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The ultimate response guideline simulation and analysis using TRACE, MAAP5, and FRAPTRAN for the Chinshan Nuclear Power Plant

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ABSTRACT

In this research, the TRACE and MAAP5 model of Chinshan BWR/4 nuclear power plant (NPP) has been established for the simulation and analysis of ultimate response guideline (URG). The main actions of URG are the depressurization and low pressure water injection of the reactor and containment venting. This research focuses to assess the usefulness of the URG under Fukushima-like conditions. This study consists of three steps. The first step is the establishment of Chinshan NPP TRACE and MAAP5 model. The second step is the URG simulation and analysis under Fukushima-like conditions by using Chinshan NPP TRACE and MAAP5 model. In this step, the base case without URG case was also performed in order to evaluate the URG effectiveness of Chinshan NPP. In order to confirm the mechanical property and integrity of fuel rods, the final step is FRAPTRAN analysis. According to TRACE and MAAP5 analysis results under Fukushima-like conditions, the URG can keep the peak cladding temperature (PCT) below the criteria 1088.7 K. It indicates that Chinshan NPP can be controlled in a safe situation. If under Fukushima-like conditions Chinshan NPP does not perform the URG, the water level may drop below the TAF (top of active fuel) which means a fuel melt safety issue may exist.

1. Introduction

Chinshan Nuclear Power Plant (NPP) was built in 1970. It is the first NPP in Taiwan. The BWR/4 plant's the original rated power was 1775 MWt for each unit. In addition, Chinshan NPP finished an SPU (stretch power uprate) and now the operating power is 1840 MWt. The safety analysis is very important to NPP safety. There is more concern for the safety of the NPPs in Taiwan after the Fukushima NPP disaster occurred. There are four operating states for Chinshan: normal operation, abnormal events/transients, accidents and severe accidents. For each operating state, there are corresponding procedures to follow to secure Chinshan's safety and integrity. Fig. 1 shows the correspondent relationship between NPP operating states and procedures. The first level is operating procedures (OPs) which focus on the operation within an acceptable range. The second level is abnormal operating procedures (AOPs) which aim at restoring the function of NPP systems that could impact the operating margins. The third level is emergency operating procedures (EOPs) which focus on bringing the NPP to a safe and stable state following a reactor trip or safety injection signal. The forth level is severe accident management procedures (SAMPs). Uncertainties may exist in both NPP status and in the outcome of actions for severe accidents. Therefore, SAMPs propose a range of possible actions and should allow for additional evaluation and alternative actions. However, EOP or SAMP are generally symptom-based procedures to mitigate transients/accidents consequence and restore the plant, depending on the real-time operational parameters of the unit. For the compound severe accidents, such as the Fukushima disaster, the impact is relatively broad, rather than only on one system or one area. Therefore, due to this fact, Taiwan Power Company developed an additional URG to prevent BWR, PWR and ABWR from encountering core damage for events beyond design basis (Taiwan Power Company, 2012; Liang et al., 2012; Liu and Hwang, 2012). In addition, several studies on strategies similar to URG have also been done (Huh et al., 2009; Nuclear Energy Institute, 2012; U.S. NRC, 2012; Vo et al., 2014; Fernandez-Cosials et al., 2015).

The aim of this study is to use multiple computer codes to evaluate the URG effectiveness for Chinshan. The advanced thermal

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Nomenclature

ADS	automatic depressurization system
AOPs	abnormal operating procedures
BAF	bottom of active fuel
BPV	bypass valve
EOPs	emergency operating procedures
MSIV	main steamline isolation valve
NPP	nuclear power plant
OPs	operating procedures
PCMI	pellet cladding mechanical interaction
PCT	peak cladding temperature
RCIC	reactor core isolation cooling
RPV	reactor pressure vessel
SAMPs	severe accident management procedures
SBO	station blackout
SNAP	symbolic nuclear analysis program
SPU	stretch power uprate
SRV	safety relief valve
TAF	top of active fuel
TCV	turbine control valve
TSV	turbine stop valve
URG	ultimate response guideline

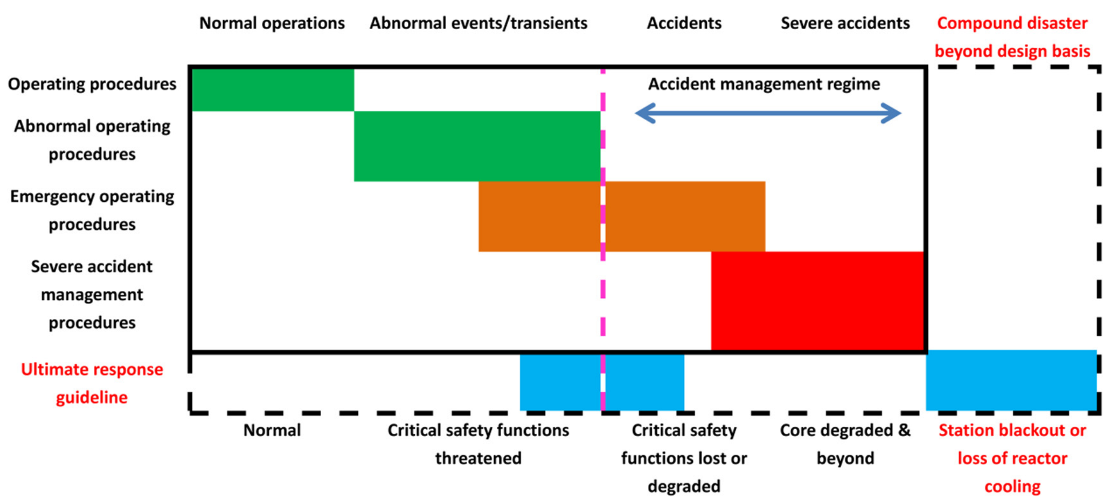

Fig. 1. Correspondent relation between NPP operating states and operating procedures. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

hydraulic code TRACE has been developed by U.S. NRC for NPP safety analysis. According to the user manual (U.S. NRC, 2014), TRACE is the product of a long term effort to combine the capabilities of the NRC's four main systems codes (TRAC-P, TRAC-B, RELAP5 and RAMONA) into one modernized computational tool. The development of TRACE is based on TRAC, combining with the capabilities of RELAP5 and other programs. SNAP (Symbolic Nuclear Analysis Program), a graphic user interface program that processes the inputs and outputs of TRACE, has also been under development. One feature of TRACE is its capacity to model the reactor vessel with 3-D geometry. It can therefore support a more accurate and detailed safety analysis for nuclear power plants.

The MAAP5 code is a fast-running severe accident analysis and management code widely used in nuclear industrial applications and developed by Fauske & Associates Inc. (2008). MAAP5 can simulate the response of light water reactors during a variety of severe accident sequences, including mitigation actions for use in accident management. This code provides a flexible, efficient, and integrated tool for evaluating the in-plant and ex-plant effects of a wide range of postulated accidents and for examining the impact of operator actions on accident progressions. The entire spectra of severe accident phenomena, including core heat-up, degradation and relocation, lower plenum phenomenology, corium-concrete interactions, containment hydraulics, hydrogen combustion, and radionuclide release and transport, are treated in MAAP5. All control volumes of the reactor, including reactor vessel, containment, and emergency core cooling system (together with the associated control logic of ECCS) are provided. Users only need to provide the plant data to use the code.

FRAPTRAN is a Fortran language computer code that calculates the transient performance of light-water reactor fuel rods during reactor transients and hypothetical accidents such as loss-of-coolant accidents, anticipated transients without scram, and reactivity-initiated accidents (Geelhood et al., 2011). Besides, a graphic user interface program, SNAP, which processes inputs, outputs, and animation models for TRACE and FRAPTRAN, was also developed by U.S. NRC.

There were three main steps in this study. First, Chinshan NPP TRACE and MAAP5 models were established in this research. Second, by using the TRACE and MAAP5 model, the URG simulation and analysis under Fukushima-like conditions was performed. In this step, a base case without URG was also performed. Subsequently, we compared the results of these two cases in order to evaluate the URG effectiveness for Chinshan. Third, in order to confirm the mechanical properties and integrity of fuel rods, FRAPTRAN analysis was performed in this study.

2. Ultimate response guideline (URG)

Chinshan's URG (Taiwan Power Company, 2012; Liang et al., 2012; Liu and Hwang, 2012), treats compound disasters beyond design basis (blue blocks in Fig. 1). When Chinshan NPP encounters