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The pressurization transient analysis for Lungmen advanced boiling water reactor using RETRAN-02

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ABSTRACT

A RETRAN-02 model was devised and benchmarked against the preliminary safety analysis report (PSAR) for the Lungmen nuclear power plant roughly 10 years ago. During these years, the fuel design, some of the reactor vessel designs, and control systems have since been revised. The Lungmen RETRAN-02 model has also been modified with updated information when available. This study uses the analytical results of the final safety analysis report (FSAR) to benchmark the Lungmen RETRAN-02 plant model. Five transients, load rejection (LR), turbine trip (TT), main steam line isolation valves closure (MSIVC), loss of feedwater flow (LOFF), and one turbine control valve closure (OTCVC), were utilized to validate the Lungmen RETRAN-02 model. Moreover, due to the strong coupling effect between neutron dynamics and the thermal-hydraulic response during pressurization of transients, the one-dimensional kinetic model with the cross-section data library is used to simulate the coupling effect. The analytical results show good agreement in trends between the RETRAN-02 calculation and the Lungmen FSAR data. Based on the benchmark of these design-basis transients, the modified Lungmen RETRAN-02 model has been adjusted to a level of confidence for analysis of pressure increase transients. Analytical results indicate that the Lungmen advanced boiling water reactor (ABWR) design satisfied design criteria, i.e., vessel pressure and hot shutdown capability. However, a slight difference exists in the simulation of the water level for cases with changes in water levels. The Lungmen RETRAN-02 model tends to predict the change in water level at a slower rate than that in the Lungmen FSAR. There is also a slight difference in void reactivity response toward vessel pressure change in both simulations, which causes the calculated neutron flux before reactor shutdown to differ to some degree when the reactor experiences a rapid pressure increase. Further studies will be performed in the future using Lungmen startup test data.

1. Introduction

The Lungmen nuclear power plant (LMNPP), which has two advanced boiling water reactors (ABWRs), is the fourth nuclear power plant built by Taiwan Power Company (TPC). The rated thermal power for each unit in the LMNPP is 3926 MW. The significant improvements in LMNPP are reactor internal pumps (RIPs), fine-motion control-rod-drive system (FMCRD), and digital control system. One specific feature that differs from the conventional ABWR design is steam bypass capability. LMNPP has the bypass capability that withstands 110% of rated steam flow under load rejection (LR) or turbine trip (TT) events. When such an event occurs, turbine control valves (TCVs) or turbine stop valves (TSVs) close rapidly to protect the turbine from excessive speed, and large vibration. A time delay exists for reactor scram and RIPs trip signals to verify the action of the bypass valves. Opening sufficient turbine bypass valves rapidly will inhibits reactor scram and RIP trip signals. The specific design of steam bypass capacity vents the steam flow into condenser and mitigates increases in vessel pressure due to the closure of TCVs or TSVs. Moreover, power will decrease due to RIP runback and automatic selected control rods run in (SCRRI) system to a controllable state rather than a shutdown condition. Another special design in LMNPP is FMCRD. The primary mechanical structures are step motors and lead screws. The control rods can be driven by hydraulic force or electric step motors. After scram, the hydraulic force provided by high-pressure water is utilized to drive the control rods to meet the rapid insertion requirement. Conversely, insertion speed provided by step motors is much slower; however, it has the ability to position control rods at 18.3 mm per step. Under normal operation, control rods are located by step motors that adjust the power shape for power control purpose. FMCRD is also a backup system for insertion of control rods when a scram signal fails.

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To construct an analytical tool for LMNPP, TPC cooperated with Institute of Nuclear Energy Research (INER) to develop the RETRAN-02 mode. RETRAN-02 is a nonlinear time domain, semi-implicit numerical scheme based code (Chang and Lahey, 1997; McFadden et al., 1981), and widely employed to simulate the best-estimate transient thermal-hydraulic analysis of light water reactors. With semi-implicit technology, the sound speed from the Courant limit of the explicit numerical scheme is eliminated, as is the improvement to numerical stability (Mahaffy, 1993). Since the two-phase flow models in RETRAN also have been compared with experimental data from various sources to demonstrate the accuracy of representations of two-phase flows (Fujita et al., 1979), RETRAN-02 is a reliable analytical tool for simulating thermal-hydraulic transients for the Lungmen ABWR.

TPC and INER have cooperated for quite a long time. The model was benchmarked against the Lungmen preliminary safety analysis report (Taiwan Power Company, 1997) several years ago (Tang et al., 2000). The same analytical methodology was benchmarked against the turbine trip transient of the Peach Bottom boiling water reactor (Kao and Chiang, 2005). Due to the changes in fuel design, reactor vessel structure, and some control system logics, the Lungmen RETRAN-02 model has been modified with updated information when available during the last few years. In this study, the final safety analysis report (FSAR) (Taiwan Power Company, 2007) analytical results are used to benchmark the modified Lungmen RETRAN-02 plant model. The Lungmen FSAR was originally proposed by vender. The employment of various analysis codes in Lungmen FSAR, i.e., ODYN, is capable to simulate the neutronic and thermal-hydraulic coupled transient behaviors with one-dimensional modeling. The calculation results furthermore defined the safety margin by the difference of initial critical power ratio (CPR) and minimal CPR, i.e., ΔCPR. Finally, the Lungmen FSAR has been approved by Taiwan Atomic Energy Council (AEC).

The benchmark of Lungmen RETRAN-02 model focuses on the high-pressure transients as these transients are a major threat to BWR and ABWR integrity due to uncontrolled power induced by positive reactivity insertion from pressure increase and consequent bubble collapse. The five transients selected to validate the Lungmen RETRAN-02 model were LR, TT, main steam line isolation valves closure (MSIVC), loss of feedwater flow (LOFF), and one turbine control valve closure (OTCVC). Generally, these events are the most limiting with respect to thermal design criteria for BWR and ABWR designs. Furthermore, a one-dimensional kinetic model with a cross-section data library is used to simulate the strong coupling effect between neutron dynamics and thermal-hydraulic response during pressurization transients. With these five anticipated accidents under reactor pressure increase transients, one can examine the transient behaviors and mitigation capability of the LMNPP. Furthermore, based on the study (Tang et al., 2000), the action of a turbine bypass system will bring the reactor to another stable state under LR. However, the bypass function is not credited for the conservative consideration in the current investigations of LR and TT transients. However, the bypass function is available during OTCVC with an assumed single failure as described in the Lungmen FSAR. Calculated results for the above postulated events are presented and compared with the Lungmen FSAR.

2. Methodology

The methodology (Kao and Chiang, 2005; Tang et al., 2008) used in this study was developed by INER and TPC for reload design evaluation, Tech Spec and design changes, transient safety evaluation, safety issue resolution, operational margin improvement, power uprating, and general support. This methodology has four codes, MICBURN-3 (Ahlin et al., 1986), CASMO-3 (Edenius et al., 1988), SIMULATE-3 (Umbarger and Digiovine, 1989), and RETRAN-02 (McFadden et al., 1981), and two interface linkage computer programs, TABLES-3 (Smith et al., 1988), and SLICK (Cronin, 1989) for a complete transient analysis. First, the one-dimensional transport depletion code, MICBURN-3, generates effective adsorption cross-sections for the fuel pin. Second, the two-group cross-sections of the fuel assembly are further homogenized by the two-dimensional multi-group transport depletion code, CASMO-3. Via the linkage function of TABLES-3, the three-dimensional nodal core analysis code, SIMULATE-3, employs a higher-order spatial flux representation and an advanced fuel assembly model. Finally, data generated by SIMULATE-3 are assessed by SLICK, a linkage interface code, to generate a cross-section library file, TAPE40, for the RETRAN-02 one-dimensional kinetics calculation (Yang, 2004). Fig. 1 shows the relationships among these codes in this methodology. Moreover, the thermo-hydraulic parameters, such as total thermal power, core inlet flow, initial values in the control system, axial power distribution, core inlet enthalpy, and feedwater enthalpy in the RETRAN-02 model were calibrated for steady state initialization criteria (Jien and Ma, 2002) prior to transient analysis.

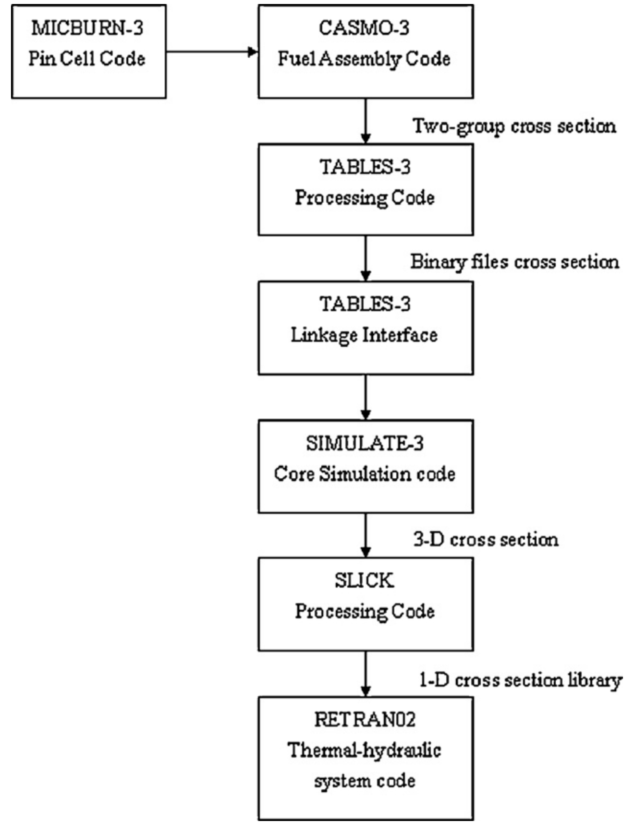

Fig. 1. The BWR/ABWR transient analysis methodology flowchart.

3. Lungmen RETRAN-02 model description

The designs of the two units of LMNPP are identical. The Lungmen RETRAN-02 model represents either unit. The nuclear steam supply system (NSSS) including 1 reactor pressure vessel (RPV), steam lines, feedwater and related controls, and safety systems, is simulated in the model. System nodalization of the Lungmen RETRAN-02 model contains 76 control volumes, 93 junctions and 50 heat conductors (Fig. 2). The reactor core in the RPV is modeled as two parallel flow channels, each with 25 nodes simulating the active core and bypass regions, respectively. Heat generation