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The study of the mitigation strategy of Lungmen ABWR nuclear power plant using RELAP5 and FRAPTRAN with the interface SNAP

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ABSTRACT

In this study, the model of Lungmen ABWR NPP (nuclear power plant) using RELAP5 with the interface SNAP was established. This RELAP5/SNAP model performed the mitigation strategy simulation and study. The main systems of the mitigation strategy are RCIC (Reactor Core Isolation Cooling System), ADS (Automatic Depressurization System), and AC-Independent Water Addition System (ACIWA). This research focuses to assess the usefulness of the mitigation strategy under Fukushima-like conditions. There are three steps in this study. The first step is the establishment of Lungmen NPP RELAP5/SNAP model using the systems data, startup tests reports, and FSAR. The second step is the mitigation strategy simulation and analysis under Fukushima-like conditions using the RELAP5/SNAP model. In this step, the case without mitigation strategy was also performed to evaluate the mitigation strategy effectiveness. Finally, the FRAPTRAN analysis with the interface SNAP was performed in this study. This can evaluate the mechanical property and integrity of fuel rods. According to the RELAP5 results under Fukushima-like conditions, the mitigation strategy can maintain the PCT (peak cladding temperature) below the criteria (1088.7 K). And the FRAPTRAN results also present that the mitigation strategy can keep the fuel rods integrity. It indicates that Lungmen NPP would be in a safe situation when Lungmen NPP performs the mitigation strategy.

1. Introduction

In 2011, the earthquake and tsunami caused the disaster to occur in the Japan Fukushima NPP. After that, people in Taiwan have more concerns for the NPP safety. Now there are four NPPs in Taiwan. Lungmen NPP is the newest constructed NPP in Taiwan and is an ABWR type. Lungmen has two identical units with 3926 MWt rated power each. The rated core flow of Lungmen is 52.2×10^6 kg/hr and the steam flow is 7.637×10^6 kg/hr at rated power. Lungmen will use GE14 fuel in the future operation. Additionally, the Lungmen reactor has ten RIPs (reactor internal pumps) which can provide 111% rated core flow at the nominal operating speed (151.84 rad/s). In order to handle SBO (station blackout) or Fukushima-like accidents, a series of mitigation strategies, including operation procedures and essential equipment, were established in Lungmen NPP. Referring to the Ultimate Response Guideline for Lungmen NPP (Taiwan Power Company, 2014a,b) and the announced FSAR in that year (Taiwan Power Company, 2014a,b), the main systems used in the mitigation strategies are:

- ◆ RCIC (Reactor Core Isolation Cooling System)
  The RCIC, powered from a diverse power source (Voltage Direct Current (VDC) system, reactor steam, and DC battery), can maintains sufficient reactor water inventory in the reactor vessel and assure the cooling effect for an extended amount of time. The parameters of the RCIC for Lungmen are shown in Table 1. The RCIC will inject water to the reactor when the water level is below level 2 or the drywell pressure is larger than 0.0135 MPa. Once the water level reaches level 8 or the RCIC turbine is overspeed, the RCIC will trip. Additionally, the RCIC can be manually activated or tripped.

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Table 1
The Lungmen RCIC parameters.

Parameters	Descriptions
Power source	• Voltage Direct Current (VDC) system • Reactor steam • DC battery (8 h)
Water source	• Condensate storage tank (CST) – 588 m^3 • Suppression pool – 3566 m^3
Operation pressure	• RCIC isolation, RPV pressure < 0.446 MPa, • RCIC rated flow, RPV pressure >1.1356 MPa
RCIC activate	• Manually activate • Water level < level 2 • Drywell pressure >0.0135 MPa (0.138 kg/cm^2)
RCIC trip	• Manually trip • Water level > level 8 • RCIC turbine speed > 7200 rpm (mechanical overspeed) or 6900 rpm (electrical overspeed)
RCIC flow rate	50 kg/s

◆ ADS (Automatic Depressurization System)
ADS can provide the reactor depressurizing. The ADS is automatically initiated by high drywell pressure with the water level below level 1 or manually opened. It can permit the core cooling with low pressure water systems (ex: ACIWA) and avoid high pressure core melt sequences. Additionally, each steam line has two ADS valves.

◆ ACIWA (AC-Independent Water Addition System)
The ACIWA can provide diverse capability to supply water to the reactor when the AC power or RCIC is unavailable. It has a diesel driven pump with an independent water supply and all needed valves can be accessed and operated manually. The water sources of the ACIWA are from outdoor fire trucks and fire protection water supply tanks. There are two tanks in Lungmen NPP. Each tank has 2300 m^3 water. In addition, the ACIWA flow rate is 60 kg/s. The ACIWA is not a first line mitigation system with respect to core damage, but it is important in mitigating severe accidents if the SBO or Fukushima-like event extends beyond eight hours.

When Lungmen encounters SBO or Fukushima-like accident, the mitigation strategy will be activated. The main objective of the mitigation strategy is to maintain the core cooling effect and water level under different core pressures. The operation procedure has several steps. Some steps are prepared and operated simultaneously and some are operated sequentially. Hence, the mitigation strategy is as follows:

- First, the RCIC starts to inject water to the reactor after SBO or Fukushima-like accident occurs.
- Second, the set-up of the ACIWA must be finished as fast as possible. According to Lungmen requests, the ACIWA preparation must be finished within one hour.
- Third, if the RCIC becomes inoperable, Lungmen can open manually the ADS to depressurize the reactor.
- Finally, when the reactor reaches the low pressure condition (about 3 kg/cm^2), the ACIWA can inject water to the reactor.

To evaluate the mitigation strategy effectiveness under SBO or Fukushima-like conditions, RELAP5 code with the interface program SNAP is used in this study. RELAP5 code (MOD3.3 Patch04) is developed for light water reactor (LWR) transient analysis at INEL (Idaho National Engineering Laboratory) (Information Systems Laboratories, Inc., 2010). RELAP5 is one of U.S. NRC codes which are used for NPPs safety analysis. RELAP5 is usually used to perform licensing audit calculations, transient evaluation, mitigation strategy study, and experiment planning analysis. In addition, SNAP is a graphic user interface program which can process inputs and outputs for RELAP5.

Accordingly, some researchers are using RELAP5 to study and analysis thermal-hydraulic phenomena. The capability of Emer-

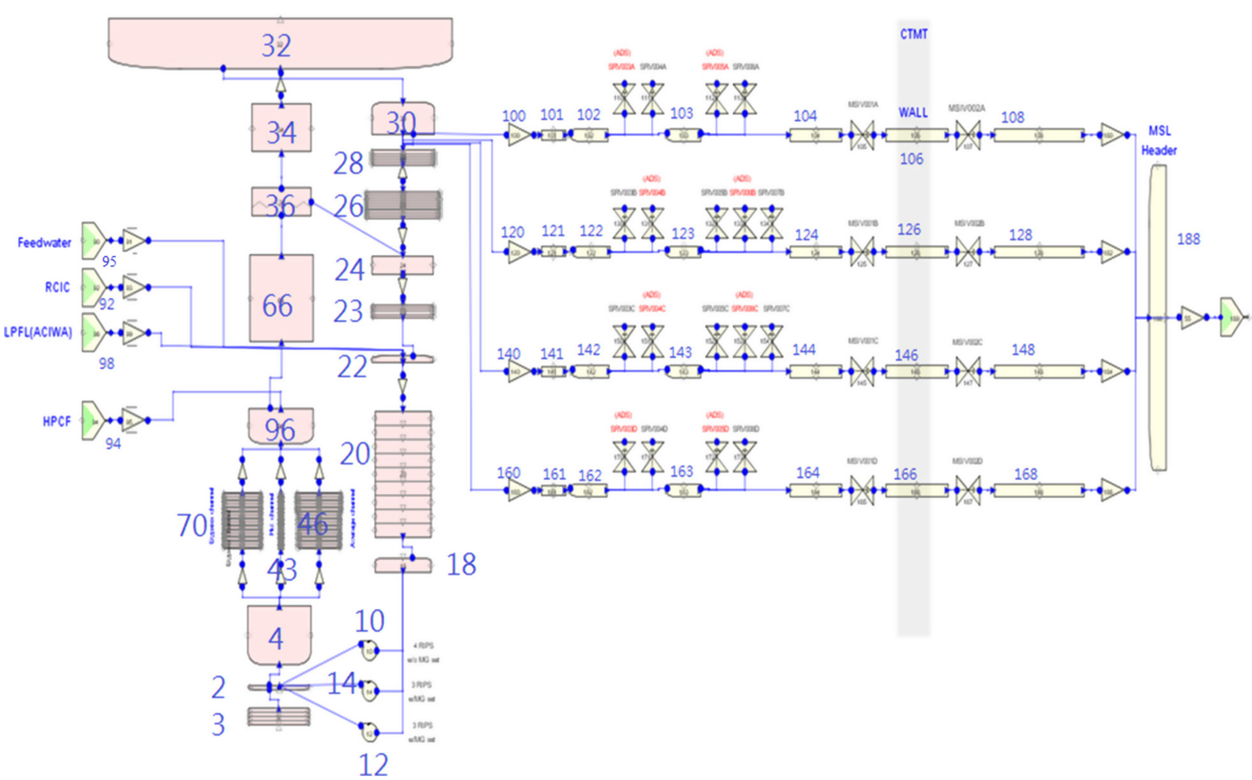

Fig. 1. The Lungmen NPP RELAP5/SNAP model.