August 26, 2005

Mr. Robert H. Leyse
P.O. Box 2850
Sun Valley, Idaho 83353

Dear Mr. Leyse:

I am responding to your letter of May 1, 2002, by which you submitted a petition for rulemaking (PRM) requesting that the U.S. Nuclear Regulatory Commission (NRC) amend 10 CFR Part 50, Appendix K, and the supporting guidance in NRC Regulatory Guide (RG) 1.157, "Best Estimate Calculations of Emergency Core Cooling System (ECCS) Performance."

Your letter contended that amendments are necessary to correct the failure of Appendix K and RG 1.157 to consider the complex thermal hydraulic conditions present during a loss-of-coolant accident (LOCA), including the potential for very high fluid temperatures.

The NRC published a notice of receipt of PRM-50-76 on August 9, 2002 (67 FR 51783). Six letters of public comment were received on the petition, including three from you. The other three letters opposed the petition arguing that runaway oxidation is prevented by the 2200 EF peak cladding temperature limit and that the Baker-Just correlation is known to be conservative, overpredicting the zirconium-water reaction by as much as 30% at the limiting temperature (2200 EF). It was also commented that the conditions of Full Length Emergency Cooling Heat Transfer (FLECHT) run 9573 (high power and high initial temperatures) were extremely severe, intentionally beyond design basis for ECCS performance and that the Cathcart-Pawel tests had adequate steam flow, so that the zirconium-water reaction rate was not limited by the availability of steam and the tests were therefore, valid. It was commented that differences between ECCS test conditions and reactor core fluid conditions during postulated LOCAs do not prevent the current zirconium-water reaction database from being applicable to ECCS analysis. The other public comments generally indicated that within the range of test parameters applicable to ECCS evaluation models, as specified in Appendix K and RG 1.157, the regulations and guidance are valid and conservative.

The Commission is denying your petition for rulemaking (PRM-50-76) for the following reasons:

> The Baker-Just correlation using the current range of parameter inputs is conservative and adequate to assess Appendix K ECCS performance. Data sets published since the Baker-Just correlation was developed have demonstrated the conservatism of the correlation for the temperature range important to clad oxidation calculations for LOCAs.

The parabolic/Arrhenius behavior of the Cathcart-Pawel isothermal experiments confirmed that there was adequate steam. An NRC analysis has confirmed that the Oak Ridge National Laboratory (ORNL) / Argonne National Laboratory assessment that the Cathcart-Pawel isothermal experiments were not steam starved and therefore the experimental data is valid.

Contrary to your assertion that there has not been appropriate testing to address issues raised by run 9573, the NRC has continued to study complex thermal-hydraulic effects on ECCS heat transfer processes during accident conditions related to LOCAs consistent with Commission direction. As part of that initiative, the NRC funded more than 50 Zircaloy clad nuclear fueled bundle reflood experiments at the National Research Universal (NRU) reactor. These experiments evaluated fuel rod and heat transfer behavior but did not include metallurgical examination to evaluate oxidation behavior. The NRC is continuing to conduct and evaluate experimental and analytical programs on fuel cladding behavior.

You did not consider the Westinghouse metallurgical analyses performed on the cladding for all four FLECHT Zircaloy clad experiments reported in WCAP-7665. You also ignored Westinghouse's application of the Baker-Just correlation to these experiments, which had the "complex thermal hydraulic phenomena" that is an issue in your petition. This application of the correlation to the metallurgical data demonstrates the conservatism of the Baker-Just correlation to 21 typical temperature transients. The NRC also applied the Baker-Just correlation to the FLECHT Zircaloy experiments with nearly identical results, confirming the application in WCAP-7665.

For the development of oxidation correlations, limited by oxygen diffusion into the metal, well-characterized isothermal tests are more important than the complex thermal hydraulics. Your suggested use of complex thermal hydraulic conditions would be counter-productive in reaction kinetics tests because temperature control is required to develop a consistent set of data for correlation development. Isothermal tests allow this needed temperature control. It is appropriate to apply the developed correlations to more prototypic transients (including complex thermal hydraulic conditions) to verify that the proposed phenomena embodied in the correlations are limiting. This is what was done by Westinghouse in WCAP-7665, by Cathcart and Pawel in NUREG-17 and by the NRC in the technical safety analysis of your petition (ADAMS Accession No. ML041210109).

The NRC applied the Cathcart-Pawel oxygen uptake and ZrO_2 thickness equations to the four FLECHT Zircaloy experiments, confirming the best-estimate behavior of the Cathcart-Pawel equations for large-break LOCA reflood transients.

Cathcart and Pawel applied their oxide thickness equation, using the BILD5 program, to 15 of their transient temperature experiments as described in ORNL/NUREG-17. The results showed that the correlation, based on numerous isothermal experiments, was conservative or best-estimate when applied to this transient data set.

The NRC evaluated your request for rulemaking and concludes that the requested action would not contribute to maintaining safety or security, nor would it improve regulatory efficiency and effectiveness, realism, or timeliness. None of the technical issues that you raised have shown safety-significant deficiencies in the research, calculation methods, or data used to support ECCS performance evaluations. NRC's technical safety analysis demonstrates that current procedures for evaluating performance of ECCS are based on sound science and that no amendments to the NRC's regulations and guidance documents are necessary. Further details are given in the enclosed Notice of Denial of Petition for Rulemaking, which will be published in the *Federal Register*.

Sincerely,

/RA/

Annette L. Vietti-Cook
Secretary of the Commission

Enclosure:
Federal Register Notice of Denial of
Petition for Rulemaking

[7590-01-P]

NUCLEAR REGULATORY COMMISSION

10 CFR Part 50

[Docket No. PRM-50-76]

Robert H. Leyse; Denial of Petition for Rulemaking

AGENCY: Nuclear Regulatory Commission.

ACTION: Petition for Rulemaking; Denial.

SUMMARY: The Nuclear Regulatory Commission (NRC) is denying a petition for rulemaking submitted by Mr. Robert H. Leyse (PRM-50-76). The petitioner requests that the NRC's regulations concerning the specified evaluation models for emergency core cooling systems (ECCS) and associated guidance documents be amended. The petitioner asserts that amendments are necessary to correct technical deficiencies in the correlations and data used for calculation of metal-water oxidation. The petitioner states that the correlations and data do not consider the complex thermal-hydraulic conditions present during a loss-of-coolant accident (LOCA), including the potential for very high fluid temperature. The Commission is denying Mr. Leyse's petition for rulemaking (PRM-50-76). None of the specific technical issues raised by the petitioner have shown safety-significant deficiencies in the research, calculation methods, or data used to support ECCS performance evaluations. NRC's technical safety analysis demonstrates that current procedures for evaluating ECCS performance are based on sound science and that no amendments to the NRC's regulations and guidance documents are necessary.

ADDRESSES: The NRC is making the documents identified in the table below available to interested persons through several means. Publicly available documents related to this petition, including the petition for rulemaking, public comments received, and the NRC's letter of denial to the petitioner, may be viewed electronically on public computers in the NRC's Public Document Room (PDR), O-1 F21, One White Flint North, 11555 Rockville Pike, Rockville, Maryland 20852. The PDR reproduction contractor will copy documents for a fee. Selected documents, including comments, may be viewed and downloaded electronically via the NRC rulemaking Web site at http://ruleforum.llnl.gov.

Publicly available documents created or received at the NRC after November 1, 1999, are also available electronically at the NRC's Electronic Reading Room at http://www.nrc.gov/reading-rm/adams.html. From this site, the public can gain access into the NRC's Agencywide Documents Access and Management System (ADAMS), which provides text and image files of NRC's public documents. If you do not have access to ADAMS or if you have problems in accessing the documents in ADAMS, contact the PDR reference staff at (800) 387-4209 or (301) 415-4737 or by e-mail to pdr@nrc.gov.

Document	**PDR**	**Web**	**ADAMS**
Federal Register Notice–Receipt of Petition for Rulemaking (67 FR 51783; Aug. 9, 2002)	X	X	ML022800472
Letter of Denial to the Petitioner	X	X	ML052220454
Penn State/US NRC "Rod Bundle Test Facility and Reflood Heat Transfer Program"			ML023040657
Petition for Rulemaking (PRM-50-76)	X	X	ML022240009
Public Comments for PRM-50-76	X	X	ML042740105
US NRC Office of Nuclear Research (RES) "Technical Safety Analysis of PRM-50-76, A Petition for Rulemaking to Amend Appendix K to 10 CFR Part 50 and Regulatory Guide 1.157"	X	X	ML041210109

US NRC, "Updated Program Plan for High-Burnup Light-Water Reactor Fuel" ML031810103

"Studies of Metal Water Reactions at High Temperatures, III. Experimental and Theoretical Studies of the Zirconium-Water Reaction," L. Baker and L.C. Just, ANL-6548 (May 1962) ML050550198

"PWR FLECHT (Full Length Emergency Cooling Heat Transfer) Final Report," April 1971 ML052230221

"Zirconium Metal-Water Oxidation Kinetics IV. Reaction Rate Studies," ORNL/NUREG-17, August 1977. ML052230079

FOR FURTHER INFORMATION CONTACT: Timothy A. Reed, Office of Nuclear Reactor Regulation, U.S. Nuclear Regulatory Commission, Washington, DC 20555-0001, telephone (301) 415-1462, e-mail TAR@nrc.gov.

SUPPLEMENTARY INFORMATION:

Background

The petition for rulemaking designated PRM-50-76 was received by the NRC on May 1, 2002. A notice of receipt of the petition and request for public comment was published in the *Federal Register* (FR) on August 9, 2002 (67 FR 51783). The notice of receipt requested comment on two questions: (1) Are the petitioner's three concerns about ECCS cooling valid, and if so, do these concerns constitute a significant safety concern? (2) Are there actions available to the Commission other than rulemaking that would effectively address the concerns raised by the petitioner?

The Petition

The petition, PRM-50-76, covers three broad issues: (1) amending Appendix K to Part 50 of the Commission's regulations, (2) amending Regulatory Guide (RG) 1.157, and

(3) the need for further analysis of the 10 CFR Part 50, Appendix K, backup data.

Issue 1: Amending Appendix K to Part 50

The petitioner describes at length alleged technical deficiencies in Appendix K Section I.A.5, "Metal-Water Reaction Rate." The petitioner claims that Section I.A.5 does not accurately describe the extent of zirconium-water reactions that may occur during a LOCA. The petitioner states that the Baker-Just equation, which is used to calculate the metal-water reaction in assessing ECCS performance, does not include any allowance for the complex thermal-hydraulic conditions during a LOCA, including the potential for very high bulk fluid temperatures within the cooling channels of the zirconium-clad fuel elements.

The petitioner cites the abstract of an Argonne National Laboratory (ANL) report (ANL-6548 "Studies of Metal Water Reactions at High Temperatures, III. Experimental and Theoretical Studies of the Zirconium-Water Reaction," L. Baker and L.C. Just, May 1962) and disputes the conclusions based on the petitioner's opinion that the tests discussed in ANL-6548 do not accurately reflect the conditions present during a LOCA. The petitioner makes the following points to support his views:

- The bulk water temperature was no greater than 315 EC (599 EF).
- The volume of water within the test apparatus was substantially greater than the volume of zirconium specimens, creating a vastly greater capacity to cool the heated zirconium particles of the Baker and Just experiment than would exist under LOCA conditions.
- Zirconium specimens were exposed to water only, while LOCA conditions include steam and nonequilibrium water-steam mixtures that reached higher bulk fluid temperatures.
- A footnote in ANL-6548 states: "This discussion is of a preliminary nature: work in this area is continuing." Based on this footnote, the petitioner concludes that it is not appropriate to apply the Baker-Just equation as prescribed in Appendix K Section I.A.5

for the calculation of energy release rates, hydrogen generation, and cladding oxidation from the metal-water reaction.

Issue 2: Amending Regulatory Guide 1.157

The petitioner states that RG 1.157, which allows use of data from NUREG-17 (ORNL/NUREG-17, "Zirconium Metal-Water Oxidation Kinetics IV, Reaction Rate Studies," by Cathcart et al., August 1977) for calculating energy release rates, hydrogen generation, and cladding oxidation for cladding temperatures greater than 1900 EF, results in flawed ECCS performance evaluations. The petitioner claims the NUREG-17 data is based on very limited test conditions and consequently the results should not be used for evaluating LOCA conditions.

In support of this contention, the petitioner describes the following test conditions:

- Zircaloy-4 specimens exposed only to steam, rather than fluid conditions as present in a LOCA.
- No documented heat transfer from the Zircaloy surface to the slow-flowing steam.
- Small-scale laboratory testing without conditions typical of the complex thermal-hydraulic conditions that prevail during a LOCA.
- An unexplained shift from the MaxiZWOK (testing apparatus for investigations in the temperature range 1652 EF to 1832 EF) to the MiniZWOK (a different testing apparatus for investigations in the temperature range 1832 EF to 2734 EF).

The petitioner believes that the investigators' conclusions include a statement that "overlooks the very substantially greater mass transfer coefficients that accompany the so-called appropriate heat transfer coefficients." The petitioner concludes that "it is those very substantially greater mass transfer coefficients that led to the temperature overshoot of the MaxiZWOK test at 1832 EF, and that would have led to very substantially greater temperature

overshoots and likely destruction of the Zircaloy tubing if MaxiZWOK had been operated over the temperature range of the MiniZWOK runs."

The petitioner contends that the NUREG-17 investigators do not warrant their work, and specifically assume no responsibility for the accuracy of their work, and therefore, that NUREG-17 is not applicable to the regulation of nuclear power reactors in the United States of America. To support this contention, the petitioner cites the following statement on the introductory page of NUREG-17:

"This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the Energy Research and Development Administration/United States Nuclear Regulatory Commission, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights."

Issue 3: Need for Further Analysis of Appendix K Backup Data

The petitioner states that the results of Zircaloy bundle test no. 9573, which was a test done for the Full Length Emergency Cooling Heat Transfer (FLECHT) tests and documented in WCAP-7665 ("PWR FLECHT (Full Length Emergency Cooling Heat Transfer) Final Report, Westinghouse Report WCAP-7665, April 1971"), are applicable to the calculation of the metal-water reaction and shows that the Baker-Just equation (referenced in Section I.A.5 of Appendix K for calculating the metal-water reaction) is not conservative. The petitioner states that the data in WCAP-7665, which includes test run 9573, includes the complex thermal-hydraulic conditions and Zircaloy-water reactions that characterize the reflood portion of the LOCA

transient. The petitioner states that these conditions are not found in the narrow test procedures of ANL-6548 or NUREG-17.

The petitioner states that a pertinent description of the complexities of thermal-hydraulic conditions during reflood, including negative heat transfer coefficients, is included in Section 3.2.3 of WCAP-7665 and that this description applies to data collected with FLECHT bundles with stainless steel cladding. The petitioner feels that another FLECHT Zircaloy bundle test, run 8874, is also pertinent to issues raised in this petition.

The petitioner cites Section 5.6 of WCAP-7665 and finds statements comparing Zircaloy to stainless steel to be misleading because they imply that stainless steel heat transfer coefficients may be used as a conservative representation of Zircaloy behavior. The petitioner believes that the differences in behavior for various test runs are explained by the differences in the thermal-hydraulic conditions leading to a different combination of heat transfer and mass transfer factors, and are not due to inconsistency of the data, as implied by the report.

The petitioner also finds WCAP-7665, Section 5.11, “Materials Evaluation,” to be misleading in view of the total experience with FLECHT run 9573. Finally, the petitioner notes that the same warning language used in NUREG-17 is on the cover page of WCAP-7665.

The petitioner further identifies several aspects of the data supporting the document entitled “Acceptance Criteria for Emergency Core Cooling Systems for Light-Water Cooled Nuclear Reactors-Opinion of the Commission,“ (Docket No. RM50-1, December 28, 1973) and notes the Commission concluded: “It is apparent, however, that more experiments with Zircaloy cladding are needed to overcome the impression left from run 9573.” The petitioner finds that there has been a lack of appropriate response to the Commission’s expressed wish for more experiments, and believes that at the very least, run 9573 should have been repeated. The petitioner emphasizes that although at least $1 billion had been expended on other analytical efforts, there has been no reported analysis of FLECHT run 9573.

The petitioner states that the test programs discussed in the petition were funded by Government agencies. He believes that most of the programs were firmly controlled by those "who were indoctrinated in the methods of the tightly regimented Naval Reactors Program." The petitioner finds that the "biased reporting of WCAP-7665 may be traced to these controls" and believes that "the lack of application of the MaxiZWOK apparatus beyond 1832 EF in NUREG-17 may likely be traced to rigid restrictions by management at the NRC." The petitioner further contends that while the Argonne work in ANL-6548 was likely less impacted by these controls, the controls likely did inhibit further analysis or reporting of FLECHT run 9573.

The petitioner notes that he has made several requests to the Knolls Atomic Power Laboratory for report KAPL-1534 and that his requests have been ignored.

Public Comments on the Petition

Six letters of public comment were received on the petition in response to the request for public comment. Three of these letters were from the petitioner. These letters are summarized below.

By letter dated September 11, 2002, the petitioner provided comments that did not raise new issues. The petitioner stated that the Baker-Just equation and the Cathcart-Pawel equation in NUREG-17 have been grossly misapplied by the NRC. According to him, it is fundamentally important that the determinations of LOCA transient chemical kinetics include the geometry of the stationary Zircaloy reactant in combination with the thermal-hydraulic conditions of the flowing water/steam reactant. In addition, he repeated in his letter that there are deficiencies in RG 1.157, since it references documents such as NUREG-17 that do not consider the complex thermal-hydraulic conditions during LOCAs, including the potential for very high fluid temperatures. The petitioner also stated that the Commission should provide a

rational basis for regulation of ECCS performance and perform additional experiments with Zircaloy cladding due to the cladding failure reported in Westinghouse report WCAP-7665.

By letter dated October 23, 2002, Westinghouse Electric Company submitted comments that opposed the proposed changes. Westinghouse commented that runaway oxidation is prevented by the 2200 EF peak cladding temperature limit. Additionally, Westinghouse commented that the Baker-Just correlation is known to be conservative, over-predicting the zirconium-water reaction by as much as 30 percent at the limiting temperature (2200 EF). Westinghouse stated that the conditions of FLECHT run 9573 (high power and high initial temperatures) were extremely severe, intentionally beyond design basis for ECCS performance. Westinghouse stated that the Cathcart-Pawel tests had adequate steam flow so that the zirconium-water reaction rate was not limited by the availability of steam, and as a result, the tests were valid. Westinghouse commented that differences between ECCS test conditions and reactor core fluid conditions during postulated LOCAs do not prevent the current zirconium-water reaction database from being applicable to ECCS analysis.

By letter dated October 25, 2002, the Nuclear Energy Institute (NEI) submitted comments supporting the Westinghouse comments, stating that extensive testing and analysis by the nuclear industry and national laboratories indicate that the Cathcart-Pawel correlation test is conservative. The NRC notes that the Cathcart-Pawel correlation is intended to be a best estimate, and is not intended to conservatively bound metal-water reaction rates. NEI commented that the test run, FLECHT 9573, was intentionally performed under very severe, beyond design-basis conditions, that post-test evaluations showed oxidation was within the expected range, and that runaway oxidation did not occur until the cladding temperature was well beyond 2300 EF. NEI further commented that the petitioner's concerns do not constitute a significant safety concern and thus, there is no need to revise Appendix K to Part 50 or RG 1.157.

By letter dated November 6, 2002, Strategic Teaming and Resource Sharing (STARS), a group of six utilities, submitted comments opposing the petition. These comments stated that within the range of test parameters applicable to ECCS evaluation models, as specified in Appendix K and RG 1.157, the regulations and guidance are valid and conservative. STARS notes that all of the data referenced in the petition was either available to the Commission and industry when the regulations and guidance were created or was assessed later when the test information became available.

On November 22, 2002, the petitioner submitted a reply to STARS but raised no new issues. On December 14, 2002, the petitioner responded to Westinghouse and NEI comments by discussing runaway oxidation in the WCAP-12610 report and severe fouling of fuel cladding during a LOCA. The petitioner stated that no allowance for higher temperatures due to fouling was made in run 9573, and repeated his request for more experiments with Zircaloy cladding.

NRC Requirements for ECCS Evaluations

Section 50.46 specifies the performance criteria against which the ECCS must be evaluated. The criteria include the maximum peak cladding temperature, the maximum cladding oxidation thickness, the maximum total hydrogen generation, and requirements to assure a coolable core geometry and abundant long-term cooling. This regulation also states that the ECCS cooling performance following postulated LOCAs must be calculated in accordance with either a realistic (also called a best-estimate) evaluation model that accounts for uncertainty or a conservative evaluation model that conforms with the required features of Appendix K to 10 CFR Part 50. If a licensee elects to calculate ECCS performance using an Appendix K evaluation model, then one important feature of that model is the way the metal-water reaction is calculated. For this calculation, Appendix K prescribes the use of the Baker-Just equation from ANL report ANL-6548 (L. Baker, L.C. Just, “Studies of Metal Water

Reactions at High Temperatures, III. Experimental and Theoretical Studies of the Zirconium-Water Reaction" May 1962). The metal-water reaction, which is predicted to occur during the LOCA and which is calculated using the Baker-Just equation, is the subject of much of this petition. The Baker-Just equation calculates a conservative rate of hydrogen generation and fuel cladding oxidation during the LOCA transient. Additionally, for licensees electing to use best-estimate calculations to evaluate ECCS performance, NRC RG 1.157 provides guidance for such evaluations. RG 1.157 allows the use of data from NUREG-17 for the calculation of the metal-water reaction.

NRC Technical Evaluation

The NRC reviewed the petitioner's request and concluded that none of the issues raised by the petitioner justified the initiation of rulemaking. The NRC's response to the technical issues raised in PRM-50-76 is based largely on a technical study by the Office of Nuclear Regulatory Research (RES) "Technical Safety Analysis of PRM-50-76, A Petition for Rulemaking To Amend Appendix K to 10 CFR Part 50 and Regulatory Guide 1.157." The NRC's responses to the petitioner's issues are as follows:

Issue 1: Amending Appendix K to Part 50

The petitioner claims that the requirement to use the Baker-Just equation in Section I.A.5 of Appendix K to 10 CFR Part 50, does not accurately describe the extent of zirconium-water reaction that may occur during a LOCA. He states that the Baker-Just equation does not include any allowance for the complex thermal-hydraulic conditions during a LOCA. The NRC disagrees with the petitioner's assertions.

In Section 3.1 of the petition, the petitioner discusses the inapplicability of the Baker-Just equation for calculating zirconium-water reaction rates during a LOCA. The NRC notes

that it is important to distinguish between the experiments performed by Baker and Just, and the equation developed by them and adopted in Appendix K to Part 50. Experiments run with 40-60 mil wires at temperatures at, or near, the zirconium melting point (~3400 EF) for one or two seconds are not typical of fuel rod cladding at temperatures in the range of 1800 EF - 2200 EF for 50 to 400 seconds that are postulated to occur in a design basis LOCA. In the Baker-Just report, only one data point from their experiments (at 3366 EF) is used in developing the Baker-Just equation. This one data point was used to anchor the Baker-Just equation at the melting point of zirconium. The remaining data from Bostrum ("The High Temperature Oxidation of Zircaloy in Water," W. A. Bostrum, WAPD-104 March 1954) and Lemmon ("Studies Relating to the Reaction Between Zirconium and Water at High Temperatures," A. W. Lemmon, Jr., BMI-1154, January 1957), at more relevant zirconium cladding conditions, were used by Baker and Just in the derivation of their equation. The use of the single data point at the melting temperature makes the Baker-Just equation very conservative. At the time of the promulgation of § 50.46, the Commission expected the NRC staff to obtain new and better zirconium-water reaction data. The petitioner also expressed concerns about the need for additional data. The substantial work of Cathcart and Pawel was performed for the NRC in response to the Commission's expectation.

The NRC compares the Baker-Just correlation to other correlations in a technical study (ADAMS accession ML041210109). The comparisons show the conservatism of the Baker-Just correlation in the temperature range important for clad oxidation calculations for LOCAs. In the discussion of Issue 3, comparisons of the Baker-Just correlation to relevant data demonstrate the substantial conservatism of the Baker-Just correlation. The petitioner expresses concern about the low water temperature (no greater than 599 EF) in the Baker-Just experiments. This temperature corresponds to the saturation temperature at 1530 psia, which was the pressure for that particular experiment. While a few degrees of liquid superheat may be possible under

LOCA/ECCS conditions, the degree of nonequilibrium required for higher liquid or “bulk” temperatures postulated by the petitioner is not possible.

The petitioner is also concerned about the large water volume compared to the zirconium sample size with respect to the quench capability of zirconium-clad fuel rods. As noted, these experiments were atypical in that respect, but barely used in the formulation of the Baker-Just correlation. Further, it should be noted that the Baker-Just report was not intended to be a heat transfer study, but rather an investigation of zirconium-water reaction kinetics at very high temperatures.

One interesting feature of the Baker-Just report is the heat and mass transfer analysis of an example case analyzed to examine the processes limiting the reaction rate. In this severe case, a 0.21 cm zirconium sphere at its melting point was dropped into water. Baker and Just were concerned that the reaction could be limited by gas phase diffusion of steam through a film of steam and hydrogen. This appears to be similar to the petitioner’s concern. As explained in the Baker-Just report, water cannot stay in contact with the hot metal and a vapor film immediately forms around the sphere. Figure 15 in that report shows that vapor phase diffusion is the limiting steam transport process for less than 0.2 seconds, during which a slight film of oxide is forming on the surface of the sphere. After that, the parabolic rate equation, (e.g., the Baker-Just equation) becomes limiting. The figure also shows that the gas phase diffusion is far less temperature-sensitive than the parabolic rate law. Certainly at lower temperatures more typical of a LOCA, the parabolic law is even more limiting than gas phase diffusion as long as the reaction is not steam starved.

Comparison of the Baker-Just equation to numerous data sets has shown the equation to be conservative. A significant example of this conservatism is discussed under Issue 3.

In summary, the NRC found no technical basis in the petition or in NRC records for the assertion that the NRC requirement to use the Baker-Just equation, along with other requirements of Appendix K, is flawed and is a significant safety concern.

Issue 2: Amending Regulatory Guide 1.157

The petitioner stated that RG 1.157, which allows use of the data and the Cathcart-Pawel equation presented in NUREG-17, results in flawed evaluations of ECCS performance. The NRC disagrees with the petitioner's assertions on this issue. In Section 3.2 of the petition, the petitioner states that the limited test conditions described in NUREG-17 preclude the use of the results for LOCA calculations. He further states that Zircaloy-4 specimens were not exposed to LOCA fluid conditions and that only steam was applied at very low velocities for the main test series. The petitioner states that there was no documented heat transfer from the Zircaloy surface to the slow-flowing steam and that as a result the conditions of the small-scale laboratory tests were not typical of the complex thermal-hydraulic conditions that prevail during a LOCA.

The petitioner suggests that without liquid water, the tests are invalid. The NRC disagrees. The presence of liquid water would invalidate the tests. Accurate steady-flow measurement would be extremely difficult. The droplets or liquid film would make it difficult to achieve the relatively constant sample temperatures that are necessary in these reaction kinetics tests. However, adequate steam flow is a concern. If the flow is too low, the reaction becomes steam starved. Otherwise, it is unnecessary to have steam flow typical of LOCA/ECCS conditions. These are not heat transfer tests. Once a reaction rate model is developed using data from experiments like these, the model should be validated against transient tests under LOCA conditions, as in the four Zircaloy tests described in WCAP-7665 and the transient tests described in the Cathcart-Pawel report.

Calculations were performed to assure that there was adequate steam flow for the MiniZWOK experiments used to derive the Cathcart-Pawel correlation in NUREG-17. These calculations are described in the RES technical study.

An important argument for the absence of steam starvation is how the isothermal Cathcart-Pawel experiments described in NUREG-17 give consistent results that support the parabolic/Arrhenius behavior. This is also discussed in the RES technical study.

Much of the petitioner's criticism of the Cathcart-Pawel work is related to a comparison of MiniZWOK and MaxiZWOK experimental conditions. MiniZWOK was used to develop a consistent set of data for correlation development. Controlling sample temperature by adjusting heater power (MiniZWOK) was much more successful than adjusting steam flow (MaxiZWOK). As the petitioner notes, temperature overshoot was a problem with MaxiZWOK and at high temperatures could have led to temperature runaway. As noted previously, temperature control is absolutely necessary in reaction kinetics experiments such as these. The petitioner implies that the experimenters abandoned MaxiZWOK in favor of MiniZWOK. Actually, the isothermal MiniZWOK experiments were essentially complete before the MaxiZWOK experiments were begun. Results from MaxiZWOK between 1652 EF and 1832 EF agreed well with MiniZWOK data at the same temperatures. Cathcart and Pawel state that:

> "The very good agreement between these two data sets is regarded as evidence that steam flow rate and steam insertion temperature do not affect significantly the kinetics of the steam oxidation of Zircaloy, at least in this temperature range."

Certainly, with steam velocities at least an order of magnitude greater in MaxiZWOK than MiniZWOK, the potential for more rapid gas phase diffusion of steam to the sample surface "mass transfer" is greater for MaxiZWOK. But clearly this is not the limiting phenomenon. This was demonstrated by the good agreement between MiniZWOK and MaxiZWOK data and the good agreement of MiniZWOK data to parabolic/Arrhenius behavior.

There is no evidence to suggest that high "mass transfer coefficients" in MaxiZWOK caused temperature overshoot in MaxiZWOK at 1832EF, as the petitioner proposes. It is true, as the petitioner suggests, that "[i]t is not possible to achieve an isothermal rate of oxidation of Zircaloy-4 if the Zircaloy-4 is exposed to LOCA fluid conditions at elevated conditions," but not for the reasons postulated by the petitioner. Rather, large-break LOCA reflood conditions are characterized by constantly decreasing power (decay heat) and increasing heat transfer coefficients after a few seconds. Under these conditions, isothermal conditions are impossible. WCAP-7665 showed that this kind of heat transfer and power behavior was universal for all tests done under design basis conditions, and as a result, these heat transfer tests did not exhibit isothermal cladding temperature behavior.

The petitioner implies that Cathcart and Pawel's statement, that scoping tests on the effect of steam pressure were in progress, is an admission of inapplicability of their work. On the contrary, the scoping work was completed and subsequent work by others has been undertaken to examine pressure effects. The petitioner's notion that the authors' statement about ongoing work applies to very low steam velocities is also unsupported.

Work in this area did not end in 1977. The NRC, foreign partners, and the industry have continued to conduct and evaluate experimental and analytical programs on fuel cladding behavior. As in the case with many other research activities and their link to the agency's regulatory framework, an important objective of this work is the confirmation of current § 50.46 criteria and models and the development of more realistic, performance-based, and contemporary criteria and models. An important link to the current work is the extensive research reported by Cathcart and Pawel.

The NRC disagrees with the petitioner's assertion that the disclaimer in the introduction to NUREG-17 causes the technical work to be inapplicable to reactor regulation. The disclaimer protects the United States Government from potential litigation. It is not intended to

discredit the technical validity of the work documented in NUREG-17. As such, the disclaimer is irrelevant to whether the NUREG-17 work is an adequate basis for reactor regulation. That is a question that should be decided solely on the technical merits of the work.

The NRC found no technical basis in the petition nor in NRC records to support the assertion that the Regulatory Guide 1.157 conditions for acceptance of the use of ORNL/NUREG-17 information result in flawed evaluation of ECCS performance.

Issue 3: Need for Further Analysis of Appendix K Backup Data

In Section 3.4 of his petition, the petitioner quotes from the AEC decision on the ECCS rulemaking [*See* Rulemaking Hearing, Acceptance Criteria for Emergency Core Cooling Systems for Light-Water Cooled Nuclear Power Reactors, RM-50-1, CLI-73-39, 6AEC1085, at 1124]: "It is apparent, however, that more experiments with Zircaloy cladding are needed to overcome the impression left from run 9573." The petitioner claims that such experiments have not been performed and are necessary. The NRC disagrees.

Run 9573 refers to one of four Zircaloy clad FLECHT experiments performed in 1969 and reported in WCAP-7665. The "impression" referred to by the AEC Commissioners in 1973 appears to be the fact that run 9573 indicates lower "measured" heat transfer coefficients than the other three Zircaloy clad tests reported in WCAP-7665 when compared to the equivalent stainless steel tests. This is not a concern about the zirconium-water reaction models. The AEC Commissioners believed that this anomaly could be cleared up with more experiments on Zircaloy cladding. Some of the anomaly can probably be explained by a deficiency in the data reduction process. As will be discussed later, additional Zircaloy clad tests were performed in the 1980s.

Regarding the data reduction process, heat transfer coefficients are not directly measurable quantities. They must be calculated from measured temperatures, known heat

sources, and known thermal properties. WCAP-7665 describes the heat transfer data reduction process using the DATAR code. For these experiments, the decay heat simulation was well known, as was the time of heater failure. However, the heat source, due to the zirconium-water reaction, had to be estimated in some way. The Baker-Just correlation was used for that purpose. Because of its conservatism, the Baker-Just correlation overestimates the amount of reaction and the associated heat generation rate. At 21 locations on 19 rods among the four Zircaloy tests, post-test oxide thickness measurements were made. Westinghouse applied the Baker-Just correlation to each temperature transient measured at or very near to each oxide thickness measurement. The comparison between predicted and measured oxide thickness was presented in Figure B-12 of WCAP-7665. The Baker-Just calculated oxide thickness is about 1.6 times the measured value. Thus for this data set, the Baker-Just correlation overpredicts the data by about 60 percent, which is quite conservative.

The NRC obtained tabular time/temperature data from Westinghouse for 19 of the 21 locations analyzed by Westinghouse for the four Zircaloy FLECHT tests. The Baker-Just correlation was applied to these 19 data sets as a check on the analysis in WCAP-7665. The RES technical study clearly demonstrates that the analysis in WCAP-7665 is correct and that the Baker-Just correlation is conservative even under the severe conditions of run 9573.

The petitioner asserts that a detailed thermal-hydraulic analysis of run 9573, including evaluation of the heating from Zircaloy-water reactions, was never performed. Contrary to that assertion, not only was an evaluation of the heating from Zircaloy-water reaction performed for run 9573, it was done for all four Zircaloy tests. Unfortunately, using the conservative Baker-Just correlation to estimate the zirconium-water heat release results is an overestimation of the derived heat transfer coefficients. Thirty-five years later, it would be difficult to replicate the DATAR code, substitute a better metal-water model, and re-derive the heat transfer coefficients. The difficulty would be in addition to the significant monetary expense of

conducting high-temperature Zircaloy tests and would have marginal benefit in terms of increased understanding of large-break LOCA heat transfer and metal-water reaction kinetics. The current programs being conducted at Pennsylvania State University and Argonne National Laboratory are far more cost-effective.

High-temperature tests similar to run 9573 would require rod bundle powers well outside the range of operation of any current or proposed pressurized water reactors (PWRs) and would produce very little useful heat transfer information. Therefore, the NRC does not believe that such tests are necessary.

The petitioner states that more experiments with Zircaloy cladding have not been conducted on the scale necessary to overcome the impression left from run 9573. The NRC disagrees. In fact additional Zircaloy tests have been performed. In the early 1980s, the NRC contracted with National Research Universal (NRU) at Chalk River, Ontario, Canada to run a series of LOCA tests in the NRU reactor. More than 50 tests were conducted to evaluate the thermal-hydraulic and mechanical deformation behavior of a full-length 32-rod nuclear bundle during the heatup, reflood, and quench phases of a large-break LOCA. The NRC is reviewing the data from this program to determine its value for assessing the current generation of codes such as TRAC-M (now renamed TRACE).

In assessing the need for further experiments like the Zircaloy-clad FLECHT tests, it is important to understand the past and current role of rod bundle reflood heat transfer tests. In the late 1960s, a mechanistic understanding of reflood heat transfer did not exist. To develop heat transfer models as expeditiously as possible, the Atomic Energy Commission (AEC), Westinghouse, and Electric Power Research Institute (EPRI), cooperatively developed the PWR FLECHT program. The principal objective was to determine reflood heat transfer coefficients as a function of key initial and boundary conditions, rod elevation, and time after the beginning of reflood and to develop empirical correlations based on that dependency. As long

as a sufficiently large matrix of tests was performed with full-scale rod bundles, there was no great need for a comprehensive mechanistic understanding. The key parameters were:

A. Pressure

B. Peak power

C. Decay power

D. Flooding rate

E. Inlet subcooling

F. Initial temperature

G. Bundle size

H. Cladding material

I. Housing temperature

When nuclear plant behavior and design conditions are outside the envelope defined by these test parameters or the design of the experimental system, there is no basis for extrapolation, since the derived heat transfer models are not necessarily based on the physical models governing the reflood heat transfer processes. For the very empirical process used in the early FLECHT experiments, limited effort was expended obtaining data needed for development of mechanistic physical models. It would have been impractical to obtain sufficient Zircaloy heat transfer coefficient data for the empirical process used with the early FLECHT experiments.

As the FLECHT program and other rod bundle reflood heat transfer programs have progressed over the last 30 years, more information appropriate for mechanistic model development has been obtained. As better mechanistic models are developed, careful extrapolation has a better chance of success, and the role of experiments like FLECHT has shifted from model development to developmental assessment. In fact, many of the FLECHT-SEASET experiments are used to assess the new code models. As mentioned previously, the

NRC is reviewing the NRU Zircaloy-clad nuclear fuel bundle test results to establish their value for further code assessment.

Conclusions

The NRC investigated each of the petitioner's key concerns. The NRC concludes that Appendix K of 10 CFR Part 50 and the existing guidance on best-estimate ECCS evaluation models are adequate to assess ECCS performance for US light water reactors (LWRs) using Zircaloy-clad UO_2 at burnup levels currently permitted by regulations. This general conclusion is based on the following considerations:

The Baker-Just correlation using the current range of parameter inputs is 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 for the temperature range important to clad oxidation calculations for LOCAs.

The parabolic/Arrhenius behavior of the Cathcart-Pawel isothermal experiments confirmed that there was adequate availability of steam. An NRC analysis confirms the ORNL/ANL assessment that the Cathcart-Pawel isothermal experiments were not steam starved by at least two orders of magnitude. Therefore, the experimental data is valid.

NRC has continued to study complex thermal hydraulic effects on ECCS heat transfer processes during LOCA accident conditions consistent with Commission direction. As part of that initiative, the NRC funded more than 50 Zircaloy-clad nuclear fueled bundle reflood experiments at the NRU reactor. These experiments evaluated fuel rod and heat transfer behavior but did not include metallurgical examination to evaluate oxidation behavior. The NRC is continuing to conduct and evaluate experimental and analytical programs on fuel cladding behavior.

The petitioner did not take into account Westinghouse's metallurgical analyses performed on the cladding for all four FLECHT Zircaloy-clad experiments reported in WCAP-7665. The petitioner also ignored the Westinghouse application of the Baker-Just correlation to these experiments, which had the "complex thermal hydraulic phenomena" deemed important by the petitioner. This application of the correlation to the metallurgical data clearly demonstrates the conservatism of the Baker-Just correlation for 21 typical temperature transients. The NRC also applied the Baker-Just correlation to the FLECHT Zircaloy experiments with nearly identical results, confirming the WCAP-7665 results.

For the development of oxidation correlations, limited by oxygen diffusion into the metal, well-characterized isothermal tests are more important than the complex thermal hydraulics suggested by the petitioner. The petitioner's suggested use of complex thermal-hydraulic conditions would be counter-productive in reaction kinetics tests because temperature control is required to develop a consistent set of data for correlation development. Isothermal tests allow this needed temperature control. It is more appropriate to apply the developed correlations to more prototypic transients (including complex thermal hydraulic conditions) to verify that the proposed phenomena embodied in the correlations are indeed limiting. This is what was done by Westinghouse in WCAP-7665, by Cathcart and Pawel in NUREG-17 and by the NRC in its technical safety analysis of PRM-50-76.

The NRC applied the Cathcart-Pawel oxygen uptake and ZrO_2 thickness equations to the four FLECHT Zircaloy experiments, confirming the best-estimate behavior of the Cathcart-Pawel equations for large-break LOCA reflood transients.

Cathcart and Pawel applied their oxide thickness equation, using the BILD5 program, to 15 of their transient temperature experiments as described in ORNL/NUREG-17. The results showed that the correlation, based on numerous isothermal experiments, was conservative or best-estimate when applied to this transient data set.

Petitioner's Public Comments

The petitioner submitted two public comment letters in which he again asserted that the Baker-Just and Cathcart-Pawel equations are grossly misapplied by the NRC. The first comment letter basically repeated the arguments in the petition. No new technical information was supplied. The second comment letter introduced the issue of severe fouling, which was the subject of PRM-50-78 and addressed by the staff's evaluation of that petition for rulemaking. Other issues addressed in the second letter are related to the issues already discussed in this document, and therefore, no further response is necessary.

Reasons for Denial

For the reasons cited in this document, the Commission is denying the petition for rulemaking (PRM-50-76) submitted by Mr. Robert Leyse. The NRC believes that the requested rulemaking would not make a significant contribution to maintaining safety because current regulations and regulatory guidance already adequately address the evaluation of performance of the ECCS. No data or evidence was provided by the petitioner or found in NRC records to suggest that the research, calculation methods, or data used to support ECCS performance evaluations were sufficiently flawed so as to create significant safety problems. NRC's technical safety analysis demonstrates that current procedures for evaluating performance of ECCS are based on sound science and that no amendments to the NRC's regulations and guidance documents are necessary. Additionally, the petitioner has not shown, nor has the NRC found, the existence of any safety issues regarding calculation methods or data used to support ECCS performance evaluations that would compromise the secure use of licensed radioactive material. The proposed revisions would not improve efficiency, effectiveness, and

realism because licensees and the NRC would be required to generate additional information (as part of the evaluation of ECCS performance) that has no safety value and does not significantly improve realism.

Dated at Rockville, Maryland, this 26th day of August, 2005.

For the Nuclear Regulatory Commission.

/RA/

Annette L. Vietti-Cook,
Secretary of the Commission.