IRSN
INSTITUT
DE RADIOPROTECTION
ET DE SÛRETÉ NUCLÉAIRE

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Chef de DPAM/SEMCA
DPAM/SEMCA 2009-00456

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Secretary
US Nuclear Regulatory Commission
Washington, DC 20555-0001

Subject : Comments on Proposed Rulemaking on 10 CFR 50.46 (ECCS Acceptance Criteria) [RIN 3150-AH42]

Dear Secretary,

Enclosed you will find the IRSN comments on proposed Rulemaking on 10 CFR 50.46, prepared by our expert, Claude Grandjean.

Yours sincerely

François BARRE

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DS 10

IRSN Comments on Advanced Notice of Proposed Rulemaking (ANPR) for Performance-Based Emergency Core Cooling System Acceptance Criteria (RIN 3150-AH42)

By Claude Grandjean

Applicability Considerations

Objective 1describes a conceptual approach to expanding the applicability of §50.46 to any fuel cladding material.

#1. Based on the findings of the recent LOCA research program (which conducted testing on a wide range of Zr-based alloys), the NRC intends to expand the applicability of the rule to all Zr-based alloys. In addition, the NRC is considering further application of the rule's applicability to include any LWR fuel cladding material. To accomplish such a change, the NRC is considering a cladding-specific regulatory approach that would require applicants with non-Zr cladding materials to propose specific detailed criteria to demonstrate how 1) minimal generation of combustible gases, 2) coolable geometry, and 3) long-term cooling would be ensured, that is to satisfy the three currently existing criteria in §50.46(b)(3)-to-(5).

From IRSN's view, it is not clear why in Section III, under *Objective 1*, the change being considered by NRC to expand the rule's applicability to any cladding material does not mention the requirement of preserving cladding integrity following high temperature oxidation, requirement which is expressed by the limits on peak cladding temperature and maximum local oxidation in the current rule. As the Objective 2, which addresses the preservation of cladding ductility, refers specifically to Zr-based cladding materials, one may wonder if the preservation of cladding integrity would be explicitly required for non-Zr materials.

Among three unchanged criteria, the requirement of satisfying §50.46(b)(4), that is to demonstrate the core coolability following any change in geometry, underlines the pending need to make this requirement more quantitative and to take account of updated considerations on the ballooning and flow blockage coolability issues related to high burnup fuel. IRSN is presently investigating an alternative methodology that could be used in a future revision of the LOCA safety criteria which includes the requirement on flow blockage coolability.

For non-Zr cladding materials, this requirement is expected to involve extensive new research programs to be performed by the applicants and a wide reviewing effort by the NRC.

#2. Due the use of mixed oxide fuel rods in the fuel management for some NPP in some countries, there is a clear need that the revised rule be not limited to UO2 fuel.

The use of performance-based requirements and acceptance criteria for ensuring the preservation of cladding ductility *a priori* eliminates the need to specify the fuel type. However, while the requirements for cladding ductility preservation may be disconnected from fuel characteristics, this appears fully questionable for the requirement §50.46(b)(4) on coolable geometry. For high burnup fuel, the clad ballooning process is expected to be influenced by the fuel structure near the cladding ID, e.g. the rim structure and bonding thicknesses which may depend on fuel type. Furthermore, the relocation of fragmented fuel in

the clad balloon, which will influence the coolability of the ballooned area, is also expected to depend on fuel type.

New Embrittlement Criteria Considerations

#3. The requested information related to maximum time span with cladding surface temperature above 1200°F (649°C) may ultimately keep of low interest for setting a specified minimum time to breakaway in the proposed rule's statement.

Based on the existing data on breakaway oxidation, the search for the minimum breakaway time and the corresponding isothermal temperature does not seem to require testing down to 649°C. The Leistikow and Schanz test data, from tests on pickled samples of 1970s vintage standard Zry-4 have indicated breakaway oxidation times of 1800 s at the ~1000°C minima, and several times longer near a lower minima at ~800°C. ANL and CEA data from tests on modern Zircaloy polished samples have indicated breakaway oxidation times greater than 5000 seconds near the 1000°C minima. Therefore, the breakaway oxidation time at ~800°C minima for the current modern Zircaloy is expected to be longer than 10,000 seconds and makes unnecessary any investigation at lower temperatures in consideration of the expected time at high temperature in SBLOCA transients. Although the current level of understanding of breakaway oxidation remains rather limited, the above-mentioned indications appear sufficient, from IRSN point of view, to limit the breakaway requirement to a simple screening test for a sufficiently conservative specified oxidation time at 1000°C.

#4. General comments.

Section III of the ANPR states that *"For LWRs using Zr-based alloys, cladding-specific criteria can and will be specified in the regulations based on the results of the NRC's LOCA research program. These criteria will ensure adequate cladding ductility is maintained via specified performance requirements."*

As a preliminary comment, IRSN underlines that, while the ductility-based criteria issued in 1973 in the following of the ECCS Hearing were adopted by the whole nuclear community, there is presently no more a worldwide consensus for considering the preservation of cladding ductility as a necessary requirement for the maintaining of cladding integrity under LOCA conditions. In particular, it is noticeable that Japan has moved, since 1981, from a ductility-based criterion to a strength-based criterion for the oxidation limit, with reference to the results of integral-type tests with quench under constrained conditions. Even if the loads that apply to a fuel rod under LOCA conditions still remain to be evaluated in more detail, it is now quite clear that the loading conditions corresponding to ring compression testing is far more severe than the actual conditions experienced by a fuel rod under a postulated LOCA transient. As a consequence, the criteria based on one or the other requirement would correspond to significantly different limits on the parameter quantifying the time-at-temperature, namely the local cladding oxidation. JAEA performed recently ring compression tests on samples taken from the irradiated rods that survived the quench in previous integral-type tests ; results indicated brittle behavior under ring compression testing for almost all samples of the various cladding materials.

A ductility-based criterion derived from ring compression tests (RCT) refers to the ductile-brittle transition conditions determined on the tested cladding rings whose pre-test characteristics (geometry, hydrogen content...) may generally be well identified. On the other hand, a strength-based criterion derived from integral-type tests refers to the structural

behavior of a fuel rod with pellets, where the failure location is not pre-determined due to the cumulative influences of wall thinning, oxidation and secondary hydriding ; the failure conditions are thus not so clearly identified as in RCT.

The main difficulty which appeared in the ductility-based approach is linked with the drastic influence of hydrogen content on the ductile-brittle threshold : the extrapolation of the data to high hydrogen content would lead to zero embrittlement oxidation rate (CP-ECR) at ~800 wppm hydrogen. Even if a direct extrapolation may appear inaccurate and could be somewhat refined, it remains that, as already indicated in the Research Information Letter 0801, no criteria can be found that would ensure ductility in the whole cladding balloon where locations with high hydrogen content (~2000 wppm and more) may be expected due to inner side oxidation under stagnant steam conditions. Since the original rule is specified to apply at any location of the fuel rod cladding, the difficulty is pending. However, it has been observed in bending tests or quench constrained tests on ballooned and burst rods that the failure location was located near the burst midplane where hydrogen concentration is low ; considerations of these results may be reassuring, but appear insufficient to IRSN for exempting the whole ballooned region from a revised rule.

Based on these considerations, IRSN would investigate the opportunity to develop a strength-based approach, as far as the loading conditions applied to the fuel rod under a postulated LOCA transient could be realistically evaluated so as to define a set of appropriate testing conditions. Work is in progress at IRSN to support this objective.

Section III of the ANPR indicates:" *It is important to recognize that **the loss of cladding ductility is the result of oxygen diffusion into the base metal and not directly related to the growth of a zirconium dioxide layer**...In the current provision, the peak local oxidation limit is used as a surrogate to limit time at elevated temperature and associated oxygen diffusion. In the recent LOCA research program, the Cathcart-Pawel (CP) weight gain correlation was used to quantify the time at elevated temperature at which ductility was lost. For this reason, the proposed amendment would include a requirement that local cladding oxidation (which is used as a surrogate for limiting time-at-temperature) be calculated using the same Cathcart-Pawel correlation rather than the Baker-Just correlation cited in 10 CFR 50, Appendix K."*

From IRSN point of view, while this proposed change in the correlation used to calculate local oxidation ensures consistency with the data analysis of ANL test results, it may introduce some confusion if comparisons were made on oxidation limits obtained with the Baker-Just correlation, for instance on the oxidation limit for as-received Zircaloy cladding (old Hobson's data), or the oxidation limits obtained in other research programs (Japan...). Furthermore, since the local oxidation rate (ECR) is recognized as only a surrogate for limiting time-at-temperature, the use of a best-estimate model rather than a conservative one is unnecessary and the comparison of measured versus CP-calculated values, as was done in the data analysis of ANL LOCA research program, might reinforce the erroneous idea that the local oxidation, which is mainly related to the ZrO_2 layer thickness, is the right physical parameter that controls the cladding embrittlement. In this respect, IRSN would favor the use of an alternative parameter related to the oxygen profile in the base metal, as was done by Chung and Kassner in their proposed revised criteria based on the extensive research program conducted at ANL in the early 1980s. Such an approach would allow a more physical treatment of the oxygen diffusion into the base metal from a pre-existing corrosion layer on the outside diameter and from a bonding layer on the inside diameter. Work is in progress at IRSN, both

on the experimental and code development aspects towards the definition and future use of such an alternative parameter.

Testing Considerations

#6.d in Section IV indicates : "The NRC is considering defining an acceptable measure of cladding ductility as the accumulation of ≥1.0 percent permanent strain prior to failure during ring compression loading at a temperature of 135°C and a displacement rate of 0.033 mm/s."

IRSN wonders if and why the proposed rule would favor a permanent strain criterion (rather than an offset strain criterion) while the procedure developed at ANL for determining ductile-to-brittle transition, as detailed in Section 2.3 of NUREG/CR-6967, makes use of a combination of both parameters. It should thus be kept in mind that permanent strain can only be determined for ring samples that fail with a single, tight, through-wall crack, while offset strain can be determined for every ring being tested.

In line with ANL comments in response to this part of the ANPR, IRSN has reservations regarding the variability in results that may arise in data interpretation from testing in various labs. The question is basically linked with the shape of the permanent (or offset) strain vs. oxidation level as illustrated on Figure 1.

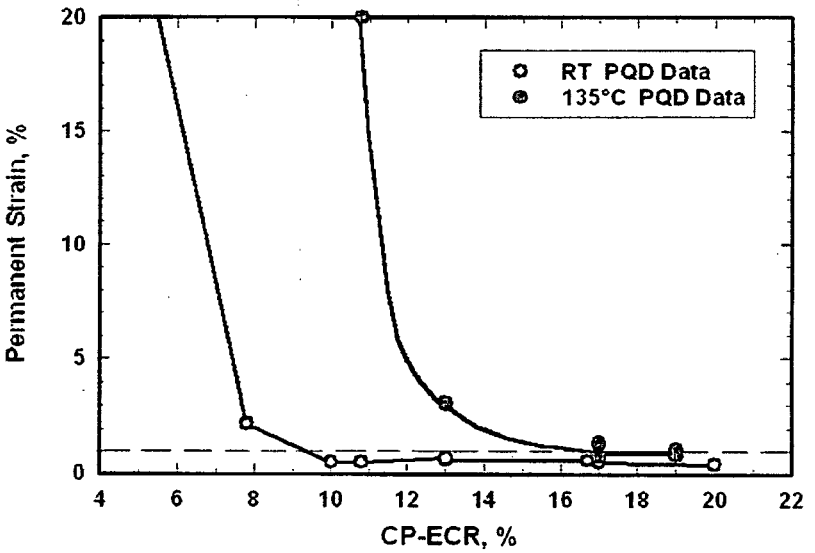

Figure 1 : Room Temperature & 135°C Post Quench Ductility for As-Fabricated Alloys. 17x17 Zry-4 Oxidized at 1200°C, 800°C Quench.

As the shape of the permanent strain as function of ECR shows a near horizontal branch around the low threshold value chosen to define the ductile-brittle transition (1%), significant uncertainty may be expected to locate the embrittlement threshold on the ECR parameter in the corresponding interval. In addition, variability in hydrogen content (for pre-hydrided or irradiated samples) and more or less influence of the heating rate for different target CP-ECR, make the data interpretation even more tricky. Interpolation is required to obtain the threshold value, but different techniques may be used, leading unavoidably to different results. Figure 2 illustrates the difference in threshold ECR values that was observed between data interpretation at ANL and RRC Kurchatov Institute on the same data set.

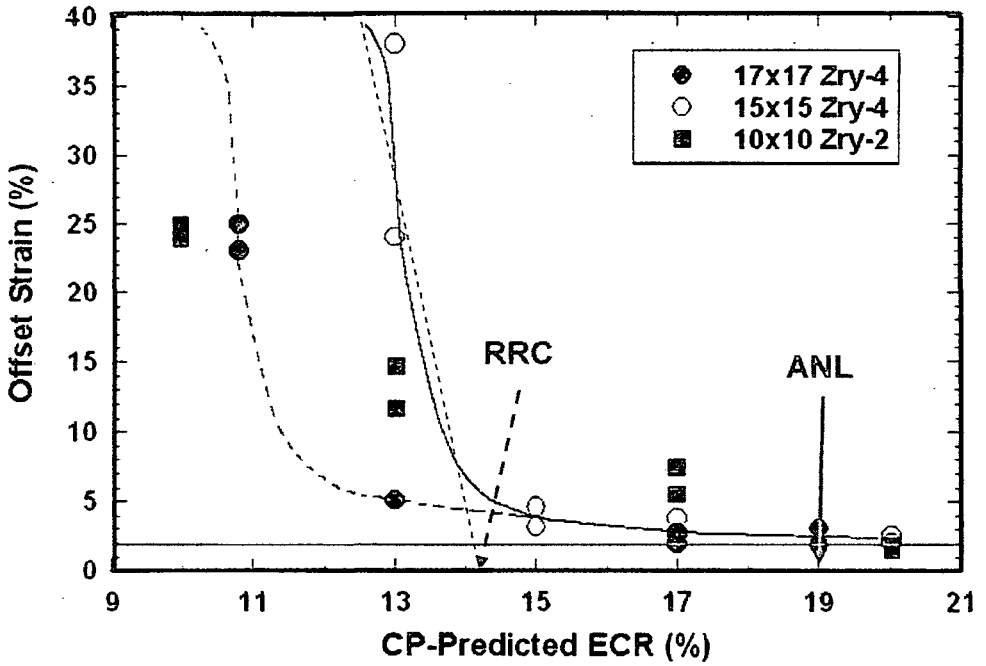

Figure 2 : Differences in ANL and RRC Interpretation of Ductile-to-Brittle Transition Oxidation Level for Same Data Set

(figure presented by M. Billone, ACRS Subcommittee Meeting, December 2, 2008)

This illustration suggests than significant inconsistencies may arise between results from tests performed in different places using different test procedures and data interpretations. In view of the allowance of an approach where cladding-specific analytical limits would be defined by an applicant, the above considerations underline the need of an independent peer-review process for both test conducting and data interpretation. Such a process was efficient in the open scientific scrutiny of the LOCA research program conducted at ANL. This appears to be a necessary process so as to ensure consistency and a same level of confidence between analytical limits established in different places for different cladding alloys and/or different oxidation conditions. Ultimately, this would provide the required legibility to allow future adoption of the rule at an international level, as is the case for the current rule.

Such a review process should also be considered for alternative approaches and methodologies that are, or could be, investigated in parallel in other countries.

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Rulemaking Comments

From: JEGOU Viviane [viviane.jegou@irsn.fr]
Sent: Friday, December 18, 2009 9:10 AM
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Cc: Voglewede, John; Clifford, Paul; Scott, Harold; Landry, Ralph; QUENIART Daniel; JOREL Martial; SCOTT-DE-MARTINVILLE Edouard; VOLANT Philippe; MICAELLI Jean-Claude; CADET-MERCIER Sylvie; BOIREL David; PETIT Marc; MARCHAND Olivier; GRANDJEAN Claude; CHAUMONT Bernard; BAUDRY Michel; BARRE François
Subject: IRSN comments on ANPR
Attachments: Doc.pdf

ATTN: Rulemakings and Adjudications Staff.

Enclosed are comments from IRSN on the ANPR (RIN 3150-AH42).

The comments are written in letter format addressed to Secretary, U.S. Nuclear Regulatory Commission, Washington, DC

20555-0001,

We also intend to send a paper copy by postal mail to this address.

However, the enclosed PDF version will be much easier to incorporate as an electronic file.

Please accept the enclosed comments.

Thank you,

François BARRE

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