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Analysis on the LODHR Event during Refueling Pool Operation

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1. Introduction

In the present low power and shutdown (LPSD) probabilistic safety assessment (PSA) thermal hydraulic (T-H) analysis for dealing with various different plant operational states (POSs), the T-H analysis for the duration of refueling pool operation is omitted as it is considered less severe procedure during overhaul period for optimized power reactor 1000 (OPR1000). Instead only spent fuel pool analysis has been performed representing refueling operation mode (operation mode 6).

However, in NUREG-1449 [Reference 1], the NRC staff identified twelve technical issues that warrant further evaluation regarding shutdown and low power operation at U.S commercial nuclear power plants. One of issues identified for further evaluation is to evaluate the effect of PWR upper internals, that is, the PWR upper internals may inhibit water in the refueling pool from entering the core during a loss of decay heat removal event (LODHR). Per a commission paper (SECY-91-283 [Reference 2]) which reported progress to date on the evaluation, the NRC staff requested to address this safety issue by performing a quantitative and qualitative analysis.

An analysis of LODHR was performed [Reference 3] for advanced power reactor 1400 (APR1400) but it was focused to evaluate the initiation time of core boiling.

In this paper, the analysis is performed to evaluate the time to core uncovery and core damage as well as the time to core boiling.

To analyze thermal hydraulic behaviors during refueling pool operation, RELAP5/MOD3.3 is used adopting the Henry-Fauske (H-F) critical flow model. The input modeling method adopts the method of SFP [Reference 4].

The purpose of the analysis is to study the major results and T-H behaviors regarding to safety aspect during LODHR event at the refueling pool operation.

2. Analysis Method

The LODHR event at refueling pool operation is simulated for the Hanbit Nuclear Power Plant Units 3 and 4 (HBN 3&4). The nodalization of RELAP5/MOD3.3 is shown in Figure 1.

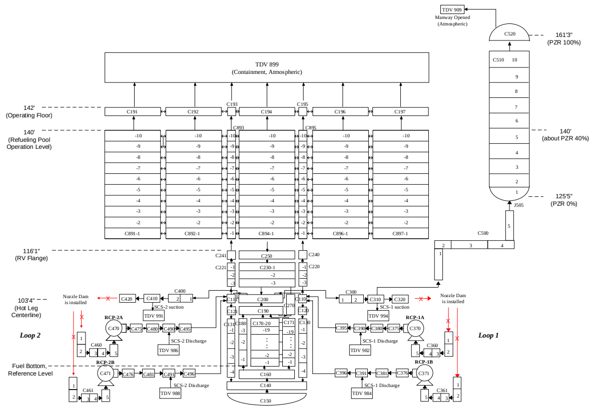

Figure 1. Nodalization for HBN 3&4 Refueling Pool Operation Analysis

2.1 Cases analyzed

Only one case which is LODHR during refueling pool operation is performed using RELAP5/MOD3.3 patch 4 with the H-F critical flow model.

2.2 Major assumptions and initial conditions

During refueling pool operation, refueling pool is filled with the water up to 140' to transfer spent fuel to SFP.

Major assumptions used in refueling pool operation analysis are as follows:

- Only the upper part of the refueling pool is considered. (above the reactor vessel (RV) flange)
- Nozzle dams are installed.
- RCS temperature is assumed as 313.15 K.
- 1979 ANS decay heat curve with 1.0 multiplication factor
- The decay heat of POS6 of LPSD PSA T-H analysis is adopted.
- Fuel cladding failure temperature is 1477 K.
- The time to core uncovery is when the RCS level decreases to the top of the fuel.

To simulate the refueling pool operation analysis, time dependent decay heat power based on an average duration of 95.7-hrs after reactor shutdown is used. The other initial conditions such as refueling pool water level, reactor coolant system (RCS) pressure, follow refueling pool operation procedure conditions

[Reference 5]. Table 1 shows initial conditions of the refueling pool operation analysis.

Table 1. Initial conditions

Operation Mode	MODE 6
Initial Event	LODHR
Decay Heat	11.373 MWt (95.7-hrs after reactor shutdown)
RCS Initial Conditions	Pressure : 1 atm Cold Leg Temperature: 313.15 K
	Normal refueling pool operating level (140')
	PZR vent and manway are opened
Secondary System Initial Conditions	Nozzle dams are installed

3. Analysis Results

Figure 2 through 6 show the transient behaviors of the LODHR during the refueling pool operation period and the major results are summarized in Table 2.

Figure 2 shows that the core top pressure is decreased as the refueling pool level decreases due to the core boiling. In Figure 3a, the temperature of the core top rises due to the LODHR event and the top of the core is saturated at the time of 827 seconds. As shown in Figure 3b, the temperature of the core top behaves similar to the pressure of the core top after the top of the core is saturated.

Figure 4 and 5 show the collapsed level of the refueling pool and the RV, respectively. As shown in the figure 4 and 5, the RV level begin to decrease after core boiling and the water is introduced from the refueling pool. The hot steam which is generated in the core is condensed again due to the relatively cold water in the refueling pool and as the hot water from the core is mixed with the relatively cold water existed in the refueling pool, the refueling pool water temperature rises continuously and the refueling pool is saturated as well at the time of 40900 seconds. Since the refueling pool is saturated, the refueling pool level begins to decrease significantly and the refueling pool is empty at the time of 321000 seconds. After refueling pool is empty, the RV level start to decrease and the core is uncovered at the time of 347348 seconds. When the core is uncovered, the heat from the fuel is not removed by the water. Therefore, the fueling cladding temperature is increased after core is uncovered and the fuel cladding temperature is increased up to the failure temperature at the time of 352676 seconds.

Table 2. Major Results of the analysis

Core boiling time	827 seconds (0.23 hours)
Refueling pool boiling time	40900 seconds (11.36 hours)
Refueling pool empty time	321000 seconds (89.17 hours)
Core uncovery time	347348 seconds (96.49 hours)
Fuel failure time	352676 seconds (97.97 hours)

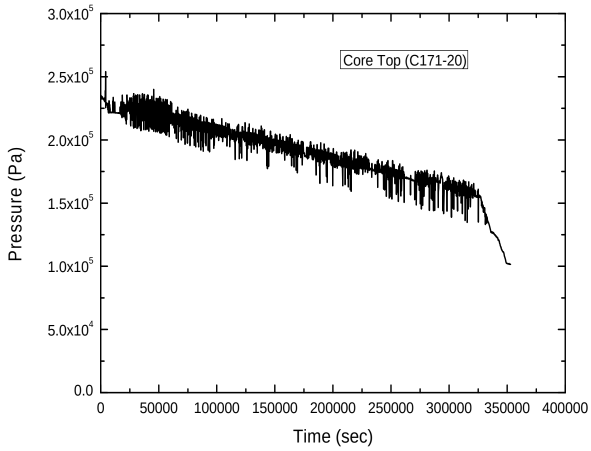

Figure 2. Core Top Pressure

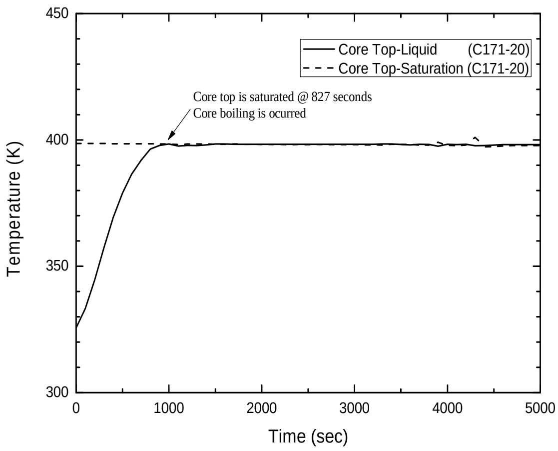

Figure 3a. Core Top Temperature(short-term)

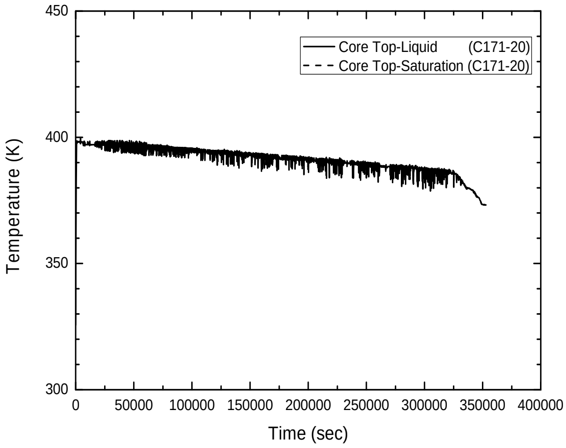

Figure 3b. Core Top Temperature(long-term)

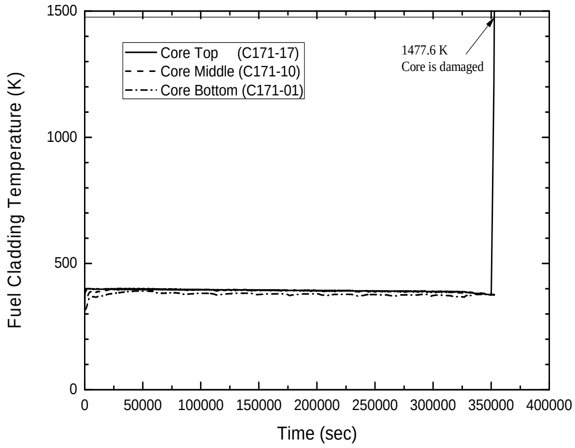

Figure 6. Fuel Cladding Temperature

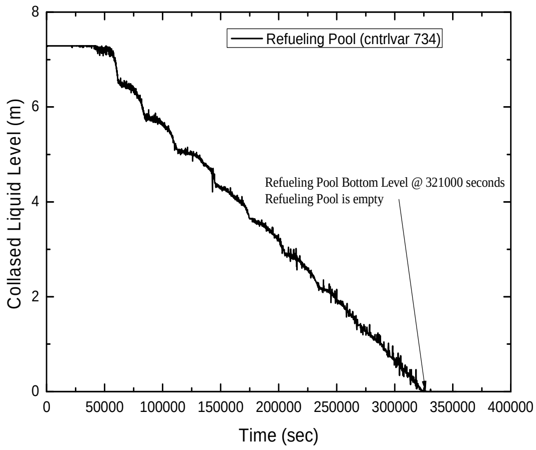

Figure 4. Refueling Pool Collapsed Level

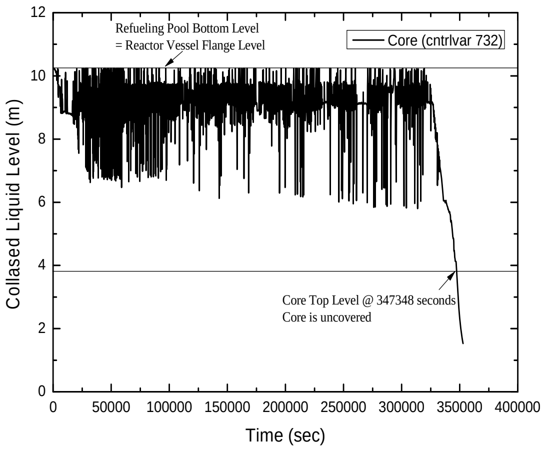

Figure 5. Reactor Vessel Collapsed Level

4. Conclusions

As the results of the analysis for the LODHR during refueling pool operation, even though the core boiling is occurred in 15 minutes, there is enough water to cover the core and it prevents the core from damaging. The time is taken more than 4 days until the core is uncovered or damaged. It is considered that there is sufficient time to take mitigating action such as inventory recovery and plant cooldown until the core is damaged.

Since the refueling pool is widely open to the containment, the pressure is not increased during the analysis so the nozzle dam is not damaged.

REFERENCES

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[3] Kee Soo Han, “Analysis of Loss of Decay Heat Removal Event during Refueling Operation for SKN 3&4,” March 6, 2011.

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