PRM-50-95
(75FR66007)

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NUCLEAR ENERGY INSTITUTE

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November 24, 2010

Ms. Annette L. Vietti-Cook
Secretary
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001
Attn: Rulemakings and Adjudications Staff

Subject: Industry Comments on Petition for Rulemaking (PRM-50-95), NRC Order Vermont Yankee to Lower the Licensing Basis PCT. Docket ID NRC–2009–0554

Project Number: 689

Dear Ms. Vietti-Cook:

The attachment to this letter provides comments from the Nuclear Energy Institute (NEI)[1] on behalf of the nuclear energy industry on the Petition for Rulemaking (PRM-50-95). This petition requests that the NRC order the licensee of Vermont Yankee to lower the licensing basis peak cladding temperature in order to provide a necessary margin of safety in the event of a Loss of Coolant Accident (LOCA).

As noted in the October 27, 2010 Federal Register Notice, the requested actions and supporting information addressed in PRM-50-95 are similar to actions requested under PRM-50-93. As such, NEI comments on the earlier petition, provided on April 12, 2010, continue to apply. Neither of the referenced tests cited in support of PRM-50-93 and PRM-50-95, whether reviewed in isolation or in combination with other tests, support the changes sought by the petitioner. NEI recommended that the petitioner's request under PRM-50-93 be denied. This recommendation applies to the actions requested under PRM-50-95.

[1] NEI is the organization responsible for establishing unified nuclear industry policy on matters affecting the nuclear energy industry, including the regulatory aspects of generic operational and technical issues. NEI's members include all utilities licensed to operate commercial nuclear power plants in the United States, nuclear plant designers, major architect/engineering firms, fuel fabrication facilities, materials licensees, and other organizations and individuals involved in the nuclear energy industry.

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As explained in the attached comments, experimental evidence shows that the current LOCA Peak Cladding Temperature (PCT) licensing limit is sufficient to ensure that the cladding can withstand post-quench LOCA loads in order to maintain a coolable geometry. Additionally, the energy released from the metal-water reaction is currently accounted for in LOCA licensing calculations used to determine PCT values. Evidence shows that with sufficient cooling to account for the heat generation from the metal-water reaction the threat of clad melting is abated. Thus, it is the industry's position that the current regulatory limit of 2200°F (1204°C) PCT is adequate to maintain plant safety in the event of a large break LOCA and the proposed reduction of Vermont Yankee's PCT to 1832°F (1000°C) is not warranted. The petitioner's requests for action under PRM-50-93 and PRM-50-95 should be denied.

If you have any questions regarding this matter, please feel free to contact me at jcb@nei.org; 202-739-8108 or Gordon Clefton at 202-739-8086; gac@nei.org.

Sincerely,

John C. Butler

Attachment

Industry Comments on Petition PRM-50-95

A petition for rulemaking pursuant to Title 10 of the *Code of Federal Regulations* (10CFR) Section 2.206 of the NRC's regulations was filed on June 7, 2010, requesting that the Nuclear Regulatory Commission (NRC) order the licensee of Vermont Yankee Nuclear Power Station to lower the licensing basis peak cladding temperature in order to provide a necessary margin of safety to help prevent a partial or complete meltdown in the event of a Loss of Coolant Accident (LOCA). The petitioner states that his interpretation of data from select multi-rod (assembly) severe fuel damage experiments indicates that the current licensed Peak Cladding Temperature (PCT) of Vermont Yankee of 1960°F (1071°C) does not provide a necessary margin of safety to help prevent a partial or complete meltdown in the event of a LOCA. The petitioner's interpretation of the data concludes that Vermont Yankee's large break PCT should be decreased to a temperature lower than 1832°F (1000°C) in order to provide a necessary margin of safety.

Background

The petitioner uses data from select multi-rod severe accident tests in an attempt to demonstrate that the cladding may reach the autocatalytic zirconium-water regime at temperatures lower than the licensed PCT for Vermont Yankee. In addition, the petitioner calls into question the adequacy of the correlations used in calculating the metal-water reaction rates. It is the Industry's position that the current licensing evaluations for Vermont Yankees PCT and the regulatory limit of 2200°F (1204°C) are valid.

Review of the Selection of 2200°F (1204°C) Criterion in 1973 ECCS Hearings

It is clear from a review of the 1973 Emergency Core Cooling System (ECCS) Hearings that the primary rationale for the selection of the embrittlement criteria (i.e., the 17%- Equivalent Clad Reacted (ECR) oxidation and the 2200°F (1204°C) peak cladding temperature) is retention of cladding ductility at temperatures higher than 275°F (135°C). The criteria are essentially based on the ductile-brittle transition data obtained from Hobson's slow-ring-compression tests performed at 73-302°F (23-150°C) [1].

The criterion that must be satisfied is that the cladding must have sufficient ductility to survive post-quench LOCA loads. From the results of post-test metallographic analysis of the slow-ring-compression specimens, Hobson [1] observed a good correlation between zero ductility temperature (ZDT) and the fractional thickness of transformed beta layer (or the sum of oxide plus alpha layer thickness) as long as the specimen was oxidized at ≤2200°F (≤1204°C). In spite of comparable thickness of transformed beta layer, specimens oxidized at 2400°F (1315°C) were far more brittle. This observation was explained on the basis of excessive solid-solution hardening of transformed-beta phase at high oxygen (O) concentrations that are characteristic of oxidation at the high temperature. Because of the solubility limit of oxygen in the beta phase, this high O concentration cannot be reached at 2200°F (1204°C) but can be reached at 2400°F (1315°C). Thus, embrittlement is not simply a function of the extent of oxidation alone, but is related to the exposure temperature. Although not well addressed at the time of the 1973 Hearings, the accuracy of Hobson's oxidation temperatures of 2200°F (1204°C) and 2400°F (1315°C) has been challenged by the subsequent investigators. The temperature reported in Reference 1 was the furnace temperature rather than actual specimen temperature that is more accurately measured with a directly spot-welded thermocouple as has been done by investigators such as Cathcart-Pawel and more recently at ANL. Considering the high oxidation heat, actual specimen temperature reported as 2200°F (1204°C) in the Hobson experiments was probably close to ~2300°F (~1260°C).

The petition calls into question the Baker-Just correlation that is specified in Appendix K of 10CFR50.46 for the calculation of the energy release rate due to oxidation, hydrogen generation, and ECR. The Baker-Just correlation using the current range of parameter inputs has been shown to be conservative and adequate to assess Appendix K ECCS performance. Virtually every data set published since the Baker-Just correlation was developed has clearly demonstrated the conservatism of the correlation above 1800°F (982°C). Recent tests conducted at ANL have demonstrated that the correlation over-predicts the zirconium-water reaction by as much as 30% at the limiting temperature 2200°F (1204°C) with no observable zirconium-water autocatalytic reactions. Thus, use of the Baker-Just correlation is still appropriate.

The 1989 USNRC Regulatory Guide 1.157 allowed the use of a best-estimate correlation to calculate the zirconium-water reaction for temperatures greater than 1900°F (1038°C) and recommended the use of the Cathcart-Pawel correlation (NUREG-17). The NRC, foreign organizations such as JAEA in Japan and CEA in France, and the United States nuclear industry are currently conducting and evaluating experimental and analytical programs on fuel cladding behavior under LOCA conditions. The research includes the effects of various types of zirconium-based cladding, high burnup, mixed oxides, ZrO_2 phase change hysteresis, and system pressures. These tests including both well-characterized isothermal high temperature oxidation tests and integral rodlet tests conducted at temperatures up to 2200°F (1204°C) have confirmed predictive capability of the Cathcart-Pawel correlation with no observable zirconium-water autocatalytic reactions. Thus, use of the Cathcart-Pawel correlation is still appropriate.

As pointed out by the petitioner, prevention of runaway oxidation was a consideration when limiting peak cladding temperatures to 2200°F (1204°C). Since heat generation from a metal-water reaction could become excessive and an autocatalytic type of situation could occur at high cladding temperatures, design considerations still address the heat balance near this temperature.

The effects of the exothermic zirconium-water reaction are considered in the ECCS design because of their potential influence on the thermal and mechanical behavior of the system. A review of available literature concludes that the zirconium-water reaction is relatively slow and corrosion-like under most conditions; however, at very high temperatures a self-sustaining reaction with steam can occur. The term autocatalytic oxidation has been misused by the industry for some time to identify the situation in which the heating rate resulting from the metal-water reaction is so rapid that any reasonable cooling process cannot arrest the cladding heatup. At any temperature approaching the 10CFR50.46 limit, a significant decrease in cooling could lead to a rapid increase in heating rate. Such a situation would have to be analyzed on a case-by-case basis, since so many variables exist. A balance between heat addition and removal must be understood in order to make conclusions about any phenomena impacting the system while experiencing such a self-sustaining reaction.

The petitioner states that Zircaloy fuel assemblies would incur an autocatalytic oxidation, if they reach local cladding temperatures between approximately 1832ºF (1000°C) and 2192ºF (1200°C) (page 64 of PRM 50-95). An autocatalytic reaction does not occur at a specific temperature, but it occurs when the heat generation from the cladding metal-water reaction exceeds the cladding cooling by convection and radiation. This accounts for the lack of a fixed temperature for the accelerated reaction observed in the severe accidents mentioned by the petitioner. A range between 2012ºF (CORA 2-3 tests) and 2200ºF (1204°C) (FLHT-1 test) is indicated in the petition. The reaction initiating temperature is dependent upon each experiment's cladding cooling condition. If enough cooling is provided, the reaction can be terminated as occurred in the FLHT-1 test at 2150ºF

Severe accident tests are designed to result in the failure of the fuel, so that the melting behavior of the assembly can be studied. Under these scenarios steam is provided mainly to ensure the water-metal reaction occurs and is not used to maintain a realistic balance of heat input and removal. In the specific CORA tests referenced by the petition, the combined cooling capability of both the steam and argon is insufficient to arrest temperature increases from the electrical heat input. Furthermore, in the CORA tests a sustained heat input is provided at a constant rate with inadequate heat removal, whereas, heat input under realistic LOCA conditions decreases exponentially with time while heat removal capability increases with time.

The effect of heat balance, expressed in terms of heat transfer coefficients, on accelerated oxidation is illustrated in a case study shown in Figure 1. In this evaluation, double sided Cathcart-Pawel correlation was used for the metal-water reaction. Clearly with a heat transfer coefficient of ~20 W/m^2K the reaction is autocatalytic and cannot be stopped. This is comparable to what happens in the severe accidents tests, since the test objective is to melt the rods. However, with a heat transfer coefficient of ~50 W/m^2K, a rate significantly lower than what is calculated in realistic LOCA case, the reaction is not autocatalytic and temperatures above 2200°F (1204°C) can be reached without oxidation runaway. This demonstrates that the escalation of cladding temperature is a function of the balance between heat generation and removal. This is reinforced from calculations conducted in support of the Quench-06 test [2]. The maximum calculated bundle temperatures calculated in the simulated Quench-06 experiment are presented in Figure 2. This experiment showed that with the proper heat balance it is possible for the cladding to attain high temperatures without approaching runaway oxidation (until the power transient was initiated after 6000 seconds).

Thus, the differences in test conditions clearly invalidate the applicability of the CORA test to realistic LOCA conditions. The potential for excessive escalation of cladding temperature has to be determined through a balance of heat generation and removal as is presently accounted for in the LOCA licensing calculations. A proposed limit of 1832°F (1000°C) to prevent the initiation of the oxidation phenomenon as requested by the petitioner is not justified.

The petitioner also states that current BWR components (control blades) would be damaged if the cladding reaches a temperature between 1832 °F (1000°C) and 2192°F (1200°C) (page 65 of PRM 50-95). The petitioner's basis for this statement is based upon the melting reaction between B_4C and stainless steel beginning at approximately 1832°F (1000°C) and accelerating above 2192°F (1200°C). LOCA licensing calculations indicate that when the 1832 °F (1000°C) cladding temperature is reached, the temperatures in the control blades are at least 392°F (200°C) lower. This is corroborated by the CORA-16 temperature measurements (Figures 16 and 17 of FZKA 7447 report January 2009). Thus, a 2200°F (1204°C) limit in the cladding temperature is enough to ensure not reaching 1832°F (1000°C) in the control blade. The cladding temperature proposed limit of 1832°F (1000°C) to prevent the initiation of control blade melting at 1832°F (1000°C) is not justified.

High-temperature oxidation behavior has been investigated by numerous investigators including prototypic LOCA tests in TREAT and PBF test reactors and by ANL investigators. During TREAT-FRF2 test, a seven-rod cluster was oxidized at ~2399°F (~1315°C) and quenched [3]. There was no reported evidence of melting during these tests due to autocatalytic oxidation even though the tests were conducted at temperatures in excess of the regulatory limit. This information is summarized in Figure 3 [from Ref. 4 and Ref. 5]. Thus, there is further evidence to support that a cladding temperature limit of 1832°F (1000°C) to prevent the initiation of the control blade melting is not justified.

Conclusions

Experimental evidence shows that the current LOCA PCT licensing limit is sufficient to ensure that the cladding can withstand post-quench LOCA loads in order to maintain a coolable geometry. Additionally, the energy released from the metal-water reaction is currently accounted for in LOCA licensing calculations used to determine PCT values. Evidence shows that with sufficient cooling to account for the heat generation from metal-water reaction the threat of clad melting is abated. Thus, it is the Industry's position that the current regulatory limit of 2200°F (1204°C) PCT is adequate to maintain plant safety in the event of a large break LOCA and the proposed reduction of Vermont Yankee's PCT to 1832°F (1000°C) is not warranted.

References

1. D. O. Hobson, "Ductile-brittle behavior of Zircaloy fuel cladding," Proc. ANS Topical Mtg. on Water Reactor Safety, Salt Lake City, March 26, 1973, pp. 274-288.

2. W. Hering, et. al., "Comparison and Interpretation Report of the OECD International Standard Problem No. 45 Exercise (Quench-06)," FZKA 6722, Forshchungszentrum Karlsruhe GmbH, Karlsruhe, 2002.

3. R. A. Lorenz, "Fuel Rod Failure under Loss-of-Coolant Conditions in TREAT," Nucl. Tech. 11 (1971) 502-520.

4. F. M. Haggag, "Zircaloy Cladding Embrittlement Criteria: Comparison of In-Pile and Out-of-Pile Results," NUREG/CR-2757, July 1982.

5. H. M. Chung and T. F. Kassner, "Embrittlement Criteria for Zircaloy Fuel Cladding Applicable to Accident Situations in Light-Water Reactors," NUREG/CR-1344, ANL-79-48, Argonne National Laboratory, January 1980.

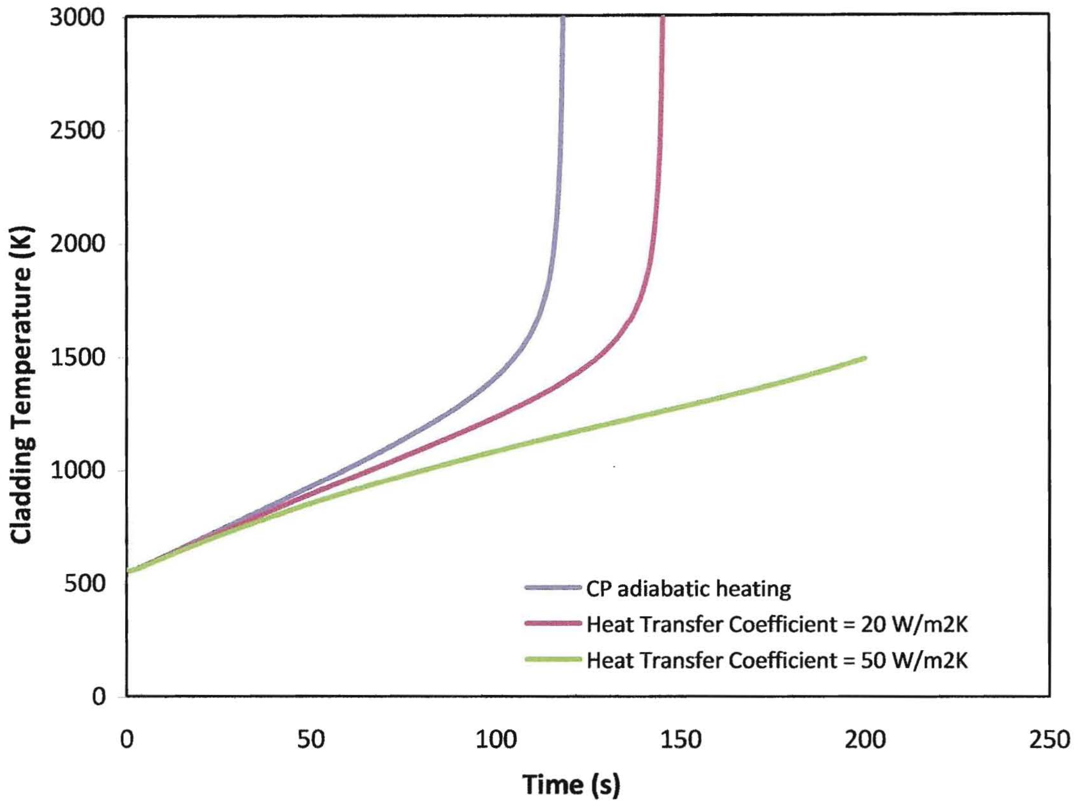

Figure 1 - PCT evolution of a rod due to decaying and two-sided oxidation heat assuming different cooling rates (heat transfer coefficients).

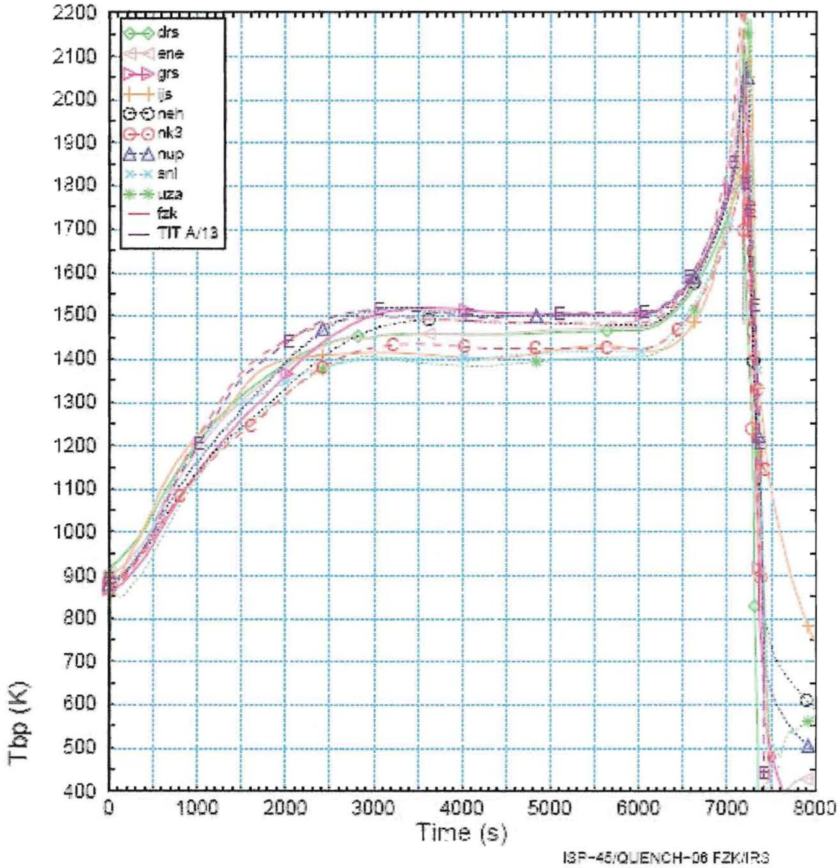

Figure 2 - Maximum bundle temperature calculated during the open phase for Quench-06 [3].

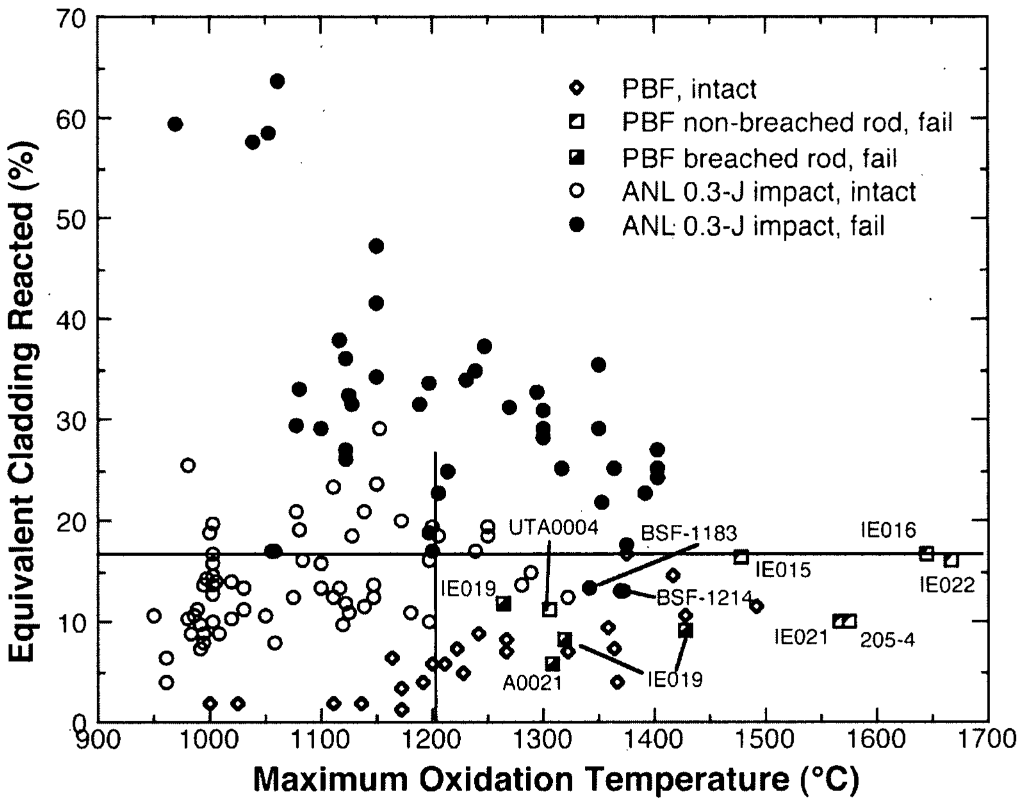

Figure 3 - Comparison of Data from Hot-Cell Handling Failure of Zircaloy Rods Exposed to High Temperature in Power Burst Facility (Ref. 4) and 0.3-J Impact Tests in ANL (Ref. 5)

Docket, Hearing

From:	Vietti-Cook, Annette
Sent:	Wednesday, November 24, 2010 2:24 PM
To:	Docket, Hearing
Subject:	FW: Industry Comments on Petition for Rulemaking (PRM-50-95), NRC Order Vermont Yankee to Lower the Licensing Basis PCT.
Attachments:	11-24-10_NRC_Industry Comments on PRM-50-95.pdf; 11-24-10_NRC_Industry Comments on PRM-50-95_Attachment.pdf

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From: BELL, Denise [mailto:dxb@nei.org] **On Behalf Of** BUTLER, John
Sent: Wednesday, November 24, 2010 2:13 PM
Subject: Industry Comments on Petition for Rulemaking (PRM-50-95), NRC Order Vermont Yankee to Lower the Licensing Basis PCT.

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If you have any questions regarding this matter, please feel free to contact me at jcb@nei.org; 202-739-8108 or Gordon Clefton at 202-739-8086; gac@nei.org.

Sincerely,

John C. Butler

Attachment

John C. Butler
Director, Engineering & Operations Support

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