Crud-Related
and
Breakaway Oxidation Presentation

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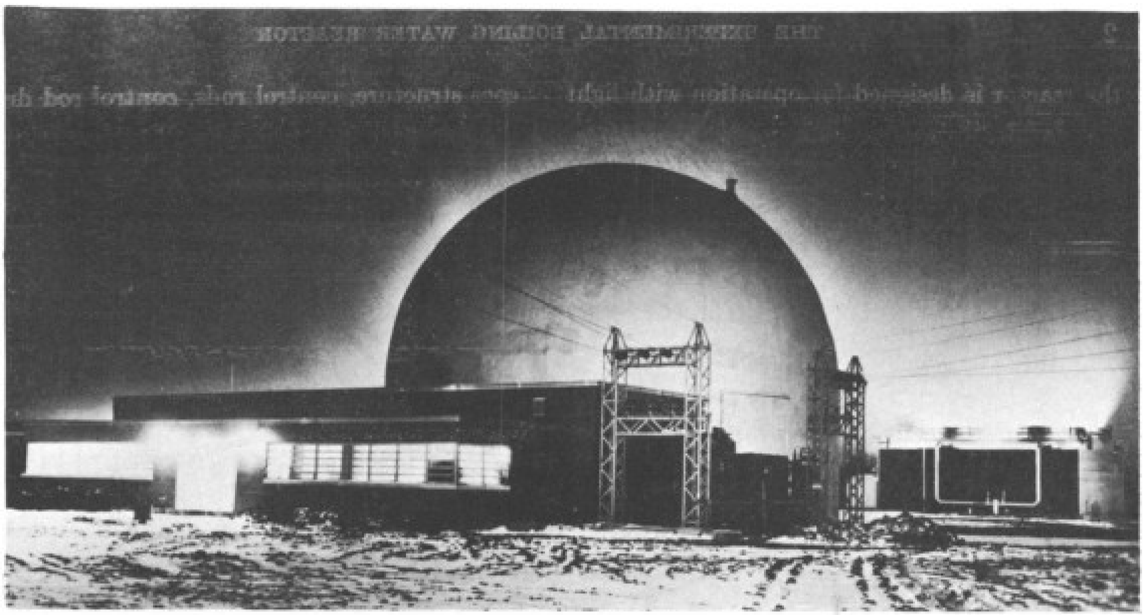
June 24, 2014

The thermal impact of crud on zirconium alloy fuel cladding was documented as far back as 1959 at Argonne National Laboratory's Experimental Boiling Water Reactor.



The maximum scale thickness (crud) was measured at about 200 microns. Heat transfer calculations based on the crud's low thermal conductivity indicated maximum fuel-cladding temperatures substantially increased during operation.

Argonne National Laboratory Reports:

1) Robert H. Leyse, “Effect of Scale Deposits on Fuel Element Temperatures with EBWR at 100 Megawatts,” June 17, 1959.

2) Robert H. Leyse, “Scale on Fuel Elements in EBWR,” June 22, 1959.

3) Robert H. Leyse, “Thermal Conductivity of Scale on EBWR Fuel Elements,” December 24, 1959.

4) C. R. Breden, I. Charak, R. H. Leyse, Argonne National Laboratory, “Water Chemistry and Fuel Element Scale in EBWR,” ANL-6136, November 1960.

Petition for Rulemaking, PRM-50-84

PRM-50-84 requested new regulations:

1) to require licensees to operate LWRs under conditions that effectively limit the thickness of crud (corrosion products) and/or oxide layers on fuel cladding, in order to help ensure compliance with ECCS acceptance criteria;

and 2) to stipulate a maximum allowable percentage of hydrogen content in fuel cladding.

PRM-50-84 also requested:

that the NRC amend Appendix K to Part 50—ECCS Evaluation Models I(A)(1), *The Initial Stored Energy in the Fuel*, to require that the steady-state temperature distribution and stored energy in the fuel at the onset of a postulated LOCA be calculated by factoring in the role that the thermal resistance of crud and/or oxide layers on cladding plays in increasing the stored energy in the fuel. PRM-50-84 also requested that these same requirements apply to any NRC-approved best-estimate ECCS evaluation models used in lieu of Appendix K to Part 50 calculations.

An attachment to a 2003 letter from Gary W. Johnsen, RELAP5-3D Program Manager, Idaho National Engineering and Environmental Laboratory, to Robert Leyse, states:

> [W]e are not aware of any user who has modeled crud on fuel elements with SCDAP/RELAP5-3D. … We suspect that none of the other [accident analysis] codes have been applied to consider [fuel crud buildup] (because it has not been demonstrated conclusively that this effect should be considered). … SCDAP/RELAP5-3D *can* be used to consider this effect, it is simply that users have not chosen to consider this phenomen[on].

Rui Hu, Mujid S. Kazimi, Mark Leyse, “Considering the Thermal Resistance of Crud in LOCA Analysis,” 2009.

A RELAP5-3D model of a reference Westinghouse four-loop PWR plant that MIT developed for a previous study was used. RELAP5-3D simulated a LB LOCA—a double-ended guillotine break—at the modeled plant: surface temperatures of clean fuel cladding were compared to those of fuel cladding with a 100 μm thick crud layer. For both cases, surface temperatures of the hottest fuel rod of the hottest assembly were examined.

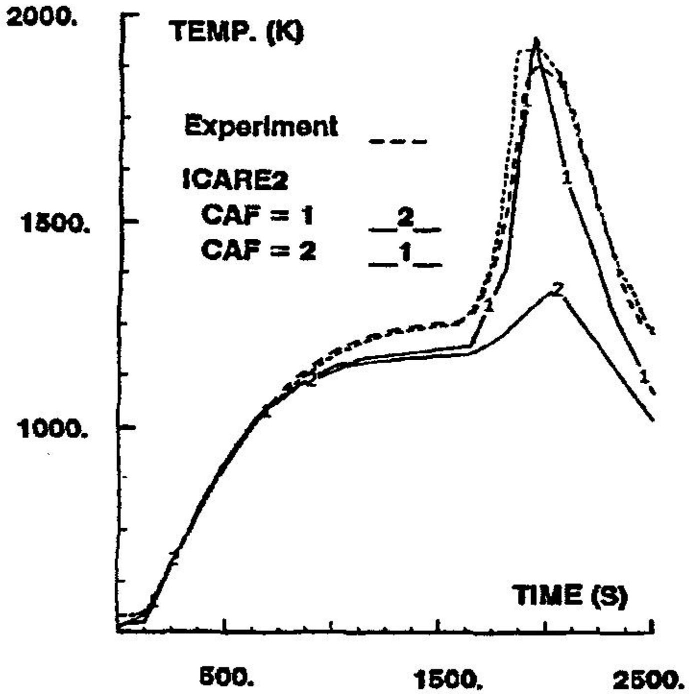
The RELAP5-3D analysis demonstrated that the peak cladding temperature (PCT) of the crud case was 77 Kelvin (139 Fahrenheit) higher than that of the clean-cladding case, for the postulated LBLOCA. Hence, the thermal resistance of crud deposits on fuel cladding needs to be considered in LOCA analysis for licensing and other related activities.

As published in the Federal Register, the proposed rule for Section 50.46(c), Paragraph (g)(2)(ii), states:

> The thermal effects of crud and oxide layers that accumulate on the fuel cladding during plant operation must be evaluated. For the purposes of this paragraph, crud means any foreign substance deposited on the surface of fuel cladding prior to initiation of a LOCA.

Paragraph (g)(2)(ii) needs to be augmented with additional instructions; it should have an additional sentence, inserted after the first sentence, stating:

> The thermal effects of crud and oxide layers must be evaluated based on the observed crud and oxide layers that are present on the fuel cladding at the start of the forthcoming operating cycle, and in addition, the projected changes in the crud and oxide layers during the course of the forthcoming operating cycle must also be included in order to provide an accurate evaluation.



Local Cladding Temperature vs. Time in the PHEBUS B9R-2 Test, which was conducted in a light water reactor with an assembly of 21 with pre-oxidized UO_2 fuel rods.

Discussing PHEBUS B9R-2, a paper, T.J. Haste *et al*., "In-Vessel Core Degradation in LWR Severe Accidents," European Commission, Report EUR 16695 EN, 1996, states:

> The B9R-2 test illustrates the oxidation in different cladding conditions representative of a pre-oxidized and fractured state. … During B9R-2, an unexpected strong escalation of the oxidation of the remaining Zr occurred when the bundle flow injection was switched from helium to steam while the maximum clad temperature was equal to 1300 K [1027°C (1880°F)].

Discussing PHEBUS B9R-2, “In-Vessel Core Degradation in LWR Severe Accidents,” also states:

> The current oxidation model was not able to predict the strong heat-up rate observed even taking into account the measured large clad deformation and the double-sided oxidation (final state of the cladding from macro-photographs).
>
> … No mechanistic model is currently available to account for enhanced oxidation of pre-oxidized and cracked cladding.