Revision to 10 CFR 50.46(b)

ECCS Performance Requirements

50.46(b) Rulemaking Workshop #2
April 28, 2010

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Revision to ECCS Requirements:

- **Revision to 50.46(b) rule language**
  - **Expand applicability to all fuel types.**
  - **Capture research findings.**
- **RG provides “specified and acceptable” set of analytical limits on peak cladding temperature and time at elevated temperature based on existing PQD database.**
- **RG provides “acceptable experimental technique” for performing PQD and breakaway oxidation tests and for establishing alternative PQD analytical limits.**

Compilation of the Top Ten Topics from Public Comments submitted on the Advance Notice of Proposed Rulemaking for 10 CFR 50.46(b) ECCS Acceptance Criteria

The tables in this document contain a high-level summary and the NRC's response to ten topics that were raised within the comments submitted in response to the advance notice of proposed rulemaking (ANPR) entitled "Performance-Based Emergency Core Cooling System Acceptance Criteria" (74FR40765). The tables in this document were prepared for the sole purpose of providing a foundation for discussion at a public workshop scheduled for April 28 – 29, 2010, in Rockville, MD, to engage the public and industry on the ongoing rulemaking effort to revise the ECCS acceptance criteria in 10 CFR 50.46(b).

The NRC emphasizes that this document does not contain a comprehensive summary of all comments received on the ANPR, nor does it reflect every organization that submitted comments. The topics and comments chosen for inclusion were based on the NRC staff's perception of the most representative and prominent issues raised by the comment submittals as a whole. A comprehensive ANPR comment response document will be issued with the proposed rule package. Lastly, the NRC notes that the absence of a particular comment or topic in this document in no way precludes it from discussion at the public workshop. There will be a designated time at the workshop to raise any topics or comments not contained herein.

Acronyms used:

ANPR	Advance Notice of Proposed Rulemaking	NRC	Nuclear Regulatory Commission
CFR	Code of Federal Regulations	NSSS	nuclear steam supply system
CP-ECR	Cathcart-Pawel equivalent cladding reacted	PCT	peak cladding temperature
ECCS	emergency core cooling system	PQD	post quench ductility
ID	inner diameter	RCT	ring compression test
LOCA	loss of coolant accident	SBLOCA	small break loss of coolant accident
LWR	light water reactor	wppm	weight parts per million

Organization Abbreviations:

Abbreviation	**Commenter**
AEKI	Hungarian Academy of Sciences, KFKI Atomic Energy Research Institute
ANL	Argonne National Laboratory
AREVA	AREVA NP, Inc.
CTP	Ceramic Tubular Products, LLC
GE	GE Hitachi Nuclear Energy Americas and Global Nuclear Fuels-Americas
IRSN	Institut de Radioprotection et de Sûreté Nucléaire
NEI	Nuclear Energy Institute
Progress	Progress Energy
STARS	Strategic Teaming and Resource Sharing alliance
UCS	Union of Concerned Scientists
Westinghouse	Westinghouse Electric Company

TOPIC #1	Adequacy / Completeness of Technical Basis (Should we proceed with rulemaking now?)	
COMMENT: (a) Substantive research to support rulemaking does not exist at this time. (b) The existing body of research is ample justification for immediate action.		ORGANIZATION: (a) NEI, GE, several licensees (b) UCS
NRC RESPONSE: (a) – (b) The NRC believes that there are sufficient data and understanding of the cladding embrittlement phenomenon to proceed with rulemaking, develop detailed experimental procedures, and establish bounding PQD analytical limits. However, additional testing would be helpful to validate the experimental procedures and expand the set of “acceptable” analytical limits (in a future RG) for alternative peak oxidation temperatures and/or cooldown rates.		

Draft Rule Language – N/A

TOPIC #2	**Applicability Expansion (All fuel designs)**	
COMMENT: (a) The rule should be expanded to include all claddings and fuel types. (b) Expansion could permit circumvention of open scientific scrutiny of new claddings.		ORGANIZATION: (a) NEI, GE, Westinghouse, AREVA, CTP (b) ANL
NRC RESPONSE: (a) The NRC intends to expand the rule's applicability to include all LWRs, regardless of fuel design or cladding material. The proposed rule would specify general performance requirements which all fuel designs must satisfy. In addition, specific performance requirements for zirconium cladding would be included. Specific performance requirements would be required for any other cladding and fuel combination, and rulemaking would be required to incorporate those requirements into the rule. (b) Because a licensee would need NRC approval to use a new cladding material, or because a vendor would need NRC approval of a topical report justifying the use of a new material, the NRC would have the opportunity to scrutinize the demonstrated performance of the new fuel design under normal and upset conditions, along with the supporting materials characterization, degradation mechanisms, mechanical testing database, and in-reactor experience. Of course, the staff may have difficulty finding reasonable assurance that a new cladding material is adequate for use, and therefore not have sufficient basis to grant approval, without an extensive testing database and independent verification by multiple entities. It is reasonable to assume that the extent of a qualification database would be proportional to the degree of departure from current cladding materials and designs.		

Draft Rule Language*

§ 50.46 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 § 50.82(a)(1) to the NRC.

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

* This draft rule language is intended to inform stakeholders of the current status of the NRC's activities to revise its fuel cladding requirements in 10 CFR 50.46(b). This draft rule language may be incomplete or in error in one or more respects and may be revised during the rulemaking process. The NRC is not requesting formal public comments on this draft rule language. If the NRC publishes a proposed rule in the *Federal Register*, the NRC will provide an opportunity for the public to submit comments on the proposed rule.

(1) Loss-of-coolant accidents (LOCA's) are hypothetical accidents 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) An evaluation model is 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.

(c) *General performance requirements.* Each LWR must be provided with an emergency core cooling system (ECCS) designed so that, following a postulated loss-of-coolant accidents (LOCA), the following performance requirements are satisfied:

(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 (2) of this section; and

(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.

TOPIC #3	**Treatment of Uncertainty and Variability**

COMMENT:	ORGANIZATION:
(a) The existing ECCS regulations include significant conservatism, and the new rule and regulatory guidance should not add excessive conservatism (e.g., by requiring bounding treatments of uncertainties with the new limits). (b) The rule should provide sufficient margin to accommodate any uncertainties in the current experimental database.	(a) Westinghouse, NEI (b) UCS

NRC RESPONSE:

(a) It is not the NRC's intention to create excessive new conservatisms with this rulemaking, however the NRC must account for uncertainties that exist in the current database and uncertainties that may arise as a result of implementation (e.g., testing and data interpretation) of the rule. The treatment of uncertainty and variability will be addressed in regulatory guidance. As such, the public will have the opportunity to comment on the treatment of uncertainty and variability as a future draft RG.

(b) In order to remove regulatory uncertainty in the review and approval of future test results, hydrogen uptake models, and LOCA analyses, a standard approach needs to be developed. These standards need to address repeatability and variability in PQD RCT results, variability and asymmetry in hydrogen measurements, and the confidence level needed in predicting cladding hydrogen content.

Draft Rule Language – N/A

TOPIC #4	Approach to Ductility / Establishing Analytical Limits (and alternative approaches)
COMMENT: (a) Instead of defining a specific parameter for ductility such as 1% permanent strain, brittle vs. ductile behavior should be determined by the characteristics of a load-displacement curve. (b) An accurate and reliable measurement of permanent strain depends on skill and experience in sample preparation, proper conduct of testing, in stopping tests at the correct time, and in data assessment and interpretation. (c) Why would the proposed rule favor a permanent strain criterion rather than an offset strain criterion? (d) Alternate definitions of cladding ductility should be permitted with the intent to find techniques that reduce data scatter, represent actual post-LOCA loading conditions, and may provide consistent results between laboratories (e) The PQD testing methodology referenced in the ANPR is overly prescriptive and restrictive. (f) Vendors should have the option to determine embrittlement threshold for as-fabricated cladding alloys (g) A pre-approved set of generic analytical limits should be provided, but plants with higher oxidations should be allowed to use limits based on cladding-specific test data. (h) A very high standard must be met for the quality of the technical basis supporting development of cladding-specific criteria, with respect to standardization of experimental protocols, reproducibility of results, and peer review. (i) Many countries have gone away from using a ductility-based criterion. Ring compression tests for ductility are far more severe than actual LOCA conditions would impose on the cladding. Strength-based testing, such as that performed by Japan, is more realistic, and some of their samples that survived quench tests were subsequently subjected to ring compression, and almost all resulted in brittle failure, thus implying that a brittle cladding could survive a LOCA, and therefore ductility is not the best measure.	ORGANIZATION: (a) AEKI (b) ANL (c) IRSN (d) Westinghouse (e) NEI, GE, Westinghouse, AREVA (f) ANL (g) Westinghouse (h) UCS (i) IRSN

TOPIC #4 (Cont.)	Approach to Ductility / Establishing Analytical Limits (and alternative approaches)

NRC RESPONSE:

(a) – (h) NRC agrees that there are multiple ways to define and demonstrate ductile and brittle behavior. The NRC is now leaning toward an approach that does not make ductility overly prescriptive. The proposed rule will require that "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 cladding alloy based upon an acceptable experimental technique". The NRC intends to issue a RG defining an "acceptable experimental technique". This experimental guidance will address uncertainty, repeatability, and variability. However, applicants may elect to use an alternative experimental technique (which may include an alternative test or definition of ductility). Of course, any alternative would require NRC review/approval and the burden of demonstrating that this alternative approach achieves the objectives of the rule and properly addresses uncertainty, repeatability, and variability would lie with the applicant.

The NRC intends to issue a RG defining "specified and acceptable analytical limits" based on the existing database. This database is quite extensive (includes as-fabricated, pre-hydrided, and irradiated cladding specimens) and has received peer review. Both RGs will be rooted in the basis that ductility will be maintained, and this ductility basis is what will be required in the rule.

(i) The NRC agrees with the concept that brittle materials can retain strength. However, a strength based criterion requires detailed knowledge and interpretation of actual loading stresses under LOCA conditions. The NRC continues to maintain the position outlined by the Commission in the ECCS hearings of 1973, that retention of ductility is the best guarantee against potential fragmentation of fuel cladding under various types of thermal shock, hydraulic, and seismic forces.

Draft Rule Language*

(d) *Requirements for fuel designs consisting of uranium oxide pellets within zirconium cladding alloys.* Each LWR fueled with an acceptable fuel design consisting of uranium oxide pellets within cylindrical zirconium alloy cladding must be provided with an ECCS designed so that its calculated cooling performance following postulated LOCA satisfies the following requirements.

(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*. The preservation of cladding ductility provides assurance that fuel rods will not experience gross failure as a result of combined thermal and mechanical loads anticipated during a postulated LOCA. To achieve this objective, 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 cladding alloy based upon an acceptable experimental technique.

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.

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TOPIC #5	Oxygen Diffusion from Inside Surfaces

COMMENT:	ORGANIZATION:
(a) The inclusion of a cladding ID oxygen source requirement is premature. Any requirement should be placed in regulatory guidance (flexible implementation document) so that as the science solidifies, the treatment of the potential phenomena can be kept appropriate.	(a) AREVA

NRC RESPONSE:
(a) Recognizing that the onset of a fuel/clad bonding layer is dependent on several factors (e.g., rod design, power history, etc.), the NRC staff envisions that the proposed rule will specify an analytical requirement (away from the burst node) to treat this potential ID oxygen source in the evaluation model, if it exists. The proposed rule would not prescribe the exact onset of the fuel/clad bonding layer, but put the burden of determining the onset on the licensee. Compliance with the analytical requirement in the proposed rule for a given fuel rod design would be part of the staff's review/approval of the LOCA methods and/or fuel design. As suggested by the commenter, as this phenomenon is better understood, methods to better address it could be included in guidance.

Draft Rule Language*

(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 nil ductility. If cladding rupture is calculated to occur, the effects of oxygen diffusion from the cladding inside surfaces in the region surrounding the rupture shall be considered in the evaluation model. In addition, 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.

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TOPIC #6	Breakaway Oxidation Requirements (periodic testing, acceptance criteria (e.g., 200 wppm), and break spectrum)

COMMENT:	ORGANIZATION:
(a) Instead of finding a minimum time to breakaway, a simple screening test for a specified time and temperature (e.g., 1000 °C) would be more compatible with the current level of understanding of breakaway oxidation. (b) Vendors should establish time to breakaway for each alloy and licensees will ensure that this time is greater than the time at temperature experienced during a SBLOCA. Breakaway testing conducted at 649 °C is overly conservative. Testing at about 1000 °C is conservative and defensible. (c) Information available in existing UFSARs concerning LOCA break scenarios (i.e., SBLOCA) should be adequate to establish an acceptable time to breakaway given the Appendix K conservatisms and the lack of consideration for operator actions. (d) Periodic testing for breakaway oxidation should be required. This phenomenon could be affected by manufacturing process changes. (e) The ANPR proposes a breakaway criterion when 200 wppm hydrogen uptake is reached. This value is conservative relative to the hydrogen concentration when cladding embrittlement will occur, which is closer to 600 wppm. (f) Additional requirements for breakaway testing, including reports, are not needed because existing regulations (10 CFR 50 Appendix B (QA) and 10 CFR 21 (vendor defect reporting)) are adequate to assure acceptable breakaway oxidation performance is maintained.	(a) ANL (b) NEI, GE (c) Westinghouse (d) ANL, UCS (e) GE (f) NEI, GE, Westinghouse

NRC RESPONSE:

(a) The NRC agrees with this suggestion. The NRC wishes to clarify that the request for information related to the maximum time span with cladding surface temperature above 1200°F (649ºC) for all NSSS/ECCS design combinations was intended to inform a specified time criteria for a given temperature. It was envisioned that demonstration of acceptable performance (i.e., no indication of breakaway behavior) at a specified temperature for a specified time would provide a straightforward, simple pass/fail test that would be far less burdensome to fuel vendors than a full suite of tests within the full range of temperatures feasible in a LOCA scenario. NRC would like to provide this reduction in testing burden, however the appropriate requirement for a minimum time without indication of breakaway for such a test must be informed by LOCA calculations.

(b) The NRC agrees with the concept that criteria are developed which are informed and measured against calculated predictions. NRC disagrees that the breakaway phenomenon is understood to the degree necessary to eliminate consideration of temperatures above and below 1000°C.

(c) Licensees may rely on information available in existing UFSARs, provided that information is relevant.

TOPIC #6 (Cont.)	Breakaway Oxidation Requirements (periodic testing, acceptance criteria (e.g., 200 wppm), and break spectrum)

NRC RESPONSE:

(d) The NRC is pursuing adding a requirement for such periodic testing for breakaway.

(e) The NRC agrees that embrittlement due to hydrogen may occur above 200 wppm hydrogen. However the criterion of 200-wppm hydrogen pickup was suggested based on ANL's studies of breakaway oxidation as indication of the *onset* of breakaway behavior, not loss of ductility. The proposed breakaway criterion was intended to supplement - rather than replace - the existing embrittlement criteria. If breakaway oxidation occurs, the embrittlement process is accelerated and the oxidation limits or time-at-temperature criteria are no longer completely sufficient to preclude embrittlement. In this way, if cladding is characterized by early breakaway behavior, it is outside of the predictive capabilities of standard oxidation rate equations such as the Cathcart-Pawel and Baker-Just equations

(f) The NRC agrees that 10 CFR 50 Appendix B and 10 CFR Part 21 would apply to breakaway testing. However, the NRC believes that a specific requirement for testing is important. Inclusion of the results of testing within the annual report currently required by 50.46 would provide the NRC information that would not otherwise be reported unless a significant safety hazard (per Part 21) was discovered. Additionally, an explicit requirement helps ensure that factors which could affect breakaway behavior are treated as critical characteristics under vendor/licensee QA and Part 21 programs.

Draft Rule Language*

(d) *Requirements for fuel designs consisting of uranium oxide pellets within zirconium cladding alloys.* Each LWR fueled with an acceptable fuel design consisting of uranium oxide pellets within cylindrical zirconium alloy cladding must be provided with an ECCS designed so that its calculated cooling performance following postulated LOCA satisfies the following requirements.

(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*. The preservation of cladding ductility provides assurance that fuel rods will not experience gross failure as a result of combined thermal and mechanical loads anticipated during a postulated LOCA. To achieve this objective, 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 cladding alloy based upon an acceptable experimental technique.

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.

Phase transformation and delamination of the zirconium dioxide layer during prolonged exposure to a high temperature steam environment promotes loss of cladding ductility. To ensure that the zirconium cladding alloy's susceptibility to this phenomenon, known as breakaway oxidation, is beyond the realm of postulated LOCA core temperature excursions, the total accumulated time that the cladding is predicted to remain above the zirconium alloy's as-fabricated $\alpha \rightarrow \alpha+\beta$ phase transition temperature shall not be greater than a specified and acceptable limit which corresponds to the measured onset of breakaway oxidation for the zirconium cladding alloy based upon an acceptable experimental technique. The onset of breakaway oxidation shall be measured periodically 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.

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<table>
<tr><td>TOPIC #7</td><td colspan="2">Reporting Requirements</td></tr>
<tr><td colspan="2">COMMENT:
(a) A graded approach for reporting PCT temperatures greater than 2090 °F should not be included in the rule. The existing 50 °F change threshold is sufficient. The NRC should indeed increase the reporting threshold for PCTs less than 2090 °F to be for changes or errors of 100 °F or more.

(b) None of the proposed reporting requirements should be included.

(c) The CP-ECR should only require reporting when the limit is approached and not be based on incremental changes from previous analyses.

(d) The reporting requirement for CP-ECR should not be as described in the ANPR, but rather when the CP-ECR exceeds 95% of its limit.

(e) If cladding material or design change substantially, different reporting criteria could be in order. Therefore, reporting requirements should be maintained in NRC documents other than the CFR so they can be kept current more easily. Further, reporting requirements should only be for changes which would degrade the margin to criteria if applied individually to the analysis of record.</td><td>ORGANIZATION:
(a) NEI, Westinghouse, GE
(b) STARS
(c) Progress
(d) NEI, Westinghouse, GE
(e) AREVA</td></tr>
<tr><td colspan="3">NRC RESPONSE:
(a) – (e) The staff recognizes that the ANPR proposed reporting requirements were a bit complex and may promote unnecessary burden and misinterpretation. As such, the staff has decided to maintain the current reporting requirements (along with an additional requirement related to breakaway oxidation testing). The staff also recognizes that further clarification is needed when addressing a change to or error in an acceptable evaluation model.</td></tr>
</table>

Draft Rule Language*

(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.

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TOPIC #8	**Consideration of CRUD**

COMMENT:	ORGANIZATION:
(a) ECCS regulations do not need to require that crud be accounted for in ECCS analyses because: (1) existing industry guidelines to perform a crud and cladding risk assessment for each fuel cycle provide sufficient assurance that crud levels will not be detrimental to fuel performance; (2) existing NRC review guidance in NUREG-0800 ensures that licensees will properly address crud in ECCS analyses, and (3) the NRC must review and approve all licensee ECCS analysis models, thus the NRC reviewer can ensure that each model properly addresses the effects of crud on ECCS performance. (b) A requirement to perform crud inspections after each fuel cycle should not be included in the rule. (c) Existing regulations require that when a significant and unexpected occurrence of crud is observed during refueling operations, the impact of the crud on past and future operation of the affected fuel assemblies be evaluated, including the impact on the LOCA analysis. Any need for reporting is already covered by existing regulatory requirements (e.g., §50.72 and 50.73).	(a) Westinghouse, NEI, STARS (b) NEI, Westinghouse, GE (c) Westinghouse

NRC RESPONSE:

(a) Compliance with either industry or NRC guidance is not a legally binding or enforceable requirement. The NRC believes that the regulations should be amended to clarify that considering the effects of crud on reactor fuel performance throughout each fuel cycle is a legally enforceable requirement. The NRC intends to propose a change to Appendix K and to guidance documents applicable to realistic LOCA evaluation models that would clearly specify that crud deposition during reactor operation must be considered in ECCS models. Licensees could comply with these requirements by implementing existing industry guidance specifying mandatory and best practice actions such as the mandatory crud and cladding risk assessment for each fuel cycle.

(b) The NRC has evaluated the supporting reasons provided by commenters regarding why periodic inspection of crud levels on fuel should not be required, and at this time the NRC does not intend to impose specific requirements to inspect fuel for crud.

(c) If a severe crud event occurred such that the analyzed consequences of the crud levels would exceed the § 50.46(b) criteria, reporting to the NRC would be required under § 50.72 and § 50.73. However, if the analyzed consequences of a crud event greatly reduced the margin to the § 50.46(b) criteria but did not exceed them, reporting to the NRC would not be required under § 50.72 or § 50.73. Since the NRC intends to propose a requirement that the effects of crud must be considered in ECCS models, unanticipated crud deposits exceeding those analyzed by the model, but not exceeding the § 50.46(b) criteria, would be considered errors in the model and must be reported to the NRC in accordance with existing § 50.46(a)(3)(ii).

Draft Rule Language[*]

For Appendix K:

The last paragraph of Appendix K, section I.B would be modified as shown below:

> 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 that may be deposited on the fuel cladding during plant operation must be evaluated.

For B.E. LOCA Models:

Since § 50.46(a)(1)(i) requires that the “analytical technique realistically describes the behavior of the reactor system during a loss-of-coolant accident” and does not specify the individual variables which the model must address, the NRC will propose to add crud to the variables specified in Reg Guide 1.175 on best-estimate models. Licensees would either have to take crud into account in their BE models or demonstrate why crud does not affect the behavior of the reactor system at their facilities.

[*] This draft rule language is intended to inform stakeholders of the current status of the NRC’s activities to revise its fuel cladding requirements in 10 CFR 50.46(b). This draft rule language may be incomplete or in error in one or more respects and may be revised during the rulemaking process. The NRC is not requesting formal public comments on this draft rule language. If the NRC publishes a proposed rule in the *Federal Register*, the NRC will provide an opportunity for the public to submit comments on the proposed rule.

TOPIC #9	Rule Implementation

COMMENT:	ORGANIZATION:
(a) A staged implementation process that doesn't require licensees to submit a new LOCA analysis until the submittal is required for a plant change may be reasonable. This approach would be supported by the understanding that safety margins are adequate. (b) A staged implementation approach should not be used. (c) Implementation costs could be reduced if, because the NRC will have already reviewed and approved revised LOCA Evaluation Models, the NRC does not review the results of the application of those LOCA Evaluation Models. (d) Implementation costs could be reduced if NRC does not require licensees to specifically determine the most limiting LOCA break scenario for breakaway oxidation. (e) Implementation costs could be reduced if the complexity of hydrogen pickup models, as referred to in question 5 of the ANPR, was reduced.	(a) NEI, GE, Westinghouse (b) UCS (c) NEI (d) NEI, GE (e) GE

NRC RESPONSE:

(a) The NRC believes that a staged implementation approach may be reasonable and could likely be achieved given appropriate safety margin and plant-specific information (e.g., core design characteristics, PCT and ECR limits, ECCS evaluation methodology used). The NRC is still evaluating the details of such an approach.

(c) The NRC must review and approve the plant-specific LOCA analyses since it is the individual plant that is obligated to comply with 10 CFR 50.46.

(d) The NRC intends to only require that licensees ensure the time to breakaway is not less than the total accumulated time that the cladding is predicted to remain above a given temperature (e.g., 800 °C) for any credible LOCA scenario.

(e) Alloy-specific hydrogen uptake models are necessary to implement the envisioned 50.46(b) revision. Variability and non-uniformity of cladding hydrogen and its impacts on measured ductile-to-brittle transition may be addressed either as part of the test database (when defining the analytical limits) or as part of the hydrogen model (implementation). Furthermore, non-uniformity in hydrogen distribution only becomes significant at higher overall concentrations (e.g., > 300 wppm). Hence, this burden is shared only by alloys with higher hydrogen uptake.

Draft Rule Language – N/A

TOPIC #10	Fuel Rod Ballooning, Burst Node Survival, Fuel Fragmentation and Dispersal

COMMENT:	ORGANIZATION:
(a) The 50.46(b)(4) (coolable geometry) criterion should be made more quantitative to account for ballooning and flow blockage coolability issues related to high burnup fuel. (b) The revised regulation should not be limited to UO_2 fuel. However, ballooning and fuel relocation phenomena will be influenced by fuel type. (c) The new ductility criteria should not apply to the ballooned region and clad adjacent to this region. (d) Embrittlement criteria should be derived from two kinds of tests based on behavior during a LOCA. If ballooning and burst don't occur, then mechanical tests (e.g., ring compression) should be applied. If ballooning cannot be excluded, the criteria should be based on tests that address embrittlement due to ballooning and secondary hydriding.	(a) IRSN (b) IRSN (c) Westinghouse (d) AEKI

NRC RESPONSE:

(a) Ballooning and flow blockage impacts on core coolability are already considered in ECCS analyses. The NRC reviews these considerations when it evaluates and approves an ECCS analysis, and the NRC currently has no information to suggest that these issues are considered non-conservatively.

(b) The NRC agrees that ballooning and fuel relocation phenomena could be influenced by fuel type.

(c) See general response below. **Until research on burst node survival has been completed, the existing analytical requirement for 2-sided oxidation calculations and consideration of wall thinning in the balloon region will be maintained**.

(d) See general response below.

GENERAL RESPONSE: The NRC is currently sponsoring research to further investigate the balloon and burst phenomena and its effect on fuel cladding integrity. Fuel fragmentation and relocation phenomena are also planned for further research. NRC is actively participating in and following the results of many LOCA-related experimental programs including those at the Halden Reactor Project and in the QUENCH program. The scope of the current rulemaking effort is not intended to encompass these phenomena and is instead based on the PQD and breakaway testing research documented in NUREG/CR-6967.

TOPIC #10 (Cont.)	Fuel Rod Ballooning, Burst Node Survival, Fuel Fragmentation and Dispersal

NRC RESPONSE:

10 CFR 50.46 defines ECCS performance requirements - providing specific requirements for which to judge the capabilities and performance of the ECCS. Since fuel rod ballooning, rod burst, and potential fuel fragmentation and dispersal occur early within a postulated LOCA (often before initiation of ECCS components), fuel design and performance requirements (e.g., rod internal pressure, cladding thickness, burnup, limited number of burst rods, etc.) may be more appropriate to limit consequences than ECCS performance requirements.

Question: **Should the NRC limit the applicability of the new rule to current licensed fuel burnup limits?**

During this rulemaking project, Halden plans to perform integral LOCA tests on PWR fuel at 60 GWd/MTU (IFA 650.10), VVER fuel at 56 GWd/MTU (IFA 650.11) and BWR fuel at 70 GWd/MTU (IFA 650.12). These tests are in addition to integral LOCA tests already completed on VVER fuel at 56 GWd/MTU (IFA 650.6) and BWR fuel at 44 GWd/MTU (IFA 650.7) which exhibited fuel fragmentation and relocation. It is important to note that IFA 650.6 and IFA 650.7 did not exhibit significant fuel dispersal (as was observed in very high burnup test specimens, e.g., IFA 650.9 PWR fuel at 90 GWd/MTU). Upon completion, these tests will be evaluated by the NRC to determine whether there exists a burnup threshold whereby fuel pellet susceptibility to fragmentation (and potential dispersion) necessitates new regulatory requirements. Until this issue is resolved, the staff is considering limiting the applicability of the proposed rule to current licensed fuel burnup limits.

Draft Rule Language for 10 CFR 50.46

NOTE: The availability of this draft rule language is intended to inform stakeholders of the current status of the NRC's activities regarding development of a proposed rule to modify the emergency core cooling system (ECCS) acceptance criteria at 10 CFR 50.46. This draft rule language may be incomplete or in error in one or more respects and may be subject to further revisions during the rulemaking process. The NRC is not soliciting formal public comments on this draft rule language, and is under no obligation to respond to any comments that are submitted at this time. Public comments may be provided when the NRC publishes the proposed rule in the *Federal Register*.

The draft rule language provided below contains some text in black font and some portions in gray. The gray text indicates language that remains substantially unchanged from the existing language and the black text is intended to highlight new or modified language.

§ 50.46 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 § 50.82(a)(1) to the NRC.

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

(1) Loss-of-coolant accidents (LOCA's) are hypothetical accidents 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) An evaluation model is 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.

(c) *General performance requirements.* Each LWR must be provided with an emergency core cooling system (ECCS) designed so that, following a postulated loss-of-coolant accidents (LOCA), the following performance requirements are satisfied:

(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 (2) of this section; and

(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) *Requirements for fuel designs consisting of uranium oxide pellets within zirconium cladding alloys.* Each LWR fueled with an acceptable fuel design consisting of uranium oxide pellets within cylindrical zirconium alloy cladding must be provided with an ECCS designed so that its calculated cooling performance following postulated LOCA satisfies the following requirements.

(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*. The preservation of cladding ductility provides assurance that fuel rods will not experience gross failure as a result of combined thermal and mechanical loads anticipated during a postulated LOCA. To achieve this objective, 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 cladding alloy based upon an acceptable experimental technique.

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.

Phase transformation and delamination of the zirconium dioxide layer during prolonged exposure to a high temperature steam environment promotes loss of cladding ductility. To ensure that the zirconium cladding alloy's susceptibility to this phenomenon, known as breakaway oxidation, is beyond the realm of postulated LOCA core temperature excursions, the total accumulated time that the cladding is predicted to remain above the zirconium alloy's as-fabricated $\alpha \rightarrow \alpha+\beta$ phase transition temperature shall not be greater than a specified and acceptable limit which corresponds to the measured onset of breakaway oxidation for the zirconium cladding alloy based upon an acceptable experimental technique. The onset of breakaway oxidation shall be measured periodically 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 nil ductility. If cladding rupture is calculated to occur, the effects of oxygen diffusion from the cladding inside surfaces in the region surrounding the rupture shall be considered in the evaluation model. In addition, 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]

(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) The Director of Nuclear Reactor Regulation 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) 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.