ECCS Long-Term Cooling Performance Requirement

Public availability of this draft document is intended to inform stakeholders of the current status of the NRC staff's preliminary draft rule language regarding long-term cooling in the § 50.46c of Title 10 of the Code of Federal Regulations (10 CFR) proposed rule and associated Statement of Considerations (SOC). The NRC staff believes that making this information public before an NRC public meeting will allow stakeholders to review the material in advance and facilitate more constructive and informed discussion during the meeting.

This draft document has not been subject to all levels of NRC management review. Accordingly, it may be incomplete or in error in one or more respects and 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).

II. Revised SOC and Rule Language

V. Proposed Requirements for ECCS Performance during LOCAs

B. Performance-Based Aspects of the Proposed Rule

5. Long-Term Cooling

Background

General Design Criteria 35, "Emergency core cooling," established the following principal ECCS design requirements:

> The system safety function shall be to transfer heat from the reactor core following any loss of reactor coolant at a rate such that (1) fuel and clad damage that could interfere with continued effective core cooling is prevented and (2) clad metal-water reaction is limited to negligible amounts.

The first requirement limits the degree of core damage to ensure "continued effective core cooling" is maintained for the long-term period required to remove decay heat. This requirement stems from an Advisory Task Force on Power Reactor Emergency Cooling, which back in 1967 concluded that:

> "The analysis of (a LOCA) requires that the core be maintained in place and essentially intact to preserve the heat-transfer area and coolant-flow geometry. Without preservation of heat-transfer area and coolant-flow geometry, fuel-element melting and core disassembly would be expected... Continuity of emergency core cooling must be maintained after termination of the temperature transient for an indefinite period until the heat generation decays to an insignificant level, or until disposition of the core is made."[1]

This conclusion highlights the importance of preserving the heat-transfer area and coolant-flow geometry over the extended period of the accident.

[1] Report of Advisory Task Force on Power Reactor Emergency Cooling, TID-24226, 1967.

During the 1973 rulemaking hearing, the AEC wrote:

> "In view of the fundamental and historical importance of maintaining core coolability, we retain this criterion as a basic objective, in a more general form than it appeared in the Interim Acceptance Criteria. It is not controversial as a criterion... Although most of the attention of the ECCS hearings has been focused on the events of the first few minutes after a postulated major cooling line break, up to the time that the cladding would be cooled to a temperature of 300°F or less, the long term maintenance of cooling would be equally important."[2]

The result of the hearing was the current regulation in § 50.46(b)(5) that requires that for long-term cooling the calculated core temperature be maintained at an acceptably low value following any calculated successful initial operation of the ECCS. It also requires that decay heat be removed for the extended period of time required by the long-lived radioactivity remaining in the core.

Commercial nuclear power plants have demonstrated compliance to these generalized requirements using numerous analytical techniques to evaluate core thermal and hydraulic behavior (e.g., core remains covered with a two-phase mixture while predicted recirculation flow exceeds heat removal flow requirements for decay heat) and to identify timing for boric acid precipitation to establish timely operator actions to preclude such precipitation (e.g., redirect injection to prevent boron precipitation for large breaks and cooldown initiated to control boric acid for small breaks). The staff has found these approaches acceptable for decades.

As described below, debris may interfere with ECCS coolant delivery and promote a temporary, post-quench reheat transient. This phenomenon necessitates more explicit LTC fuel performance goals than the existing generalized requirements. 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 below.

<u>Consideration of Debris</u>

The self-evident and non-controversial label used by the AEC strongly implies that "continued effective core cooling" requires ECCS performance such that core temperatures continue to diminish following the initial quench. Limitations in ECCS capability or phenomena interfering with ECCS coolant delivery which result in a post-quench reheat transient may be interpreted as non-compliance with the long-term cooling requirements. Consideration of debris effects in long-term cooling compliance demonstration will introduce further complexity in the simulation of accident progression and may require additional analytical rigor and operator actions. Recognizing that debris may interfere with ECCS coolant flow delivery, and that this may result in a temporary, post-quench reheat transient, the staff has decided to fortify the generalized requirements to ensure safety by limiting fuel and clad damage that could interfere with

---

[2] Atomic Energy Commission Rule-Making Hearing, Opinion of the Commission, Docket RM-50-1, December 28, 1973.

continued effective core cooling. By minimizing fuel and clad damage during the long-term portion of the accident, the original, high-level performance goals, preservation of adequate fuel cladding heat-transfer and coolant-flow geometry, are maintained.

In the absence of a debris-induced post-quench reheat transient, core geometry will remain stable and any further fuel cladding damage (beyond that experienced during the initial period of accident) would be insignificant. Hence, the current regulation in § 50.46(b)(5) minimizes the release of radioactive nuclides during the long-term period by ensuring continued effective core cooling. Under the current regulation, fuel rods that retained their integrity as a fission product barrier during the initial transient would likely continue to retain their integrity during the long term. The proposed LTC rule language would allow an applicant to predict a post-quench reheat transient during a postulated LOCA, provided the overarching safety goals of preserving a coolable geometry, removing decay heat for the extended period of time required by the long-lived radioactivity remaining in the core, and minimizing the release of fission products are satisfied.

The preservation of fuel cladding heat-transfer involves demonstrating that the fuel pellets continue to reside within the zirconium alloy cladding during the long-term portion of the accident. Preservation of adequate heat-transfer area also requires the prevention or limitation of the deposition of material on the fuel cladding surface. If an applicant calculates a post-quench reheat, they should demonstrate that no further fuel cladding failure occurs, beyond that which may occur during the short-term period. Fuel cladding failure includes, but is not limited to, perforations due to excessive local oxidation, ruptures due to differential pressure, and cladding fragmentation due to loss of ductility. Preserving fuel cladding integrity also satisfies the requirement for minimizing the release of fission products.

As described in Section V.B, a comprehensive research program was completed that identified all known degradation mechanisms and unique features, and it established performance-based objectives and analytical requirements for current fuel designs (i.e., UO2 pellets within cylindrical zirconium alloy cladding). This research program only addressed fuel performance during the initial, short-term period of the accident. If an applicant calculates a debris-induced post-quench reheat, they would need to conduct research on post-quench fuel specimens to (1) identify all degradation mechanisms, 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 which demonstrate no further fuel cladding failure occurs.

The preservation of adequate coolant-flow geometry involves demonstration that the fuel rod bundle array is maintained in a coolable geometry. In addition, preservation of coolant-flow geometry requires that the coolant-flow channels remain open and that the deposition of debris does not adversely affect the coolant flow. If an applicant calculates a post-quench reheat, they should demonstrate that no significant change in coolant-flow geometry occurs, beyond that which may occur during the short-term period. Geometric changes include, but are not limited to, fuel rod ballooning due to differential pressure and blockage caused by debris.

VI. Section-by-Section Analysis

G. Section 50.46c(g)—Fuel System Designs: Uranium Oxide or Mixed Uranium-Plutonium Oxide Pellets Within Cylindrical Zirconium-Alloy Cladding

Paragraph (g)(1)(v) would require that the applicant or licensee demonstrate that no further cladding damage occurs after the initial operation of the ECCS. The performance metric for demonstrating that no further cladding damage will occur is the calculated core temperature. This performance requirement is consistent with the current requirement to “maintain the calculated core temperature at an acceptably low value” in § 50.46(b)(5).

Rule Language:

(g)(1)(v) *Long-term cooling.* After any calculated successful initial operation of the ECCS, no further cladding damage occurs as indicated by the calculated core temperature for the extended period of time required by the long-lived radioactivity remaining in the core. As required by paragraph (d)(1)(ii) of this section, the ECCS must also provide sufficient coolant so that decay heat is removed for the extended period of time required by the long-lived radioactivity remaining in the core.