Effects of Chemical Precipitates and Debris Deposited on Fuel Rods after a LOCA

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1. Introduction

After a loss of coolant accident (LOCA), the chemical products could deposit on the hot fuel rods and insulate them. Consequently, the decay heat removal is reduced and then the core cooling may be compromised.

To address this issue in the APR1400, we analyzed the effects of chemical precipitates and debris deposited on the fuel rods using a LOCA deposition model (LOCADM) [2]. The LOCADM is a calculation tool that can be used to conservatively predict the build-up of chemical deposits on fuel cladding after a LOCA [3].

The deposit thickness and maximum cladding temperature as a function of time for the APR1400 are presented, and compared with the acceptance basis for long term core cooling (LTCC).

2. LOCADM Modeling and Major Assumptions

2.1 LTCC Acceptance Bases

The LTCC acceptance bases have been defined based on the requirements of 10 CFR 50.46 as clarified by the NRC. They are summarized as follows:

- The cladding temperature during recirculation from the containment sump will not exceed 800 °F.
- The deposition of debris and/or chemical precipitates will not exceed 50 mils on any fuel rod.

These bases will facilitate the demonstration of acceptable core cooling following a postulated large break LOCA [3].

2.2 LOCADM Modeling

The chemical inputs into LOCADM are the volumes of different debris sources such as fiberglass and calcium silicate (cal-sil) insulation. The surface areas of uncoated concrete, aluminum submerged in the sump, and aluminum exposed to spray are also required. The sump and spray pH are specified as a function of time, as are the inputs of sodium hydroxide, trisodium phosphate, lithium hydroxide and boric acid as appropriate. The materials input for LOCADM in the APR1400 are shown in table 1 and 2.

The deposition model divides the core into user defined nodes that differ in location and relative decay power. The node is identified by region number and by axial location number. A number of parameters are associated with each node. The nodal parameters are decay power, fuel surface area (or number of rods), initial zirconium oxide thickness, initial crud thickness, and average depth within the core. These values are inputs as relative values. Since the radial noding establishes a conservatively high peak rod power, the choice of axial noding is not critical. The axial location number is divided into three nodes of equal height in this study, and example of values used for radial core noding is provided in table 3.

Table 1: Materials input for LOCADM

Material	Amount
Aluminum Submerged (ft^2)	0
Aluminum not-Submerged (ft^2)	5,602
Calcium Silicate	0
NUKON (ft^3)	2,123
Silica Powder	0
Mineral Wool	0
Concrete (ft^2)	9,344

Table 2: Coolant materials input for LOCADM

Parameter	Unit	Value
IRWST Water Density	lbm/ft^3	57.9
Initial IRWST Water Volume	ft^3	41,909
Initial IRWST Water Mass	lbm	2,426,531
Core Region Water Density	lbm/ft^3	57.7
Initial Core Region Water Volume	ft^3	800
Initial Core Region Water Mass	lbm	46,160

Table 3: Example of relative power distributions

Relative Power	Rods Number	% of Rods
1.65	1	0.0017
1.56	235	0.4132
1	56,640	99.5851

2.3 Major Assumptions

The deposition method makes several assumptions that are conservative and, as a result, the predictions of deposit thickness and fuel surface temperature should be considered to be bounding rather than best estimate for the following reasons [3].

- The calculations assume an increase in deposit volume during precipitation due to the incorporation of species, such as the waters of hydration or boric acid. However, specific compounds are not assumed.

- Deposits, once formed, will not be thinned by flow attrition or by dissolution.
- No deposition takes place apart from the fuel heat transfer surfaces.
- The mass balance approach for determining material transport around the ECCS does not take into account any moisture carry-over in the steam exiting the reactor vessel.
- The effect of boiling point elevation due to the concentration of solutes is not currently modeled.
- Only species that have dissolved into solution or species that have dissolved and then precipitated into suspended particles are considered.
- All impurities transported into a deposit by boiling will be deposited at a rate that is equal to the steaming rate multiplied by the coolant impurity concentration.
- The deposition of impurities on the fuel clad surface is assumed to be distributed according to the core power distribution.

3. Analysis Results

The LOCADM code was run with input conditions simulating a 3,983 MW_{th} for the APR1400. A value of 0.11 BTU/hr-ft-°F was used for the thermal conductivity of the LOCA scale. The results are shown in figure 1 where the maximum scale thickness in the core has been plotted for a 30 day period. The maximum scale thickness is 428 microns (16.85 mils), and the peak cladding temperature is 468.7°F.

A sensitivity study was performed to evaluate the parametric effects of in-containment refueling water storage tank (IRWST) pH, spray flow, and refill time. When the minimum value of IRWST pH is used, the maximum scale thickness is decreased by about 25 %, and the peak cladding temperature is not changed as shown in figure 2. Figure 3 shows the results when the spray flow is reduced to 33 %. The maximum scale and the peak cladding temperature are similar to those of reference case (Fig. 1). The refill time also has negligible effect on the results.

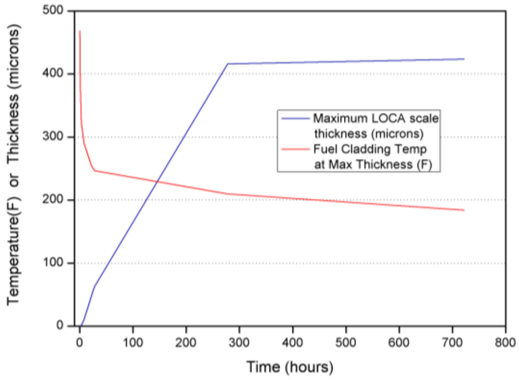

Fig. 1. Maximum scale thickness and temperature (Reference case)

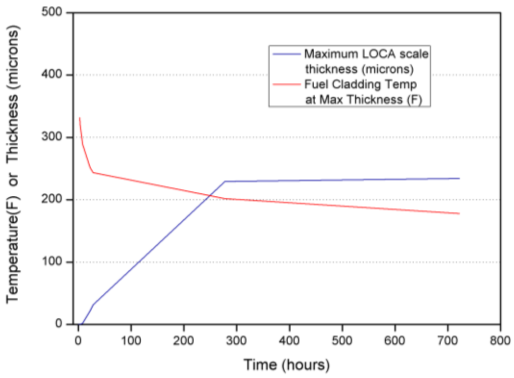

Fig. 2. Maximum scale thickness and temperature (Min. IRWST pH)

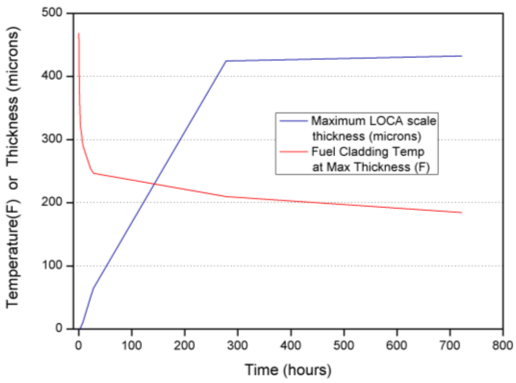

Fig. 3. Maximum scale thickness and temperature (33% reduced spray flow)

4. Conclusions

The effects of chemical precipitates and debris deposited on the fuel rods after a LOCA have been analyzed using a LOCADM. The maximum scale thickness is 428 microns (16.85 mils), and the peak cladding temperature after recirculation is 468.7°F. Thus, the LTCC is not compromised in the APR1400 since the calculation results meet the acceptance bases with sufficient margins. The modeling method of IRWST pH is significant, and the maximum value should be used to get conservative results.

REFERENCES

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