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ACCIDENT SEQUENCE ANALYSIS FOR A BWR DURING LOW POWER AND SHUTDOWN OPERATIONS[a]

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ABSTRACT

Most previous Probabilistic Risk Assessments have excluded consideration of accidents initiated in low power and shutdown modes of operation. A study of the risk associated with operation in low power and shutdown is being performed at Sandia National Laboratories for a U.S. Boiling Water Reactor (BWR). This paper describes the proposed methodology for the analysis of the risk associated with the operation of a BWR during low power and shutdown modes and presents preliminary information resulting from the application of the methodology.

INTRODUCTION

The purpose of this paper is to provide a brief overview of the work being conducted at Sandia National Laboratories (SNL) with regard to the identification and quantification of accident sequences initiated in modes of operation other than full power.

Traditionally, probabilistic risk assessments (PRAs) for nuclear power plants (including those of the recent NUREG-1150 analysis [1]) have characterized the risk associated with accidents initiated while the plant is in full-power operation. This concentration of effort on full-power events was based on the judgment that the level of risk associated with accidents that could occur during full-power operation is greater than that associated with accidents that could occur during the other modes of operation, such as low power and shutdown. The primary justification for this claim appears to be that lower decay heat levels are generally associated with these other modes of operation, so more time is available to recover from adverse situations arising in these modes. However, there are additional factors that could influence the risk associated with accidents initiated during the shutdown modes. These factors include:

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1. The greater need for operator actions to prevent core damage (due to disabling of automatic safety systems during some of the shutdown modes).

2. The increased unavailability of equipment due to planned maintenance. (This results from the demand for high equipment availability during power operation, which limits the amount and length of maintenance activities that can be performed while the plant is at power.)

3. Lack of containment integrity caused by the opening of penetrations and hatches. (These openings, which are allowed by Technical Specifications, in many cases are necessary before the activities planned for shutdown can occur.)

In addition to the above factors, the Chernobyl accident and other precursor events [2] that have occurred during non-full-power operation have pointed to the need for a study of the risk associated with accidents initiated during modes of operation other than full power.

OBJECTIVES AND SCOPE

As a first step in assessing the risk associated with accidents initiated during these other modes of operation, Sandia National Laboratories, at the direction of the U.S. Nuclear Regulatory Commission, has begun an analysis of low-power and shutdown accident sequences for a U.S. Boiling Water Reactor (BWR). The objectives of the study are to:

(1) assess the frequencies of severe accidents initiated during plant operational modes other than full power for a U.S. BWR;

(2) compare the estimated core damage frequencies, important accident sequences, and other qualitative and quantitative results of this study with those of accidents initiated during full-power operation; and

(3) demonstrate methodologies for accident sequence analysis for plants in non-full-power modes of operation.

The scope of this project includes accidents initiated during the following five modes of operation:

(1) low power (up to 15% power; identified as "Mode 1L),

(2) startup,

(3) hot shutdown,

(4) cold shutdown, and

(5) refueling (including fuel movement accidents that occur within a right circular cylinder above the core).

METHODOLOGY

Identification of Mode Change Initiating Events

The first step in estimating the risk associated with the operation of a BWR during the above modes of operation is determining why the plant changes mode. At first it may seem that this is an unimportant step, but knowing why the plant had to change its operating state provides valuable information about the availability or unavailability of systems that may be required to respond to an (accident) initiating event while the plant is in a particular mode of operation.

By grouping into categories the reasons why a plant undergoes a controlled change in operating mode, we arrive at a concept that can be identified as a "mode change initiating event". This definition specifically excludes mode changes that are necessitated by accident initiating events within a mode (e.g., any transient initiating events occurring at full power that cause the plant to scram). Potential sources of information that may be used to both identify and quantify mode change initiating events include such things as:

(1) monthly operating reports summarizing the operating status of the plant,

(2) operator log books, and

(3) Licensee Event Reports (LERs).

Identification of Plant States

The next step in estimating the risk is the identification of what can be called "Plant States". These Plant States should be defined after examining the plant's operating instructions for transitioning among the various modes of operation. The major ingredient in the definition of a Plant State is the identification of the systems that are normally expected to provide the necessary functions for maintaining the plant within a particular mode of operation. Application of this concept may result in the coalescing of two or more modes of operation into one Plant State and/or the splitting of one mode of operation into more than one Plant State.

Initiating Event Analysis

Ongoing with the above two steps is the process of identifying and quantifying potential accident initiating events. In this study for some of the Plant States, the criteria for identifying potential initiators will be the same as for any full-power study: any disruption to the normal operation of the plant which requires a rapid shutdown or trip of the plant. For the other Plant States an initiator is any event which requires an automatic or manual response to prevent core damage in the vessel. Using these definitions, information sources such as LERs, operating instructions, and previous studies are reviewed to obtain a list of potential initiators. These potential initiators are then quantified using acceptable methods and any initiator with a frequency below the truncation level of 1×10^{-8} is eliminated from further consideration.

Remaining Steps

The remaining steps in the methodology parallel those used in most full-power probabilistic risk assessments:

- determination of system success criteria,
- construction of event trees,
- construction of fault trees,
- quantification of accident sequences, and
- documentation of results.

Since this is the first study in the United States attempting to estimate the risk (core damage frequency) due to the operation of a BWR in all modes other than full-power, some means of prioritization of potential accident sequences was thought to be necessary. This prioritization will take place during a Coarse Screening Phase of this work.

This Coarse Screening Phase will use the detailed information obtained from the steps up to and including construction of event trees, along with conservative numerical estimates of the top events in the event trees, to quantify the potential accident sequences for each Plant State. The results of this coarse screening analysis will then be used to prioritize the remaining detailed analyses.

PRELIMINARY RESULTS

Identification of Mode Change Initiating Events

Table 1 depicts the seven classes of mode change initiators identified so far by this study. In addition, the table supplies current thoughts on whether the mode change class will result in possible pre-existing unavailabilities for a mode, i.e., whether the reason for the mode change involves unavailability of a system (or systems) that might be used to mitigate an accident initiated in a subsequent mode.

From an examination of Table 1 it can be seen that some of the classes may require further breakdown in order to determine whether or not pre-existing unavailabilities exist. For example, Class 2 might be divided into two subclasses:

- subclass 2A - which imposes no pre-existing unavailabilities and
- subclass 2B - which does impose pre-existing unavailabilities.

The breakdown will depend upon which Safety Limit was violated and/or which Limiting Condition of Operation was exceeded.

CLASS	POSSIBLE PRE-EXISTING UNAVAILABILITIES	COMMENTS
1. Refueling	No	Planned Shutdown
2. Controlled Shutdown required by Technical Specifications due to violation of Safety Limit or Limiting Condition of Operation	Yes	Entry into Technical Specification Action Statement(s) for systems required during post shutdown imposes unavailabilities. For systems not required no unavailabilities imposed.
3. Controlled shutdown required by Technical Specifications due to missed surveillance requirement (SR)	No	Missed SR does not imply known unavailability.
4. Controlled shutdown due to failures in non Technical Specification Equipment	Yes	For example, Circulating Water System failures render the Condenser unavailable for Turbine Bypass.
5. Preventive Maintenance	No	Nothing broken. If broken goes in Class 2 or 4.
6. Change initiated in response to accident occurring during full power operation	Yes	Out of scope for this study.
7. First time startup or final shutdown	Yes	One time events conducted under controlled conditions. Out of scope for this study.

Table 1. Preliminary Classes of Mode Change Initiators

Identification of Plant States

After examining the configuration of the plant in each mode of operation (using Technical Specification requirements and plant-specific procedures), seven preliminary Plant States have been identified. The seven Plant States are shown in Figure 1.

Initiating Event Analysis

For each of the modes of operation, a preliminary list of initiating events (IEs) with the potential to lead to core damage have been identified. At present, five major groups of initiating events have been identified:

(1) transient events,

(2) loss-of-coolant accident (LOCA) events,

(3) decay heat removal (DHR) challenge events,

(4) special events (e.g., criticality and loss of support system events), and

(5) hazard events (i.e., internal fire and flood events).

The categories listed above are not expected to change; however, the number of unique initiating events within a category may change as additional information is obtained. In addition, work is in progress to parse the IEs into appropriate Plant States. Table 2 presents the initiating events that have been identified to date.

Remaining Steps

Many of the system success criteria will be the same as for a full power analysis. For cases where full-power success criteria do not exist or are inappropriate, success criteria will be determined using thermal-hydraulic analyses.

Many of the necessary event trees have already been constructed. To date, approximately 62 detailed event trees have been developed. These trees contain approximately 2500 sequences. While many of these sequences do not lead to core damage, the number of sequences that must be evaluated is quite large. This large number of sequences is one of the driving forces behind the Coarse Screening Phase of this project. This Phase will use conservative estimates for the top events in the event trees in an attempt to prioritize the accident sequences which must undergo detailed analysis. Those accident sequences which require detailed analysis will be analyzed using the same steps as in a full-power PRA, namely:

(1) construction of fault trees,

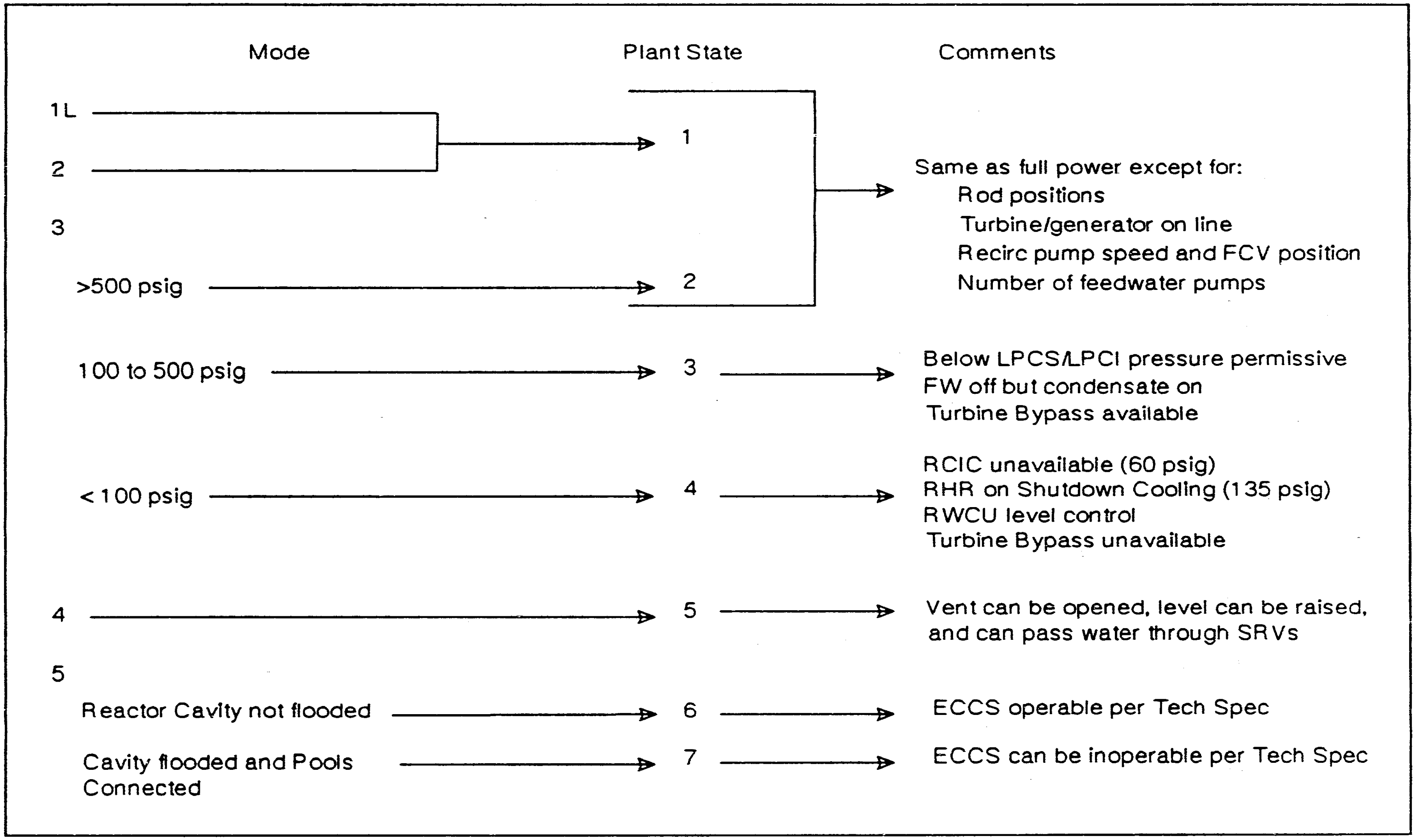

Figure 1. Preliminary Plant State Identification

INITIATING EVENTS	MODES				
	1L	2	3	4	5
TRANSIENTS					
T1: Loss of Off-Site Power	X	X	X	X	X
T2: Loss of Power Conversion System	X	X			
T3A: Power Conversion System Available	X	X			
T3B: Loss of Feedwater	X	X			
T3C: Inadvertent Open Relief Valve	X	X			
LOSS OF COOLANT ACCIDENTS (LOCAs)					
A: Large LOCA	X	X	X	X	X
S1: Intermediate LOCA	X	X	X	X	X
S2: Small LOCA	X	X	X	X	X
S3: Small-Small LOCA	X	X	X	X	X
H1: Diversion to Suppression Pool		X	X	X	X
H2: Diversion to Condenser		X	X	X	X
J: LOCA in Connected System		X	X	X	X
K: Test/Maintenance-Induced LOCA		X	X	X	X
DHR CHALLENGE INITIATORS					
E1A: Loss of Condensate (DHR)			X	X	
E1B: Loss of RHR-Shutdown Cooling		X	X	X	X
E1C: Loss of RWCU (DHR)					X
E1D: Loss of Alternate DHR System				X	X
E1E: Loss of RCIC		X	X		
E2A: Isolation of Condensate			X	X	
E2B: Isolation of RHR-Shutdown Cooling		X	X	X	X
E2C: Isolation of RWCU (RHR)					X
E2D: Isolation of Alternate DHR System				X	X
E2E: Isolation of RCIC		X	X		
SPECIAL EVENTS					
Criticality Events:					
T4A: Rod Withdrawal Error	X	X	X	X	X
T4B: Refueling Accident					X
Loss of Support Systems:					
T5A: Loss of Standby Service Water		X	X	X	X
T5B: Loss of Turbine Building Cooling Water		X	X	X	X
T5C: Loss of Plant Service Water				X	X
TIAS: Loss of Instrument Air System	T2	X	X	X	X
TEP: Loss of Electric Power			X	X	X
Other Events:					
TORV: Inadvertent Open Relief Valve-Shutdown			X		
TIOP: Inadvertant Overpressurization		X	X	X	
HAZARDS EVENTS					
Internal Fire	X	X	X	X	X
Internal Flooding	X	X	X	X	X

1L = Mode 1, Less than 15% Power X = Applicable T2 = Included Under T2 Transient

TABLE 2. Preliminary List of Initiating Events and Mode Applicability

(2) determination of event probabilities or frequencies,

(3) quantification of sequences, and

(4) documentation of results.

CONCLUSIONS

A methodology to quantify the risk (core damage frequency) associated with the operation of a BWR in modes other the full-power has been developed. Application of the methodology is ongoing and results from the Coarse Screening Phase are expected by the end of May, 1991.

ACKNOWLEDGEMENTS

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REFERENCES

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[2] Loss of Vital AC Power and the Residual Heat Removal System During Mid-Loop Operations at Vogtle Unit 1 on March 20, 1990, NUREG-1410, U.S. Nuclear Regulatory Commission, Washington, DC, June 1990.

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