CONSIDERING THE THERMAL RESISTANCE OF CRUD IN LOCA ANALYSIS

Rui Hu, Mujid S. Kazimi
Massachusetts Institute of Technology, 24-215, 77Massachusetts Avenue, Cambridge, MA 02139
ruihu@mit.edu, kazimi@mit.edu

Mark E. Leyse
P.O. Box 1314, New York, NY, 10025, mleyse@yahoo.com

INTRODUCTION

During the operation of LWRs, it is possible for thick crud deposits (corrosion products) to form on the fuel cladding. Crud has a low thermal conductivity: in some fuel cycles thick crud deposits have been estimated to increase local fuel-cladding temperatures by 270°F or greater.[1,2] Crud deposits also increase the local quantity of stored thermal energy in the fuel. The stored energy in the fuel at the onset of a loss-of-coolant accident (LOCA) is one of the primary factors that determine the peak cladding temperature (PCT). To determine if crud should be considered in LOCA analysis we investigated how the thermal resistance of thick crud deposits on fuel cladding would affect the PCT during a postulated large break LOCA (LBLOCA).

THE INVESTIGATION

For this work, we used a RELAP5-3D model of a reference Westinghouse four-loop PWR plant that MIT developed for a previous study.[3] RELAP5-3D simulated a LBLOCA—a double-ended guillotine break—at the modeled plant: surface temperatures of clean fuel cladding ("the reference case") were compared to those of fuel cladding with a 100 μm thick crud layer ("the crud case"). The reference case and the crud case both examined the surface temperatures of the hottest fuel rod of the hottest assembly. The crud layer was assigned a thermal conductivity of 0.8648 W/mK;[4,5] the heat capacity of the crud layer was assigned the same value as that of the fuel cladding: these values would be close under the high-temperature conditions of the postulated LBLOCA.[6]

The main steady-state conditions and main core and fuel parameters are summarized in Table 1. Conservatively, the initial core power is set to 102% of the assigned value; for the decay heat model, the ANS73 standard value is multiplied by 1.2.

RESULTS

A comparison of the surface temperatures of the reference case and the crud case, at six axial nodes of the hottest fuel rod, during the postulated LBLOCA are shown in Figure 1.

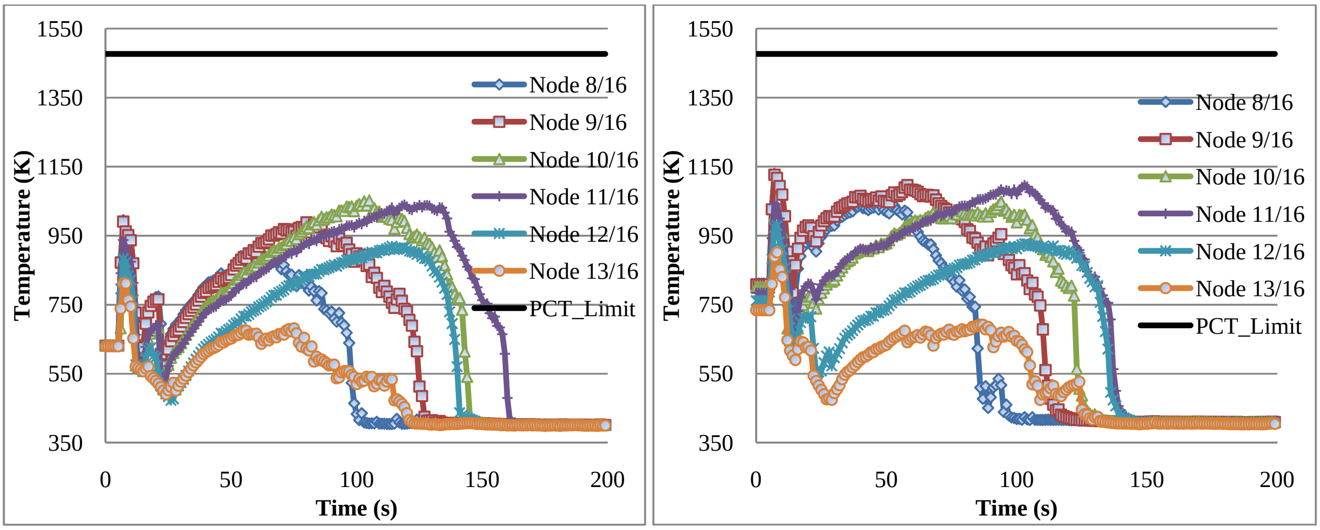
It is seen that during normal operating conditions, before the onset of the LBLOCA, that the cladding temperature of the crud case is 181°K higher than that of the reference case, at the hottest spot of the fuel rod. During the LBLOCA, the reference case PCT is 995°K at axial node eight during blowdown and 1052°K at axial node ten during reflood; the crud case PCT is 1129°K at axial node eight during blowdown and 1097°K at axial node eleven during reflood; the crud outer surface temperature peaks at 1069.5°K at axial node eight during blowdown and peaks at 1093°K at axial node eleven during reflood.

Although all the PCTs are below the NRC regulatory limit of 2200^{o} F (1477°K), the PCT of the crud case is 134°K higher than the reference case during blowdown and 45°K higher during reflood. For the transient as a whole the crud case PCT is 77°K higher than the reference case PCT.

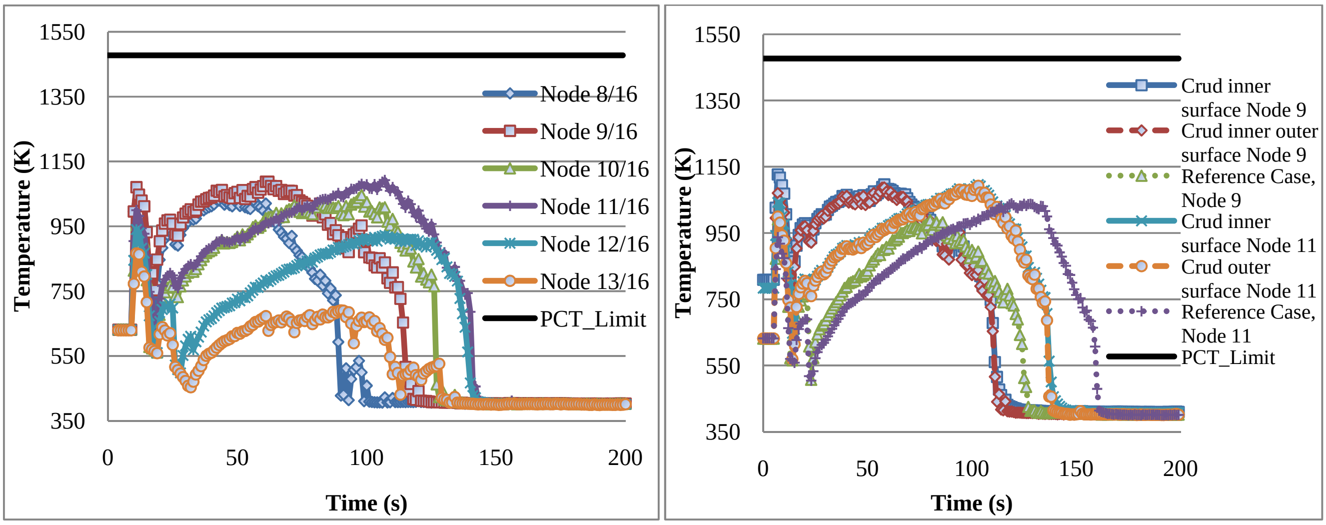
It is also seen that bottom-up and top-down quenching occurred in both the reference case and the crud case. However, the quenching speed is faster in the crud case. This may be possible due to higher axial heat conduction inside the fuel rod in the crud case, but further investigation is required.

Table 1. Main Steady-State, Core, and Fuel Parameters.

Parameters	Models
Core Power (MWth)	3479 (102% Ref. Power)
Pressurizer Pressure (bar)	155.1
Cold Leg Temperature (K)	566.6
Hot Leg Temperature (K)	598.7
Total Loop Flow (kg/s)	18633
Effective Core Flow (kg/s)	17779
Bypass Flow Fraction (%)	4.74
SG Secondary Pressure (bar)	61.3
Initial Power (MWth)	3479
Decay Heat	ANS73*1.2
Core & Fuel Modeling	
- # of Axial Nodes	16
- Core Flow Channels	Average (192 FA) and Hot (1 FA)
- Total Peaking	2.558 (MLHGR = 47.75 kW/m)
Axial Power Distribution	1.55 Chopped Cosine
Hot Assembly Peaking	1.587
Hot Pin Radial Peaking	1.65 (embedded in hot channel)
- Gap Conductance	Constant



(a) Reference clad (b) Crud inner surface



(c) Crud outer surface (d) Comparison of PCT

Figure 1. Calculated Hot Rod Temperatures for the Reference Case and the Crud Case at Six Axial Nodes.

CONCLUSION

The RELAP5-3D analysis demonstrated that the PCT of the crud case is 77°K higher than that of the reference case, for the postulated LBLOCA. Hence, the thermal resistance of crud deposits on fuel cladding should be considered in LOCA analysis for licensing and other related activities. It should be noted that, conservatively, a uniform crud layer was modeled with RELAP5-3D, not a varied crud layer, whose thinner portions would offer less thermal resistance. To better understand how crud would affect the severity of a LOCA, further investigations are required; for example, the full range of thermal conductivity of crud should be established and whether crud deposits of any thickness will continue to adhere to fuel cladding under LOCA conditions should be investigated. Finally, recent work at MIT shows considerable advantageous effect, during quenching of hot surfaces, of nano-particle deposits on the surfaces.[7] Implications of this work should be considered as well.

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