NOTE: The availability of this draft rule language, as it exists in this document, is intended to inform stakeholders of the current status of the NRC's activities to revise the requirements for emergency core cooling systems to support an upcoming meeting with the Advisory Committee on Reactor Safeguards. The NRC staff is considering restructuring the current Section 50.46 regulation to distinguish ECCS performance requirements (i.e., criteria governing acceptable capability of ECCS to perform its cooling function during and after a design basis LOCA) from fuel/cladding performance requirements (i.e., criteria intended to ensure that the fuel and cladding do not result in prevention of successful cooling during and after a design basis LOCA, and any other effects with adverse impacts on the capability or other safety systems). Additionally, the NRC staff may add new paragraphs to address long standing issues and concerns with the current regulation. As such, this draft rule language may be incomplete or in error in one or more respects, and will be subject to further revisions during the rulemaking process. The NRC is not requesting formal public comments on this draft rule language. The NRC may post updated materials, including updated draft rule language, to this page. Interested stakeholders should periodically check this page for updates and added materials.

Draft Rule Language for 10 CFR 50.46c

§ 50.46c Requirements **for emergency core cooling systems for light-water nuclear power reactors.**

(a) *Applicability*. The requirements of this section apply to each holder of an operating license for any light water nuclear power reactor (LWR), regardless of fuel design or cladding material, except for a licensee who has submitted the certifications required under 10 CFR 50.82(a)(1) to the NRC.

(b) *Definitions*. As used in this section:

(1) *Loss-of-coolant accident (LOCA)* means a hypothetical accident that would result from the loss of reactor coolant, at a rate in excess of the capability of the reactor coolant makeup system, from breaks in pipes in the reactor coolant pressure boundary up to and including a break equivalent in size to the double-ended rupture of the largest pipe in the reactor coolant system.

(2) *Evaluation model* means the calculational framework for evaluating the behavior of the reactor system during a postulated loss-of-coolant accident (LOCA). It includes one or more computer programs and all other information necessary for application of the calculational framework to a specific LOCA, such as mathematical models used, assumptions included in the programs, procedure for treating the program input and output information, specification of those portions of analysis not included in computer programs, values of parameters, and all other information necessary to specify the calculational procedure.

(3) *Breakaway oxidation* means, for the purposes of this section, the fuel cladding oxidation phenomenon in which weight gain rate deviates from normal kinetics. This change occurs with a rapid increase of hydrogen pickup during prolonged exposure to a high temperature steam environment, which promotes loss of cladding ductility

(c) *General performance requirements for any fuel design or cladding material.* Each LWR must be provided with an emergency core cooling system (ECCS) designed so that, when fueled with an acceptable fuel design, the following performance requirements are satisfied in the event of a postulated loss-of-coolant accident (LOCA):

(1) Core geometry remains amenable to cooling;

(2) Generation of combustible gas is limited to the maximum extent practicable;

(3) Core temperature is maintained at a value sufficient to ensure compliance with criteria in paragraphs (c)(1) and (c)(2) of this section;

NOTE: The availability of this draft rule language, as it exists in this document, is intended to inform stakeholders of the current status of the NRC's activities to revise the requirements for emergency core cooling systems to support an upcoming meeting with the Advisory Committee on Reactor Safeguards. The NRC staff is considering restructuring the current Section 50.46 regulation to distinguish ECCS performance requirements (i.e., criteria governing acceptable capability of ECCS to perform its cooling function during and after a design basis LOCA) from fuel/cladding performance requirements (i.e., criteria intended to ensure that the fuel and cladding do not result in prevention of successful cooling during and after a design basis LOCA, and any other effects with adverse impacts on the capability or other safety systems). Additionally, the NRC staff may add new paragraphs to address long standing issues and concerns with the current regulation. As such, this draft rule language may be incomplete or in error in one or more respects, and will be subject to further revisions during the rulemaking process. The NRC is not requesting formal public comments on this draft rule language. The NRC may post updated materials, including updated draft rule language, to this page. Interested stakeholders should periodically check this page for updates and added materials.

(4) Decay heat is removed for the extended period of time required by the long-lived radioactivity remaining in the core.

(5) ECCS cooling performance must be calculated in accordance with an acceptable evaluation model and must be calculated for a number of postulated loss-of-coolant accidents of different sizes, locations, and other properties sufficient to provide assurance that the most severe postulated loss-of-coolant accidents are calculated. The evaluation model must include sufficient supporting justification to show that the analytical technique realistically describes the behavior of the reactor system during a loss-of-coolant accident. Comparisons to applicable experimental data must be made and uncertainties in the analysis method and inputs must be identified and assessed so that the uncertainty in the calculated results can be estimated. This uncertainty must be accounted for, so that when the calculated ECCS cooling performance is compared to the applicable specified and acceptable analytical limits there is a high level of probability that the limits would not be exceeded. Appendix K, Part II Required Documentation, sets forth the documentation requirements for each evaluation model.

(d) Specific *requirements for fuel designs consisting of uranium oxide or mixed uranium-plutonium oxide pellets within zirconium-alloy cladding material.* Each LWR must be provided with an ECCS designed so that, when fueled with an acceptable fuel design consisting of uranium oxide or mixed uranium-plutonium oxide pellets within cylindrical zirconium-alloy cladding, the following performance requirements are satisfied in the event of a postulated LOCA:

(1) *Coolable geometry*. Calculated changes in core geometry shall be such that the core remains amenable to cooling.

(i) *Peak cladding temperature*. Except as provided in paragraph (d)(1)(ii) of this section, the calculated maximum fuel element cladding temperature shall not exceed 2200º F.

(ii) *Cladding embrittlement*. Specified and acceptable analytical limits on peak cladding temperature and time at elevated temperature shall be established which correspond to the measured ductile-to-brittle transition for the zirconium-alloy cladding material based on an acceptable experimental technique. The calculated maximum fuel element temperature and time at elevated temperature shall not exceed the established analytical limits.

If the peak cladding temperature established to preserve cladding ductility is lower than the 2200º F limit specified in (d)(1)(i), then the lower temperature shall be used in place of the 2200º F limit.

iii) *Zirconium fuel cladding oxidation limits.* To ensure that the zirconium-alloy cladding material's susceptibility to breakaway oxidation is beyond the realm of postulated LOCA core temperature excursions, the total accumulated time that the cladding is predicted to remain above a temperature at which the zirconium alloy has been shown to be susceptible to this phenomenon shall not be greater than a specified and acceptable limit which corresponds to the measured onset of breakaway oxidation for the zirconium-alloy cladding material based on an acceptable experimental technique. The onset of breakaway oxidation shall be measured periodically on as-manufactured

NOTE: The availability of this draft rule language, as it exists in this document, is intended to inform stakeholders of the current status of the NRC's activities to revise the requirements for emergency core cooling systems to support an upcoming meeting with the Advisory Committee on Reactor Safeguards. The NRC staff is considering restructuring the current Section 50.46 regulation to distinguish ECCS performance requirements (i.e., criteria governing acceptable capability of ECCS to perform its cooling function during and after a design basis LOCA) from fuel/cladding performance requirements (i.e., criteria intended to ensure that the fuel and cladding do not result in prevention of successful cooling during and after a design basis LOCA, and any other effects with adverse impacts on the capability or other safety systems). Additionally, the NRC staff may add new paragraphs to address long standing issues and concerns with the current regulation. As such, this draft rule language may be incomplete or in error in one or more respects, and will be subject to further revisions during the rulemaking process. The NRC is not requesting formal public comments on this draft rule language. The NRC may post updated materials, including updated draft rule language, to this page. Interested stakeholders should periodically check this page for updates and added materials.

cladding material and any changes in the time to the onset of breakaway oxidation shall be reported at least annually as specified in § 50.4 or § 52.3 of this chapter, as applicable, and shall also be addressed in accordance with § 21.21 of this chapter.

(2) ***Maximum** hydrogen generation*. The calculated total amount of hydrogen generated from the chemical reaction of the cladding with water or steam shall not exceed 0.01 times the hypothetical amount that would be generated if all of the metal in the cladding cylinders surrounding the fuel, excluding the cladding surrounding the plenum volume, were to react.

(3) *Long-term cooling*. After any calculated successful initial operation of the ECCS, the calculated core temperature shall be maintained at an acceptably low value and decay heat shall be removed for the extended period of time required by the long-lived radioactivity remaining in the core.

(4) *Evaluation model*. ECCS cooling performance must be calculated in accordance with an acceptable evaluation model and must be calculated for a number of postulated loss-of-coolant accidents of different sizes, locations, and other properties sufficient to provide assurance that the most severe postulated loss-of-coolant accidents are calculated. Except as provided in paragraph (d)(4)(i) of this section, the evaluation model must include sufficient supporting justification to show that the analytical technique realistically describes the behavior of the reactor system during a loss-of-coolant accident. Comparisons to applicable experimental data must be made and uncertainties in the analysis method and inputs must be identified and assessed so that the uncertainty in the calculated results can be estimated. This uncertainty must be accounted for, so that when the calculated ECCS cooling performance is compared to the analytical limits established in accordance with paragraph (d)(1), (2), and (3) of this section, there is a high level of probability that the limits would not be exceeded. Appendix K, Part II Required Documentation, sets forth the documentation requirements for each evaluation model.

(i) Alternatively, an ECCS evaluation model may be developed in conformance with the required and acceptable features of appendix K ECCS Evaluation Models.

(ii) Oxygen diffusion from the cladding inside surfaces will reduce the allowable time at elevated temperature to embrittlement. If an oxygen source is present on the inside surfaces of the cladding at the onset of the LOCA, the effects of oxygen diffusion from the cladding inside surfaces shall be considered in the evaluation model.

(e) [Reserved]

(f) [Reserved]

(g) [Reserved]

(h) [Reserved]

(i) [Reserved]

NOTE: The availability of this draft rule language, as it exists in this document, is intended to inform stakeholders of the current status of the NRC's activities to revise the requirements for emergency core cooling systems to support an upcoming meeting with the Advisory Committee on Reactor Safeguards. The NRC staff is considering restructuring the current Section 50.46 regulation to distinguish ECCS performance requirements (i.e., criteria governing acceptable capability of ECCS to perform its cooling function during and after a design basis LOCA) from fuel/cladding performance requirements (i.e., criteria intended to ensure that the fuel and cladding do not result in prevention of successful cooling during and after a design basis LOCA, and any other effects with adverse impacts on the capability or other safety systems). Additionally, the NRC staff may add new paragraphs to address long standing issues and concerns with the current regulation. As such, this draft rule language may be incomplete or in error in one or more respects, and will be subject to further revisions during the rulemaking process. The NRC is not requesting formal public comments on this draft rule language. The NRC may post updated materials, including updated draft rule language, to this page. Interested stakeholders should periodically check this page for updates and added materials.

(j) [Reserved]

(k) *Reporting*.

(1) Each applicant for or holder of an operating license or construction permit issued under this part, applicant for a standard design certification under part 52 of this chapter (including an applicant after the Commission has adopted a final design certification regulation), or an applicant for or holder of a standard design approval, a combined license or a manufacturing license issued under part 52 of this chapter, shall estimate the effect of any change to or error in an acceptable evaluation model or in the application of such a model to determine if the change or error is significant. For this purpose, a significant change or error is one which results in a calculated peak fuel cladding temperature different by more than 50 °F from the temperature calculated for the limiting transient using the last acceptable model, or is a cumulation of changes and errors such that the sum of the absolute magnitudes of the respective temperature changes is greater than 50 °F.

(2) For each change to or error discovered in an acceptable evaluation model or in the application of such a model that affects the temperature calculation, the applicant or holder of a construction permit, operating license, combined license, or manufacturing license shall report the nature of the change or error and its estimated effect on the limiting ECCS analysis to the Commission at least annually as specified in § 50.4 or § 52.3 of this chapter, as applicable. If the change or error is significant, the applicant or licensee shall provide this report within 30 days and include with the report a proposed schedule for providing a reanalysis or taking other action as may be needed to show compliance with § 50.46 requirements. This schedule may be developed using an integrated scheduling system previously approved for the facility by the NRC. For those facilities not using an NRC approved integrated scheduling system, a schedule will be established by the NRC staff within 60 days of receipt of the proposed schedule. Any change or error correction that results in a calculated ECCS performance that does not conform to the analytical limits established in accordance with this section, as applicable, is a reportable event as described in §§ 50.55(e), 50.72, and 50.73. The affected applicant or licensee shall propose immediate steps to demonstrate compliance or bring plant design or operation into compliance with § 50.46 requirements.

(3) For each change to or error discovered in an acceptable evaluation model or in the application of such a model that affects the temperature calculation, the applicant or holder of a standard design approval or the applicant for a standard design certification (including an applicant after the Commission has adopted a final design certification rule) shall report the nature of the change or error and its estimated effect on the limiting ECCS analysis to the Commission and to any applicant or licensee referencing the design approval or design certification at least annually as specified in § 52.3 of this chapter. If the change or error is significant, the applicant or holder of the design approval or the applicant for the design certification shall provide this report within 30 days and include with the report a proposed schedule for providing a reanalysis or taking other action as may be needed to show

compliance with § 50.46 requirements. The affected applicant or holder shall propose immediate steps to demonstrate compliance or bring plant design into compliance with § 50.46 requirements.

(l) *Authority to impose restrictions on operation.* The Director of the Office of Nuclear Reactor Regulation (for licenses issued under 10 CFR 50) or the Director of the Office of New Reactors (for licenses issued under 10 CFR 52) may impose restrictions on reactor operation if it is found that the evaluations of ECCS cooling performance submitted are not consistent with the requirements of this section.

(m) *Relationship to other NRC regulations.* The requirements of this section are in addition to any other requirements applicable to ECCS set forth in this part. The analytical limits established in accordance with this section, with cooling performance calculated in accordance with an acceptable evaluation model, are in implementation of the general requirements with respect to ECCS cooling performance design set forth in this part, including in particular Criterion 35 of appendix A of this part.

(n) *Implementation.*

(1) Construction permits issued under Part 50 after [EFFECTIVE DATE OF RULE] must comply with the requirements of this section.

(2) Operating licenses issued under Part 50 which are based upon construction permits in effect as of [EFFECTIVE DATE OF RULE] (including deferred and reinstated construction permits) must comply with the requirements of § 50.46c by no later than the applicable data set forth in Table 1. Until such compliance is achieved, the requirements of this section continue to apply.

(3) Operating licenses issued under Part 50 after [EFFECTIVE DATE OF RULE] must comply with the requirements of this section.

(4) Operating licenses issued under Part 50 as of [EFFECTIVE DATE OF RULE] must comply with the requirements § 50.46c by no later than the applicable date set forth in Table 1. Until such compliance is achieved, the requirements of this section continue to apply.

(5) Standard design certifications under part 52 of this chapter, whose applications (including applications for amendment) are pending as of or docketed after [EFFECTIVE DATE OF RULE], and new branches of these certifications whose applications are pending as of or docketed after [EFFECTIVE DATE OF RULE] must be amended to reflect compliance with this section no later than 36 months after [EFFECTIVE DATE OF RULE]. For purposes of this paragraph, a "branch" represents an alternative to the

certified design as approved in the original design certification rulemaking. Such amendments l are not subject to either the issue finality provisions under 10 CFR 52.103(g) or the backfitting requirements under 10 CFR 50.109.

(6) Standard design certifications under part 52 of this chapter, or branches of standard design certifications in effect on [EFFECTIVE DATE OF RULE] but not referenced in an application for combined license or in a combined license, must be amended to reflect compliance with this section 36 months after the design certification rule is referenced in a combined license application or upon renewal, whichever is later. Such amendments are not subject to either the issue finality provisions under 10 CFR 52.103(g) or the backfitting requirements under 10 CFR 50.109.

(7) Combined licenses under part 52 of this chapter must comply with this section no later than completion of the first refueling outage after initial fuel load. Until such compliance is achieved, the requirements in § 50.46 continue to apply.

(8) Standard design approvals under part 52 of this chapter issued before [EFFECTIVE DATE OF RULE] must comply with this section before the design approval may be referenced in a construction permit, operating license, design certification, combined license or manufacturing license issued by the NRC.

(9) Applications for standard design approvals under part 52 of this chapter issued after [EFFECTIVE DATE OF RULE] must comply with this section.

(10) Applications for manufacturing licenses under part 52 of this chapter submitted after [EFFECTIVE DATE OF RULE] must comply with this section.

NOTE: The availability of this draft rule language, as it exists in this document, is intended to inform stakeholders of the current status of the NRC's activities to revise the requirements for emergency core cooling systems to support an upcoming meeting with the Advisory Committee on Reactor Safeguards. The NRC staff is considering restructuring the current Section 50.46 regulation to distinguish ECCS performance requirements (i.e., criteria governing acceptable capability of ECCS to perform its cooling function during and after a design basis LOCA) from fuel/cladding performance requirements (i.e., criteria intended to ensure that the fuel and cladding do not result in prevention of successful cooling during and after a design basis LOCA, and any other effects with adverse impacts on the capability or other safety systems). Additionally, the NRC staff may add new paragraphs to address long standing issues and concerns with the current regulation. As such, this draft rule language may be incomplete or in error in one or more respects, and will be subject to further revisions during the rulemaking process. The NRC is not requesting formal public comments on this draft rule language. The NRC may post updated materials, including updated draft rule language, to this page. Interested stakeholders should periodically check this page for updates and added materials.

Table 1: Implementation dates for Nuclear Power Plants with operating licenses as of [EFFECTIVE DATE OF RULE] or operating licenses which are based upon construction permits in effect as of [EFFECTIVE DATE OF RULE] (including deferred and reinstated construction permits).

Calculated Local Oxidation (ECR[1]) Reported in UFSAR	**Latest Date for Demonstrating Compliance**
ECR ≥ 10.0	No later than 36 months from effective date of rule
10.0 > ECR > 5.0	No later than 48 months from effective date of rule
ECR ≤ 5.0	No later than 60 months from effective date of rule

[1] Equivalent cladding reacted

NOTE: The availability of this draft rule language, as it exists in this document, is intended to inform stakeholders of the current status of the NRC's activities to revise the requirements for emergency core cooling systems to support an upcoming meeting with the Advisory Committee on Reactor Safeguards. The NRC staff is considering restructuring the current Section 50.46 regulation to distinguish ECCS performance requirements (i.e., criteria governing acceptable capability of ECCS to perform its cooling function during and after a design basis LOCA) from fuel/cladding performance requirements (i.e., criteria intended to ensure that the fuel and cladding do not result in prevention of successful cooling during and after a design basis LOCA, and any other effects with adverse impacts on the capability or other safety systems). Additionally, the NRC staff may add new paragraphs to address long standing issues and concerns with the current regulation. As such, this draft rule language may be incomplete or in error in one or more respects, and will be subject to further revisions during the rulemaking process. The NRC is not requesting formal public comments on this draft rule language. The NRC may post updated materials, including updated draft rule language, to this page. Interested stakeholders should periodically check this page for updates and added materials.

In Appendix K to 10 CFR Part 50: (I)(B)

(B). Swelling and Rupture of the Cladding and Fuel Rod Thermal Parameters

Each evaluation model shall include a provision for predicting cladding swelling and rupture from consideration of the axial temperature distribution of the cladding and from the difference in pressure between the inside and outside of the cladding, both as functions of time. To be acceptable the swelling and rupture calculations shall be based on applicable data in such a way that the degree of swelling and incidence of rupture are not underestimated. The degree of swelling and rupture shall be taken into account in calculations of gap conductance, cladding oxidation and embrittlement, and hydrogen generation.

The calculations of fuel and cladding temperatures as a function of time shall use values for gap conductance and other thermal parameters as functions of temperature and other applicable time-dependent variables. The gap conductance shall be varied in accordance with changes in gap dimensions and any other applicable variables. The thermal effects of crud and oxide layers that accumulate on the fuel cladding during plant operation must be evaluated.

In Appendix K to 10 CFR Part 50: (II)(5)

5. General Standards for Acceptability--Elements of evaluation models reviewed will include technical adequacy of the calculational methods, including: For models covered by §50.46c(d)(4)(i) compliance with required features of section I of this Appendix K; and, for models covered by § 50.46c(d)(4), assurance of a high level of probability that the performance criteria of § 50.46c(b) would not be exceeded.