analysis and this document.

An overview of the quantitative estimates for the proposed and final 10 CFR 50.46c rule is provided in Table 52 and Table 53.

Table 52 Proposed and Final Rule Costs (Cladding Embrittlement)

Cost Type	Cladding Embrittlement		
	Draft Regulatory Analysis	Final Regulatory Analysis	Difference
Industry Implementation	\$ (18,703,000)	\$ (27,280,000)	\$ 8,577,000
Industry Operation	\$ (7,780,000)	\$ (9,630,000)	\$ 1,850,000
NRC Implementation	\$ (5,337,000)	\$ (530,000)	\$ (4,807,000)
NRC Operation	\$ (4,330,000)	\$ -	\$ (4,330,000)
Total	\$ (36,150,000)	\$ (37,440,000)	\$ 1,290,000

Table 53 Proposed and Final Rule Costs (Risk-Informed)

Cost Type	Risk-Informed		
	Draft Regulatory Analysis	Final Regulatory Analysis	Difference
Industry Implementation	\$ (3,700,000)	\$ 336,690,000	\$ (340,390,000)
Industry Operation	\$ (550,000)	\$ (12,800,000)	\$ 12,250,000
NRC Implementation	\$ (720,000)	\$ (940,000)	\$ 220,000
NRC Operation	\$ -	\$ (2,630,000)	\$ 2,630,000
Total	\$ (4,970,000)	\$ 320,320,000	\$ (325,290,000)

7 Decision Rationale

The decision rationale is based upon the following conceptual approach for evaluating the quantitative (monetized) and qualitative (non-monetized) benefits and costs. Alternative 1 is defined as the regulatory baseline, and the benefits and costs of Alternatives 2 and 3 are evaluated relative to the Alternative 1 baseline.

Inasmuch as the § 50.46c rulemaking has four objectives (as described above), the benefits and costs for Alternatives 2 and 3 are presented for each of the four objectives (relative to the Alternative 1 baseline). The uncertainty of the quantitative result for these objectives is evaluated to demonstrate to the decisionmaker the robustness of the quantitative result.

Then, the quantitative costs and benefits for the four objectives are integrated into a single net benefit/cost result for that Alternative. The uncertainty of the overall net benefit/cost result for the Alternative is evaluated (there is no evaluation of the uncertainty of the non-monetized benefits and costs). Alternative 2 and Alternative 3 use the same uncertainty analysis as both Alternatives utilize the same data set for estimating the costs of activities. The primary differences between Alternative 2 and Alternative 3 are timing of activities, and the exclusion of certain activities that are not performed (e.g., the averted exemption requests for more recent cladding alloys, allowed by the Technology Neutral portion of Alternative 3). Therefore the same variables drive the sensitivity and uncertainty in both Alternatives.

The quantitative overall net benefit/cost result, the uncertainty of the net quantitative result, and the qualitative benefits and costs for both Alternative 2 and 3 are evaluated against the regulatory baseline (Alternative 1) in order to determine the recommended alternative.

7.1 Technology Neutral

This analysis describes the cost-averted benefits of establishing technology-neutral performance-based criteria to expand the applicability of 10 CFR 50.46 to all fuel design and zirconium based fuel cladding materials.

7.2 Research Findings

This analysis is predicated upon the fact that cladding embrittlement provisions of this final rule resulting from new research information into the behavior of fuel cladding under accident conditions is required for adequate protection (the bases for this determination are set forth in the *Federal Register* Notice of Final Rulemaking). The Regulatory Analysis Guidelines state that, "The level of protection constituting 'adequate protection' is that level which must be assured *without regard to cost*" (emphasis added). The Guidelines also state that, "... a proposed backfit to one or more of the facilities regulated under 10 CFR Part 50 does not require a regulatory analysis if the resulting safety benefit is required for purposes of compliance or adequate protection under 10 CFR 50.109(a)(4)." A regulatory analysis is performed for § 50.46c to examine the cost effectiveness of various ways to achieve compliance or reach a level of adequate protection, to enable the decisionmaker to select the most cost-effective approach for achieving adequate protection.

7.3 Crud Effects

Existing rule language does not specifically address the concerns and effects of crud, but NRC staff licensees consider crud. This final rule language is intended to clarify actions already taken by Industry and the NRC, and therefore there is no cost or benefit change as a result of the new rule language regarding crud.

7.4 Risk-Informed

The regulatory analysis for the risk-informed portion of 10 CFR 50.46c indicates a significant financial averted cost to industry. As detailed above, this benefit derives largely from operating reactors using the risk-informed analysis alternative to address the effects of debris on long-term cooling and to justify that additional removal of fibrous insulation from the containments of the ten identified sites is not necessary.

7.5 Results of Comparison of Alternatives 2 and 3 against the Alternative 1 Baseline

Table 54 provides the quantified and nonquantified costs and benefits for Alternative 2 - Case-by-Case, and Alternative 3 - § 50.46c rule implementation. For the quantitative analysis, the best estimate values are used.

Table 54 Summary of Totals

Net Monetary Savings (or Costs) – Total Present Value	Non-Monetary Benefits or (Costs)
Alternative 1: No Rulemaking Action – Safe Harbor	
\$0 (Regulatory baseline)	Regulatory baseline
Alternative 2: No Rulemaking Action – Case-by-Case (requires regulatory action but no final rule)	
<p>Industry:</p> <ul style="list-style-type: none"> • Technology Neutral \$0 • Research Findings (\$31.0 million) using a 7% discount rate (\$38.5 million) using a 3% discount rate • Crud Effects \$0 (clarification of existing actions) • Risk-Informed Alternative \$0 <p>NRC:</p> <ul style="list-style-type: none"> • Technology Neutral \$0 (clarification of existing actions) • Research Findings (\$3.2 million) using a 7% discount rate (\$3.8 million) using a 3% discount rate • Crud Effects \$0 (clarification of existing actions) 	<p>Non-Monetary Benefits:</p> <ul style="list-style-type: none"> • Public Health (Accident) – ensures that the core remains in a coolable geometry should a loss-of-coolant accident occur. • Occupational Health (Accident) – due to the above, results in an incremental decrease in the frequency of an accident resulting in averted worker radiological exposure when compared to the regulatory baseline. • Improvements in Knowledge – The case-by-case alternative incorporates research findings that identified new cladding embrittlement mechanisms. As a result, future LOCA analyses will improve the predictions of cladding embrittlement. • Regulatory Efficiency – Alternative 2 does not consist of rulemaking, therefore will result in a regulatory environment of considerable uncertainty <p>Non-Monetary Costs: Industry and NRC Costs</p>

Net Monetary Savings (or Costs) – Total Present Value	Non-Monetary Benefits or (Costs)
<ul style="list-style-type: none"> • Risk-Informed Alternative \$0 <p>Net Benefit (Cost):</p> <ul style="list-style-type: none"> • Technology Neutral \$0 (clarification of existing actions) • Research Findings (\$34.2 million) using a 7% discount rate (\$42.3 million) using a 3% discount rate • Crud Effects \$0 (clarification of existing actions) • Risk-Informed Alternative \$0 (performed similar to Alternative 1) <p>The quantified results show that the risk informed, crud effects, and technology neutral (no change) portions are cost neutral, and the research findings portions are not cost-beneficial and approximately equal to the costs for Alternative 3.</p>	<p>associated with Research Findings – If the number of planned industry submittals or the effort to prepare these submittals are less than the NRC assumes within the regulatory analysis, then the quantified costs are overstated.</p> <p>The NRC staff’s evaluation of nonquantitative benefits and costs show that Alternative 2 is preferred over Alternative 1.</p>
Alternative 3: Implement § 50.46c Rule (The Rule Alternative)	
<p>Industry:</p> <ul style="list-style-type: none"> • Technology Neutral \$1.39 million using a 7% discount rate \$1.55 million using a 3% discount rate • Research Findings (\$33.0 million) using a 7% discount rate (\$38.5 million) using a 3% discount rate • Crud Effects \$0 (clarification of existing actions) • Risk-Informed Alternative \$328 million using a 7% discount rate \$324 million using a 3% discount rate <p>NRC:</p> <ul style="list-style-type: none"> • Technology Neutral \$1.42 million using a 7% discount rate \$1.58 million using a 3% discount rate • Research Findings (\$1.88 million) using a 7% discount rate (\$2.11 million) using a 3% discount rate • Crud Effects \$0 (clarification of existing actions) • Risk-Informed Alternative (\$2.81 million) using a 7% discount rate (\$3.59 million) using a 3% discount rate 	<p>Non-Monetary Benefits:</p> <ul style="list-style-type: none"> • Public Health (Accident) – ensures that the core remains in a coolable geometry should a loss-of-coolant accident occur and that the ECCS recirculation phase would not be impaired by problematic material clogging the containment sump, containment spray nozzles, or the core cooling channels. • Occupational Health (Accident) – due to the above, results in an incremental decrease in the frequency of an accident resulting in averted worker radiological exposure when compared to the regulatory baseline. • Occupational Health (Routine) – The removal of debris sources from containment including the replacement of fibrous insulation with nonfibrous insulation to comply with GSI-191 requirements could result in an increase in worker exposures, which may be avoided if the licensee uses the risk-informed approach to justify retaining the current installed insulation. • Improvements in Knowledge – The revised rule alternative incorporates research findings that identified new cladding embrittlement mechanisms. As a result, future LOCA analyses will improve the

Net Monetary Savings (or Costs) – Total Present Value	Non-Monetary Benefits or (Costs)
<p>Net Benefit (Cost):</p> <ul style="list-style-type: none"> • Technology Neutral \$2.8 million using a 7% discount rate \$3.1 million using a 3% discount rate • Research Findings (\$34.9 million) using a 7% discount rate (\$40.6 million) using a 3% discount rate • Crud Effects \$0 (clarification of existing actions) • Risk-Informed Alternative \$325 million using a 7% discount rate \$320 million using a 3% discount rate <p>The quantified results show that the Technology Neutral and Risk-Informed portions of Alternative 3 are cost-beneficial, the crud effects portion is cost neutral, and the remainder of Alternative 3 is not cost beneficial. The quantified results show that Alternative 3 is the most cost-effective alternative that achieves adequate protection while fulfilling all four objectives of this rulemaking. Additionally, Alternative 3 is more cost effective on average on a per unit basis, as shown in Section 5.3.</p>	<p>predictions of cladding embrittlement. A licensee using the alternative risk-informed approach would identify which pipe break locations inside containment are important to risk and which locations do not contribute to failure of the strainers or core cooling. This information could be fed back into the inservice inspection (ISI) program. Also, this information could be useful in determining where problematic insulation should be replaced if such is necessary to meet the acceptance criteria.</p> <ul style="list-style-type: none"> • Regulatory Efficiency – <ul style="list-style-type: none"> ○ Expanding the applicability of this rule to different fuel designs and additional cladding materials under Alternative 3 would contribute to regulatory efficiency by eliminating the need for licensees to submit exemption requests for different fuel designs or cladding material. ○ The rule and regulatory guides would provide a clear, consistent process for Industry submittals to the NRC to demonstrate adequate protection in response to the research findings mentioned above. ○ The regulatory guides also establish regulatory efficiency in this process by providing industry with fuel performance and analysis parameters that are acceptable to the NRC and would require no further regulatory oversight. As a result, the revised rule alternative would improve regulatory efficiency. <p>Non-Monetary Costs: Industry and NRC Costs associated with Research Findings – If the number of planned industry submittals or the effort to prepare these submittals are less than the NRC assumes within the regulatory analysis, then the quantified costs are overstated.</p> <p>The NRC staff's evaluation of nonquantitative benefits and costs show that Alternative 3 is preferred over Alternatives 1 and 2.</p>

7.6 Staff Recommendation

The staff recommends Alternative 3, because from both a quantitative and qualitative standpoint, it is the most desirable approach for achieving adequate protection with respect to each of the four key objectives of the rulemaking, as well as on an integrated basis. Table 55

shows a comparison of the cost/benefit of each objective and the net cost/benefit, between Alternative 2 and Alternative 3.

Table 55 Cost/Benefit Comparison of Alternatives

Objective	Alternative 2 – Case-by-Case (7% NPV)	Alternative 3 – The Rule Alternative (7% NPV)	Preferred Alternative
Technology Neutral	\$0	\$2.8 million	Alternative 3
Research Findings	(\$34.2 million)	(\$34.9 million)	Either ³³
Crud Effects	\$0	\$0	Either
Risk-Informed	\$0	\$325 million	Alternative 3
Net Benefit	(\$34.2 million)	\$293 million	Alternative 3

Table 54 and Table 55 show, from a quantitative standpoint, that Alternative 3 is the most cost-effective way of achieving adequate protection with respect to: (1) obtaining a technology neutral, risk informed regulatory infrastructure for addressing loss of coolant accidents, (2) new cladding embrittlement phenomena identified from research findings, (3) ensuring consideration of crud in ECCS analysis, and (4) providing a risk-informed alternative for addressing debris during long term cooling. The staff notes that Alternative 3, with respect to the second objective of addressing new cladding embrittlement phenomena, does not show a positive net benefit result. The difference in cost between Alternative 2 and Alternative 3 for this objective is \$0.7 million, or 2.0%, and the standard deviation according to the uncertainty analysis above is \$3.83 million.³⁴ Therefore, this percentage difference is within the sensitivity of the uncertainty analysis, meaning that effectively the cost of this objective is equivalent between Alternative 2 and Alternative 3. The staff also notes that Alternative 3 shows a positive net benefit result of \$325 million with respect to the fourth objective of providing a Risk-Informed alternative for addressing problematic debris sources, compared to Alternative 2.

Alternative 3 is preferable because it meets all four objectives, and is quantitatively the most cost-beneficial alternative as a whole. From a qualitative standpoint, Alternative 3 (the Rule Alternative) provides greater regulatory certainty than Alternative 2 (the Case-by-Case Alternative), meets all four objectives, and is qualitatively the preferred alternative.

When the total benefit/cost results for each of the four objectives are then integrated into a single result for each Alternative, Table 54 and Table 55 show that Alternative 3:

- Is the most cost-effective alternative overall when integrating the costs for achieving all of the four objectives, and
- Is cost-beneficial as a whole

Alternative 3 is also preferred when considering the non-monetized considerations. Alternative 3 has the benefit of meeting the NRC goal of ensuring the protection of public health and safety

³³ Alternative 2 and 3 are within the sensitivity of the uncertainty analysis and are therefore effectively equal in cost for this objective.

³⁴ As discussed in Section 5.14, a full, separate uncertainty analysis was performed for Alternative 2, and the standard deviations in that analysis were effectively the same as Alternative 3.

and the environment through addressing the research findings with rulemaking action in a certain regulatory environment. In addition, this alternative would help ensure that the NRC's actions are effective, efficient, realistic, and timely by eliminating the need for the NRC review of plant-specific alternative requests. Based upon the uncertainty analysis discussed in Section 5.14, there is a reasonable basis for concluding that there is high reliability in an NRC finding that the final rule represents a socially efficient use of resources.

The NRC finds Alternative 3 is preferred regardless of whether the quantitative information is considered by itself, the non-quantitative information is considered by itself, or the quantitative and non-quantitative information are considered in an integrated fashion, and when considering the uncertainties in the information. Therefore, the NRC has determined that Alternative 3 should be selected, and the rule be adopted.

8 Rule Implementation

The NRC staff assumes that the rule would take effect 30 days after publication of the final rule in the *Federal Register*. The rule would establish a staged implementation approach to improve the efficiency and effectiveness of the migration to the new ECCS requirements. Licensees' would have 7 years (84 months) after the rule's effective date to comply. As the first step, vendors would develop, and submit to the NRC for review, topical reports and LOCA model updates. Submittals are expected to begin in 2017, the first year of implementation. Also, during the first year, the vendors would obtain PQD analytical methods by either: (1) using the analytical limits provided in an NRC RG, or (2) using an NRC-approved experimental method provided in an RG. A third option, which involves the vendors developing their own experimental method for NRC approval, is available but was not considered further in this analysis because of the higher cost and burden of this option (i.e., the NRC assumes that no vendors will develop their own experimental method). The PQD analytical limits that are obtained through the approved experimental method would be submitted for NRC review in the form of a topical report. Finally, during the first year after the rule becomes effective, the vendors would perform initial breakaway testing. The results of the initial breakaway tests would be submitted by the licensee via their LAR, which is necessary to demonstrate compliance with the final rule.

As part of this implementation plan, licensees must comply within 84 months of the effective date of the rule. All COL holders and existing applicants must comply with the requirements of the rule by the initial fuel loading or 84 months from the effective date of the rule, whichever is later. Design certification holders and existing design certification applicants do not need to comply with the rule until the time of renewal.

The final rule would allow licensees to use an alternative risk-informed approach to evaluate the effects of debris on long-term cooling. The NRC would allow partial early implementation of the proposed requirements of 10 CFR 50.46c, limited to the alternate approach. However, the NRC assumes in this analysis that the alternatives would be submitted the same year as compliance with the embrittlement criteria is demonstrated. Entities that choose this approach would submit the alternative approach to the NRC for review and approval. Additionally, the licensees would have to submit all changes to the approved alternatives to the NRC for review.

Four RGs were developed to support implementation of the final rule. The four RGs are: RG 1.222, "Measuring Breakaway Oxidation Behavior" (ADAMS Accession No. ML15238B044), RG 1.223, "Determining Post-Quench Ductility" (ADAMS Accession No. ML15238B079),

RG 1.224, "Establishing Analytical Limits for Zirconium-Alloy Cladding Material" (ADAMS Accession No. ML15238B155), and RG 1.229, "Risk-Informed Approach for Addressing the Effects of Debris on Post-Accident Long-Term Cooling," (ADAMS Accession No. ML15252A125). These RGs will be available for use as guidance immediately upon their issuance in final form. Thus, the guidance will be available for use with sufficient time to support the necessary date for licensees and applicants to comply with the final rule, as specified in 10 CFR 50.46c(p).

9 References

- U.S. Nuclear Regulatory Commission (NRC), October 29, 2008, "Summary of September 24 2008 Meeting To Discuss the Technical Basis for Planned 10 CFR 50.46(B) Rulemaking," (ADAMS Accession No. ML083010496).
- — — — —, July 1990, "Backfitting Guidelines," NUREG-1409 (ADAMS Accession No. ML032230247).
- — — — —, February 1992, "Generic Cost Estimates: Abstracts from Generic Studies for Use in Preparing Regulatory Impact Analyses," NUREG/CR-4627 (ADAMS Accession No. ML13137A259).
- — — — —, January 1997, "Regulatory Analysis Technical Evaluation Handbook," NUREG/BR-0184 (ADAMS Accession No. ML050190193).
- — — — —, December 23, 1998, "Options for Risk-Informed Revisions to 10 CFR Part 50— 'Domestic Licensing of Production and Utilization Facilities,'" SECY-98-300 (ADAMS Accession No. ML992870048).
- — — — —, May 31, 2000, "Nuclear Energy Institute; Receipt of Petition for Rulemaking," PRM-50-71, *Federal Register*, 65 FR 34599, <http://www.gpo.gov/fdsys/pkg/FR-2000-05-31/pdf/00-13515.pdf>.
- — — — —, March 29, 2002, "Update to SECY-01-0133, 'Fourth Status Report on Study of Risk-Informed Changes to the Technical Requirements of 10 CFR Part 50 (Option 3) and Recommendations on Risk-Informed Changes to 10 CFR 50.46 (ECCS Acceptance Criteria),' " SECY-02-0057 (ADAMS Accession No. ML020660607).
- — — — —, March 31, 2003, "Staff Requirements—SECY-02-0057—Update to SECY-01-0133, 'Fourth Status Report on Study of Risk-Informed Changes to the Technical Requirements of 10 CFR Part 50 (Option 3) and Recommendations on Risk-Informed Changes to 10 CFR 50.46 (ECCS Acceptance Criteria),' " SRM-SECY-02-0057 (ADAMS Accession No. ML030910476).
- — — — —, September 2004, "Regulatory Analysis Guidelines of the U.S. Nuclear Regulatory Commission," NUREG/BR-0058, Rev. 4 (ADAMS Accession No. ML042820192).
- — — — —, May 30, 2008, "Technical Basis for Revision of Embrittlement Criteria in 10 CFR 50.46," RIL-0801 (ADAMS Accession No. ML081350225).
- — — — —, May 23, 2007, "Mark Edward Leye; Receipt of Petition of Rulemaking," PRM-50-84, *Federal Register*, 72 FR 28902, <http://www.gpo.gov/fdsys/pkg/FR-2007-05-23/pdf/E7-9901.pdf>.
- — — — —, July 7, 2008, "Cladding Embrittlement during Postulated Loss-of-Coolant Accidents," NUREG/CR-6967 (ADAMS Accession No. ML081780360).

— — — — —, November 6, 2008, “Anthony R. Pietrangelo, Nuclear Energy Institute; Consideration of Petition in the Rulemaking Process,” PRM-50-71, *Federal Register*, 73 FR 66000, <http://www.gpo.gov/fdsys/pkg/FR-2008-11-06/pdf/E8-26463.pdf>.

— — — — —, November 25, 2008, “Mark Edward Leyse; Consideration of Petition in Rulemaking Process,” PRM-50-84, *Federal Register*, 73 FR 71564, <http://www.gpo.gov/fdsys/pkg/FR-2008-11-25/pdf/E8-27938.pdf>.

— — — — —, January 7, 2013, “Staff Requirements—SECY-12-0034—Proposed Rulemaking—10 CFR 50.46c: Emergency Core Cooling System Performance during Loss-of-Coolant Accidents (RIN 3150-AH42),” SRM-SECY-12-0034 (ADAMS Accession No. ML13007A478).

— — — — —, March 2014, Draft Regulatory Guide (DG) for “Conducting Periodic Testing for Breakaway Oxidation Behavior,” DG-1261 (ADAMS Accession No. ML12284A324).

— — — — —, March 2014, Draft Regulatory Guide for “Testing for Post-Quench Ductility,” DG-1262 (ADAMS Accession No. ML12284A325).

— — — — —, March 2014, Draft Regulatory Guide for “Establishing Analytical Limits for Zirconium-Based Alloy Cladding,” DG-1263 (ADAMS Accession No. ML12284A323).

— — — — —, August 2015, “Reassessment of NRC’s Dollar per Person-Rem Conversion Factor Policy,” NUREG-1530, Rev. 1 (Draft for Comment) (ADAMS Accession No. ML15237A211).

— — — — —, Regulatory Guide for “Measuring Breakaway Oxidation Behavior,” RG 1.222 (ADAMS Accession No. ML15238B044).

— — — — —, Regulatory Guide for “Determining Post Quench Ductility,” RG 1.223 (ADAMS Accession No. ML15238B079).

— — — — —, Regulatory Guide for “Establishing Analytical Limits for Zirconium-Alloy Cladding Material,” RG 1.224 (ADAMS Accession No. ML15238B155).

— — — — —, Regulatory Guide for “Risk-Informed Approach for Addressing the Effects of Debris on Post-Accident Long-Term Core Cooling,” RG 1.229 (ADAMS Accession No. ML15252A125).

Office of Management and Budget (OMB), December 2014, “Discount Rates for Cost-Effectiveness, Lease Purchase, and Related Analyses,” Circular No. A-94 Appendix C, https://www.whitehouse.gov/omb/circulars_a094/a94_appx-c.

U.S. Code of Federal Regulations, “Backfitting,” Section 50.109, Chapter 1, Title 10, “Energy” (10 CFR 50.109) <http://www.nrc.gov/reading-rm/doc-collections/cfr/part050/part050-0109.html>.

— — — — —, “Combustible Gas Control for Nuclear Power Reactors,” Section 50.44, Chapter 1, Title 10, “Energy” (10 CFR 50.44) <http://www.nrc.gov/reading-rm/doc-collections/cfr/part050/part050-0044.html>.

— — — — —, “Acceptance Criteria for Emergency Core Cooling Systems for Light-Water Nuclear Power Reactors,” Section 50.46, Chapter 1, Title 10, “Energy” (10 CFR 50.46)
<http://www.nrc.gov/reading-rm/doc-collections/cfr/part050/part050-0046.html>.

— — — — —, “Acceptance Criteria for Reactor Coolant System Venting Systems,” Section 50.46a, Chapter 1, Title 10, “Energy”
<http://www.nrc.gov/reading-rm/doc-collections/cfr/part050/part050-0046a.html>.

ADAMS Accession No.: ML15323A122;			*concurrence via e-mail		NRR-106
OFFICE	NRR/DPR/PRMB	NRR/DPR/PRMB	NRR/DPR/PRMB/RATL*	NRR/DPR/PRMB/BC	NRR/DPR/DD
NAME	ASanders	AGomez	Fschofer	TInverso	AMohseni
DATE	11/17/2015	11/17/2015	11/17/2015	12/1/15	12/4/15
OFFICE	NRR/DPR/D	OGC/GCLR/RMR	NRR/D		
NAME	LKokajko	Gmizuno*	Wdean*		
DATE	12/10/2015	1/12/2016	1/15/2016		

OFFICIAL RECORD COPY

Appendix A—Supplementary Tables

Table 56 Uncertainty Analysis Variables

Activity	Mean Estimate	Distribution	Low Estimate	Best Estimate	High Estimate
Industry Labor Rates					
Executive	\$199.77	PERT	\$142.17	\$203.67	\$246.50
Managers	\$125.44	PERT	\$96.70	\$126.27	\$151.75
Technical Staff	\$98.46	PERT	\$81.68	\$98.52	\$115.01
Admin Staff	\$64.25	PERT	\$47.45	\$64.63	\$79.86
Licensing Staff	\$126.84	PERT	\$87.68	\$129.47	\$155.87
Research engineer	\$143.19	PERT	\$104.57	\$145.12	\$173.53
Cladding Embrittlement Activities					
Develop Breakaway Oxidation Test and Write Procedure					
Hours to develop test and write procedures (Physicist)	345	PERT	270	300	600
Hours to develop test and write procedures (Technician)	288	PERT	225	250	500
Initial Breakaway Oxidation Test to Support Analyzed Limit					
Vendor staff hours to conduct test	2,956.3	PERT	1,793.7	1,993.0	7,972.0
Technical staff hours to conduct test	13,256.6	PERT	8,043.3	8,937.0	35,748.0
Confirmatory Breakaway Oxidation Testing					
Hours to conduct test	10.5	PERT	7.2	8	24
Number of ingots	345.0	PERT	270	300	600
Topical Reports on BWR and PWR Evaluation Models					
Technical staff hours	2530.0	PERT	1980	2200	4400
Administrative staff hours	86.3	PERT	67.5	75	150
Licensing staff hours	345.0	PERT	270	300	600
Manager hours	57.5	PERT	45	50	100

Activity	Mean Estimate	Distribution	Low Estimate	Best Estimate	High Estimate
Topical Reports on Breakaway Oxidation					
Vendor staff hours	780.0	PERT	240	740	1480
Administrative staff hours	53.3	PERT	20	50	100
Licensing staff hours	113.3	PERT	20	110	220
Manager hours	31.7	PERT	10	30	60
Topical Reports on Hydrogen Models and Fuel Mechanical Design					
Vendor staff hours	183.3	PERT	50	150	450
Administrative staff hours	73.3	PERT	20	60	180
Licensing staff hours	73.3	PERT	20	60	180
Manager hours	36.7	PERT	10	30	90
Licensee Amendment Requests for 50.46c Compliance					
<i>Licensee Amendment Request for 50.46c Compliance, Level 1</i>					
Vendor staff hours	415.3	PERT	196	406	672
Administrative staff hours	89.0	PERT	42	87	144
Licensing staff hours	59.3	PERT	28	58	96
Manager hours	29.7	PERT	14	29	48
<i>Licensee Amendment Request for 50.46c Compliance, Level 2</i>					
Vendor staff hours	632.3	PERT	280	574	1218
Administrative staff hours	135.5	PERT	60	123	261
Licensing staff hours	90.3	PERT	40	82	174
Manager hours	45.2	PERT	20	41	87
<i>Licensee Amendment Request for 50.46c Compliance, Level 3</i>					
Vendor staff hours	1661.3	PERT	560	1232	4480
Administrative staff hours	356.0	PERT	120	264	960
Licensing staff hours	237.3	PERT	80	176	640
Manager hours	118.7	PERT	40	88	320

Activity	Mean Estimate	Distribution	Low Estimate	Best Estimate	High Estimate
High Temperature Steam Oxidation Chamber					
Equipment Cost and Installation	\$461,333	PERT	\$288,000	\$320,000	\$1,200,000
Technician Installation	23.0	PERT	18	20	40
Technician Qualification	57.5	PERT	45	50	100
Hydrogen Content Measurement Device					
Equipment Modification	\$28,750	PERT	\$22,500	\$25,000	\$50,000
Per alloy testing	\$17,250	PERT	\$13,500	\$15,000	\$30,000
Hydrogen Precharging Equipment					
Vendor staff hours	57.5	PERT	45	50	100
Ring Compression Test Device					
Vendor staff hours	218.5	PERT	171	190	380
Prepare and Submit Exemption Requests (averted)					
Staff hours to prepare and submit	557.5	PERT	425	480	1000
Number of exemptions	25.0	PERT	20	25	30
NRC Review: Submitted Exemption Requests (averted)					
Hours to process exemptions	540.5	PERT	423	470	940
NRC Review: Topical Report on Breakaway Oxidation Test					
Hours to review report	115	PERT	90	100	200
Prepare safety evaluation	138	PERT	108	120	240
Industry Preparation and Submit LAR					
Technical staff hours	249.2	PERT	151	168	672
Administrative staff hours	53.4	PERT	32.4	36	144
Licensing staff hours	35.6	PERT	21.6	24	96
Manager hours	17.8	PERT	10.8	12	48
NRC Review: License Amendment Requests					
Hours to review report	148.3	PERT	90	100	400
NRC Review: Cladding Hydrogen Uptake Models					
Hours to review report	148.3	PERT	90	100	400

Activity	Mean Estimate	Distribution	Low Estimate	Best Estimate	High Estimate
NRC Review of LOCA Models (PQD, Breakaway)					
Hours to review report	148.3	PERT	90	100	400
NRC Review of LOCA Models (Fuel Mech Design)					
Hours to review report	148.3	PERT	90	100	400
NRC Review of LOCA Models (BWR/PWR)					
Hours to review report	148.3	PERT	90	100	400
Risk-Informed Approach Activities					
Industry Removal of Fibrous Insulation (FAI)					
Cost for vendor staff to remove FAI (\$/ft ³)	\$2,252	PERT	\$1,860	\$2,200	\$2,850
Amount of insulation to remove (ft ³)	5,575	PERT	1,600	5,600	9,450
Number of units to remove insulation from	12	PERT	11	12	14
Industry Dosage Calculations for Removal of FAI					
Dosage cost per person-rem	\$3,550	PERT	\$2,000	\$3,550	\$5,100
Dosage per unit (person-rem)	46.6	PERT	13	47	79
Number of units to remove insulation from	12	PERT	11	12	14
Industry Material Costs for Insulation Disposal					
Removed insulation (ft ³)	5575.0	PERT	1,600	5,600	9,450
Disposal cost (ft ³)	\$321	PERT	\$128	\$300	\$600
Number of units to install insulation	12	PERT	11	12	14
Shipping and handling costs to depository	\$291,667	PERT	\$100,000	\$300,000	\$450,000
Industry Installation of Replacement Insulation					
Cost for vendor staff to install replacement insulation (\$/ft ³)	\$4,610.00	PERT	\$2,860	\$4,600	\$6,400
Amount of replacement insulation to install (\$/ft ³)	2450.0	PERT	1,100	2,400	4,000
Number of units to install insulation	12.0	PERT	11	12	14
Industry Dosage Calculations for Replacement Insulation					
Dollar per person-rem conversion factor	\$3,550	PERT	\$2,000	\$3,550	\$5,100
Dosage per unit (person-rem)	20.5	PERT	9	20	33
Number of units to install insulation	12.0	PERT	11	12	14

Activity	Mean Estimate	Distribution	Low Estimate	Best Estimate	High Estimate
Industry Material Costs for Replacement Insulation					
Replacement insulation (ft ³)	2450.0	PERT	1,100	2,400	4,000
Replacement insulation cost (ft ³)	\$1,475.00	PERT	\$1,200	\$1,400	\$2,050
Number of units to install insulation	12.0	PERT	11	12	14
NRC Review of Removal of Fibrous Insulation					
Hours to review report	520.0	PERT	240	480	960
Number of models to review	12.0	PERT	11	12	14
Topical Reports on FAI Removal Evaluation Models					
Hours to contribute to report	166.1	PERT	100.8	140	336
Number of Sites	7.8	PERT	7	8	8
Number of TRs for BWR and PWR Evaluation models	7.0	PERT	7	7	7
Administrative hours to contribute to report	35.6	PERT	21.6	30	72
Licensing hours to contribute to report	23.7	PERT	14.4	20	48
Management hours to contribute to report	11.9	PERT	7.2	10	24

Table 57 Industry Implementation Costs (Cladding Embrittlement Alternative 2)

Industry Implementation Costs (Indirect - Vendor Implementation Costs)

Year	Activity	Regulatory Uncertainty Factor	Number of Models / Cladding Alloys	Per Model/Cladding Alloy		Cost		
				Hours	Weighted Hourly rate	Undiscounted	7% NPV	3% NPV
2019	Cladding Hydrogen Uptake Models (Including Topic Rpts)	1.2	6	367	\$121	(\$320,096)	(\$279,585)	(\$301,721)
2019	Topical Reports for Breakaway (incl. spec & drawing changes), PQD	1.2	3	1028	\$135	(\$500,130)	(\$436,833)	(\$471,421)
2019	Topical Reports for Fuel Mech Design	1.2	6	367	\$121	(\$320,096)	(\$279,585)	(\$301,721)
2019	LOCA Models and Topical Reports for BWR / PWR	1.2	7	1509	\$137	(\$1,741,603)	(\$1,521,183)	(\$1,641,627)
2020				1509	\$137	(\$1,741,603)	(\$1,421,666)	(\$1,593,813)
2019	Initial Breakaway Test (Develop)	1.2	3	633	\$122	(\$277,991)	(\$242,808)	(\$262,033)
2020	Initial Breakaway Test (Perform)	1.2	4	16213	\$106	(\$8,274,876)	(\$6,754,763)	(\$7,572,683)
2021	Initial Breakaway Test (Perform)	1.2	2	16213	\$106	(\$4,137,438)	(\$3,156,432)	(\$3,676,060)
Total:						(\$17,313,833)	(\$14,092,855)	(\$15,821,081)

Industry Implementation Costs (Direct - Vendor Implementation Costs)

Year	Item	Number of Item	Item Cost	Cost		
				Undiscounted	7% NPV	3% NPV
2019	High Temperature Steam Oxidation Chamber	3	(\$625,675)	(\$1,877,024)	(\$1,639,466)	(\$1,769,276)
2019	Hydrogen Content Measurement Device	3	(\$63,250)	(\$189,750)	(\$165,735)	(\$178,858)
2019	Hydrogen Pre-Charging Equipment	3	(\$16,308)	(\$48,924)	(\$42,732)	(\$46,116)
2019	Ring Compression Test Device	3	(\$61,971)	(\$185,912)	(\$162,382)	(\$175,239)
Total:				(\$2,301,610)	(\$2,010,315)	(\$2,169,488)

Industry Implementation Costs: License Amendment Requests

Year	Activity	Regulatory Uncertainty Factor	Number of Units/LARs	Per Unit		Cost		
				Hours	Weighted Hourly rate	Undiscounted	7% NPV	3% NPV
2020	Level 1 LAR - Vendor Preparation*	1.1	28	475	\$128	(\$1,866,077)	(\$1,523,275)	(\$1,707,725)
2021	Level 1 LAR - Industry Processing/Submission*	1.1	28	119	\$97	(\$355,510)	(\$271,217)	(\$315,866)
2020	Level 2 LAR - Vendor Preparation	1.1	5	723	\$128	(\$507,330)	(\$414,133)	(\$464,279)
2021	Level 2 LAR - Industry Processing/Submission	1.1	5	181	\$97	(\$96,652)	(\$73,736)	(\$85,874)
2021	Level 3 LAR - Vendor Preparation	1.1	13	1899	\$128	(\$3,465,572)	(\$2,643,868)	(\$3,079,116)
2022	Level 3 LAR - Vendor Preparation	1.1	14	1899	\$128	(\$3,732,154)	(\$2,660,974)	(\$3,219,389)
2022	Level 3 LAR - Industry Processing/Submission	1.1	13	475	\$97	(\$660,232)	(\$470,737)	(\$569,522)
2023	Level 3 LAR - Industry Processing/Submission	1.1	14	475	\$97	(\$711,020)	(\$473,782)	(\$595,468)
Total:						(\$11,394,548)	(\$8,531,721)	(\$10,037,239)

Table 58 Industry Implementation Costs (Cladding Embrittlement Alternative 3)

Industry Implementation Costs (Indirect - Vendor Implementation Costs)

Year	Activity	Number of Models/Cladding Alloys	Per Model/Cladding Alloy		Cost		
			Hours	Weighted Hourly rate	Undiscounted	7% NPV	3% NPV
2017	Cladding Hydrogen Uptake Models (Including Topic Rpts)	6	367	\$121	(\$266,747)	(\$266,747)	(\$266,747)
2017	Topical Reports for Breakaway (incl. spec & drawing changes), PQD	3	1028	\$135	(\$416,775)	(\$416,775)	(\$416,775)
2017	Topical Reports for Fuel Mech Design	6	367	\$121	(\$266,747)	(\$266,747)	(\$266,747)
2017	LOCA Models and Topical Reports for BWR / PWR	7	1509	\$137	(\$1,451,335)	(\$1,451,335)	(\$1,451,335)
2018			1509	\$137	(\$1,451,335)	(\$1,356,388)	(\$1,409,064)
2017	Initial Breakaway Test (Develop)	3	633	\$122	(\$231,659)	(\$231,659)	(\$231,659)
2018	Initial Breakaway Test (Perform)	4	16213	\$106	(\$6,895,730)	(\$6,444,607)	(\$6,694,883)
2019	Initial Breakaway Test (Perform)	2	16213	\$106	(\$3,447,865)	(\$3,011,499)	(\$3,249,943)
Total:					(\$14,428,194)	(\$13,445,758)	(\$13,987,154)

Industry Implementation Costs (Direct - Vendor Implementation Costs)

Year	Item	Number of Item	Item Cost	Cost		
				Undiscounted	7% NPV	3% NPV
2017	High Temperature Steam Oxidation Chamber	3	(\$625,675)	(\$1,877,024)	(\$1,877,024)	(\$1,877,024)
2017	Hydrogen Content Measurement Device	3	(\$63,250)	(\$189,750)	(\$189,750)	(\$189,750)
2017	Hydrogen Pre-Charging Equipment	3	(\$16,308)	(\$48,924)	(\$48,924)	(\$48,924)
2017	Ring Compression Test Device	3	(\$61,971)	(\$185,912)	(\$185,912)	(\$185,912)
Total:				(\$2,301,610)	(\$2,301,610)	(\$2,301,610)

Industry Implementation Costs: License Amendment Requests

Year	Activity	Number of Units/LARs	Per Unit		Cost		
			Hours	Weighted Hourly rate	Undiscounted	7% NPV	3% NPV
2018	Level 1 LAR - Vendor Preparation*	33	475	\$128	(\$1,999,368)	(\$1,868,569)	(\$1,941,134)
2019	Level 1 LAR - Industry Processing/Submission*	33	119	\$97	(\$380,903)	(\$332,696)	(\$359,038)
2018	Level 2 LAR - Vendor Preparation	5	723	\$128	(\$461,209)	(\$431,037)	(\$447,776)
2019	Level 2 LAR - Industry Processing/Submission	5	181	\$97	(\$87,866)	(\$76,745)	(\$82,822)
2019	Level 3 LAR - Vendor Preparation	16	1899	\$128	(\$3,877,563)	(\$3,386,814)	(\$3,654,975)
2020	Level 3 LAR - Vendor Preparation	16	1899	\$128	(\$3,877,563)	(\$3,165,246)	(\$3,548,519)
2020	Level 3 LAR - Industry Processing/Submission	16	475	\$97	(\$738,722)	(\$603,017)	(\$676,035)
2021	Level 3 LAR - Industry Processing/Submission	16	475	\$97	(\$738,722)	(\$563,567)	(\$656,345)
Total:					(\$12,161,916)	(\$10,427,690)	(\$11,366,644)

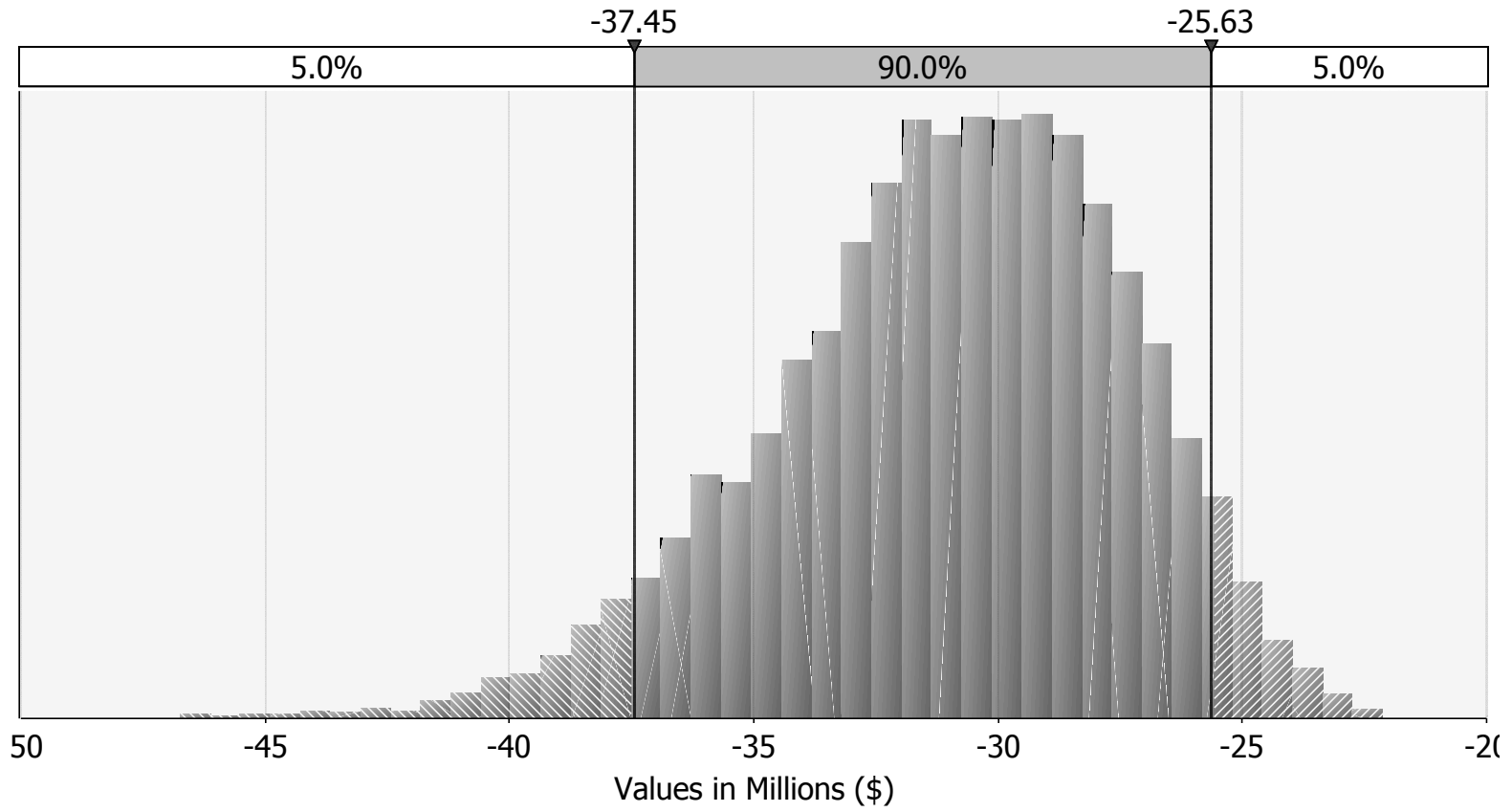
Year	Activity	Number of Exemption Requests	Per Exemption Request		Cost		
			Hours	Weighted Hourly rate	Undiscounted	7% NPV	3% NPV
2017-2021	High Burnup LAR or Exemption Request (ER) Preparation and Submission	25	558	\$121	\$1,689,902	\$1,385,787	\$1,547,852
Total:					\$1,689,902	\$1,385,787	\$1,547,852

Table 59 Industry Operation Costs for Operating Reactors (Cladding Embrittlement)

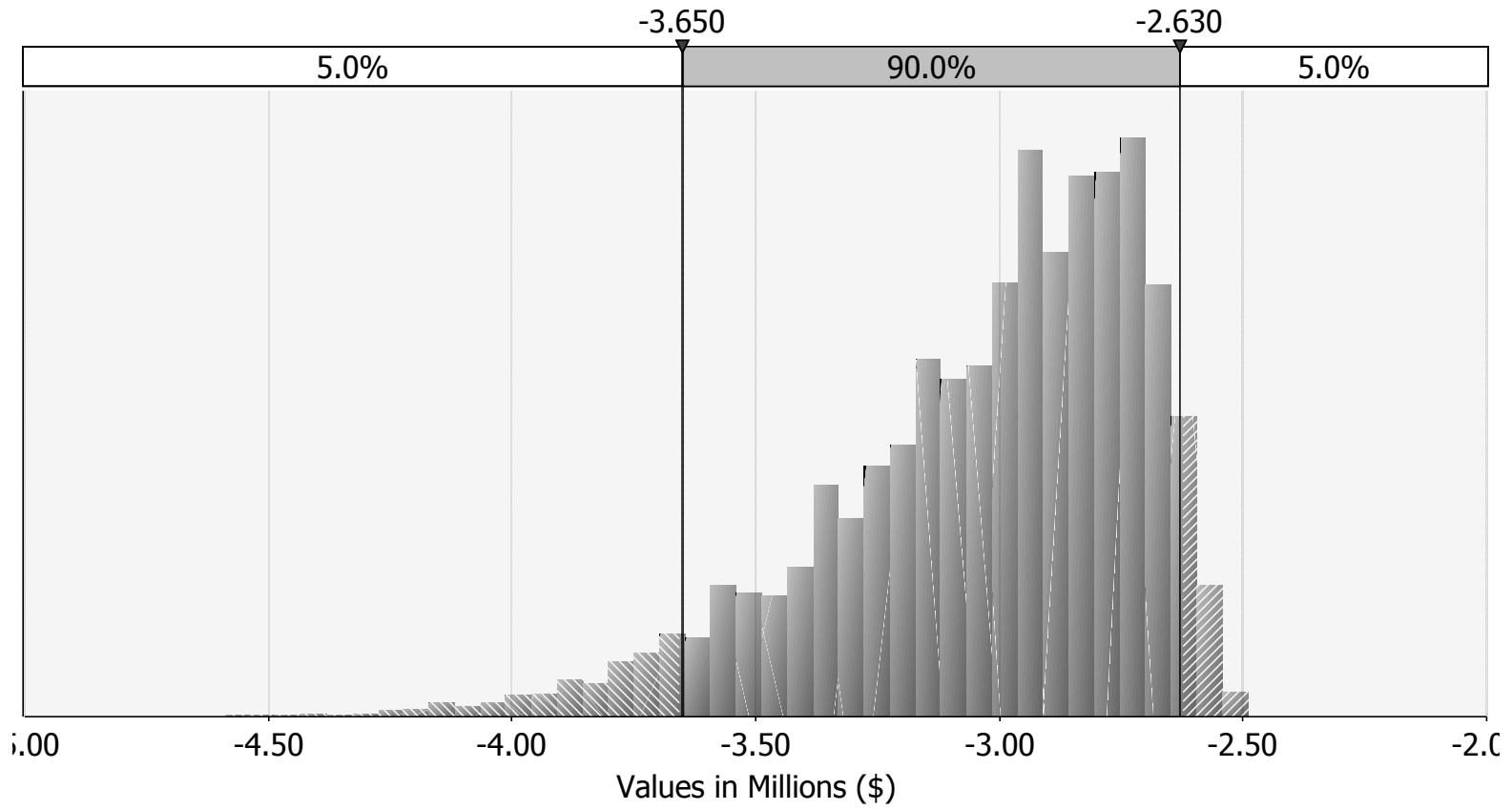
Year	Activity	Number of Ingots Tested	Per Ingot		Cost per Year		
			Hours	Weighted Hourly Rate	Undiscounted	7% NPV	3% NPV
2018	Periodic Breakaway Tests	300	11	\$142	(\$448,116)	(\$418,800)	(\$435,064)
2019	Periodic Breakaway Tests	300	11	\$142	(\$448,116)	(\$391,402)	(\$422,393)
2020	Periodic Breakaway Tests	320	11	\$142	(\$477,991)	(\$390,183)	(\$437,429)
2021	Periodic Breakaway Tests	320	11	\$142	(\$477,991)	(\$364,657)	(\$424,689)
2022	Periodic Breakaway Tests	320	11	\$142	(\$477,991)	(\$340,801)	(\$412,319)
2023	Periodic Breakaway Tests	320	11	\$142	(\$477,991)	(\$318,505)	(\$400,310)
2024	Periodic Breakaway Tests	320	11	\$142	(\$477,991)	(\$297,669)	(\$388,650)
2025	Periodic Breakaway Tests	320	11	\$142	(\$477,991)	(\$278,195)	(\$377,330)
2026	Periodic Breakaway Tests	320	11	\$142	(\$477,991)	(\$259,995)	(\$366,340)
2027	Periodic Breakaway Tests	320	11	\$142	(\$477,991)	(\$242,986)	(\$355,670)
2028	Periodic Breakaway Tests	320	11	\$142	(\$477,991)	(\$227,090)	(\$345,311)
2029	Periodic Breakaway Tests	320	11	\$142	(\$477,991)	(\$212,234)	(\$335,253)
2030	Periodic Breakaway Tests	320	11	\$142	(\$477,991)	(\$198,349)	(\$325,488)
2031	Periodic Breakaway Tests	320	11	\$142	(\$477,991)	(\$185,373)	(\$316,008)
2032	Periodic Breakaway Tests	320	11	\$142	(\$477,991)	(\$173,246)	(\$306,804)
2033	Periodic Breakaway Tests	320	11	\$142	(\$477,991)	(\$161,912)	(\$297,868)
2034	Periodic Breakaway Tests	320	11	\$142	(\$477,991)	(\$151,320)	(\$289,192)
2035	Periodic Breakaway Tests	320	11	\$142	(\$477,991)	(\$141,420)	(\$280,769)
2036	Periodic Breakaway Tests	320	11	\$142	(\$477,991)	(\$132,168)	(\$272,591)
2037	Periodic Breakaway Tests	320	11	\$142	(\$477,991)	(\$123,522)	(\$264,652)
2038	Periodic Breakaway Tests	320	11	\$142	(\$477,991)	(\$115,441)	(\$256,944)
2039	Periodic Breakaway Tests	320	11	\$142	(\$477,991)	(\$107,889)	(\$249,460)
2040	Periodic Breakaway Tests	310	11	\$142	(\$463,054)	(\$97,680)	(\$234,625)
2041	Periodic Breakaway Tests	300	11	\$142	(\$448,116)	(\$88,345)	(\$220,444)
2042	Periodic Breakaway Tests	280	11	\$142	(\$418,242)	(\$77,061)	(\$199,755)

Year	Activity	Number of Ingots Tested	Per Ingot		Cost per Year		
			Hours	Weighted Hourly Rate	Undiscounted	7% NPV	3% NPV
2043	Periodic Breakaway Tests	260	11	\$142	(\$388,367)	(\$66,875)	(\$180,084)
2044	Periodic Breakaway Tests	230	11	\$142	(\$343,556)	(\$55,289)	(\$154,665)
2045	Periodic Breakaway Tests	200	11	\$142	(\$298,744)	(\$44,932)	(\$130,574)
2046	Periodic Breakaway Tests	170	11	\$142	(\$253,933)	(\$35,693)	(\$107,755)
2047	Periodic Breakaway Tests	140	11	\$142	(\$209,121)	(\$27,472)	(\$86,155)
2048	Periodic Breakaway Tests	120	11	\$142	(\$179,247)	(\$22,007)	(\$71,696)
2049	Periodic Breakaway Tests	110	11	\$142	(\$164,309)	(\$18,853)	(\$63,807)
2050	Periodic Breakaway Tests	100	11	\$142	(\$149,372)	(\$16,018)	(\$56,317)
2051	Periodic Breakaway Tests	90	11	\$142	(\$134,435)	(\$13,473)	(\$49,209)
2052	Periodic Breakaway Tests	80	11	\$142	(\$119,498)	(\$11,193)	(\$42,467)
2053	Periodic Breakaway Tests	70	11	\$142	(\$104,560)	(\$9,153)	(\$36,077)
2054	Periodic Breakaway Tests	60	11	\$142	(\$89,623)	(\$7,332)	(\$30,022)
2055	Periodic Breakaway Tests	60	11	\$142	(\$89,623)	(\$6,852)	(\$29,148)
2056	Periodic Breakaway Tests	60	11	\$142	(\$89,623)	(\$6,404)	(\$28,299)
2057	Periodic Breakaway Tests	60	11	\$142	(\$89,623)	(\$5,985)	(\$27,475)
2058	Periodic Breakaway Tests	60	11	\$142	(\$89,623)	(\$5,594)	(\$26,674)
2059	Periodic Breakaway Tests	60	11	\$142	(\$89,623)	(\$5,228)	(\$25,897)
2060	Periodic Breakaway Tests	60	11	\$142	(\$89,623)	(\$4,886)	(\$25,143)
2061	Periodic Breakaway Tests	50	11	\$142	(\$74,686)	(\$3,805)	(\$20,342)
2062	Periodic Breakaway Tests	50	11	\$142	(\$74,686)	(\$3,556)	(\$19,750)
2063	Periodic Breakaway Tests	50	11	\$142	(\$74,686)	(\$3,323)	(\$19,175)
2064	Periodic Breakaway Tests	50	11	\$142	(\$74,686)	(\$3,106)	(\$18,616)
2065	Periodic Breakaway Tests	50	11	\$142	(\$74,686)	(\$2,903)	(\$18,074)
2066	Periodic Breakaway Tests	50	11	\$142	(\$74,686)	(\$2,713)	(\$17,548)
2067	Periodic Breakaway Tests	50	11	\$142	(\$74,686)	(\$2,535)	(\$17,036)
2068	Periodic Breakaway Tests	50	11	\$142	(\$74,686)	(\$2,370)	(\$16,540)
2069	Periodic Breakaway Tests	40	11	\$142	(\$59,749)	(\$1,772)	(\$12,847)

Year	Activity	Number of Ingots Tested	Per Ingot		Cost per Year		
			Hours	Weighted Hourly Rate	Undiscounted	7% NPV	3% NPV
2070	Periodic Breakaway Tests	40	11	\$142	(\$59,749)	(\$1,656)	(\$12,473)
2071	Periodic Breakaway Tests	40	11	\$142	(\$59,749)	(\$1,547)	(\$12,109)
2072	Periodic Breakaway Tests	40	11	\$142	(\$59,749)	(\$1,446)	(\$11,757)
2073	Periodic Breakaway Tests	40	11	\$142	(\$59,749)	(\$1,352)	(\$11,414)
2074	Periodic Breakaway Tests	40	11	\$142	(\$59,749)	(\$1,263)	(\$11,082)
2075	Periodic Breakaway Tests	40	11	\$142	(\$59,749)	(\$1,181)	(\$10,759)
2076	Periodic Breakaway Tests	40	11	\$142	(\$59,749)	(\$1,103)	(\$10,446)
2077	Periodic Breakaway Tests	40	11	\$142	(\$59,749)	(\$1,031)	(\$10,141)
2078	Periodic Breakaway Tests	40	11	\$142	(\$59,749)	(\$964)	(\$9,846)
Total:					(\$15,952,940)	(\$5,897,104)	(\$9,646,779)



**Figure 13 Cladding embrittlement: Total industry costs (7% NPV)
Alternative 2**



**Figure 14 Cladding embrittlement: Total NRC costs (7% NPV)
Alternative 2**

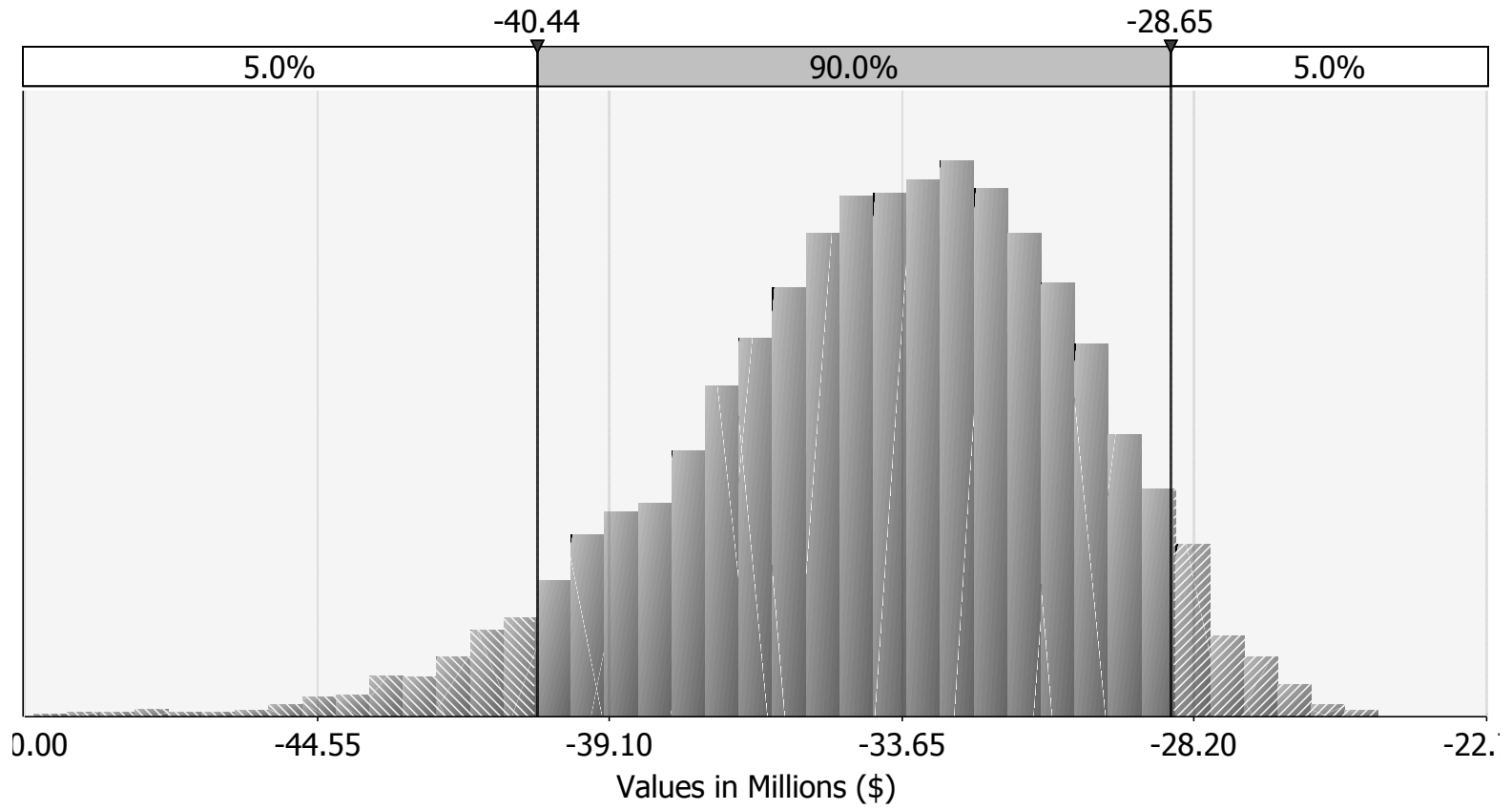


Figure 15 Cladding embrittlement: Net Benefit (7% NPV) Alternative 2

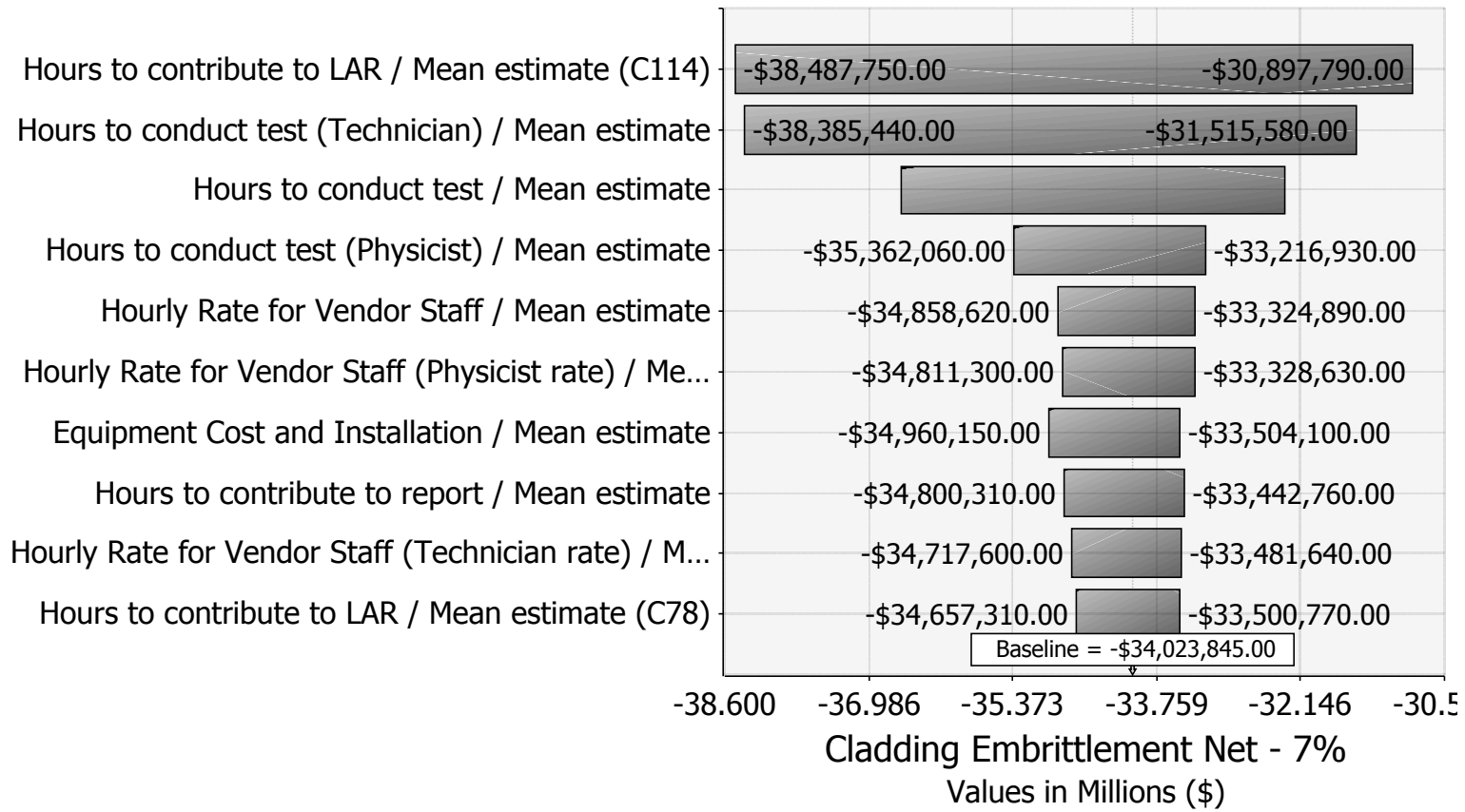


Figure 16 Top ten variables where uncertainty drives the largest impact on cladding embrittlement costs (7% NPV) Alternative 2