A Plant Damage State Early Warning System

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Abstract: In case of a severe accident, operators need to follow the emergency operating procedures (EOPS) to limit the damage. In order to assist operators to face a lot of Plant Damage States (PDS) suddenly, we try to predict and identify the Plant Damage State (PDS) for early warning and decision making. In this study, Containment Event Tree (CET) is used in this event-oriented approach to help severe accident management. The Taipower Lungmen nuclear power station (LNPS), an advanced boiling water reactor, is chosen for case study. The LNPS full scope engineering simulator is used to generate the testing data for method development.

Keyword: severe accident, accident management, reactor safety analysis, ABWR

1 Introduction

1.1 Severe accident management

Severe accident management (SAM) is used to prevent or mitigate a severe accident like core-meltdown in nuclear power plant (NPP) during its early stage. With the defense in depth approach to assure nuclear safety, beyond design basis accidents need to be considered. The probability of occurrence of a beyond design basis accident is very low, but such an accident may lead to significant consequences \([1]\). Accident conditions more severe than a design basis accident and involving significant core damage are termed severe accidents. The following are common severe accident initiators: loss of coolant accidents (LOCA), total loss of feedwater (TLOFW), loss of offsite power (LOOP), station blackout (SBO).

An initiating event may lead to a severe accident if operators do not follow the appropriate accident management or the plant safety functions have been challenged. In order not to get worse, an important task is to identify the correct plant damage states (PDS). With the correct PDS, Containment Event Tree (CET) is used for probabilistic risk assessment (PRA). PRA is combined by event trees and fault tree analysis. It is a comprehensive system of contemplation sources of risk to identify failure scenarios. It can also be used to assist in developing severe accident management strategies because it gives information regarding severe accidents such as insights into their progression, the associated accident environment and recovery requirements \([2]\). PRA can be combined with hard data (statistical techniques) and soft data (expert opinion and human reliability), providing strategy makers the diversity of determination basis.

1.2 Lungmen Nuclear Power Station

The Lungmen nuclear power station (LNPS), Taiwan’s fourth nuclear power plants, is an advanced boiling water reactor (ABWR) with fully digitized instrumentation and control (I&C) system. In this study, LNPS full scope engineering simulator is used to simulate various kinds of accidents. Fig. 1 shows the conceptual design of the combination of operator, simulator and the severe accident management (SAM) system.

![Fig.1 The conceptual design of the present study.](image-url)
2 Simulator

The Full Scope Simulator for Lungmen nuclear power station (LNPS) has been completed its Site Acceptance Test (SAT) and 500 hours of Availability Test (AVT), thus it is ready for training and operator licensing. This enables operator training and licensing to be performed and completed before plant start-up and commercial operation [3].

2.1 Model

The software of the LNPS full scope engineering simulator can be implemented on the PC Windows environment. Its core modeling is developed by TRACS and NEMO model. The following systems have interfaces with TRACS/NEMO in simulator:

1. Main Steam (MS)
2. Reactor Internal Pumps (RIP)
3. Turbine (TURB)
4. Containment (CONT)
5. Residual Heat Removal System (RHR)
6. High Pressure Core Flooding System (HPCF)
7. Reactor Core Isolation Cooling System (RCIC)
8. Control Rod Drive System (CRD)
9. Feedwater System (FWS)
10. Neutron Monitoring System (NMS)

Other system model is built on the Western Services Corporation's (WSC) 3KeyMaster simulation platform, a detailed simulation model to establish a complete reactor core and 105 plant systems in the simulator. Simulations can be conducted in a quad-core PC with a Windows operating system. More than 20,000 logic diagram and over 1000 graphical screen are used to control and monitor the LNPS. It is easy to operate the plant for each system. In addition, there are hundreds of normal / abnormal initial conditions and incident / accident pre-defined. It can be started manually by the operator or automatically by pre-defined timer and plant conditions.

As shown in Fig. 2, monitoring and controlling functions of these 105 plant systems can be easily manipulated.

3 METHODOLOGY

3.1 Plant Damage State

The Plant Damage State (PDS) means the state of plant onset of core damage. The PDS reflects the phases of increasing severity in the progression of the accident. They refer to an identification of the state of the core and containment with respect to challenges to the fission product barriers of the plant. The PDS is helpful to select strategies because some strategies can be effective in one plant damage state, but may be ineffective or even detrimental in another. An accident sequence is different from a plant damage state. The PDS is an observable damage condition at the plant while the accident sequence means that it has already led to damage condition. To reduce the number of PDS, they are grouped based on similarity of accident progression.

The PDS group would be expected to have similar effects on containment response. It is therefore important to identify those attributes of an accident progression that will influence either the containment response or the release of fission products to the environment [4].

If we want to define the PDS, several consequence parameters are need as shown in the Figs. 3 and 4. The PDS is defined by the combination of the possible values for each of the PDS parameter. Thus, the PDS identifies the containment status (e.g. intact and isolated, intact and not isolated, intact but not isolated, isolated, not isolated, etc.).
failed or bypassed) and, for bypass, the type and size of the bypass (e.g. interfacing system loss of coolant accident (LOCA)). For the PDS in which the containment is intact, a Containment Event Tree (CET) analysis will need to be performed. There may be differences related to direct containment damage. Events such as earthquakes or external missiles may lead to containment failure as well as core damage. Additional PDS or existing PDS can be created to cover these events.

3.2 Containment Event Tree

The containment event tree (CET) is used to model the containment responses by depicting the various phenomenological processes, containment conditions, and containment failure modes that could occur during severe accidents.

The event tree technique is particularly useful in modelling containment response because it allows for the logical consideration of relatively large numbers of accident progression paths. Event trees start with an initiating event, branch to the right as various safety functions are questioned for success (up) or failure (down) as shown in Fig. 5 [5].

The top event in a CET defines the failure or success of a system or component. Fault trees are used to determine the probability of the top event. It uses a structure of logical operations to calculate the probability of the top event as a result of basic events inputs as shown in Fig. 6.

4 Event Simulation

In this section, Station Blackout (SBO) is chosen as a sample test. The accident assume all offsite AC power fail and emergency power diesel generators fail to start. No AC power is available in this case.
Once the SBO condition occurs, the plant starts to alarm. At the same time, the Plant Damage State (PDS) parameters start to change as shown in Figs. 7 and 8.

![Fig.7 PDS parameters when SBO.](image)

There are 10 Top Events in this CET:

1. INSERTION OF CONTROL ROD
2. ALL SRV RECLOSED
3. COOLANT INJECTION BY RCIC (SHORT TERM)
4. COOLANT INJECTION BY RCIC (LONG TERM)
5. COOLANT INJECTION BY HPCF
6. RPV DEPRESSURIZATION
7. COOLANT INJECTION BY LPFL
8. ALTERNATE INVENTORY MAKEUP
9. LONG TERM HEAT REMOVAL
10. CORE COOLING AFTER CTMT FAILURE

For the in-vessel stage of a SBO-common severe accident initiators, water should be added to the vessel as soon as it is made available to the operators [6]. Reactor Core Isolation Cooling (RCIC) and High Pressure Coolant Injection (HPCI) are steam driven and battery depletion. Only these two system are available to cool the reactor core. But high suppression pool temperatures and high containment back-pressure may affect the availability of these systems. If the Automatic Depressurization System (ADS) fail, system is unavailable to be depressurized and still at high pressure.

With the CET of SBO, it is obvious that the core melt frequency is determined by RCIC (short term) and RCIC (long term) & HPCF failure. Once RCIC (short term) fail, the event will directly lead to core meltdown.

![Fig.9 Reactor pressure vessel water level, pressure and reactor power.](image)

After identifying the PDS, we use CET to realize the containment responses as shown in Fig. 10.

![Fig.10 Containment Event Tree of SBO.](image)
On the other hand, if RCIC (long term) & HPCF fail and RPV is unavailable to be depressurized, it may also directly lead to core meltdown. If RCIC and HPCI do not fail (short term sequence), they will fail eventually if power is not restored (long term sequence). However, Low Pressure Coolant Injection (LPCI) system requires AC power so that core will finally melt. The recovery of AC (or DC) power will be the goal of in SBO events so that the system is available to cool by other coolant system.

5 Conclusion
The conceptual design of a plant damage state early warning system has been presented. The system provides a systematic approach for severe accident management to assist operators to identify the Plant Damage State (PDS). The containment event tree is used to provide a structured way for containment management. The proposed design uses the event oriented approach for accident management. Thus, the system provides a more completed coverage for plant emergency response.

References