A Study on Core Uncovery Time during Decrease in Heat Removal by the Secondary System Events at the Low Power and Shutdown (LPSD) Conditions

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1. Introduction

Safety Analysis Report (SAR) Chapter 15 presents the accident analysis based on the event categories established by Reg. Guide (RG) 1.70. SAR Chapter 15 presents only the limiting event or event combinations within the event category in analytical detail; qualitative discussions are provided to explain why other events or event combinations are not limiting.

This study is to address Decrease in Heat Removal by the Secondary System events at the low power and shutdown conditions (LPSD) with the deterministic safety analysis methodology, and shows that core uncovery time is greater than 30 minutes.

Decrease in Heat Removal by the SCS events at Mode 4 is chosen as a representative event for core uncovery time because the SCS is only available as a heat removal system without the steam generator.

2. Methods and Results

2.1 SAR Chapter 15 Event Categories

After reactor shutdown, the initial phase of cooldown is accomplished by heat removal via the steam generators (SGs) to the condenser or atmosphere. The later phase of cooldown is accomplished by the Shutdown Cooling System (SCS) after the reactor coolant temperature and pressure have been reduced to shutdown cooling entry condition.

The scope of this study is limited to the LPSD conditions when decay heat removal is performed by the SCS. The associated operational modes are Mode 4 (Hot Shutdown), Mode 5 (Cold Shutdown), and Mode 6 (Refueling).

For the purposes of this study, a loss of SCS is conservatively assumed, either by series of mechanical or electrical faults or operator errors that combine such that a loss of decay heat removal occurs.

However, the event categories specified in RG 1.70 are established for the postulated limiting events and, in some cases, are not applicable to LPSD conditions when decay heat removal is performed by the SCS. Therefore, the event categories for LSPD events as compared to SAR Chapter 15 events are shown in Table 1.

The LPSD event category is considered appropriate since they reflect the operational design features specific to LPSD conditions. Decrease in Heat Removal by the SCS events with a loss of SCS at Mode 4 is chosen as a representative event on the characteristics.

Table 1. LPSD Event Categories

SAR Chapter 15 Event Category	LPSD Event Category
Increase in Heat Removal by the Secondary System	Increase in Heat Removal by the SCS
Decrease in Heat Removal by the Secondary System	Decrease in Heat Removal by the SCS
Decrease in RCS Flow	Decrease in SCS Flow
Reactivity/Power Distribution Anomalies	Reactivity/Power Distribution Anomalies
Increase in RCS Inventory	Increase in RCS Inventory
Decrease in RCS Inventory	Decrease in RCS Inventory
Radioactive Material Release	Radioactive Material Release
ATWS	ATWS

2.2 Decay Heat

1979 ANS 5.1 decay heat curve [1] with 2 sigma is applied. After an event occurs, the decay heat is simulated so that it changes with time according to the decay heat curve rather than the constant decay heat at the initiation time of the event. Based on this, the level of decay heat at 3.5 hours after reactor trip is 43.9 MW_{th}.

2.3 Computer Program

The computer program, the RELAP5 [2], is used in the quantitative evaluation of the Decrease in Heat Removal events with a loss of SCS at Mode 4. Sections 2.3 through 2.6 provide the relevant information.

RELAP5 code is a transient thermal-hydraulic analysis code designed for use in best-estimate evaluation of light water reactor systems, and RELAP5 nodalization of the primary and secondary systems and the major components of the APR1400 are used.

Two primary side loops are modeled as Loop 1 and Loop 2, and each loop consists of one hot leg, steam generator, U-tube and two suction legs, two RCPs, and two cold legs. The PZR and surge line are connected to Loop 1. Metal masses such as RV, PZR, suction legs, loops and SGs are modeled using the heat structure of RELAP5.

2.4 Acceptance Criteria

The core uncovery time shall be greater than 1,800 seconds. The definition of the core boiling time, core uncovery time and fuel damage time are defined as follows:

- core boiling time: when a void appears on any fuel region
- core uncovery time: when the core collapsed level decreases to the fuel top
- fuel damage time: when a fuel cladding temperature exceeds 2200˚F

2.5 Selection and Preparation of the Input Data

The major initial conditions used are summarized in Table 2.

Table 2. Initial Conditions

Parameters	Values
Operating Power at Reactor Trip, %	102
Time after Reactor Trip, hrs	3.5
RCS Pressure, MPa	3.02
Pressurizer Water Level, %	30
Steam Generator	Secured

For the core uncovery time, the analysis point is the SCS in-service condition, and the initial event is a loss of SC flow at Mode 4. Loss of SCS is assumed at 3.5 hours after a plant cooldown or a reactor trip and LTOP-2 valve (LTOP valve at Loop 2) stuck open is assumed as a single failure.

The reactor is operating at 102% of the design core power before a cooldown or reactor trip. RCS temperature is on the normal SCS entry temperature of 176.7˚C (350˚F) at the event initiation time. SGs are secured so that no contribution to heat removal by SGs is assumed during the loss of shutdown cooling.

The time for reaching the SCS entry condition (Mode 4) after a reactor trip is assumed as 3.5 hours considering the maximum cooldown rate of 41.7℃/hr (75˚F/hr) which is limited throughout the cooldown.

2.6 Results

Core uncovery is predicted to occur at about 2,500 seconds after a loss of SCS in Mode 4 without operator action. One SIP injection by operator at 1,800 seconds after event initiation prevents core uncovery and rod heat-up. Prediction of no rod heat-up means that the rods are maintained at nucleate boiling or subcooled boiling heat transfer conditions, consequently, there is no fuel failure such as clad burst or ballooning.

The SCS is put into operation at the SCS entry conditions (approximately 350°F and 450 psia) 3.5 hours after reactor trip. At this time, time zero, there is a loss of SCS and one LTOP valve opens and remains open (i.e., fails to reclose). Table 3 shows the relevant sequence of event summarizing the major events.

Table 3. Sequence of Event

Time (Seconds)	Sequence of Event
-3.5 hours	Reactor Trip from 102%
0.0	SCS entry conditions
0.0	A loss of SCS occurs.
0.0	LTOP valve at Loop 2 is stuck open
1,800	Operator initiates SIP injection
1,800	Event terminated
~ 2,500*	Core is uncovered.

* without SIP injection (operator action) at 1,800 seconds

Fig. 1 and Fig. 2 show core top pressure and temperature, respectively, and Fig. 3 shows hot leg and cold leg void fraction, and Fig.4 shows core void fraction, and Fig. 5 shows the resultant core collapsed level, and the core is uncovered at about 2,500 seconds if there is no operator action at 1,800 seconds.

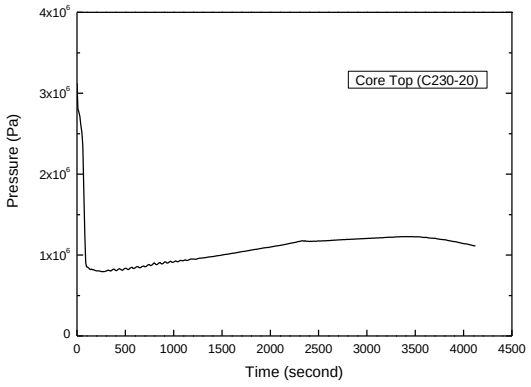

Fig. 1. Core Top Pressure vs. Time

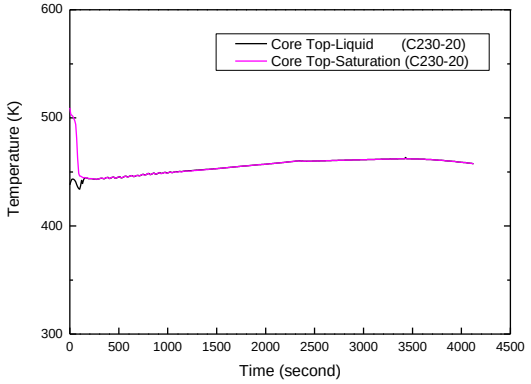

Fig. 2. Core Top Temperature vs. Time

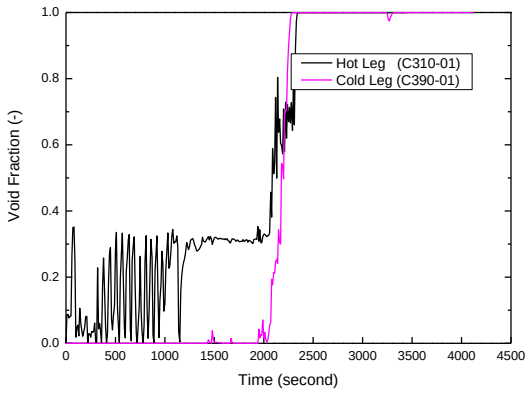

Fig. 3. Hot Leg and Cold Leg Void Fraction vs. Time

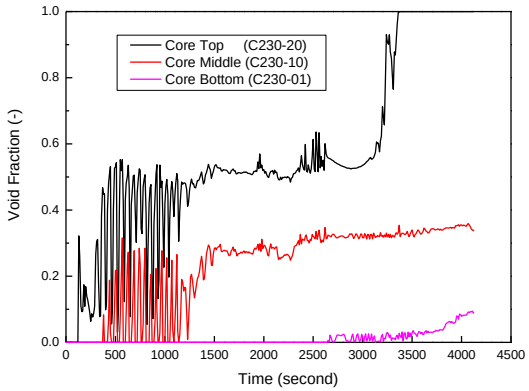

Fig. 4. Core Void Fraction vs. Time

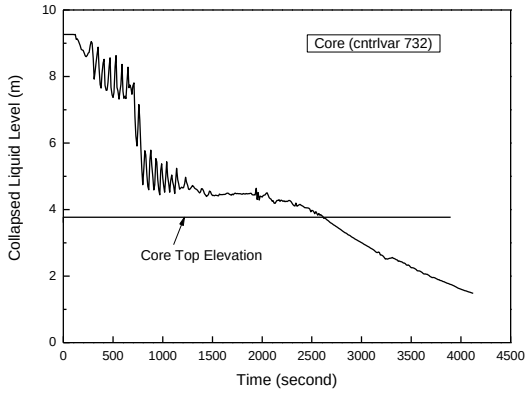

Fig. 5. Core Collapsed Level vs. Time

3. Conclusions

The results show the time to core uncovery is about 2,500 seconds which is greater than 1,800 seconds without operator action, and operator action to initiate Safety Injection is credited at 1,800 seconds, terminating the event. As the core remains covered, no fuel failure occurs and there is no offsite dose consequence.

Therefore, it could be said that postulated events in LPSD are not limiting compared to those of Decrease in Heat Removal events in SAR Chapter 15.

REFERENCES

[1] ANSI/ANS-5.1-1979, "Decay Heat Power in Light Water Reactors," ANS, August 29, 1979.

[2] NUREG/CR-5355/Rev.P4, "RELAP5/MOD3.3 Code Manual," Information System Lab., Inc., October 2010.