February 23, 2009

MEMORANDUM TO: William H. Ruland, Director
Division of Safety Systems
Office of Nuclear Reactor Regulation

FROM: Paul Clifford, Senior Level Advisor /RA/
Division of Safety Systems
Office of Nuclear Reactor Regulation

SUBJECT: Plant Safety Assessment of RIL 0801 (non-Proprietary)

In a memorandum dated July 15, 2008 (ML081620302) you forwarded an assessment of operating plant safety to Jack Grobe, Associate Director for Engineering and Systems that considered the information provided in Research Information Letter (RIL) 0801, "Technical Basis for Revision of Embrittlement Criteria in 10 CFR 50.46.

Attached is a revision to that plant safety assessment that removes all proprietary information and is therefore suitable for public release. The attached revision also includes some editorial changes.

Enclosure:
As stated

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(301) 415-4043

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Plant Safety Assessment for Research Information Letter 0801

10CFR 50.46(b) specifies fuel criteria which ensure that the fuel cladding maintains a degree of post-quench ductility (PQD) during a postulated loss-of-coolant accident (LOCA). The current criteria, 2200 °F and 17% equivalent cladding reacted (ECR), are based upon ring-compression tests performed on un-irradiated zircaloy specimens. Ten years ago, the Office of Nuclear Regulatory Research initiated a LOCA research program to investigate potential burnup and alloying effects on the 10 CFR 50.46(b) criteria. The principle findings of this research program and their potential impact to operating plant safety are discussed below.

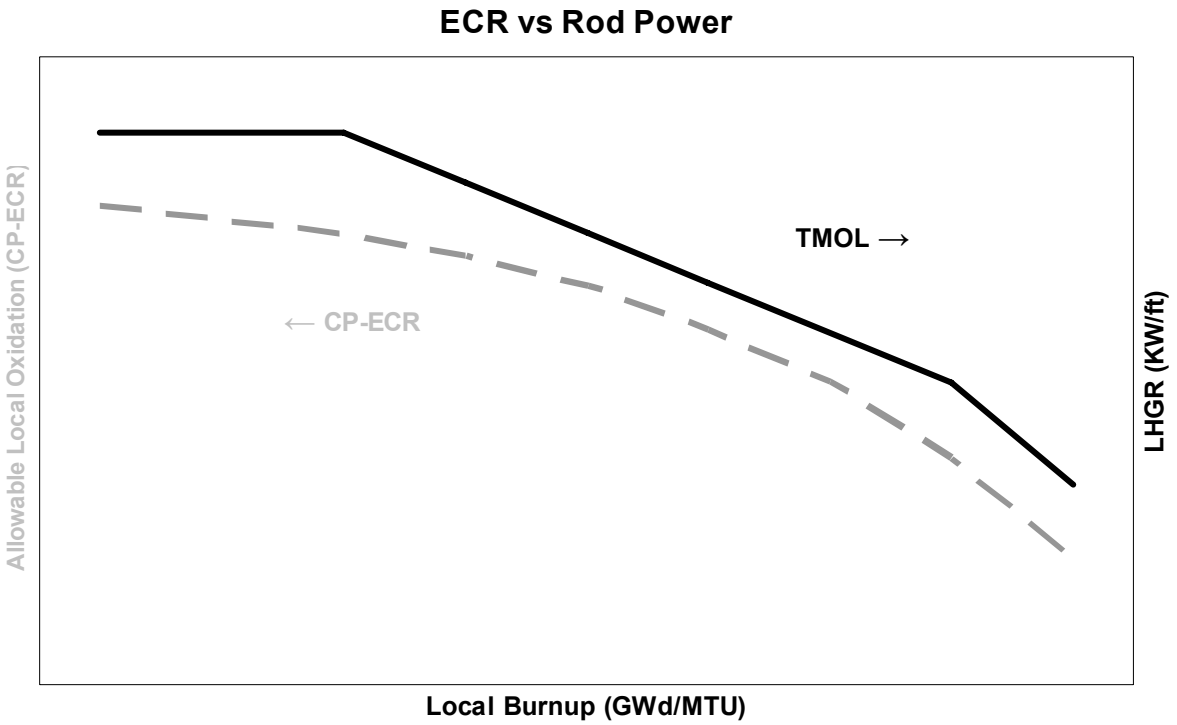
Peak Cladding Temperature Limit:

No change in 2200 °F peak cladding temperature limit. Current UFSAR LBLOCA and SBLOCA Analyses-of-Record (AORs) demonstrate compliance to this criterion.

Impact of Reduced Local Oxidation Limit:

The ANL LOCA Research Program concluded that the current 50.46(b) criterion of 17% ECR is not always adequate to preserve PQD. Hydrogen within the cladding, absorbed during in-reactor steady-state cladding corrosion, tends to reduce the allowable time-at-temperature threshold for PQD.

As in-core residence time increases, cladding corrosion builds along with hydrogen content. The figure below illustrates the anticipated degradation in embrittlement threshold (converted to burnup) along with a typical Technical Specification LHGR rod power curve. During a postulated LOCA, low burnup fuel rods operating at a high local power density will experience a more severe temperature transient (i.e., high PCT, more localized oxidation) relative to a high burnup fuel rod operating at a lower power density. The low burnup, high power fuel rods (which experiences the more severe transient) would be required to meet the relatively high allowable local oxidation criterion (due to lower residence time and lower corrosion). Whereas, the high burnup, low power fuel rods (which experience a benign temperature transient) would be required to meet a lower allowable oxidation criterion (due to longer residence time and more corrosion).

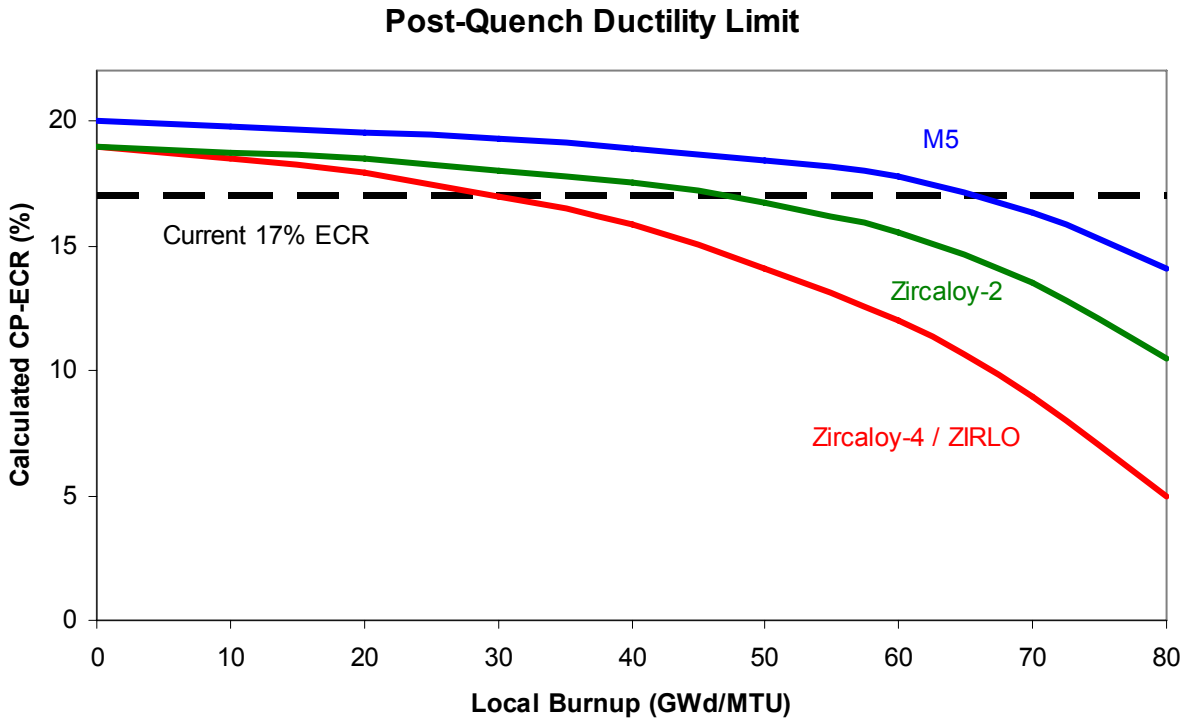


The ANL LOCA Research Program measured the embrittlement threshold for several commercial zirconium cladding alloys. All of the current cladding alloys exhibit an unirradiated threshold at or above the current 50.46(b) 17% ECR criterion.

- Typical BWR Zry-2 remained ductile up to 19% CP-ECR
- AREVA PWR fuel cladding remained ductile up to 19% (Zry-4) and 20% (M5)
- Westinghouse PWR fuel cladding remained ductile up to 19% (ZIRLO) and 17% (Zry-4)

Hence, for fresh-to-low burnup fuel rods operating at high local power density, the ANL research results demonstrate that the current UFSAR AORs remain valid.

For low-to-mid burnup fuel rods operating at high local power density, several factors offset the impact of the ANL research results. First, a vast majority of the plants are fueled with cladding alloys with a measured initial embrittlement threshold above the current 17% oxidation limit. As illustrated on the figure below, these plants would maintain PQD up to the current 17% ECR limit up till a certain burnup (depending on alloy-specific hydrogen pickup characteristics). By this time, rod power density would be diminishing (due to depletion). In the case of M5 (which exhibits favorable corrosion rates), PQD is preserved above 17% CP-ECR up through licensed burnup.



Second, all UFSAR LBLOCA and SBLOCA AORs satisfy the current 17% ECR regulatory limit. Within these calculations, the rupture node will yield the peak local oxidation due to the requirement for double-sided oxidation in this local region of the fuel rod. The calculated local oxidation from a recent [ ] listed below.

Node	Calculated Local Oxidation
Rupture Node	[ ]
1 Node Above	[ ]
2 Nodes Above	[ ]
3 Nodes Above	[ ]

The [ ] demonstrates that away from the rupture node, where only single-sided oxidation occurs (for lower burnup rods), calculated local oxidation is significantly lower than in the rupture node. Hence, away from the rupture node, significant safety margin exists relative to the current 17% regulatory limit. Since the embrittlement of the balloon region occurs as a result of a separate phenomena unrelated to calculated local oxidation (see below), the current AORs maintain significant margin. As a result, even the worst case scenario (e.g., a high power low-to-mid burnup rod coupled with a cladding alloy susceptible to hydrogen pickup) would maintain margin to the anticipated PQD threshold (in the curve above).

In addition, licensing calculations are performed with conservative models. For oxidation considerations, small break LOCAs are most important since oxidation is more severe for events involving extended time at high temperatures. LBLOCA events have too rapid a turnaround in temperature for oxidation to be limiting. All plants use Appendix K models for SBLOCA. Appendix K requires the use of a conservative decay heat source (1.2 times the 1971 ANS standard for infinite operation). Appendix K also requires that the calculated oxidation rate must be based upon the Baker-Just correlation. The Baker-Just correlation was

developed in 1962. It has subsequently been shown to conservatively over-predict measured oxidation. For example, at 2200 ºF, Baker-Just will predict 17% oxidation for conditions that will produce only 13% measured oxidation (similar C-P calculated ECR). Thus, there is considerable conservatism in the calculated post-accident oxidation levels.

For high burnup fuel rods operating at low local power density, the temperature transient experienced during a postulated LOCA will be benign relative to the more limiting lower burnup fuel rods. While this trade-off of initial rod power and allowable embrittlement threshold is plant-specific and alloy-specific, the staff believes it provides reasonable assurance that plant operations and public safety are not challenged.

Impact of New Breakaway Oxidation Limit:

RIL 0801 recommended that a new regulatory limit be developed to protect against zirconium oxide degradation and hydrogen uptake. Results from the ANL LOCA Research Program indicated that this time to breakaway oxidation is alloy-specific and sensitive to manufacturing. Breakaway times were measured for commercial alloys and found to exceed the typical small break LOCA transient time history. A new regulatory criterion and periodic testing may be required to ensure that future alloys and/or changes to manufacturing practices do not introduce unfavorable characteristics.

The staff has concluded, with reasonable assurance, that plant operations and public health are not challenged.

Loss of Ductility within Balloon/Burst Node:

The ANL LOCA Research Program confirmed that gross hydrogen uptake within the balloon/burst node makes it unlikely that PQD will be maintained in the burst node. Early during a large break LOCA scenario, rod internal pressure promotes outward creep of the cladding during the RCS blowdown/de-pressurization phase. A significant percentage of the fuel rods within the core are predicted to balloon and even burst. Steam entering the burst opening results in cladding ID oxidation and enhanced hydrogen uptake.

Addressing the balloon node was not an objective of the ANL LOCA Research Program. Further research is needed to better address this localized, non-ductile section of the fuel rod. Note that integral thermal-shock LOCA testing conducted by JAEA (Japan) has shown that the fuel rod remains as a single rod (with only limited fuel loss) and the core itself maintains a coolable geometry up to 20% ECR. This information provides reasonable assurance that plant operation and public health are not challenged.

Fuel relocation and dispersal may result when the fuel rod experiences ballooning and burst. Further research is needed to better understand the potential consequences of possible fuel relocation and dispersal. In-pile LOCA test programs at Halden (IFA-650.4) have measured significant amounts of fuel relocation and dispersal on a high burnup fuel rod segment (92 MWd/kgU). This phenomenon is related to fuel rod burnup. At current licensed burnup limits (62 MWd/kgU), it is believed that any fuel dispersal would be minimal. Fuel relocation and dispersal will need to be addressed prior to approving increases in licensed burnup.

LOCA Radiological Consequences:

None of the targeted research at ANL adversely impacts current LOCA radiological assessments because of conservative assumptions related to core damage and isotopic inventories for purposes of dose analysis. Hence, based on current information, there is no need to alter any assumptions related to radiological consequences.

Conclusion:

Results from the LOCA research program indicate that fuel criteria specified within 10 CFR 50.46(b) need to be revised and expanded to ensure our regulations require an acceptable degree of PQD following a postulated LOCA. Taking into account measured results for different cladding alloys, analytical conservatism, and realistic fuel rod power history, there is reasonable assurance that plant operations and public health are not challenged. Hence, revising 10 CFR 50.46(b) and implementing these new requirements into the operating fleet may proceed on a reasonable schedule.