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Reactivity Initiated Accident Analysis for the APR1400 PWR Using FALCON Fuel Performance Code

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1. Introduction

The USNRC has issued Revision 3 of the Standard Review Plan (SRP) Section 4.2 to provide interim acceptance criteria for the reactivity initiated accident [1]. This section specifies the safety criteria that must be meet as parts of the RIA analysis, which are summarized below:

1) For Hot Zero Power (HZP) condition, fuel cladding failure is assumed to occur due to pellet-clad mechanical interaction (PCMI) if the enthalpy rise exceeds the limit shown in Figure 1. This limit is dependent on the oxide to wall thickness ratio of the fuel clad and can be converted to a fuel burnup.

2) For HZP condition, fuel cladding is also assumed to fail due to high temperature if the fuel pellet average enthalpy exceeds 170 cal/g for rods with an internal pressure less than or equal to system pressure, or 150 cal/g for rods with an internal pressure greater than system pressure.

3) For initial reactor power greater than or equal to 5% of rated thermal power, fuel cladding is assumed to fail due to high temperature if the departure from nucleate boiling ratio (DNBR) is calculated to be less than the safety analysis limit.

4) To maintain a coolable geometry, the peak pellet average enthalpy must be less than 230 cal/g.

5) No fuel melting during the transient is also required.

It would be helpful to evaluate the fuel safety analysis for the RIA event if the current fuel design and safety methodology satisfy the revised licensing criteria.

Falcon code [2], a finite element analysis (FEA) code designed to compute the "best estimate" thermomechanical response of a single Light Water Reactor (LWR) fuel rod, was used for this RIA event analysis.

2. Core Description

The reference steady state core design for this analysis is based on a typical APR1400 equilibrium reload cycle design. The fuel rod design data is used according to PLUS7^{TM} for this analysis. For the transient analysis, the RIA event, control rod ejection, is initiated for the Hot Zero Power (HZP) (Fig. 2) and Hot Full Power (HFP) (Fig. 3) conditions respectively. The transient events analysis was performed for 4 seconds.

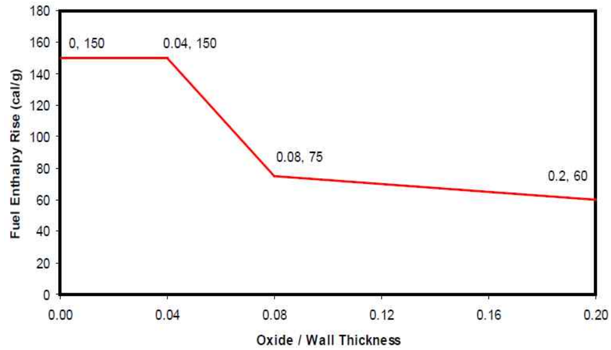

Fig. 1 Interim PCMI Criteria for the HZP Condition

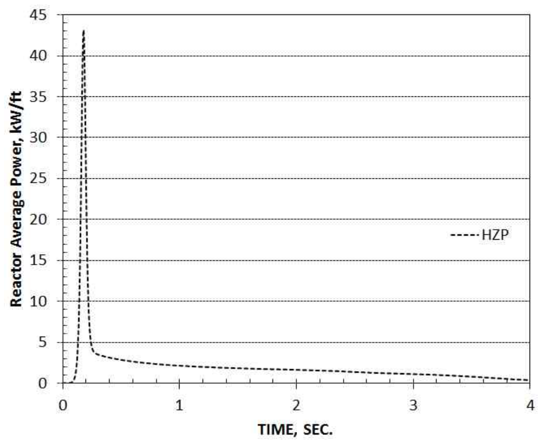

Fig. 2 Reactor Average Power During the RIA Event for the HZP Condition

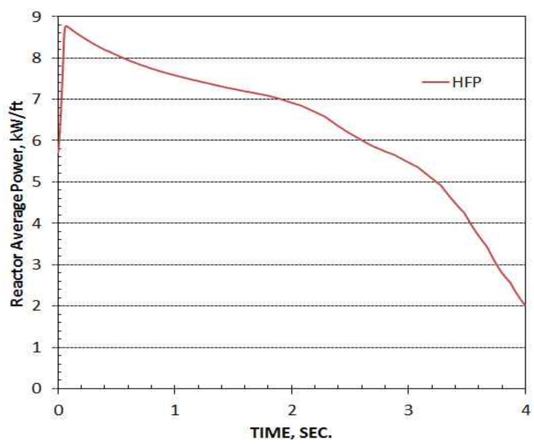

Fig. 3 Reactor Average Power During the RIA Event for the HZP Condition

3. Analysis Results

2.1 PCMI Criteria for HZP condition

The PCMI analyses were performed for 1st, 2nd and 3rd cycle of the HZP conditions to investigate the value of fuel enthalpy increase and effect of burnup respectively (Table 1). The calculated fuel enthalpy increases are 35.4, 37.9 and 39.6 cal/g and those values are within the PCMI safety criteria associated with oxide/wall thickness ratio.

Table 1. Results of PCMI Analysis During the RIA Event for the HZP Conditions

Case	Calculated ΔH(cal/g)	Oxide/ Wall ratio	Criteria ΔH(cal/g)	Satisfa-ction
1st cycle HZP	35.4	0.0019	150	Yes
2nd cycle HZP	37.9	0.0073	150	Yes
3rd cycle HZP	39.6	0.0165	150	Yes

2.2 Fuel Pellet Average Enthalpy Criteria for HZP Condition

The fuel pellet average enthalpy are under calculating for 1st, 2nd and 3rd cycle of the HZP conditions to investigate if the fuel pellet average enthalpy satisfies the safety criteria (Table 2). The calculated fuel pellet average enthalpy values will be presenting.

Table 2. Results of Fuel Pellet Average Enthalpy Analysis During the RIA Event for the HZP Conditions

Case	Calculated H_{avg}(cal/g)	Burnup (MWD /MTU)	Criteria H_{avg}(cal/g)	Satisfa-ction
1st cycle HZP	-	0	170	-
2nd cycle HZP	-	23,020	170	-
3rd cycle HZP	-	40,905	170	-

2.3 Coolable geometry criteria for HFP conditions

Table 3. Results of Coolable Geometry Criteria Analysis During the RIA Event for the HFP Conditions

Case	Calculated Hmax(cal/g)	Max Fuel Center T (℃)	Criteria Hmax (cal/g)	Satisfa-ction
1st cycle BOC	121	2361	230	Yes
1st cycle EOC	135	2533	230	Yes
2nd cycle BOC	137	2556	230	Yes
2nd cycle EOC	145	2632	230	Yes
3rd cycle BOC	146	2637	230	Yes
3rd cycle EOC	150	2653	230	Yes

The analysis results of peak pellet average enthalpy of the fuel rod for 1st, 2nd and 3rd cycle of the HFP conditions and maximum fuel centerline temperature are illustrated in Table 3. Each cycle are divided to beginning of cycle (BOC) and end of cycle (EOC) respectively to investigate the effects of burnup on the peak pellet average enthalpy and fuel centerline temperature. The calculated values of the peak pellet average enthalpy are between 121 and 150 that meet the requirement of the safety criteria previously described in introduction section of this paper.

For the fuel melting criteria, the estimated values of fuel maximum temperature are between 2,361 and 2,653 ℃ those values are under the UO2 fuel melting temperature, 2843 ℃.

4. Conclusions

RIA safety analysis for the APR1400 PWR reference core was performed using FALCON fuel performance code. PCMI criteria and fuel pellet average enthalpy criteria for the HZP condition and coolable geometry criteria for the HFP condition were assessed respectively. The analyzed results were compared with the NRC's interim safety criteria and have shown that all of the estimated values were within the safety criteria. As a future plan, DNBR and fuel rod ballooning/burst criteria will be evaluated for this APR1400 LWR fuel rod design.

References

[1] NUREG-0800, U.S. Nuclear Regulatory Commission Standard Review Plan, Section 4.2, Revision 3, March 2007.

[2] Fuel Reliability Program: Falcon Fuel Performance Code, EPRI TR-1022711, September 2012