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Our ref: LTR-NRC-08-42
September 2, 2008

Subject: Westinghouse Comments on the Technical Basis for New Performance-Based Emergency Core Cooling System Requirements (Non-Proprietary)

On July 31, 2008, the Federal Register (FR) published a Notice of Availability and Solicitation of Public Comment on Documents Under Consideration to Establish the Technical Basis for New Performance-Based Emergency Core Cooling System Requirements (73 FR 44778). The NRC announced the availability of Research Information Letter (RIL) 0801, "Technical Basis for Revision of Embrittlement Criteria in 10 CFR 50.46" and NUREG/CR-6967, "Cladding Embrittlement During Postulated Loss-of-Coolant Accidents". The NRC solicited comments to confirm that a sufficient technical basis exists to proceed with new performance based regulations on Emergency Core Cooling System (ECCS) acceptance criteria, and to identify issues that may arise with respect to experimental data development or regulatory costs or impacts of new requirements.

This letter provides Westinghouse's general comments regarding 73 FR 44778. The attachment provides specific responses to the questions posed by the NRC.

General Comments

1. The documents do not provide a sufficient technical basis to proceed with rulemaking.

   The existing 10 CFR 50.46 rule was established with conservative limits after a considerable effort by industry and regulators. The test program at Argonne National Laboratory has significantly advanced knowledge of the effects of burnup on fuel clad performance. It can provide the groundwork for guidelines on the qualification of advanced cladding alloys using unirradiated hydrogen-charged material. However, it does not provide a sufficient technical basis to proceed with rulemaking.

   The proposed new criteria are suggested in Figure 1 of RIL 0801. This figure shows Percentage of Cladding Oxidized as a linear function of clad hydrogen content. The test data supporting the criteria are sparse and should be augmented prior to rulemaking. The basis for the linear dependence of the limit has not been established.

   The high burnup testing that is the basis for Figure 1 was done at bounding conditions that cannot be achieved in commercial reactors. As fuel burnup increases, fuel power decreases. The freshest fuel in the core generates the highest power and thus operates at the highest temperature. Since the temperature of the fresh fuel is limited by regulation, the higher burnup fuel cannot reach the temperatures used in the ANL tests. This introduces excess conservatism in the proposed new limit in Figure 1 of RIL 0801.

   Additional testing should be performed to establish limits for high burnup fuel at temperatures which are credible. It is expected that these tests would provide a family of curves above the line depicted in Figure 1.

2. The cost of implementing the proposed rule is likely to exceed 250 million dollars, but implementation of the rule is not expected to benefit the health and safety of the public. The basis for the cost estimate is provided in the attachment.

As explained above, demonstrating that fresh fuel meets existing criteria as described in 10 CFR 50.46 (b) and IN 98-29 will assure that the lower power, higher burnup fuel remains at temperatures considerably below the fresh fuel and that the fuel will remain in a coolable geometry.

3. There is no compelling reason to rush to rulemaking with an inadequate, excessively conservative database. Systematic testing should be conducted at conditions that high burnup fuel could credibly attain during a LOCA. Discrepancies in test results should also be resolved.

4. Modifications to 10 CFR 50.46 are needed to address newer cladding alloys and eliminate the need for routine exemption requests as these alloys are deployed in operating reactors. However, this is a matter of convenience in avoiding the need for exemption requests, and must be weighed against the cost of developing and implementing a new rule.

Specific Responses on Questions Posed by NRC

The FR Solicitation of Public Comments identified three broad aspects for comment, with detailed areas under each aspect. For clarity, the attachment restates each of these detailed areas and provides Westinghouse's comments.

Westinghouse also noted technical issues in NUREG/CR-6967. We will follow up on these issues in a separate communication.

Westinghouse appreciates the opportunity to provide comments on the technical basis for the proposed regulations. We look forward to working with NRC and other stakeholders at the planned public workshop tentatively scheduled for September 2008.

Correspondence with respect to this correspondence should reference LTR-NRC-08-42 and should be addressed to J. A. Gresham, Manager, Regulatory Compliance and Plant Licensing, Westinghouse Electric Company LLC, P.O. Box 355, Pittsburgh, Pennsylvania 15230-0355.

Very truly yours,

J. A. Gresham, Manager
Regulatory Compliance and Plant Licensing

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Westinghouse Comments on the Technical Basis for New Performance-Based Emergency Core Cooling System Requirements (Non-Proprietary)

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Comments on the Aspects of the Adequacy of Technical Information in RIL 0801 and NUREG/CR-6967 Called Out in Federal Register Notice

I. Technical Basis

1. RIL 0801 Figure 1 provides the measured embrittlement threshold for all fresh and irradiated cladding specimens investigated during the ANL research program. Hydrogen dependent post-quench ductility regulatory criteria, similar to the lines on this figure, may be established from these experimental results.

a. Is the technical information presented within NUREG/CR-6967 sufficient in scope and depth to justify specific regulatory criteria applicable to all current zirconium cladding alloys?

Comment

The technical information in NUREG/CR-6967 provides information on the behavior of current zirconium cladding alloys under bounding LOCA conditions. Unfortunately, since this work was done at bounding conditions, there has been no new information generated for hydrogen-charged or high-burnup materials under the temperature conditions which high-burnup fuel could attain in a reactor which satisfies the current 10 CFR 50.46 acceptance criteria for Emergency Core Cooling Systems. Uranium dioxide fuel limited to 5 weight percent U-235 cannot lead the core (in terms of achievable linear heat rates) after a burnup of between 25-30 GWD/MTU (Figure I-1). As burnup increases, the power decreases, and the peak cladding temperature and corresponding maximum local oxidation decrease accordingly, relative to the fresh fuel in the core. Prior studies (e.g., References 1 through 3) have shown on the order of 200^oC or more reduction in peak cladding temperature for realistic high burnup fuel assessments.

Metallurgical analyses performed by CEA (Table 3 of Reference 4) showed a reduction in the oxygen content in the prior-beta phase in samples with comparable weight gains, as the oxidation temperature is reduced. This is consistent with the decreasing solubility of oxygen as temperature is reduced. This would be expected to offset the increase in oxygen solubility in the presence of hydrogen. Ring compression testing of hydrogen-charged samples oxidized at bounding temperatures for high burnup fuel (e. g., 1000 ^oC) should be performed prior to rulemaking. Reactor operation should not be artificially limited by high burnup fuel testing at conditions that are not credible.

Other areas that are of concern include the justification of single- versus double-sided oxidation testing, the criteria for determining acceptable ductility, the completeness of the database, the test techniques and testing reproducibility.

In summary, the technical information provided in NUREG/CR-6967 is not sufficient to justify the proposed regulatory criteria.

References:

1) Nissley, M. E., Frepoli, C., and Ohkawa, K., "Realistic High Burnup UO_2 Response to a LOCA in a PWR," SEGFSM Topical Meeting on LOCA Issues, Argonne National Laboratory, May 25-26, 2004 (NEA/CSNI/R(2004)19, published November 2004).

2) Frepoli, C., Nissley, M. E., and Ohkawa, K., "Comparison of High and Low Burnup UO_2 Fuel Response to a LOCA Using a Non-Parametric Statistical Method," Paper 210, 11th International Topical Meeting on Nuclear Reactor Thermal-Hydraulics (NURETH-11), Avignon, France, October 2-6, 2005.

3) Nissley, M. E., Frepoli, C., and Ohkawa, K., "Realistic Assessment of Fuel Rod Behavior Under Large-Break LOCA Conditions," NUREG/CP-0192, October 2005, pp.231-273.

4) Portier, L., Bredel, T., Brachet, J-C., Maillot, V., Mardon, J-P., and Lesbros, A., "Influence of Long Service Exposures on the Thermal-Mechanical Behavior of Zy-4 and M5™ Alloys in LOCA Conditions," Zirconium in the Nuclear Industry, ASTM STP 1467, B. Kammenzind and P. Rudling, Eds., American Society for Testing and Materials, 2005, pp. 896-920.

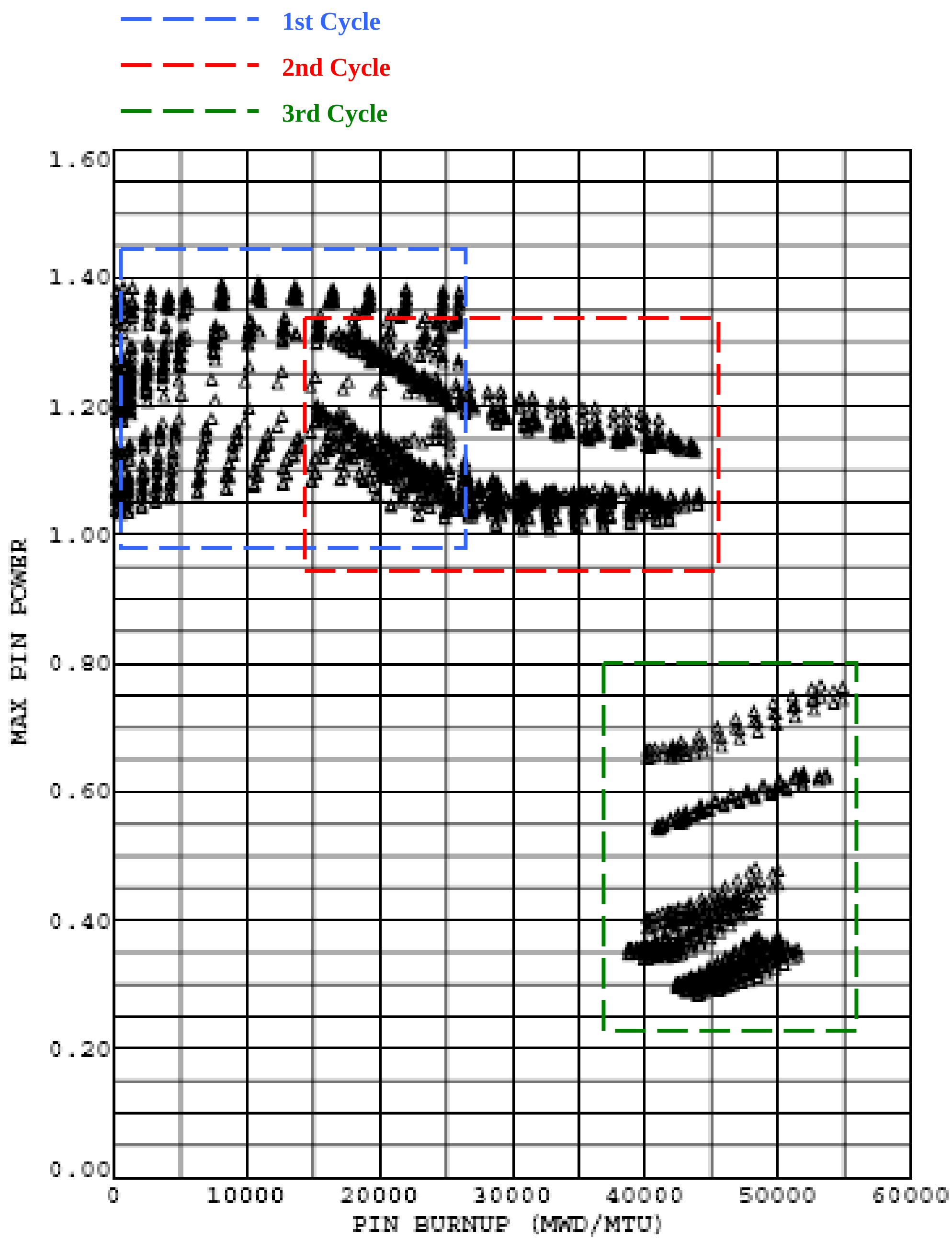

Figure I-1. Achievable Pin Power vs. Burnup for Typical Westinghouse 3-loop PWR

b. Is the technical information presented within NUREG/CR-6967 sufficient in scope and depth to justify periodic testing on as-fabricated cladding material?

Comment

Most of the testing on the effects of potential manufacturing variations on clad performance described in NUREG/CR-6967 was associated with breakaway oxidation testing of E110, a Russian alloy. Considerable testing was done to investigate the effects of surface treatments. The fabrication process for E110 refines zircon ore using an electrolytic process, while Western manufacturers use a Kroll refining process. While the breakaway oxidation testing indicated that surface variations could affect the E110 performance, tests on Western alloys showed little effect. For example, tests on ZIRLO™ with a belt polished surface indicated a time to breakaway oxidation of 3600 seconds, while tests with a scratched surface indicated a reduction in time to breakaway oxidation of only 200 seconds. Westinghouse has performed tests which demonstrate that the time to breakaway oxidation for ZIRLO™ is in excess of 5400 seconds (Reference). Therefore, there is no basis in NUREG/CR-6967 to justify periodic testing of as-fabricated material. Vendors typically have change management processes to assure that the cladding meets requirements when significant changes are made to the manufacturing process or alloy composition.

Reference:

J. A. Gresham (Westinghouse) to U.S. NRC Document Control Desk, "Updated Westinghouse Breakaway Oxidation Testing / Behavior", LTR-NRC-08-29, June 12, 2008.

c. Is the technical information presented within NUREG/CR-6967 sufficient in scope and depth to address sensitivities to alloy composition, trace elements, manufacturing practices, fuel rod burnup, and transient temperature profile?

Comment

The scope of testing performed by ANL included the primary alloying systems (e.g., Zr-Sn, Zr-Nb, and Zr-Nb-Sn) currently in use for fuel cladding. Their test results indicate that ductility was not a direct function of alloy composition. The chemistry variations between the alloys (e.g., Zircaloy-4, Zircaloy-2, ZIRLO™, and M5™) are significantly larger than the variations that would occur for a given alloy. Based upon the similarity in the ductility of the multiple alloys, further testing to assess the impact of alloy composition variations within an alloy is not warranted.

The impact of trace elements and manufacturing practice was evaluated based upon the available materials that were provided to ANL for testing. While no systematic evaluation of trace impurities or manufacturing practices was included in the study, the tubing was processed from multiple ingot vendors and tubing suppliers. The major sensitivity to manufacturing processes was for breakaway oxidation with alloy E110 exhibiting much shorter times to breakaway oxidation than the other alloys. Variables of importance that were identified were ingot source (i.e., electrolytic refining versus Kroll process) and surface condition (e.g., impurities such as fluorine and surface roughness). Based upon the testing at ANL, it appears that LOCA testing for current materials is needed only if an alternate refining process other than the Kroll process is implemented for Western alloys.

The fuel rod burnups examined in this program bound current end-of-life conditions (i.e., standard licensed limit of 62 GWD/Mtu lead rod), but do not provide sufficient information for the conditions between middle-of-life and end-of-life, when the cladding potentially makes contact with the pellet and the formation of hard contact (fuel-cladding bonding) begins. The possibility of ID oxidation away from the burst region may not have to be considered for the limiting fuel in the core which is at a relatively low burnup and does not have hard contact.

The transient temperature profile used in the ANL LOCA tests (Figure II-1) was sufficiently conservative to bound those expected for the fuel that is capable of achieving limiting linear heat rates. The initial heat-up rate from 300°C to ~1130°C (572°F to ~ 2070°F) is about 42°C/sec (75°F/sec), followed by a heat-up rate of ~ 10°C/sec (18°F/sec)to 1200°C. This bounds expected heat-up transients to the limiting temperatures in small and large break LOCAs. It is overly conservative for high-burnup fuel, as discussed in the comment on item I.1.a.

The temperature profiles seen in LOCA analyses of small and large break scenarios can vary widely. Sample temperature profiles are provided in Figures II-2 and II-3. The few "generic" comments that can be made are as follows:

- *Small break heat-up rates (~ 2-5°F/sec) are noticeably lower than for large break events (~10-15°F/sec), and the time at elevated temperature is longer (but at lower temperatures).*
- *Large break LOCAs can quench at somewhat higher temperatures at low elevations due to the heat transfer mechanisms involved (e. g., inverted annular film boiling at the bottom of the core vs. dispersed flow film boiling higher in the core). Note that the limiting elevations for corrosion are in the high elevations of the core.*
- *It is Westinghouse experience that the heat-up rates used in the ANL LOCA tests bound those observed in small and large break LOCAs, and that a quench temperature of 800°C bounds those reasonably expected by a considerable amount.*

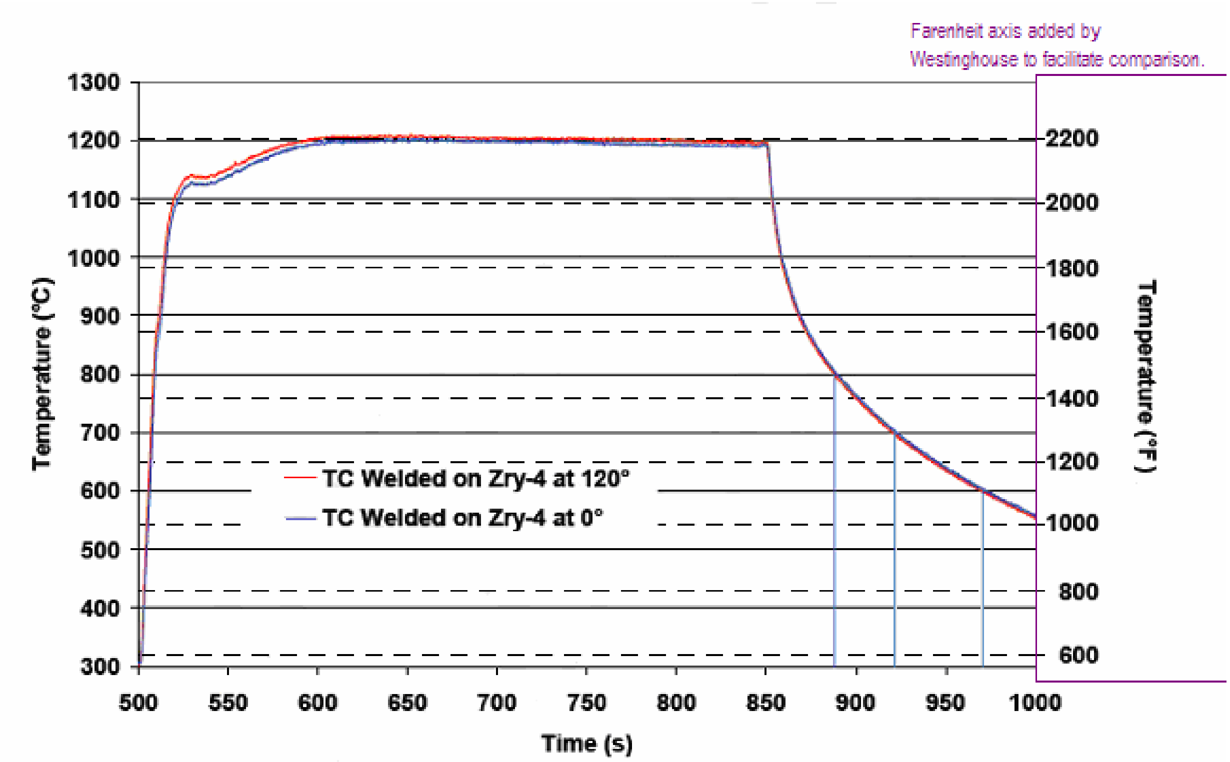

Figure II-1. Typical Transient Temperature Transient Used in ANL LOCA Testing

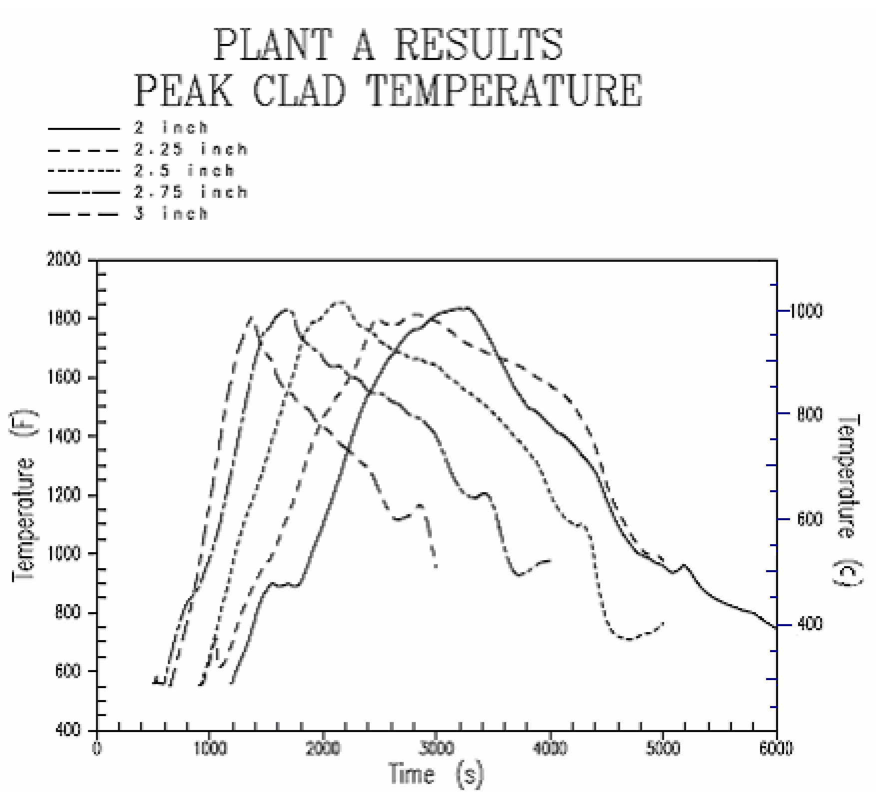

Figure II-2 Transient Temperature Profiles for a Sample Small Break LOCA

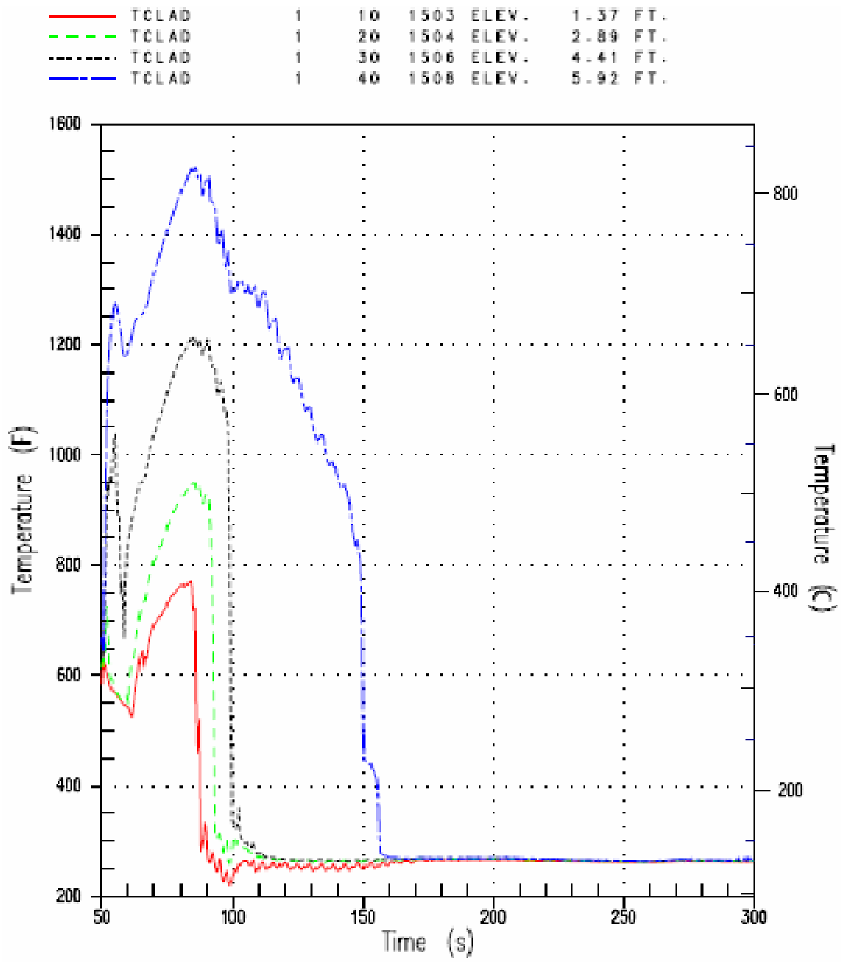

Figure II-3a. Transient Temperature Profiles in the Bottom Half of the Core for a Sample Large Break LOCA

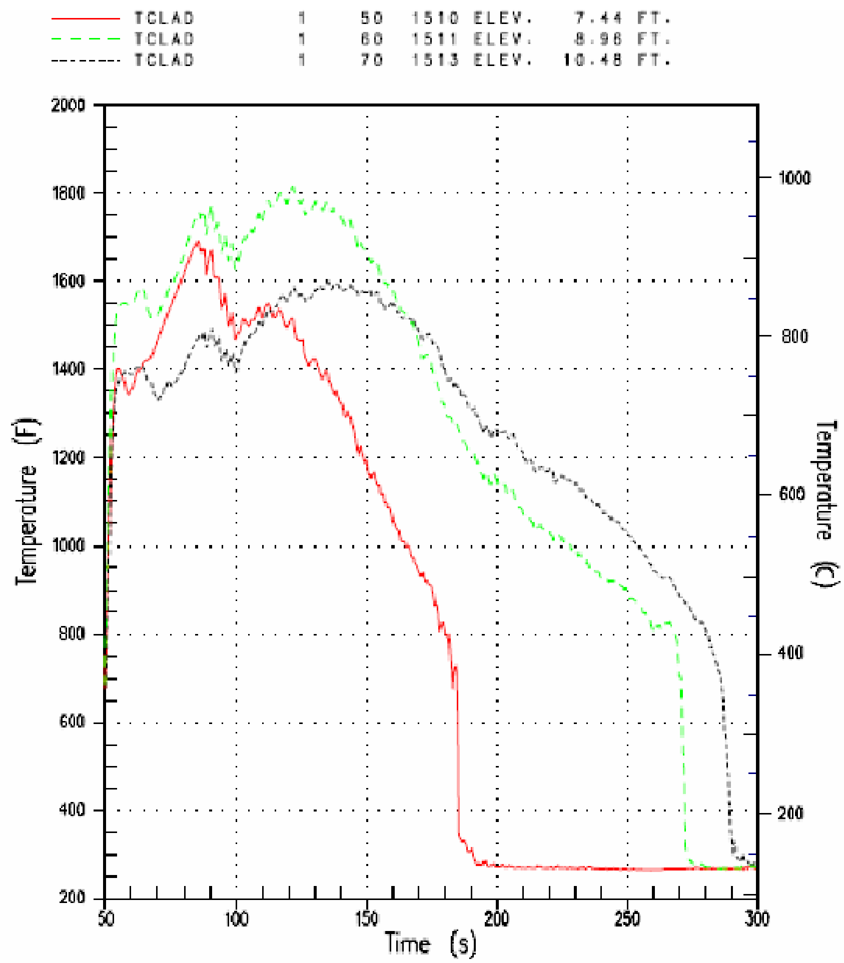

Figure II-3b. Transient Temperature Profiles in the Top Half of the Core for a Sample Large Break LOCA

2. Section 2 of NUREG/CR-6967 details the experimental techniques and procedures employed at ANL to assess cladding properties.

a. Were the experimental techniques and procedures adequate for their intended purpose of defining acceptable fuel criteria (e.g., specimen preparation, specimen size, heating/cooling rates, ring-compression techniques, test temperature, acceptance criteria for post-quench ductility and breakaway oxidation, etc.)?

Comment

Some, but not all, of the experimental techniques and procedures were adequate for the purpose of defining acceptable fuel criteria. A systematic review of the techniques and criteria should be conducted to identify areas where improvements are needed, and these areas should be addressed prior to additional testing and rulemaking.

For example, as demonstrated in breakaway oxidation tests performed at ANL and Westinghouse, different breakaway oxidation times were reported from the two test facilities. Additional work is required to better define the test procedures to ensure that consistent results are achieved.

The procedure used to evaluate the results of a ring compression test for ductile or brittle outcome and to then determine the ductile-to-brittle transition is arbitrary. A more detailed procedure needs to be described such that independent laboratories can produce consistent results for a given alloy. There should be provision for the use of alternative test methods such as the 3-point bend test which might provide better resolution of the ductile–to-brittle transition.

ANL performed extensive testing to identify the test variables that play a significant role in the embrittlement of cladding during a LOCA. Among the variables are peak temperature, heating/cooling rates, quench temperature, and hydrogen content. While NUREG/CR-6967 documents the parameters used in the ANL testing, the range of the test variables was limited and included non-prototypic test conditions. For example, all of the high temperature oxidation of hydrogen-charged Zircaloy-4 samples as well as the high-burnup samples was performed at the limiting temperature of 1200ºC. Since high-burnup samples with higher hydrogen levels are limited to peak temperatures that are less than 1200ºC, additional testing to assess the sensitivity of post-LOCA ductility to lower peak temperatures needs to be performed prior to rule making. Similarly, testing that uses LOCA-relevant quench and cooling rates prior to quench needs to be performed to establish the impact of these test variables on ductility.

Testing of high burnup fuel, and hydrogen charged specimens simulating high burnup fuel, should be done at conditions that are credible, given that fresher fuel in the core must meet the LOCA acceptance criteria.

b. Is the technical information presented within NUREG/CR-6967 sufficient in scope and depth to address uncertainties related to and repeatability of measured results?

Comment
No. For example, ANL agrees that a reproducible, reliable testing method has yet to be developed for breakaway oxidation testing.

"Differences in ANL and W results highlight the importance of establishing standardized procedures for pretest surface cleaning, heating, temperature monitoring and control, and steam flow rates for breakaway oxidation tests." (page 120, NUREG/CR-6967)

"Westinghouse and Argonne used different sample cleaning methods, different furnaces (resistance-heating vs. radiant-heating), and different temperature control and monitoring. It is recommended that these differences be evaluated before breakaway oxidation tests are standardized." (Page 378 NUREG/CR-6967)

II. Performance-Based Testing Requirements

1. Due to potential sensitivities to manufacturing processes, performance based testing may be required to characterize the loss-of-coolant accident (LOCA) performance of new cladding alloys.

a. Section 2.1 of NUREG/CR-6967 details all of the fresh and irradiated cladding specimens investigated during the ANL research program. Is the extent of the ANL material database sufficient to justify the applicability of experimental results to future cladding alloys?

Comment
Insight gained from the ANL tests will likely be applicable to future cladding alloys. However, given that the composition and performance of future alloys are unknown at present, testing may be required to confirm the applicability of the ANL results for those alloys.

b. Conducting testing on irradiated specimens is more difficult and expensive than similar tests performed on unirradiated specimens. Does a sufficient technical basis exist to justify testing on hydrogen charged, unirradiated cladding specimens as a surrogate for irradiated fuel cladding?

Comment
Testing on hydrogen-charged samples to simulate the effects of burnup on clad performance is a practical method for obtaining performance data in a timely manner, given that results can be obtained in a matter of weeks, compared with the years required to irradiate material to the desired burnup, ship it to a hot cell, and test the irradiated material. Testing has shown that the performance of hydrogen-charged unirradiated material is representative of irradiated material.

2. Due to potential sensitivities to manufacturing processes, routine testing may be required to verify material performance. Are there difficulties or limitations with periodic testing that would make such a requirement impractical?

Comment
Westinghouse does not agree that routine testing is justified. However, if periodic testing is implemented, these tests will take several days to complete and will require more sophisticated testing (e.g., maintenance of high temperatures and steam flow) that may be impractical in a manufacturing environment. Additionally, standardized testing methods (e.g., ASTM standards) have not yet been developed.

III. Implementation

1. Implementing new regulatory criteria for 10 CFR 50.46(b) may necessitate further testing and new licensing activities (e.g., revised methods, updated safety analyses, etc.). What is the cost-benefit for implementing new regulatory requirements similar to those discussed in RIL 0801?

Comment
Westinghouse can comment on the costs that would be associated with:

- *obtaining a material performance database using repeatable tests at credible conditions to establish performance limits*
- *modifying all existing LOCA Evaluation Models, providing information for use in submittals to NRC and updating the plant's licensing basis*
- *performing additional (yet to be determined) periodic testing on fabricated cladding*

Cost to Establish Database
The ANL test program has provided much information on the effects of burnup and hydrogen on clad performance. However the testing has been carried out at conditions that are not credible at the burnup levels under consideration. Furthermore, repeatability is questionable for some of the tests. In order to implement a new rule, a comprehensive database would need to be constructed using both hydrogen-charged and irradiated material over a range of burnups. Testing on hydrogen-charged samples could cost a few million dollars. Hot cell testing on irradiated material would be much more expensive, likely several million dollars. The total cost to develop the database is estimated to be on the order of 10 million dollars per vendor.

Cost to Modify LOCA Evaluation Models
The cost to modify LOCA evaluation models and demonstrate compliance with the new rule is estimated based on the assumptions that:

- *All LOCA Evaluation Models currently in use will need to be modified, and re-submitted for NRC review so that the design basis licensing analyses are consistent with the new requirements.*
- *The scope of the NRC reviews of these submittals will be limited to implementation of the new requirements (questions on the Evaluation Models unrelated to the new requirements will not be raised)*
- *All 104 reactors currently licensed for operation in the US will have new small break/large break analyses performed by their fuel vendor, submit Licensing Amendment Requests to revise their licensing basis analyses, update their latest Safety Analysis Reports, and respond to any USNRC Requests for Additional Information arising from this process.*
- *Each licensee will follow their own internal processes for updating their plant's design basis*

The cost per utility is expected to average on the order of $2M (or more) per plant. Given that there are 104 plants, the cost to implement modified LOCA Evaluation Models would be over 200 million dollars.

Cost to Conduct Periodic Testing
Given that the periodic testing has only been discussed in abstract terms, a credible estimate of cost cannot be made. Depending on the required testing, significant direct cost could be incurred and potentially greater indirect costs could be incurred associated with the need to segregate and hold production pending completion of tests and possible rejection of "good" material due to issues associated with test repeatability and/or "false positives."

Thus the total cost to implement the new rule is likely to exceed 250 million dollars, based only on the work expected to be done by the vendors and licensees.

This estimate does not include the costs that will be incurred by NRC in promulgating the new rule and reviewing submittals to confirm compliance with the new rule. Other potential costs might include implementation (development, approval, monitoring/inspections, and enforcement) of additional surveillance requirements by licensees (e.g., burnup dependent peaking factor limits).

While the cost is large, the benefit of a new rule is not apparent
It is not clear what benefit to the health and safety of the public will be realized by an overhaul of the current acceptance criteria of 10 CFR 50.46, and re-licensing of every plant in the U.S.

Based on the above, the proposed change would fail a cost-benefit analysis.

2. Implementing hydrogen-based regulatory criteria may require the development of high confidence corrosion and hydrogen pickup models.

a. What type of information is needed to develop such models and is such information readily available?

Comment
Hydrogen is liberated as the cladding oxidizes. Most of the hydrogen is carried away in the coolant. However, some hydrogen diffuses into the cladding. Since the hydrogen is generated by oxidation, a model for predicting oxidation and subsequent hydrogen pickup can be used in design. An associated design evaluation of the oxide thickness can be established to assure that the impact of hydrogen is addressed.

A database of clad oxide thickness over a range of burnup, fuel duty and coolant chemistry conditions is needed to develop a corrosion model.

b. What performance indicators (e.g., pool-side measurements, hot cell examinations, etc.) could be used to validate models?

Comment
Oxide thickness data from poolside eddy current (EC) measurements are the most useful indicators of clad performance. The data can be obtained relatively quickly and can provide feedback on corrosion performance within a month of the end of a cycle of irradiation. Limited hot cell metallography measurements confirm the accuracy of EC measurements. Hot cell results typically take much longer to obtain (over two years after completion of irradiation) than poolside exams, so poolside EC measurements of clad oxide are preferable as a timely indicator of in-core clad performance.

c. What additional regulatory requirements would be necessary to assure that the fuel is performing in accordance with the approved models? How will compliance with the rule be demonstrated on a cycle by cycle basis?

Comment
Additional regulatory requirements will not benefit the public health and safety. As explained in the comment under item III.2.a, a design evaluation on oxide thickness versus burnup can address the impact of hydrogen. Using this approach, the normal corrosion analysis typically performed as part of the reload analysis is sufficient to demonstrate compliance on a cycle by cycle basis.

3. Crud deposits on the fuel cladding surface may affect fuel stored energy, fuel rod heat transfer, and cladding corrosion.

a. What role does plant chemistry and crud deposits play on these items?

b. How should normal and abnormal levels of crud deposits be addressed from a regulatory perspective?

Comment
A summary of the industry position on crud is provided in the Reference.

Reference:

Letter from James H. Riley (NEI) to Annette L. Vietti-Cook (NRC), Subject: Leyse Petition for Rulemaking: PRM-50-84, Project Number 689, Docketed USNRC August 3, 2007 (4:16 PM)