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The Analysis of TRACE/PARCS in the Simulation of Ultimate Response Guideline for Lungmen ABWR

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***Abstract*—**In this research, the TRACE/PARCS model of Lungmen ABWR has been developed for verification of ultimate response guideline (URG) efficiency. This ultimate measure was named as DIVing plan, abbreviated from system depressurization, water injection and containment venting. The simulation initial condition is 100% rated power/100% rated core flow. This research focuses on the estimation of the time when the fuel might be damaged with no water injection by using TRACE/PARCS first. Then, the effect of the reactor core isolation system (RCIC), control depressurization and ac-independent water addition system (ACIWA), which can provide the injection with 950 gpm are also estimated for the station blackout (SBO) transient.

***Keywords*—**ABWR, TRACE, safety analysis, PARCS.

I. Introduction

WHEN the nuclear power plants (NPPs) happen the events or transients, there are corresponded emergency operating procedures (EOPs) and severe accident management procedures (SAMPs) as the operating category. However, EOP or SAMP is generally based on events refers plant status and parameters to mitigate the events consequence. For the compound severe accidents, such as Fukushima nuclear accident, its impact to NPP is relatively spread, rather than focus on one system or one area influence. Therefore, with regard to this fact, Taiwan Power Company developed an additional ultimate measure category, URG, to prevent BWR, PWR and ABWR from encountering core damage for events beyond design basis [1]. Fig. 1 shows the URG procedure.

The aim of this study is using the computer programs to verify the URG efficiency of Lungmen NPP. Lungmen NPP is the first ABWR power plant in Taiwan and still under construction. Lungmen NPP has two identical units with 3926 MWt rated power and 52.2×10^{6} kg/hr rated core flow each, and the reactor core is comprised of 872 GE-14 fuel assemblies with 205 control rods. There are 10RIPs in the reactor vessel, providing 111% rated core flow at the nominal operating speed of 151.84 rad/sec.

The advanced thermal hydraulic code named TRACE has been developed by U.S.NRC for NPP safety analysis. In the future, TRACE is expected to replace NRC's present four main systems codes (TRAC-P, TRAC-B, RELAP5 and RAMONA) as the main code used in thermal hydraulic safety analysis. Besides, a graphic user interface program, SNAP (Symbolic Nuclear Analysis Program), which processes inputs, outputs, and the animation model for TRACE, is also developed by NRC.PARCS is a multi-dimensional reactor core simulator which involves a 3-D calculation model for the realistic representation of the physical reactor while 1-D modeling features are also available. PARCS is capable of coupling the thermal-hydraulics system codes such as TRACE directly, which provide the temperature and flow field data for PARCS during the calculations.

In a separate research work, a corresponding TRACE model of Lungmen NPP has been established, where the transient data from FSAR and RETRAN were used to verify the Lungmen NPP TRACE model [2]-[4]. Analytical results indicate that the Lungmen NPP TRACE model could predict not only the behaviors of important plant parameters reflecting consistent trends with FSAR and RETRAN data, but also their numerical values with respectable accuracy [5],[6]. Additionally, the startup tests of Lungmen NPP will be performed in 2014 and the measured data of Lungmen NPP will be used to estimate and modify the TRACE model of Lungmen NPP.

In this study, the TRACE/PARCS model of Lungmen ABWR has been developed in order to verify the URG efficiency of Lungmen NPP. This ultimate measure was named as DIVing plan, abbreviated from system depressurization, water injection and containment venting. This research focuses on the estimation of the time when the fuel might be damaged with no water injection by using TRACE/PARCS first. Then, the effect of theRCIC, control depressurization andACIWA, which can provide the injection with 950 gpm are also estimated for the SBO transient.

II. TRACE/PARCS Modeling of Lungmen ABWR

SNAPv2.2.1 and TRACE v 5.0p3,PARCS 3.0are used in this research. The process is as follows: First, the system and operating data for the FSAR cases of Lungmen NPP are collected [1]-[7]. Second, several important control systems such as RIPs control system, steam bypass &pressure control system and feed water control system etc. are established by SNAP and TRACE. Next, other necessary components (e.g., RPV (Reactor pressure vessel) and main steam piping) are added into the TRACE model to complete the TRACE model for Lungmen NPP. Fourth, CASMO-4 is used to carry out the lattice calculations. CASMO-4 data are employed to establish

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the PARCS model. Then, the Lungmen TRACE model is coupling with the PARCS model. Finally, the Lungmen TRACE/PARCS model is verified by the FSAR data under the steady state and transient conditions.

The TRACE/PARCS model of Lungmen NPP is shown in Fig. 2. In this model, the vessel is divided into 11 axial levels, four radial rings, and six azimuthal sectors (separated 36°, 36°, 108°, 36°,36°, and 108° apart), and connected with four steam lines (connected to the 36° azimuthal sector of the vessel), six feedwater lines (connected to six azimuthal sectors separately, one for each sector), 18 channels which are used to simulate the fuel region (one for each azimuthal sector in three inner radial rings), and 10 RIPs (connected to six azimuthal sectors separately, one for every 36°). The water rods and partial length rods are also simulated in the channels and each channel component multiple some bundles (30 bundles× 6 + 40 bundles× 6 + 75 bundles× 4 + 76 bundles× 2 = 872 bundles). Besides, each steam line has one MSIV and several SRVs. The 10 RIPs are classified into three groups, three RIPs for each of the first and second groups, and four RIPs for the third group. The RIPs in the third group are not connected to the motor generator (M/G) set; the other six RIPs are connected to the M/G set. Besides, the TRACE/PARCS neutronics model is a 3-D model. The TRACE/PARCS neutronics model is comprised of 872 assemblies with a rated power of 3926 MWt, and 205 control rods are simulated as well. Each fuel assembly is represented by a single neutronics node. Fig. 2 also shows the assembly rotations map and the control rod pattern in the PARCS model.

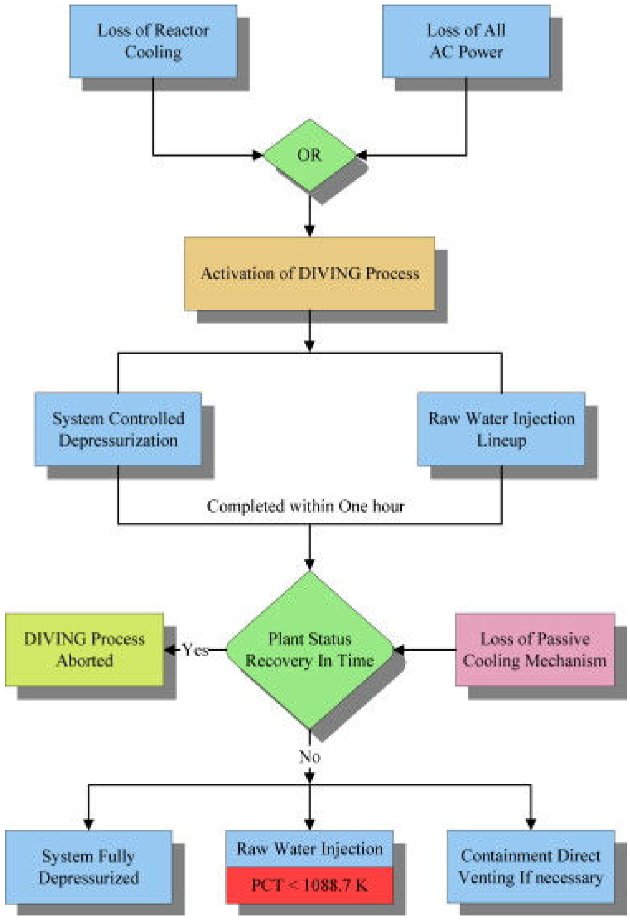


Fig. 1 URG procedure

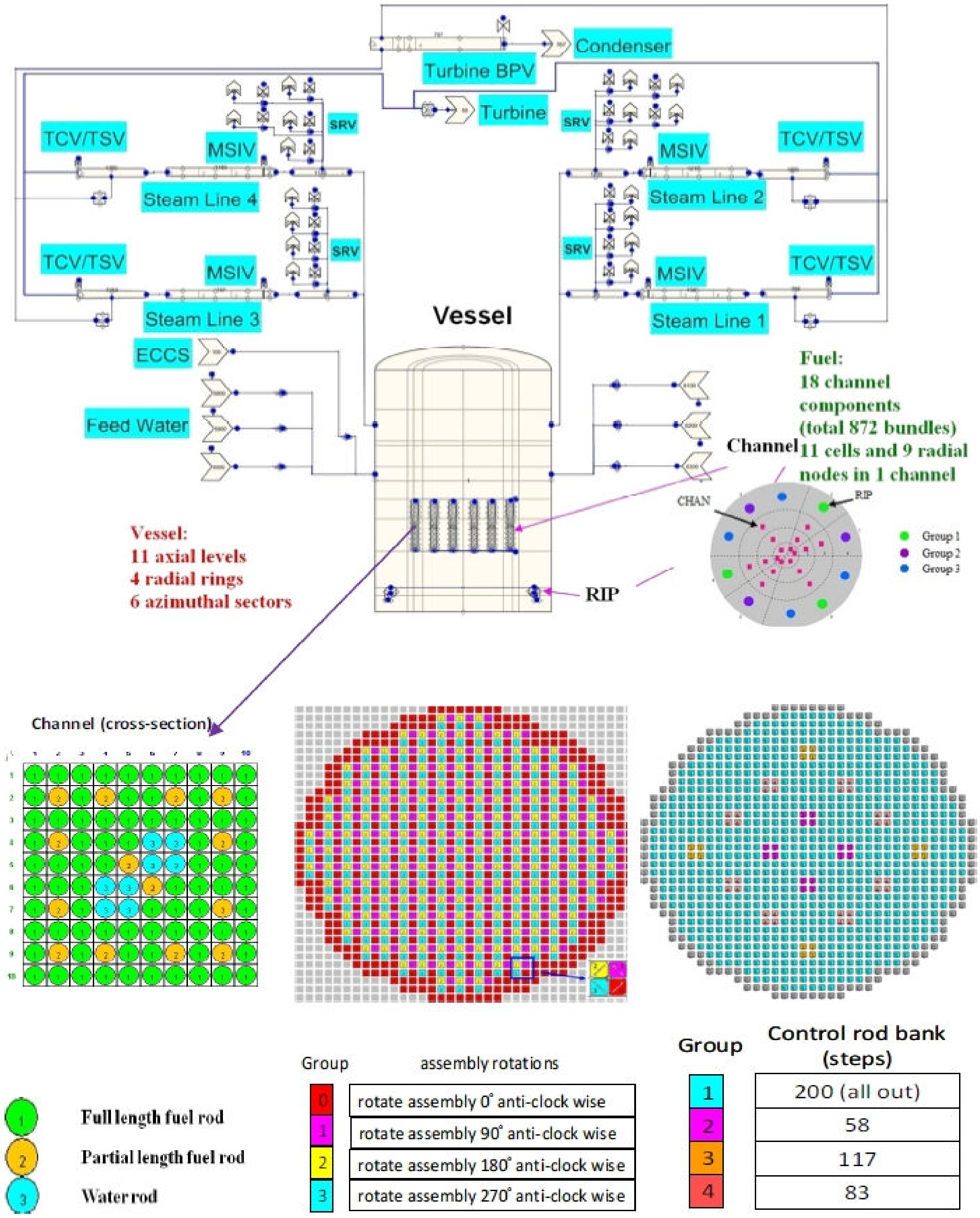


Fig. 2 Lungmen NPP TRACE/PARCS model

III. Results

In this study, there are four assumed cases in the TRACE/PARCS Lungmen NPP SBO model analysis, as follows:

Case 1:RCIC failed and ACIWA failed.

Case 2:RCIC failed, ACIWA activated with 200 gpm injection

Case 3: Depressurization first, RCIC activated and ACIWA activated.

Case 4:Depressurization first, RCIC tripped at 3900 sec and ACIWA activated.

Besides, there are some assumptions have been made inthis analysis, including: (1) the simulation of steady state isperformed during 0~300 sec; (2) the scram of reactor, all RIPs and feed water pumps trip, MSIVs closed are performed at 300sec; (3) the safety relief valves activate in this transient; (4) the decay heat model ANS-73 is used in this transient simulation.

Figs. 3~5 show the results of TRACE/PARCS for case 1 and 2. Fig. 3 shows the WRWL (wide range water level, based on the bottom of dryer skirt.), the feed water flow tripped which resulted in the WRWL drop and the oscillation occurred during 300~1400sec was caused by the safety relief valves (SRV) activated. When the WRWL drop to L1, Automatic Depressurization System (ADS) is activated causing the WRWL and dome pressure drop shapely (shown in Figs. 3 and 4). Besides, the activation of the ADS increases the core flow and the steam flow which leads to the decrease of the fuel temperature (shown in Fig. 5, see 1500~2000sec).Within the ACIWA activated with 200 gpm injection, case 2 maintain higher WRWL than case 1 after 2000 sec. However, for case 1 (RCIC failed and ACIWA failed), the max fuel temperature reach 1088.71 K at 3200sec. For the case 2 (RCIC failed and ACIWA injection), the max fuel temperature also reaches 1088.71 K at 5800 sec. When the temperature is larger than 1088.71 K, the zirconium-water reaction generates which causes the cladding of fuel rods oxidation and may damage the fuels.

Figs. 6~8 show the results of TRACE/PARCS for case 3 and 4. For case 3 and 4, the depressurization to 1.5 MPais performed first which results in the WRWL and dome pressure drop during 300~700sec. When the WRWL drops to L2, the RCIC is activated and the WRWL rises. Because Lungmen NPP has the ability to prepare the ACIWA in 1800 sec, therefore, case 3 depressurized again and activated ACIWA after 2100 sec (shown in Figs. 6 and 7). Then, the WRWL increases and max fuel temperature decreases after 2100 sec (see Figs. 6 and 8). For case 4,it simulates the worse state which assumes the RCIC tripped at 3900 sec, follows the URG to emergency depressurize, and activates ACIWA. Figs. 6 and 7 show the case 4's WRWL and dome pressure decrease after depressurized again. Case 4's max fuel temperature also decreases after depressurized again (see Fig. 8). Finally, the WRWL increases after ACIWA injection (shown in Fig. 6). As the result, the max fuel temperature can both keep below the limit (1088.71K) in case 3 and 4.

In addition, the animation of Lungmen NPP TRACE/PARCS model is presented by using the animation function of SNAP with above models and TRACE/PARCS analysis results. The Lungmen NPP animation model is shown in Fig. 9. The results of TRACE/PARCS in the SBO transient (case 1) can be observed in Fig. 9.

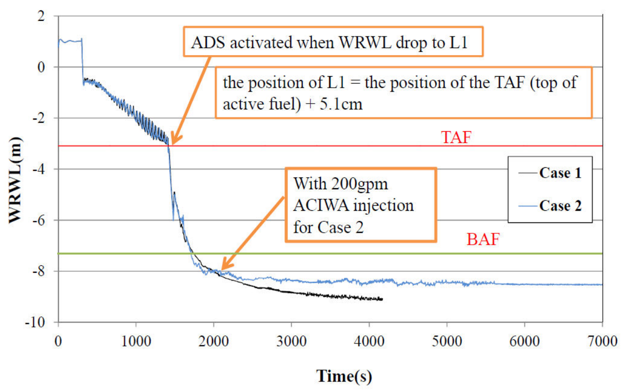


Fig. 3 The WRWL result of case 1 and 2

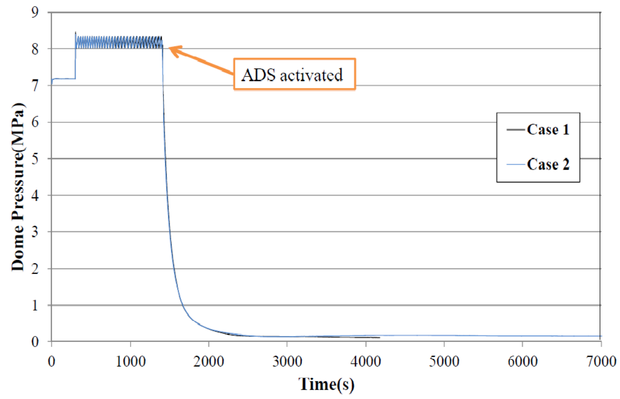


Fig. 4 The dome pressure result of case 1 and 2

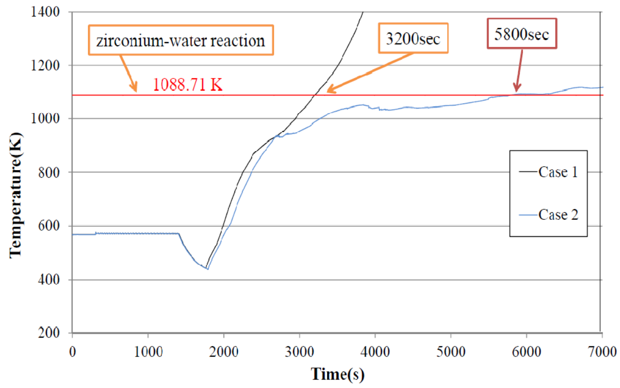


Fig. 5 The max fuel temperature result of case 1 and 2

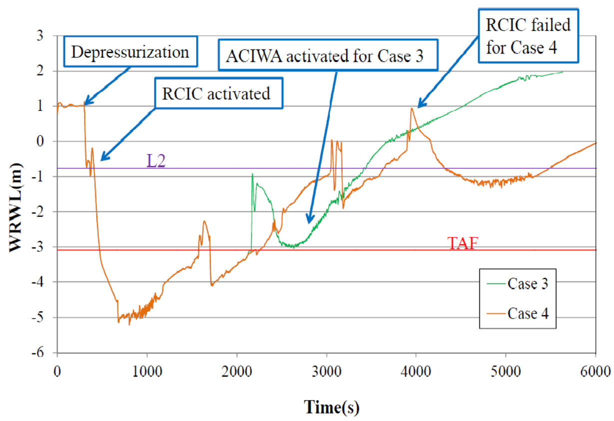


Fig. 6 The WRWL result of case 3 and 4

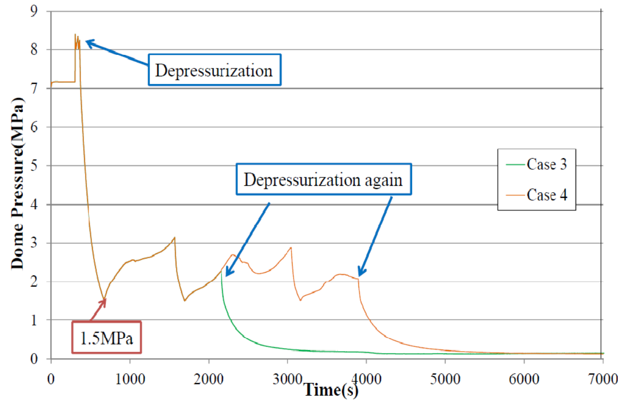


Fig. 7 The dome pressure result of case 3 and 4

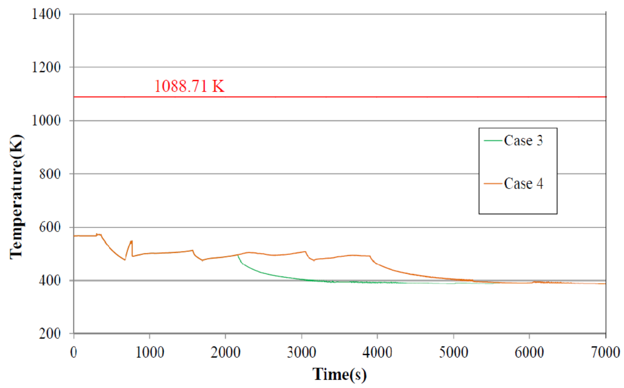
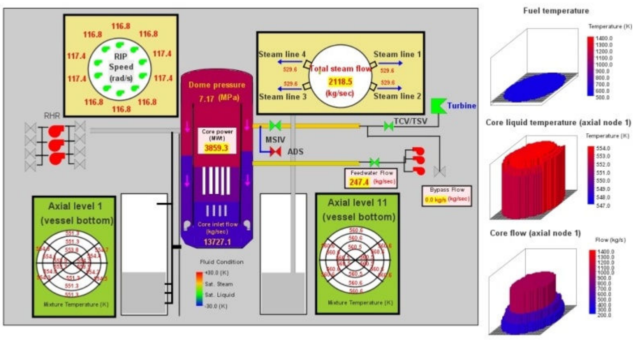
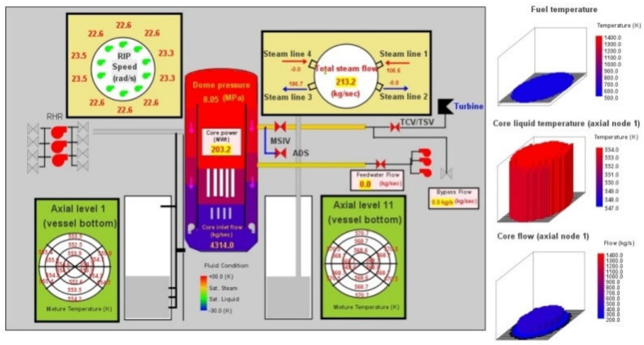


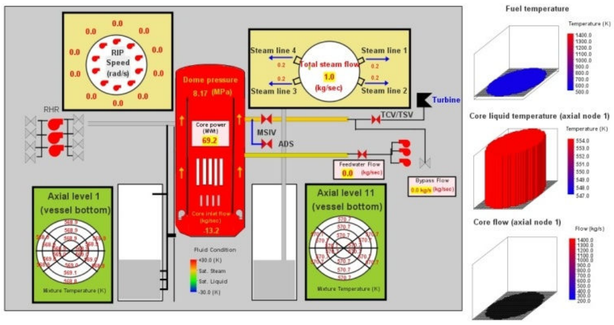
Fig. 8 The max fuel temperature result of case 3 and 4



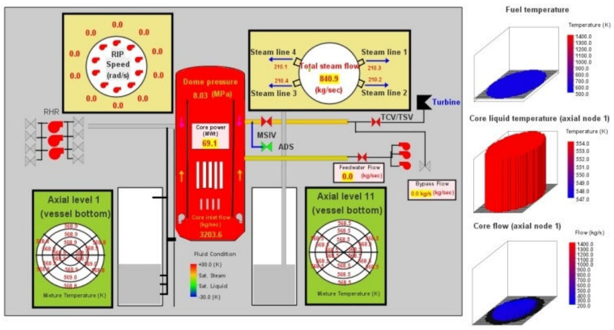
(a) 300 sec



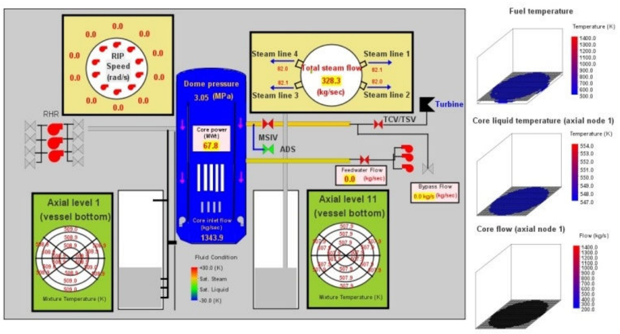
(b) 310 sec



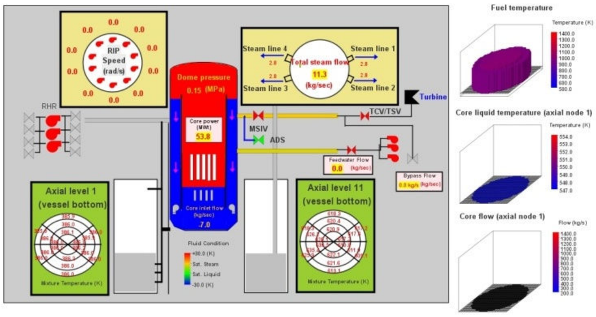
(c) 1400 sec



(d) 1401 sec



(e) 1500 sec



(f) 3000 sec

Fig. 9 The animation model of Lungmen NPP for the SBO transient (case 1),(a) 300 sec, (b) 310 sec, (c) 1400 sec, (d) 1401 sec, (e) 1500 sec, (f) 3000 sec

IV. Conclusion

By using SNAP/TRACE/PARCS, this study has developed the model to verify the effectiveness of URG for Lungmen NPP. Within the four cases are simulated, the analytical result indicated that the max fuel temperature reached the criteria of 1088.71 K at 3200 sec when RCIC and ACIWA failed. Besides, the max fuel temperature also reached the criteria at 5800sec when RCIC failed, but ACIWA injected with 200 gpm flow rate. However, depressurizing to 1.5 MPa first and then inject the well prepared ACIWA can avoid the above condition. And the simulation result indicates that, following the URG can keep the max fuel temperature below the criteria in worse case.

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