PRELIMINARY DRAFT

Public availability of this draft document is intended to inform stakeholders of the current status of the NRC staff's preliminary draft final rule package and associated documents for § 50.46c of Title 10 of the Code of Federal Regulations (10 CFR). These preliminary draft documents are in support of an October 22, 2015, Category 3 public meeting, and a November 2, 2015, Advisory Committee on Reactor Safeguards (ACRS) subcommittee meeting.

This draft document has not been subject to all levels of NRC management review. Accordingly, it is incomplete and may be in error in one or more respects. The document may be subject to further revision before the staff provides the final draft rule language package to the Commission (currently scheduled to be provided to the Commission in February 2016). In particular, the preliminary draft language in paragraph (e), ***Alternate risk-informed approach for addressing the effects of debris on long term core cooling****, is under current staff discussion with respect to the manner in which the risk-informed alternative may be used in the initial NRC approval of new reactor designs, and for modifications of both new reactor designs and currently operating nuclear power reactors.*

FOR: The Commissioners

FROM: Victor M. McCree
Executive Director for Operations

SUBJECT: FINAL DRAFT RULEMAKING – 10 CFR 50.46c: EMERGENCY CORE COOLING SYSTEM PERFORMANCE DURING LOSS-OF-COOLANT ACCIDENTS (RIN 3150-AH42)

PURPOSE:

To obtain Commission approval to publish a draft final rule (final rule) that amends the U.S. Nuclear Regulatory Commission's (NRC's) current requirements governing emergency core cooling systems (ECCS), which are set forth in § 50.46 of Title 10 of the *Code of Federal Regulations* (10 CFR).

SUMMARY:

The staff has prepared a draft final rule (Enclosure 1) that replaces the current regulations for ECCS, found in 10 CFR § 50.46, by establishing performance-based requirements. The final rule incorporates recent research findings that identified previously unknown cladding embrittlement mechanisms and expanded the NRC's knowledge of previously identified mechanisms. The final rule also expands applicability of ECCS acceptance criteria to all light water reactors, regardless of fuel design or cladding materials (in response to Commission direction and petition for rulemaking (PRM) PRM-50-71). Additionally, the final rule requires licensees to evaluate the thermal effects of crud and oxide layers that may have developed on the fuel cladding during normal operation (this requirement addresses PRM-50-84).

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Finally, the draft final rule provides a provision that allows licensees to use a risk-informed alternative to address the effects of debris in the long-term.

The NRC research program identified that zirconium-based fuel cladding materials may be subject to embrittlement at a lower combination of temperature and level of oxygen absorption than currently allowed under the current regulations due to absorption of hydrogen during normal operation. Therefore, under the current regulations, post quench ductility (which is necessary to ensure coolable core geometry)[1] is not assured following a postulated loss-of-coolant accident (LOCA). The portion of the final rule addressing post quench ductility is necessary to ensure adequate protection to the public health and safety. The final rule effectively maintains the level of protection (i.e., reasonable assurance of adequate protection) that the NRC thought was achieved (throughout the entire term of licensed operation) by the current regulations, but new research shows is not necessarily the case. The other portions of the final rule - establishing technology neutral, performance based and risk informed requirements for ECCS and the fuel system - would replace the current deterministic requirements. The current deterministic requirements are considered to be necessary for adequate protection.[2] Therefore, the new § 50.46c requirements, upon transition and, as applicable after NRC approval of the risk-informed alternative, will also be regarded as adequate protection. Finally, the portion of the rule which sets forth a voluntary alternative for risk-informed consideration of debris during long-term cooling, addresses a matter of adequate protection. For these reasons, the final rule is described as addressing adequate protection to the health and safety of the public, and that a backfit analysis need not be prepared under the adequate protection exception in 10 CFR § 50.109(a)(4)(ii). In addition, the applicability and implementation approach as applied to Part 52 licenses and regulatory approvals is such that there is no violation or inconsistency with any issue finality provision in Part 52. This is consistent with past Commission direction on this rulemaking (SRM-SECY-12-0034, "Proposed Rulemaking – 10 CFR 50.46c: Emergency Core Cooling System Performance During Loss-of-Coolant Accidents (RIN 3150-AH42), dated January 7, 2013).

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 (Agencywide Documents Access and Management System (ADAMS) Accession No. ML992870048), the NRC began to explore approaches to risk-informing its regulations for nuclear power reactors. The industry identified two regulations that would benefit from risk-informed changes: 10 CFR 50.44 and

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[1] The Commission concluded, as part of the 1973 ECCS rulemaking, that retention of ductility in the zircaloy cladding material was determined to be the best guarantee of its remaining intact during the hypothetical LOCA, 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).

[2] As the staff discussed in Attachment 3 to SECY-13-0132, many of the NRC's technical safety requirements were adopted without a clear statement as to their character as needed for adequate protection, or adopted as a safety enhancement. The emergency core cooling system requirements in 10 CFR § 50.46, originally adopted in an on-the-record rulemaking in 1974, is an example where one can strongly infer that the regulation was regarded as an adequate protection measure, but where no express AEC statement to that effect can be identified in the rulemaking record.

50.46. On March 23, 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),'" 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 a number of specific areas. Included in this SRM was the direction to the staff to modify the ECCS acceptance criteria to provide for a performance-based approach to meeting the ECCS requirements in 10 CFR 50.46.

Additionally, on March 14, 2000, as amended on April 12, 2000, the Nuclear Energy Institute (NEI) submitted a PRM (ADAMS Accession No. ML010880245), docketed as PRM-50-71 (65 FR 34599), requesting that the NRC amend its regulations in 10 CFR 50.44 and 50.46 to expand the applicability of these regulations beyond the two zirconium-based fuel claddings identified in the regulations (zircaloy and ZIRLO™). The petition noted that these two regulations apply only to zircaloy and ZIRLO™, but that reactor fuel vendors had developed new cladding materials other than the two acknowledged by the regulations, and that in order for licensees to use these new materials under the existing regulations, licensees had to request NRC approval of exemptions from 10 CFR 50.44 and 50.46.

Separately from the Commission's efforts to modify its regulations to provide a more risk-informed, performance-based regulatory approach, the NRC had also undertaken a fuel cladding research program intended to investigate the behavior of high exposure fuel cladding under accident conditions. 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 this research program. The research identified new cladding embrittlement mechanisms and expanded the NRC's knowledge of previously identified mechanisms. One of the major findings of the research program was that hydrogen, which is absorbed in the cladding during normal operation, has a significant influence on the embrittlement during a postulated LOCA. The 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).

On March 15, 2007, Mark Leyse submitted a PRM to the NRC (PRM-50-84, ADAMS Accession No. ML070871368). The petitioner requested rulemaking in three specific areas, including the consideration of the thermal effects of crud and oxide layers and the inclusion of a maximum allowable percentage of hydrogen content in [fuel rod] cladding. A notice of receipt for the petition was published in the *Federal Register* on May 12, 2007 (72 FR 28902), and public comments were requested. After evaluating the public comments, the NRC resolved the petition by deciding that each of the petitioner's issues should be considered in the rulemaking process. This decision was published in the *Federal Register* on November 25, 2008 (73 FR 71564).

The technical basis for this rulemaking was published for public comment in the *Federal Register* on July 31, 2008 (73 FR 44778). Comments received can be found at http://www.regulations.gov by searching on Docket ID NRC-2008-0332. On August 13, 2009, the NRC published an Advance Notice of Proposed Rulemaking (ANPR). The NRC received a total of 19 comment submissions during the ANPR's public comment period. As a result of these comments, the NRC made a number of changes to the proposed rule and provided the

proposed rule to the Commission for vote in SECY-12-0034, "Proposed Rulemaking – 10 CFR 50.46c: Emergency Core Cooling System Performance During Loss-of-Coolant Accidents (RIN 3150-AH42)," dated March 19, 2012. The Commission approved publication of the proposed rule and provided additional direction on January 7, 2013.

Of note, the staff was directed to include in the proposed rule a provision that allows NRC licensees, on a case-by-case basis, to use risk-informed alternatives to assess the impact of debris on long term core cooling. This would allow some licensees to use risk-informed approaches to address GSI-191 without the need for exemptions from 10 CFR 50.46 or the general design criteria (GDC) that pertain to ECCS and containment spray performance (i.e., GDCs 35, 38, and 41).

On March 24, 2014, the NRC published the proposed rule and three associated draft regulatory guides for comment (79 FR 16106). These draft regulatory guides (DG) were as follows: 1) "Conducting Periodic Testing for Breakaway Oxidation Behavior" (ADAMS Accession No. ML110840089); 2) "Testing for Post Quench Ductility" (ADAMS Accession No. ML110840283); and 3) "Establishing Analytical Limits for Zirconium-Based Alloy Cladding" (ADAMS Accession No. ML110871607). The draft guidance for implementing a risk-informed alternative was not published for comment concurrent with the rule (per Commission's approval). The staff developed this guidance in parallel with its review of the South Texas Project pilot submittal, and published the guidance, "Alternate Risk-Informed Approach for Addressing the Effects of Debris on Post-Accident Long-Term Cooling," (ADAMS Accession No. ML15023A022), for comment on April 20, 2015 (75 FR 21658). The staff intends to publish all final guidance concurrent with the final rule.

The public comment periods for the proposed rule and draft regulatory guides provided interested stakeholders an opportunity to comment on the draft preliminary provisions under consideration by the NRC. In addition, the NRC sought comment on 12 specific questions. The comment period was originally 75 days and was subsequently expanded to 150 days in response to multiple extension requests. During the public comment period, the NRC hosted several public meetings to facilitate development of public comments. On April 29-30, 2014, the NRC conducted a public meeting to provide an overview of the proposed rule. On June 24-26, 2014, the NRC conducted an additional public meeting to further discuss the proposed rule and draft regulatory guides. During this meeting, members of the nuclear industry provided presentations on various aspects of the rule. Additionally, Mr. Mark Leyse provided a presentation related to PRM-50-84. On July 23, 2014, the NRC conducted a meeting to discuss topics specific to boiling water reactors (BWR). The comment periods for the proposed rule and three draft regulatory guides closed on August 21, 2015. The NRC received 36 comment submissions; 17 were from private citizens, and 19 were from the nuclear industry. Enclosure 2 provides a detailed breakdown and analysis of the comments.

Operating Plant Safety

In response to the research findings in RIL-0801, "Technical Basis for Revision of Embrittlement Criteria in 10 CFR 50.46", the NRC performed a preliminary safety assessment of currently operating reactors (ADAMS Accession No. ML081620302 (Proprietary), ML090340073 (Non-Proprietary)). This assessment found that, due to cladding performance measured during the NRC's LOCA research program, realistic fuel rod power history, and current analytical

conservatisms, sufficient safety margin to the proposed new requirements exists for operating reactors. Therefore, the staff determined that immediate regulatory action was not required, and that changes to the ECCS acceptance criteria to account for these new findings can reasonably be addressed through the rulemaking process.

Recognizing that finalization and implementation of the new ECCS requirements would take several years, the staff decided that a more detailed safety assessment was necessary. As a voluntary industry effort and alternative to responding to an NRC request for information under 10 CFR 50.54(f), the Pressurized Water Reactor (PWR) Owners Group (OG) (ADAMS Accession No. ML11139A309) and BWROG (ADAMS Accession No. ML111950139), under the auspices of NEI, submitted ECCS margin assessment reports. After grouping plants based on similar design features, cladding alloys, or evaluation models and defining cladding alloy-specific analytical limits, the OG reports identified, where necessary, analytical credits or performed new LOCA analyses to demonstrate that the limiting plant within each grouping had positive margin relative to the proposed new requirements. The NRC conducted an audit of the OG reports and supporting General Electric – Hitachi, AREVA, and Westinghouse engineering calculations. Based on the OG reports and supplemental information collected during the audits, the staff was able to confirm and document, for every operating reactor, current safe operation. In other words, in the unlikely event that an actual LOCA had occurred at any operating reactor, there is a level of assurance that the ECCS would have performed in an acceptable manner (relative to the new requirements) and a coolable core geometry would have been maintained. This conclusion is partly based on analyses that may not contain the level of conservatism or precision inherent in currently approved models and methods.

As documented in the audit report and safety assessment ("ECCS Performance Safety Assessment and Audit Report," dated February 10, 2012 (ADAMS Accession No. ML12041A078)), the NRC intends to verify, on an annual basis, continued safe operation until each licensee has implemented the new ECCS requirements. Updates to the ECCS safety assessment for 2013, 2014, and 2015 are available in ADAMS Accession Nos. ML14022A161 ML14358A493, and (PLACEHOLDER) respectively.

While the updated safety assessment provides a level of assurance that no imminent safety concern exists for operating reactors, licensees should be required by regulation to demonstrate acceptable ECCS performance.

DISCUSSION:

The draft final rule establishes a performance-based rule governing ECCS performance for light water nuclear power reactors (LWR), regardless of fuel design or cladding material. This represents a significant change from the current ECCS regulations, which apply to "uranium oxide pellets within cylindrical zircaloy or ZIRLO™ cladding." Because ECCS requirements must be expressed independent of fuel type, and because ECCS performance ultimately must be based upon maintaining the fuel used in a safe (analyzed) condition, the new rule separates the ECCS requirements from the need for the applicant/licensee to establish the *fuel system design performance criteria* constituting a safe condition.

In the draft final 10 CFR 50.46c, the specified performance objectives of the systems, structures, and components of the ECCS are to provide residual heat removal during and

following a postulated LOCA. As with the current regulations, proposed § 50.46c requires demonstrating adequate ECCS performance using acceptable evaluation models. Specific performance objectives and analytical limits, which account for recent research findings, have been established for fuel designs consisting of uranium oxide or mixed uranium-plutonium oxide pellets within zirconium cladding alloys. For other fuel designs, new performance objectives and analytical limits may be necessary. Such objectives and limits would need to take into consideration all degradation mechanisms and any unique performance features of the particular fuel system. Additionally, the rule provides a provision that would allow an entity to use a risk-informed approach to address the effects of debris on long-term cooling.

The draft final rule follows the general regulatory approach of the existing regulations, yet it establishes non-prescriptive, performance-based regulatory language for demonstrating acceptable ECCS performance and determining the fuel performance characteristics. In addition, the embrittlement criteria in the current regulations for fuel with zirconium-based cladding continue to be acceptable (although incomplete, as discussed below). Therefore, the draft final rule retains the existing acceptance criteria (located in § 50.46(b)(1) through (3)) for fuel with zirconium-based cladding, including the 2200 °F peak cladding temperature limit as well as limitations on core-wide oxidation and hydrogen generation.

The organization and CFR designations of the NRC's requirements governing ECCS (currently in 10 CFR § 50.46) and reactor cooling venting systems (currently in 10 CFR § 50.46a) are expected to change, as a result of: 1) ongoing rulemaking activities; 2) the implementation schedule for those activities; and 3) the need to maintain the current requirements in place for those licensees that have not transitioned to the new requirements (following the implementation schedule provided in the draft final rule). A detailed description of the transition of 10 CFR designations is provided in Section VI, "Section by Section Analysis," of the Federal Register notice (FRN) for the proposed rule.

The following table provides a summary of the major changes from 10 CFR 50.46 to the draft final 10 CFR 50.46c; these changes are further discussed in the text below.

Category	Item	§ 50.46	§ 50.46c
Overall ECCS Methodology	Rule Structure	Prescriptive	Performance-Based
	Applicability	Zircaloy or ZIRLO Cladding	All LWR Cladding
	Burnup Related Phenomena	None	Cladding Inner Surface Oxygen Ingress
	Corrosion Related Phenomena	None	Hydrogen-Enhanced Embrittlement
	Fabrication Related Phenomena	None	Breakaway Oxidation
	Debris Consideration	Implicit	Explicit
	LTC Regulatory Criteria	General	Explicit

	Crud Treatment	None	Explicit
Risk-Informed Alternative to Address the Effects of Debris on Long-Term Cooling	Risk-informed Debris Treatment	N/A	Allowed

Applicability and NEI PRM

The draft final rule is applicable to applicants for and holders of construction permits, operating licenses, combined licenses and standard design approvals and for applicants for certified designs and for manufacturing licenses. The only exception to the applicability of the rule is for any licensee that has submitted certifications for permanent cessation of operations and permanent removal of fuel from the reactor vessel, in accordance with 10 CFR 50.82(a)(1) or 52.11(a)(1).

The draft final rule also expands the applicability of the rule and addresses PRM-50-71 submitted by NEI in 2000 (ADAMS Accession No. ML010880245) by removing the terms "zircaloy" and "ZIRLO™" from § 50.46. This eliminates the need for a licensee to seek an exemption to use cladding alloys other than zircaloy or ZIRLO™, thereby facilitating the introduction of advanced zirconium-based alloy claddings.

The applicability of this draft final rule is largely unchanged from the proposed rule stage, but has been revised to clarify that the rule applies to certain applicants, and applies to renewals of Part 50 operating licenses, renewals of Part 52 combined licenses, and renewals of manufacturing licenses.

ECCS Performance Criteria

The current ECCS rule is specific to uranium oxide pellets within cylindrical zircaloy or ZIRLO™ cladding and therefore, the current rule does not provide specific performance objectives for the ECCS. In draft final 10 CFR 50.46c, the specified performance objectives of the systems, structures, and components of the ECCS are to provide residual heat removal during and following a postulated LOCA. This aspect of the draft final rule is unchanged from the proposed rule stage.

Risk-Informed Alternative to Address the Effects of Debris on Long-Term Cooling

The draft final rule contains a provision that would allow licensees to use an alternative, risk-informed approach to evaluate the effects of debris on long-term cooling. Use of the alternative approach must be requested by a licensee and approved by the NRC. The draft final rule contains acceptance criteria that apply to the risk-informed approach. The rule also specifies the content required for applications requesting to implement the alternative approach. NRC approval of a risk-informed approach would allow the entity to exclude the effects of debris in its analysis of long-term cooling as required in paragraph (d)(1)(ii) of § 50.46c. The NRC does not intend for this approach to be used to justify the use of problematic debris sources in new designs, including new reactors or plant modifications made by licensees. Similar to Generic Safety Issue (GSI)-191, the NRC intends to approve use of the alternative risk-informed

approach only in cases where (1) an issue emerges that could not have been readily foreseen during the design or implementation processes and where (2) removal of such debris could pose an undue burden not justified by the risk posed by the debris.

Based on public comments, the staff revised the description of the risk-informed approach by reorganizing it for greater clarity, including an explicit requirement for a monitoring program, and adding a requirement for a quality assurance program.

Zirconium-clad Uranium Fuel Assemblies

The existing ECCS performance rule applies specifically to uranium oxide pellets within cylindrical zircaloy or ZIRLO™ cladding. The existing rule also requires, among other things, that (1) the peak cladding temperature remain below 2200 °F, and (2) the calculated total oxidation of the cladding nowhere exceed 0.17 times the total cladding thickness before oxidation. The latter requirement was established to prevent cladding embrittlement. While the findings from the fuel cladding research program confirmed that the peak cladding temperatures should remain below 2200 °F, the findings also showed that more highly exposured fuel can embrittle at total calculated oxidation levels less than 17 percent. In the draft final rule, the objectives and methodology for evaluating ECCS performance for uranium oxide or mixed uranium-plutonium oxide pellets within cylindrical zirconium-alloy cladding remain largely the same as the existing ECCS performance regulations. However, the criteria in the existing ECCS performance regulations are technically appropriate only to zirconium-based cladding. The draft final rule provides a technology-neutral, performance-based approach for developing design-specific criteria which account for the effects of exposure.

<u>Post-Quench Ductility Performance Requirement</u>

General

For uranium oxide or mixed uranium-plutonium oxide pellets within cylindrical zirconium-alloy cladding, the draft final rule requires analytical limits for peak cladding temperature and integral time-at-temperature to be developed that account for the effects of exposure. A Regulatory Guide (RG) was developed to provide a test method to measure embrittlement behavior for zirconium alloys. Another RG was developed to provide a method for using test data to develop and support analytical limits for peak cladding temperature and integral time-at-temperature that account for the effects of exposure. This requirement is substantively unchanged from the proposed rule. There were few comments on this part of the proposed rule, and no comments that the NRC accepted.

Testing requirement as applied to future design certifications

In developing the draft final rule, the staff determined that design certification applicants, specifically those expected concurrent with the implementation of the 10 CFR 50.46c final rule, could be impacted by the timing of cladding tests required by the rule. (For instance, the staff is aware that NuScale expects to submit its design certification application in late CY 2016.) While this impact could be mitigated through the exemption process, the staff plans to further explore whether such a problem is better addressed by guidance.

However, the staff maintains its recommendation that the draft final rule be published as provided in Enclosure 1. This adequate protection rulemaking is the culmination of a multi-year

effort and should be issued as soon as possible to maintain adequate protection of the operating fleet (i.e., without the delay caused by the staff's exploration of this issue related to a much smaller set of entities (i.e., design certification applicants)).

Breakaway Oxidation Performance Requirement

The findings of the NRC's fuel cladding research program also developed significant understanding of a phenomenon termed "breakaway oxidation" which is not addressed with the existing ECCS performance regulations. The draft final rule requires an analytical limit to prevent breakaway oxidation under postulated LOCA conditions. This requirement, along with a periodic test requirement, would confirm that slight composition changes or manufacturing changes have not inadvertently altered the cladding's susceptibility to oxidation. A RG was developed to provide a test method for measuring breakaway oxidation behavior. The requirement to establish a breakaway oxidation analytical limit has not changed from the proposed rule; however, the testing and reporting requirements have changed. In the proposed rule, there was a requirement to report the results of periodic testing to the NRC on an annual basis. In the proposed rule FRN, the NRC requested comment on the type of data that should be reported and the required frequency of testing for breakaway oxidation. The NRC received many comments on this part of the rule. The commenters generally expressed views that the sample frequency should be reduced and be more flexible. The NRC agreed that the objective of the rule can be achieved with rule language that requires a fuel vendor to submit breakaway oxidation testing program for NRC review and approval and that the requirement for licensees to report breakaway oxidation results could be removed. The NRC changed the rule and associated RG as a result of these comments.

Applicability of Ductility-Based Analytical Limits in the Rupture Region

During a postulated LOCA, fuel rods may be predicted to balloon and rupture as a result of elevated cladding temperature and differential pressure (i.e., difference between rod internal pressure and system pressure, which is decreasing due to a break in the reactor coolant pressure boundary). While it is typical for undistorted fuel rods to undergo oxygen diffusion embrittlement under LOCA conditions, a ballooned or ruptured section of a fuel rod may experience additional degradation mechanisms. These mechanisms include significant amounts of hydrogen uptake from steam entering the fuel rod through the rupture. The RG developed to support implementation of this performance-based rule provides a test method to measure embrittlement behavior for zirconium alloys that uses uniform, unflawed cladding segments, and these measurements may not fully represent the region of the fuel rod surrounding the cladding rupture. Furthermore, the overall goal of preserving cladding ductility may not apply to ballooned or ruptured fuel, which may contain non-uniform distributions of flaws, cladding thickness, hydrogen distribution, and oxidation levels.

The current rule explicitly prescribes how to calculate the equivalent cladding reacted in ballooned and ruptured regions of fuel rods. In the proposed rule, this prescription was removed from the rule language. The NRC developed an RG describing an acceptable approach for evaluating post-quench ductility for the ballooned region. The NRC did not receive any comments on this part of the proposed rule. Therefore, this approach is reflected in the draft final rule and final RG.

Long-Term Cooling Performance Requirement

The draft final rule requires licensees to demonstrate that the long-term ECCS recirculation coolant delivery to the core exceeds the minimum flow necessary to remove decay heat loads such that core temperature tends to decline, or for cases where debris loading interferes with coolant delivery and prompts a post-quench reheat transient, the entity must demonstrate that no further fuel cladding failure occurs. If an entity predicts a debris-induced, post-quench reheat transient that could reasonably result in further cladding failure, the entity would need to conduct research on post-quench fuel specimens. The purpose of the additional research would be to: (1) identify all degradation mechanisms, all cladding failure modes, and any unique features of fuel rod performance during the predicted long-term temperature history and, (2) establish analytical limits and analytical requirements that demonstrate no further fuel cladding failure occurs.

The draft final rule requirement regarding long-term cooling (LTC) has evolved relative to the proposed rule. The proposed rule introduced a new requirement in 10 CFR 50.46c(g)(1)(v), which stipulated that a LTC peak cladding temperature analytical limit be established, which preserved cladding ductility based upon an NRC approved test program. In the proposed rule package, the NRC requested input regarding this new performance requirement to determine (1) if cladding ductility was the most suitable performance-based metric, (2) if peak cladding temperature was the most suitable analytical limit, and (3) if a technical bases existed for long-term cladding performance. No commenter supported the proposed new requirement. Several commenters questioned whether cladding ductility was the most appropriate performance-based metric. These commenters noted that different cladding degradation mechanisms may exist at different post-quench temperature regimes. Several commenters questioned the use of a single analytical limit on PCT noting that time-at-temperature may be more appropriate to capture the degradation mechanisms. No commenter identified an existing technical basis for long-term, post-quench fuel performance. Several commenters requested that the existing 50.46 rule language be maintained. In the absence of a debris-induced post-quench reheat transient, the staff has determined that (1) currently approved analytical models and methods continue to be acceptable and (2) no further fuel testing and analysis is required to satisfy the more explicit performance requirement discussed in Enclosure 1.

Crud and Oxide Layer Analytical Requirement:

The draft final rule addresses PRM-50-84 submitted by Mr. Mark Leyse by requiring, in explicit terms, licensees to evaluate the thermal effects of crud and oxide layers that accumulate on the fuel cladding during plant operation. This requirement remains unchanged from the proposed rule.

Reporting and Corrective Action Requirements

The draft final rule clarifies the existing reporting and corrective action requirements in order to resolve recurring issues involving the interpretation of the current regulations' requirements. The draft final rule distinguishes three possible combinations of reporting criteria based upon predicted response, level of significance (i.e., significant or not significant, as defined by the proposed rule), and whether the error, change or operation would result in any exceeded acceptance criteria. For each scenario, the proposed rule provides the required actions,

reports, and a time frame for providing the necessary reports. Additionally, some of the requirements apply to all entities subject to 10 CFR 50.46c; others apply to those entities demonstrating acceptable long-term cooling using the alternative risk-informed approach. Section III, "Discussion: Requirements for ECCS Performance during LOCAs," of Enclosure 1 describes the three scenarios, and requirements for each, in detail.

Presently, the reporting requirements in 10 CFR 50.46(a)(3) require that licensees report changes to or errors in an ECCS evaluation model, or in the application of the evaluation model, and the estimated effect of the changes or errors on predicted peak cladding temperature. The draft final rule expands the definition of a significant change or error to include integral time-at-temperature. The NRC made this change to improve the content and communications of reports submitted to the NRC. The NRC also made this change to inform the staff's response to future changes to or errors discovered in ECCS evaluation models, or in the applications thereof.

Many comments were received on Paragraph (m) corrective actions and reporting requirements. Based on these comments, the rule was modified to improve clarity and allow 60 days for reporting significant errors or changes that do not cause acceptance criteria to be exceeded.

Implementation

The proposed 10 CFR 50.46c rule included a 3-track implementation plan with codified plant assignments. The goal of this proposed approach was to manage the workload with consideration of available ECCS performance margin and the anticipated work scope on both the agency and the industry, given the limited vendor resources. Comments received from the industry emphasized a desire for greater flexibility and identified an alternative plan, which eliminated the track assignments from the rule. The staff held multiple public meetings on implementation to discuss the industry's plan and identify a strategy to manage the workload related to implementation on a defined schedule. As a result of these comments and public meetings, the staff revised this aspect of the rule language by requiring licensees to submit an implementation plan within 180 days of the effective date of the rule. Schedule requirements have been established within the rule for: (1) submitting a license amendment request documenting compliance and (2) complying with the rule. Licensees must be in compliance with 10 CFR 50.46c no later than 84 months after the effective date of the rule. This prolonged implementation period is justifiable based on the ECCS performance safety assessment that is being maintained by the staff, and which shows positive margin to the proposed regulations for each plant in the fleet. Additionally, the statements of consideration (SOC) clarifies resolution of debris issues (e.g., GSI-191), whether by deterministic or risk-informed approach, is being addressed outside of the 10 CFR 50.46c implementation schedule. The implementation provisions in paragraph (p) of the final rule have also been re-written and expanded to clarify the compliance path for each type of applicants, licensee and regulatory approval.

Cumulative Effects of Regulation

The staff has fully engaged external stakeholders throughout this rulemaking, beginning with the publication of an Advance Notice of Proposed Rulemaking (ANPR) on August 12, 2009 (74 FR 40767). The ANPR provided interested stakeholders an opportunity to comment on the

options under consideration by the NRC during a formal, 75-day public comment period. In addition, the NRC requested public comments on 12 questions in the following categories: Applicability Considerations, New Embrittlement Criteria Considerations, Testing Considerations, Revised Reporting Requirements Considerations, Crud Analysis Considerations, and Cost Considerations.

In developing the proposed § 50.46c rule, the NRC had public interaction in areas related to possible implementation approaches for this rule. A two-day public workshop was conducted on April 28-29, 2010, during which the draft proposed rule language, NRC staff responses to major comments on the ANPR were discussed. In addition, possible bases for an NRC confirmation of current plant safety pending a final rule were discussed. The summary of this public workshop can be found under ADAMS Accession No. ML101300490.

To address the cumulative effects of regulation, the FRN for the proposed rule included a request for specific comment on the cost estimates provided in the Regulatory Analysis, implementation schedule, and potential unintended consequences of the proposed rule.

The staff published DGs along with the proposed rule, as discussed in the "Background" of this document. The availability of these DGs was necessary and essential to the implementation of the proposed, performance-based requirements because they provide guidance on the new provisions of the proposed rule; the availability of these DGs meets the intent of SRM-SECY-11-0032, "Consideration of the Cumulative Effects of Regulation in the Rulemaking Process," dated October 11, 2011.

After the close of the formal period for submission of public comments on the proposed rule, the NRC conducted six public meetings continue dialogue with stakeholders on key issues, and facilitate development of the draft final rule. On March 17-19, 2015, the NRC conducted a public meeting to seek clarification regarding comments previously received on implementation and the regulatory analysis associated with the proposed rule. As a result of this public meeting, the NRC held a series of three follow-on public meetings to further discuss a draft preliminary implementation plan that would represent an alternative to that in the proposed rule. These follow-on meetings were held on April 23, 2015, May 7, 2015, and June 4, 2015. Additionally, on April 29-30, 2015, the NRC conducted a public meeting at Oak Ridge National Laboratory to discuss specific comments received on the DGs referenced above. On June 9, 2015, the NRC conducted a public meeting to discuss the long-term cooling provision in the proposed rule.

In addition to publishing the new regulatory guides, the staff has also identified existing guidance[3] that may need to be updated to "conform" the guidance to the draft final requirements (e.g., to add references to specific paragraphs of the draft final rule, add new discussion which

[3] This guidance includes: Regulatory Guide (RG) 1.157, "Best Estimate ECCS Calculations," RG-1.203, "Transient and Accident Analysis Methods," Standard Review Plan (SRP) 4.2, "Fuel System Design," SRP 4.4, "Thermal and Hydraulic Design," SRP 6.2.1, "Containment Functional Design," SRP 6.3, "Emergency Core Cooling System," SRP 15.0, "Transient and Accident Analyses," SRP 15.02, "Review of Transient and Accident Analyses Methods," and SRP 15.6.5, "Loss-of-Coolant Accidents Resulting from Spectrum of Postulated Piping Breaks Within the Reactor Coolant Pressure Boundary."

explain how the current rule's provisions and existing guidance relate to the new requirements in the draft final rule). The conforming changes, while they would be desirable to ensure that all guidance documents represent a complete, integrated set of guidance on ECCS requirements in 10 CFR §§ 50.46, 50.46a and 50.46c, are not needed to provide guidance to licensees on how to comply with the draft final rule. Because of the resources and scope of effort required to revise this guidance which is not needed to implement the final § 50.46c, the staff has determined that it would not be prudent to revise these supporting guidance until the Commission has approved the final rule and primary implementing guidance.

Fuel Fragmentation, Relocation, and Dispersal

The staff previously advised the Commission regarding fuel fragmentation, relocation, and dispersal phenomena in SECY-12-0034. In response to SRM-SECY-12-0034, the staff has recently provided the Commission with SECY-15-XXXX, which explains the current status of NRC research on these phenomena and why this 50.46c rulemaking may proceed without concern that they will be revised based on the anticipated research.

RECOMMENDATIONS:

The staff recommends that the Commission:

(1) Approve the enclosed draft final rule (Enclosure 1) for publication in the *Federal Register*.

(2) Note the following:

a. The staff has prepared a regulatory analysis for this rulemaking (Enclosure 3).

b. The staff will publish four RGs concurrent with the publication of the draft final rule.

c. The staff will inform the appropriate congressional committees.

d. The Office of Public Affairs will issue a press release when the NRC publishes the final rule in the *Federal Register*.

COORDINATION:

This paper has been prepared by NRR. The Office of the General Counsel has no legal objection to this SECY paper and rulemaking package.

Coordination with Advisory Committee on Reactor Safeguards

Since 2002, the NRC has met with the Advisory Committee on Reactor Safeguards (ACRS) multiple times to discuss the progress of the LOCA research program. A table that lists the dates and ADAMS accession numbers of the relevant ACRS meetings and associated correspondence is located in Section III, "Opportunities for Public Participation," of the FRN for the draft final rule Enclosure 1.

Victor M. McCree
Executive Director
for Operations

Enclosures:
1. *Federal Register* notice
2. Public Comment Responses
3. Regulatory Analysis