The methodology of Plant Damage State and Containment Event Tree development in the Low Power Shutdown Probabilistic Safety Assessment Level 2 using T/H analysis code

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Abstract: This paper outlines the Low Power and Shutdown (LPSD) Probabilistic Safety Assessment (PSA) portion of a methodology for the determination of the Plant Damage State (PDS) and Containment Event Tree (CET). The pressure of Reactor Coolant System (RCS) and containment are the important characteristic to determine PDS and CET development. This methodology provides the technical basis for the classification of Reactor Coolant System (RCS) pressure category in the PDS analysis and containment pressure category in the CET analysis. So, the T/H analysis results using MAAP code are provided as the technical basis to define the Success Criteria of the In-vessel injection to develop the PDS logic diagram, and to define containment failure phenomena by severe accident and to develop the CET logic diagram. The analysis cases include RCS Intact as well as RCS with Manway Open in Modes 4 and 5.

Keywords: LPSD Level 2 PSA, Plant Damage State, Containment Event Tree

1. INTRODUCTION

The interface between the Level 1 systems analysis and Level 2 Containment analysis is the classification of accident sequences into plant damage states (PDSs). The purpose of this classification is to reduce the number of accident analysis required while retaining the essential spectrum of probable accident progressions. These PDSs are defined by the set of functional characteristics of system operation that are important to subsequent accident progression, containment failure, and source term analysis. In particular, the Reactor Coolant System (RCS) pressure at the time of core damage after accident initiation is the important characteristic to define success criteria to develop the PDS logic diagram about in-vessel injection and/or external reactor vessel cooling.

The Containment Event Tree (CET) is developed to model the containment response during severe accident progressions. The CET depicts the various phenomenological processes, containment conditions, and containment failure modes that could occur under severe accident conditions. The important phenomena, which can affect the containment failure modes and the source terms, are also addressed as top events in the CET. In particular, the containment pressure at the time of containment failure after accident initiation is the important characteristic to define success criteria to develop the CET logic diagram about the determination of containment failure mode. The parameters to define accident progression for the containment pressure are over-pressurization due to steaming, Rupture Before Core Melt(RBCM), and the status of Containment Heat Removal.

2. PLANT DAMAGE STATE (PDS) ANALYSIS

The entry points to the containment event trees are PDSs. The PDS characteristics are defined by selecting key parameters important to the accident progression in the containment and the radionuclide source term. The parameters used to define the PDSs include the functional status of important systems, variables determined by systems operation (e.g., RCS pressure), accident initiator type, and the timing of key events. The assumptions for this Thermal Hydraulic analyses are as below.

○ For all sequences, the initiating event is Loss of Shutdown Cooling

○ For all the sequences, the safety systems such as containment spray system for containment heat removal and auxiliary feedwater system for decay heat removal are unavailable

○ The pressure at upper compartment represents the containment pressure.

The followings are key parameters to define accident progression for the RCS pressure.

2.1 RCS Integrity

The RCS integrity is the parameter that could affect the occurrence probability of severe accident phenomena.

When RCS is intact (POSs 3A through 4A, 12B through 13), the occurrence probability of severe accident phenomena is assumed conservatively the same as that estimated in the at-power analysis.

When RCS has Manway Open (POSs 4B through 6 and 10 through 12A), the severe accident progression is significantly different from that of the at-power because RCS pressure is low. Therefore, two attributes such as RCS Intact and RCS with Manway Open are defined for this parameter. Table 3-1 represents RCS integrity about POSs 3A through 13.

2.2 RCS Pressure at the time of Core Damage (RCSPRE)

The RCS pressure at the time of core damage can impact on the timing of containment failure, accident progression and the failure mode of containment. This parameter has three values based on NUREG-1150 and NUREG/CR-4551.

○ High Pressure (HIGH, 1,200 psia ≤ Pressure).

○ Medium Pressure (MED, 250 psia ≤ Pressure < 1,200 psia)

○ Low Pressure (LOW, Pressure < 250 psia))

The Low Temperature Overpressure Protection (LTOP) valves are the spring operated relief valves which are isolated during normal power operation. The isolation valves are open in POS 3A for overpressure protection of the RCS when the shutdown cooling system operates. The pressure setpoint to open is about 500 psig. Thus, high pressure events with pressures higher than 1,200 psia are not considered when LTOP valves are in operation. Medium pressure is defined to be a pressure between about 1.72 MPa (250 psia) and about 8.27 MPa (1,200 psia).

Medium pressure is asked for the sequences which are assigned as intact RCS and normal RCS inventory. For the sequences of medium pressure, potential for Direct Containment Heating (DCH) is considered in CET analysis.

Low pressure is defined to be primary system pressure less than about 1.72 MPa (250 psia). Sequences with RCS with Manway Open would have low RCS pressure. For these low pressure sequences, DCH is considered to be very unlikely. However, the potential for steam explosion at low pressure is greater than at high pressure. Low pressure is assigned to the sequences of RCS with Manway Open (POSs 4B through 6 and 10 through 12A). Low pressure is also assigned to the sequences of RCS Intact with stuck open of LTOP valve. Figure 2-1 represents PDS Logic Diagram based on RCS Pressure. Several MAAP calculations are performed to determine the RCS pressure at the time of core damage and are summarized in Table 3-1, and Figure 2-2.

According to the analysis results, the maximum RCS average pressure reaches 547 psia in RCS intact and 34 psia in RCS with Manway Open within simulation time of 72 hours. Therefore, RCS intact in the PDS analysis is assigned into medium RCS pressure which is potential for DCH. RCS with Manway Open is assigned into low RCS pressure which is not potential for DCH but steam explosion.

3. CONTAINMENT EVENT TREE (CET) ANALYSIS

The purpose of the CET is to quantify the probabilities of various containment failure modes affecting radionuclide releases. The various containment failure modes and the major phenomena that have a significant impact on the radionuclide release are represented as top events in the CET. Detailed evaluation of phenomena which affect containment failure mode are treated through the use of Decomposition Event Trees (DETs). This CET/DET approach allows a relatively detailed treatment of the phenomena affecting containment performance, while maintaining a relatively simple and easily understood CET.

The major phenomena are the containment pressure at the time of containment failure after accident initiation because it determines containment failure modes. The followings are key parameters to define accident progression for the containment pressure and they are to define success criteria to develop the CET logic diagram.

3.1 Over-pressurization due to steaming

Gradual pressurization of the containment building would result from the protracted generation of steam or non-condensable gases from the interaction of molted core material with water on the containment floor or the concrete basemat. This pressurization process could last from several hours to several days, depending upon factors such as the availability of water in the containment and the operability of engineered safety features. Gradual containment pressurization by steam production and from the non condensable gases generated during debris concrete attack is considered explicitly in this analysis.

3.2 Rupture Before Core Melt (RBCM)

This event defines whether the containment fails before the onset of core damage (or the reactor-vessel breach). Following the PDS analysis in Section 2, the PDS 106 is characterized as RBCM sequences which can result from a loss of containment heat removal even though core damage was initially prevented. Those RBCM sequences include events with safety injection but failure of the containment sprays or a transient with failure of secondary heat removal followed by successful feed and bleed cooling, but with failure of containment sprays and IRWST cooling. If containment fails before core damage, the containment would be immediately and rapidly depressurized. Figure 3-1 represents CET (LCF-DET) Logic Diagram based on Containment Pressure.

Several MAAP calculations are performed to determine the containment pressure until 72 hours after accident initiation and are summarized in Table 3-1 through 3-2 and Figure 3-2.

4. CONCLUSIONS

Thermal Hydraulic analyses were performed to provide the classification of RCS pressure and containment pressure in Modes 4 and 5 using MAAP code.

For this analysis, if the early containment failure does not occur, it takes long time to over-pressurize the containment without containment heat removal. The containment failure may occur due to over-pressurization by steam generation and non-condensable gas generation.

According to the analysis results, the containment pressure reaches 122 psia where the cavity is flooded and 61 psia where the cavity is not flooded. Therefore, the CET analysis is assumed that the containment may fail by steam over-pressurization where the reactor cavity is flooded, but the containment may not fail by steam over-pressurization where the reactor cavity is not flooded. The containment failure probabilities at maximum containment pressure of each accident sequence are determined from the ultimate pressure capacity (UPC) analysis for APR1400 containment.
The RCS average pressure reaches 547 psia in RCS intact and 34 psia in RCS with Manway Open. Therefore, RCS intact in the PDS analysis is assigned into medium RCS pressure and RCS with Manway Open is assigned into low RCS pressure.

As a results, T/H analysis results using MAAP code for each Mode provide the technical basis for the classification of RCS pressure category in the PDS analysis and containment pressure category in the CET analyses.

References

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Table 3-1 The T/H Analysis Results in RCS and containment for each POS during LPSD (Dry Cavity)

POS(Mode)	RCS Integrity	Time to Core Damage (hours)	Time to Reactor Vessel Failure (hours)	Max. RCS Pressure (Pa(Psia))	Max. Containment Pressure (Pa(Psia))(72 hrs)
POS3A(4)	Intact	6.6	9.1	3.77E+06(547)	4.22E+05(61)
POS3B(5)	Intact	7.8	12.2	3.77E+06(547)	3.66E+05(53)
POS4A(5)	Intact	12.0	15.4	3.75E+06(544)	3.10E+05(45)
POS4B(5)	Manway Open	3.0	8.1	2.22E+05(32)	3.65E+05(53)
POS5(5)	Manway Open	2.1	6.9	1.31E+05(19)	3.47E+05(50)
POS6(6)	Manway Open	2.2	7.1	2.37E+05(34)	2.94E+05(43)
POS10(6)	Manway Open	3.6	12.6	1.65E+05(24)	2.10E+05(30)
POS11(5)	Manway Open	5.3	18.1	1.65E+05(24)	1.78E+05(26)
POS12A(5)	Manway Open	8.0	29.9	1.70E+05(25)	2.03E+05(29)
POS12B(5)	Intact	32.6	59.4	3.76E+06(545)	1.81E+05(26)
POS13(4)	Intact	23.4	45.4	3.76E+06(545)	1.78E+05(26)

** LTOP valves are in automatic mode in all POS's*

Table 3-2 The T/H Analysis Results in RCS and containment for each POS during LPSD (Wet Cavity)

POS(Mode)	Max. Containment Pressure (Pa(Psia))(72 hours)
POS3A(4)	8.39E+05(122)
POS3B(5)	8.38E+05(122)
POS4A(5)	5.84E+05(85)

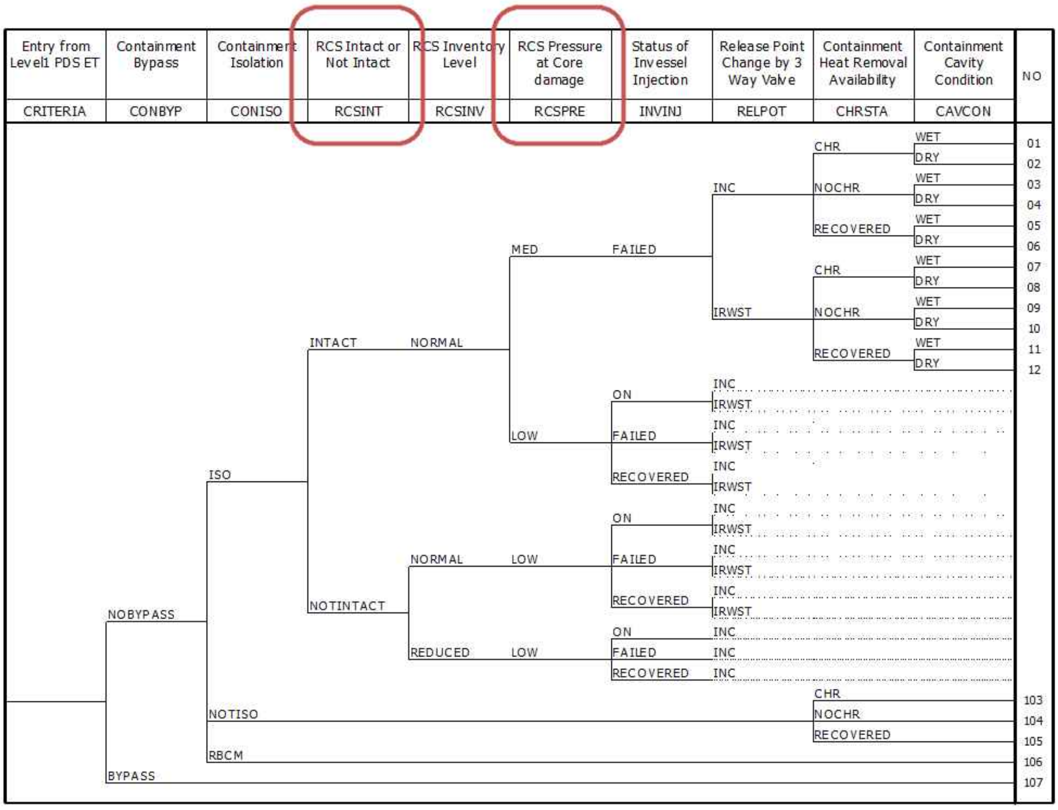

Figure 2-1 PDS Logic Diagram

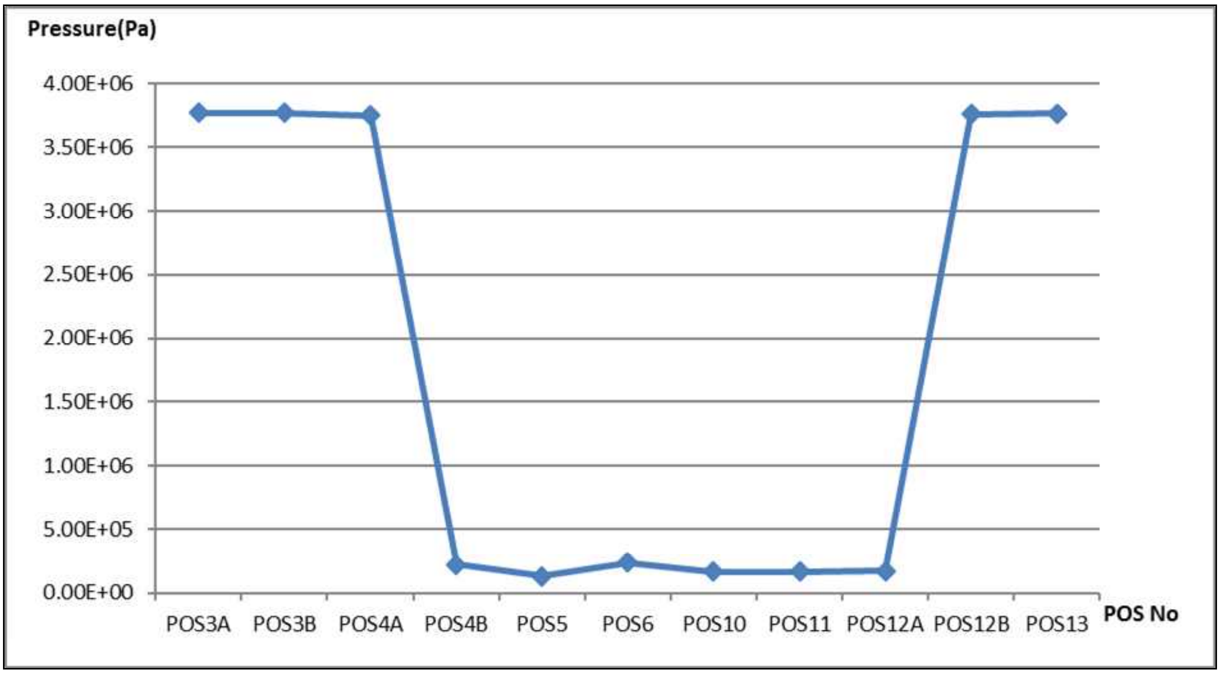

Figure 2-2 Max. RCS Pressure for each POS (72 hrs)

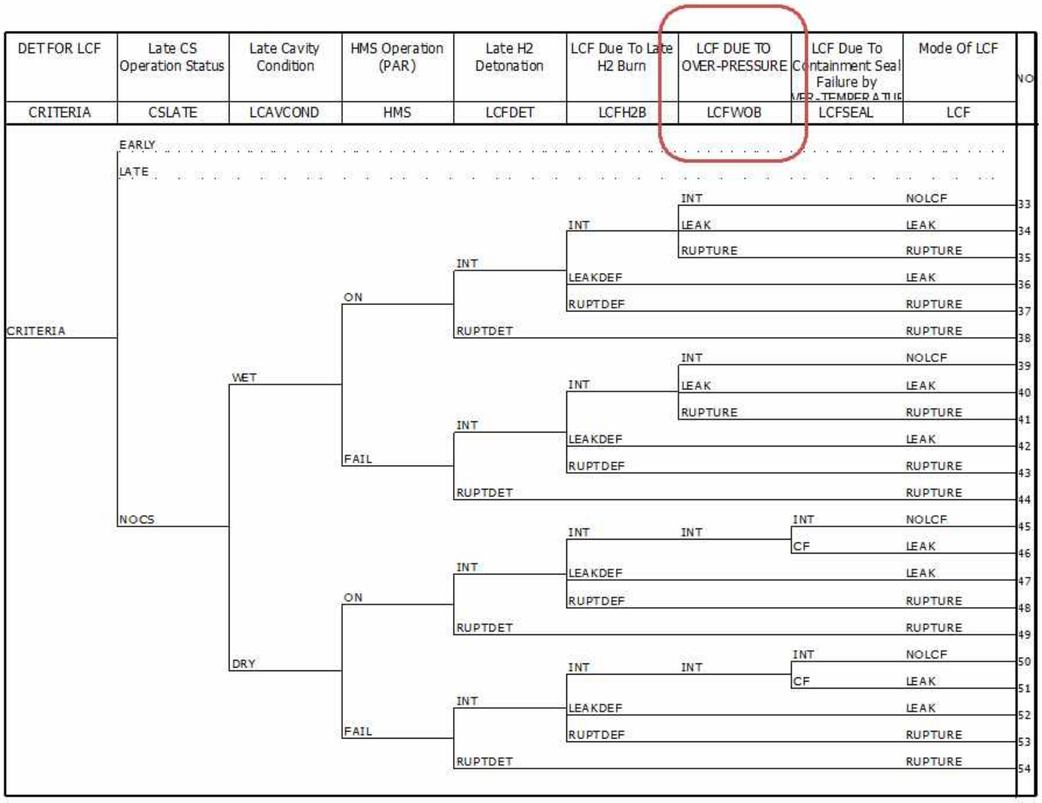

Figure 3-1 LCF-DET Logic Diagram

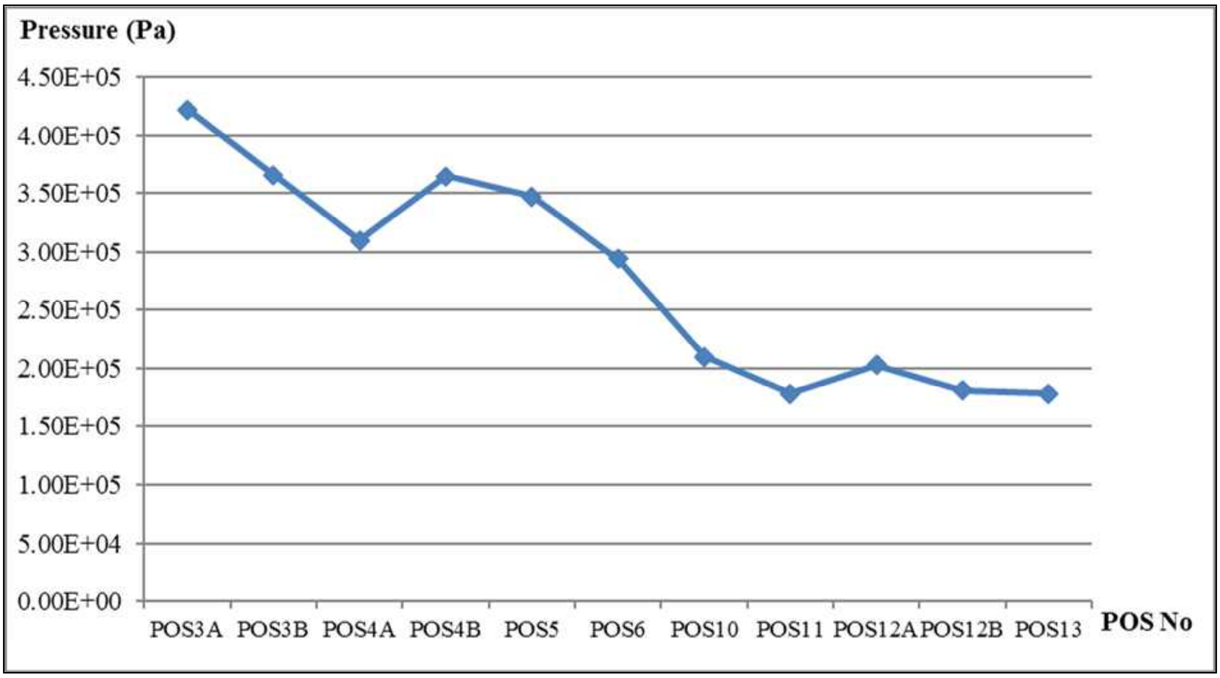

Figure 3-2 Max. Containment Pressure for each POS (Dry cavity, 72 hrs)