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The Study of Ultimate Response Guideline of Kuosheng BWR/6 Nuclear Power Plant Using TRACE and SNAP

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***Abstract*—**In this study of ultimate response guideline (URG), Kuosheng BWR/6 nuclear power plant (NPP) TRACE model was established. The reactor depressurization, low pressure water injection, and containment venting are the main actions of URG. This research focuses to evaluate the efficiency of URG under Fukushima-like conditions. Additionally, the sensitivity study of URG was also performed in this research. The analysis results of TRACE present that URG can keep the peak cladding temperature (PCT) below 1088.7 K (the failure criteria) under Fukushima-like conditions. It implied that Kuosheng NPP was at the safe situation.

***Keywords*—**BWR, TRACE, safety analysis, URG.

I. INTRODUCTION

WHEN the NPPs meet the transients or events, there are corresponded operating categories: EOPs (emergency operating procedures) and SAMPs (severe accident management procedures). Fig. 1 presents the correspondent relationship for the NPP operating states and procedures. However, EOP or SAMP is generally based on events refers NPP parameters and status to mitigate the consequence of events. For the compound severe accidents, such as Fukushima accident, EOP and SAMP cannot handle these accidents. Hence, Taiwan Power Company established the URG to avoid NPPs from encountering core damage for events beyond design basis [1], [2]. The URG procedure was presented in Fig. 2.

The aim of this study is using TRACE and SNAP code to confirm the URG efficiency of Kuosheng NPP. Kuosheng NPP is located on the northern coast of Taiwan. Kuosheng NPP is BWR/6 plant and the power is 2894 MWt. After the project of SPU (Stretch Power Uprate), the operating power is 3001 MWt now.

U.S. NRC developed the new code-TRACE for NPPs safety analysis [3]. This code development is based on TRAC, combining with the capabilities of other programs (TRAC-P, TRAC-B, RAMONA, and RELAP5). To model the reactor vessel with 3-D geometry is one of the features of TRACE. It could support a more accurate and detailed safety analysis for NPPs. Additionally, Symbolic Nuclear Analysis Program (SNAP) is a graphic user interface program which processes inputs, outputs, and the animation model for TRACE and is also developed by U.S. NRC.

In this study, by using TRACE and SNAP, the model of Kuosheng NPP was established to confirm the URG efficiency. In addition, the sensitivity study of depressurization and low pressure water injection was also performed in this research.

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II. TRACE MODELING OF KUOSHENG NPP

TRACE v 5.0 patch4 and SNAP v 2.2.9 are used in this research. The process of Kuosheng NPP TRACE/SNAP model establishment is as follows: First, the URG report [2], system and operating data [4], [5] for Kuosheng NPP are collected. Second, several important control systems such as pressure control system, recirculation flow control system, and feedwater flow control system etc. are established by using SNAP and TRACE. Next, the other necessary components (e.g., safety relief valves (SRVs), main steamline isolation valve (MSIV), main steam piping, and Reactor pressure vessel (RPV)) are added into this model. Finally, the Kuosheng TRACE/SNAP model is verified with the cases of FSAR and startup tests. The TRACE/SNAP model of Kuosheng NPP is presented in Fig. 3.

The reactor of Kuosheng NPP was divided into two azimuthal sectors, four radial rings, eleven axial levels, altogether eighty-eight cells, were simulated by a 3-D vessel component. There are two recirculation loops which connect to the reactor. Each loop has one recirculation pump. All jet pumps were merged to two equal jet pump components. Six channels which were one dimensional component were used for simulating 624 fuel bundles. These channel components also simulated full length fuel rods, partial length fuel rods, and water rods. Four steam lines connected with the vessel, and each steam line had one MSIV, one TCV (turbine control valve), several SRVs, and one TSV (turbine stop valve). The MSIV, SRVs, TCV, TSV, and bypass valve (BPV) were simulated using valve components with the critical flow models. Fig. 3 also presents the wetwell, suppression pool, drywell, vent annulus, upper pool, horizontal vent, and reactor building. And these parts are the components of containment. In Kuosheng NPP TRACE/SNAP model, there were three simulation control systems as follows: (1) recirculation flow control (2) steam bypass and pressure control (3) feedwater flow control. In addition, the power calculations of this model were using "point kinetic" parameters (void reactivity coefficient, Doppler reactivity coefficient, delay neutron fraction, etc.).

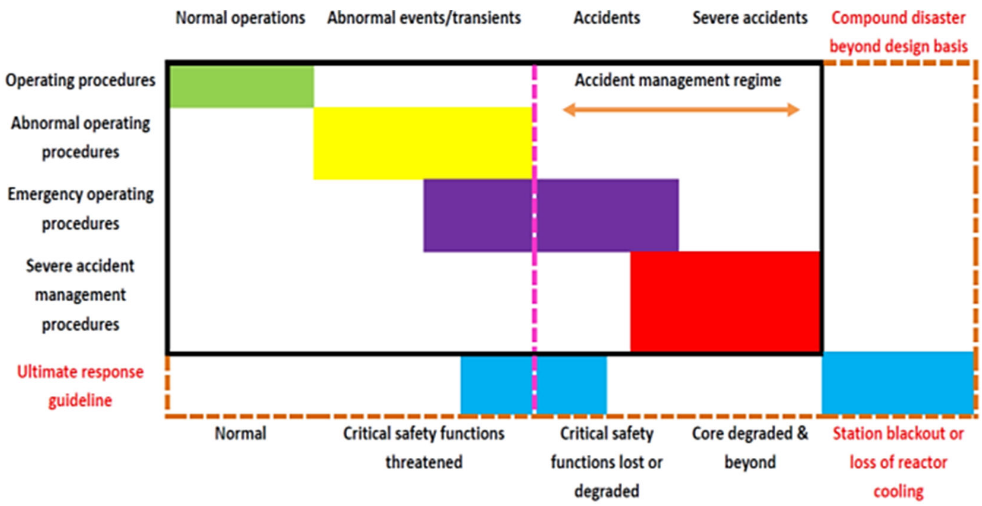

Fig. 1 Correspondent relation for the NPP operating procedures and states

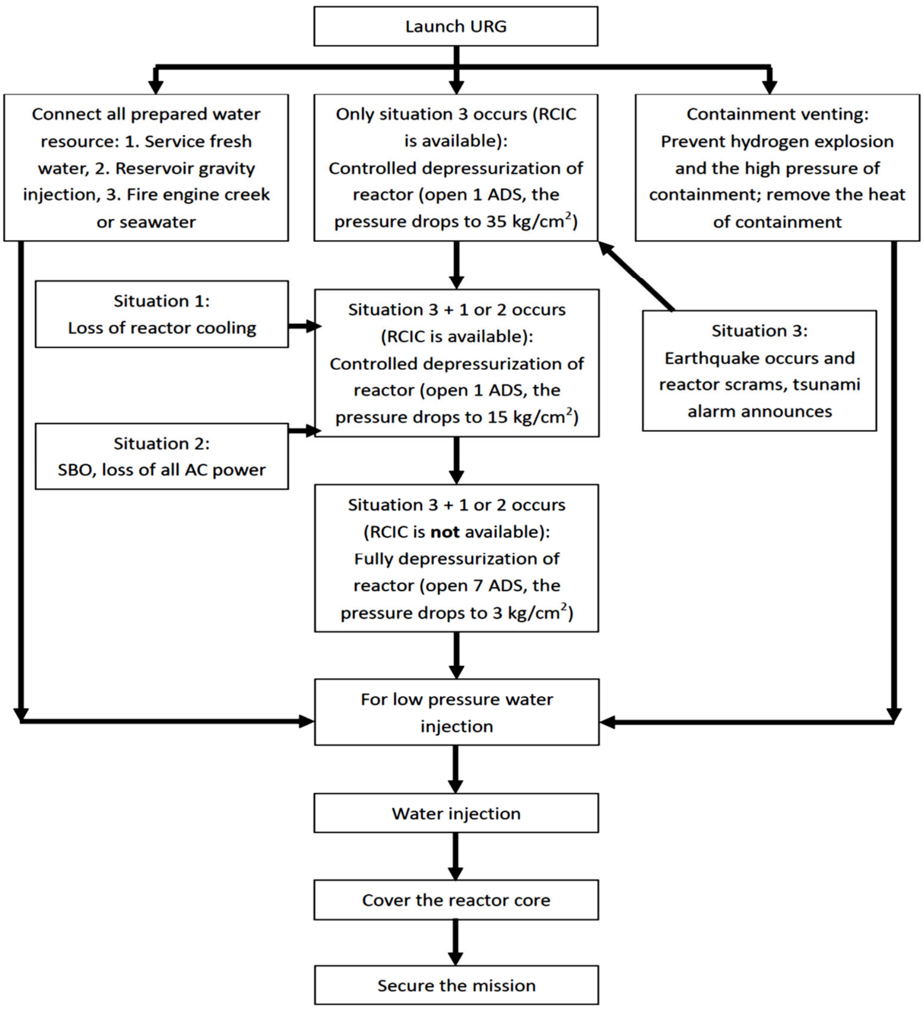

Fig. 2 URG flowchart

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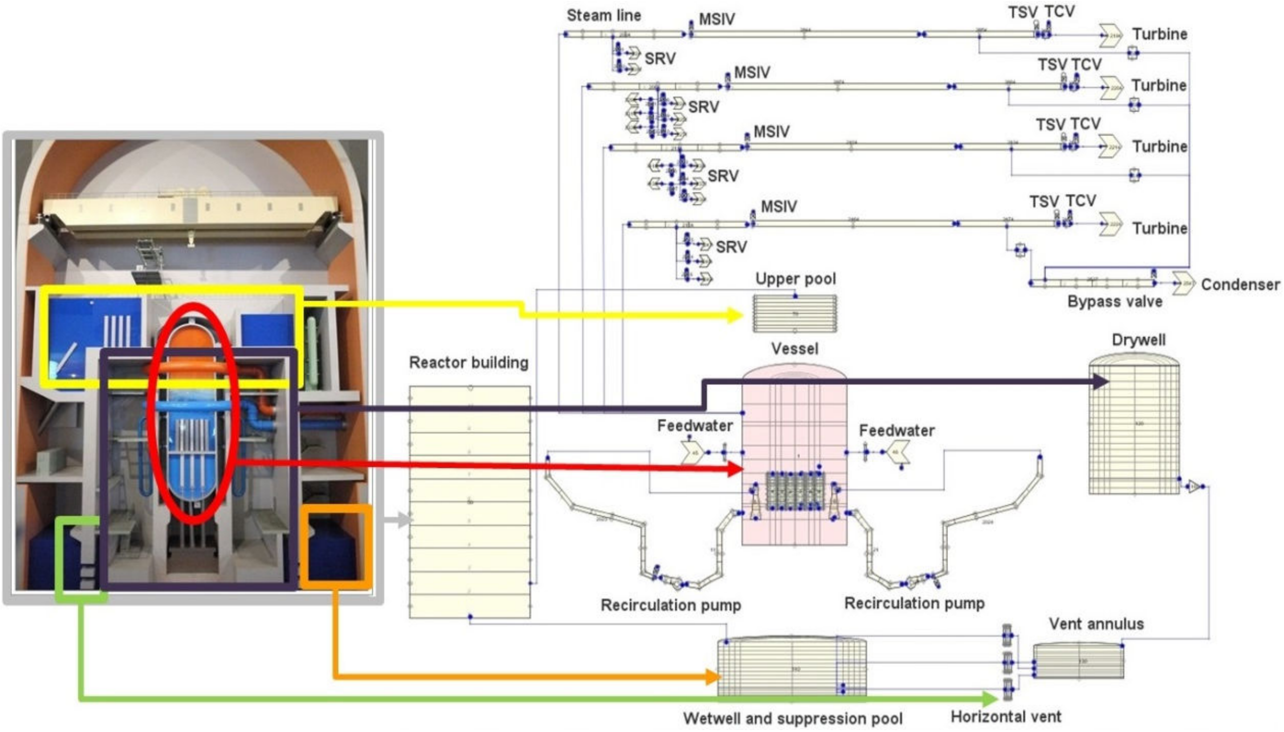

Fig. 3 Kuosheng NPP TRACE/SNAP model

III. Results

In order to estimate the URG efficiency under Fukushima-like conditions, there were six cases in this study. Table I presents the initial conditions of the cases. Table II shows the sequence of URG under Fukushima-like conditions (base case, Case 1). Additionally, there are some assumptions which were made in this analysis, including: (1) the decay heat model ANS-73 is used in this transient simulation; (2) the safety relief valves activate in this transient; (3) the low pressure water injection is 32.8 kg/sec. The sensitivity study of depressurization and low pressure water injection were shown in Tables III and IV. In addition, the depressurization of the reactor consists of the controlled and fully depressurization.

For Case 1 (base case), the simulation of steady state was first performed during 0~300 sec. We assumed that the earthquake and tsunami alarm happened at 300 sec., and this caused the reactor scram. The controlled depressurization of reactor and MSIV closure were also performed at 300 sec. In this controlled depressurization step, one ADS opened which caused that the dome pressure dropped to 35 kg/cm^2 and kept at this level (shown in Fig. 5). Fig. 4 presents that RCIC was activated and the water level was kept at level 2~level 8 during 300~5700 sec. Then, SBO (station blackout) occurred at 2100 sec. Subsequently, the controlled depressurization of reactor was performed again. Therefore, one ADS opened and the dome pressure dropped to 15 kg/cm^2 and kept at this level (see Fig. 5). Because RCIC failed at 5700 sec, the fully depressurization of reactor was performed in order to start low pressure water injection. At this step, seven ADS were opened and the dome pressure dropped to 3 kg/cm^2 (shown in Fig. 5). The low pressure water injected to the reactor at 6700 sec. The fire engine from the creek or seawater, reservoir gravity injection, fresh water service is the source of low pressure water (shown in Fig. 2). After the low pressure water injected, the cladding temperature (PCT) went down and water level increased (see Figs. 4 and 6). Finally, the transient finished at 86400 sec.

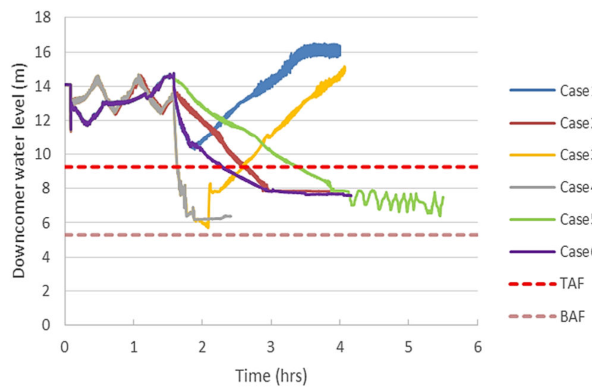

Fig. 4 The water level results

No URG case is Case 2. The dome pressure of Case 2 was kept at about 8 MPa, and there was an oscillation in Case 2 due to SRVs activated. After RCIC failure, the water level of Case 2 started to decrease and was lower than TAF at about 2.6 hr. The PCT of Case 2 increased after the water level lower than TAF and reached 1088.7 K at 3.7 hr (1088.7 K is the criteria of URG [2]). It presented that the zirconium-water reaction was able to generate. The above results of Case 2 depicted that Kuosheng NPP was not at the safe situation. In the comparison of Case 1 and 2, it shows that URG can keep Kuosheng NPP at the safe situation under Fukushima-like conditions.

TABLE I
THE INITIAL CONDITIONS OF CASES

Parameter	TRACE
Power (MWt)	3001
Dome Pressure (MPa)	7.17
Feedwater Flow (kg/sec)	1622.4
Steam Flow (kg/sec)	1621.2
Core inlet flow (kg/sec)	10643.1

TABLE II
THE SEQUENCE OF CASE 1

Action	Time (sec)
Start	0
Reactor scrams (because earthquake occurs and tsunami alarm announces), MSIV closes, Recirculation pumps trip, Feedwater trip, **Controlled depressurization of reactor (open 1 ADS, the pressure drops to 35 kg/cm^2)** (RCIC is available, L2 start, L8 stop)	300
SBO (loss of all AC power), **Controlled depressurization of reactor (open 1 ADS, the pressure drops to 15 kg/cm^2)**	2100
RCIC is not available, **Fully depressurization of reactor (open 7 ADS, the pressure drops to 3 kg/cm^2), Containment venting**	5700
Low pressure water injection	6700
End	86400

TABLE III
THE SENSITIVITY STUDIES OF URG

Action	Case 1	Case 2	Case 3
Controlled depressurization of reactor	√	--	--
Fully depressurization of reactor	√	--	√
Low pressure water injection	√	--	√

√: Perform this action --: Do not perform this action

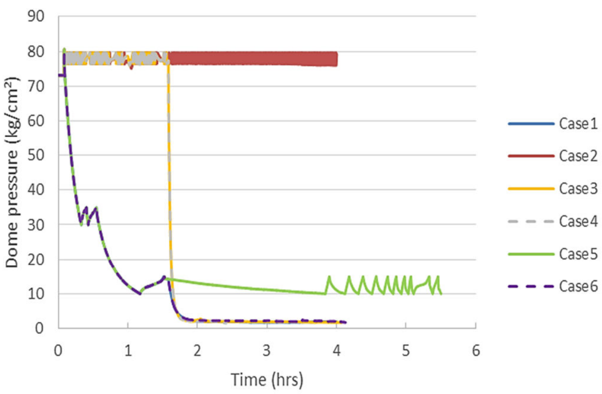

Fig. 5 The dome pressure results

Comparing Case 1, 3, and 4, the water level dropping (only fully depressurization, Case 3 and 4) was larger than the Case 1 (controlled depressurization+ fully depressurization). Subsequently, if the above cases happened no water injection, the PCT was over 1088.7 K (shown in Fig. 6, Case 4) which indicated that Kuosheng NPP was not at the safety situation. Comparing Case 1, 2, 5, and 6, if there was only the controlled depressurization of reactor in URG (Case 5), TRACE results depicted that the water level was lower than TAF at about 3.4 hr. The PCT reached 1088.7 K at 5.2 hr. It indicated that the controlled depressurization of reactor can delay the time of the increase of PCT.

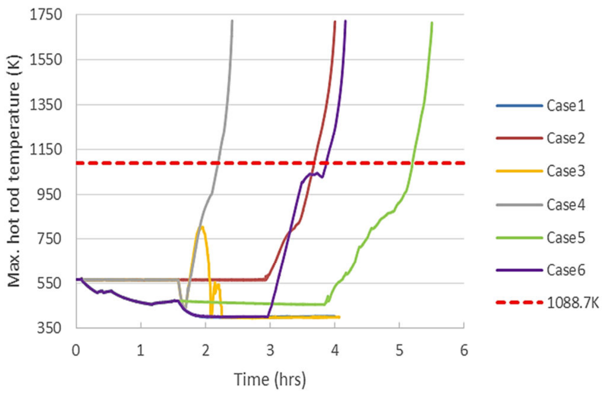

Fig. 6 The max fuel PCT results

Additionally, the sensitivity study of the required raw water injection for URG was performed in this research. The low pressure water injection is 32.8 kg/sec for Case 1. Therefore, we assumed that the low pressure water injection is 16.4 kg/sec for Case 1-2; 10.6 kg/sec for Case 1-3; 8.2 kg/sec for Case 1-4. Fig. 7 depicts the water level results, and Fig. 8 shows the PCT results. It presented that the water level of Case 1-4 was lower than TAF and the water level of Case 1-3 increased very slowly. However, their PCTs were lower than 1088.7 K. Therefore, in order to the concern of the safety, we think that the required raw water injection must be larger than 16.4 kg/sec.

By using SNAP animation function and analysis results, Kuosheng NPP animation model was established. Kuosheng NPP animation model is shown in Fig. 9, and the results of TRACE can be observed.

TABLE IV
THE SENSITIVITY STUDIES OF URG

Action	Case 4	Case 5	Case 6
Controlled depressurization of reactor	--	√	√
Fully depressurization of reactor	√	--	√
Low pressure water injection	--	--	--

√: Perform this action --: Do not perform this action

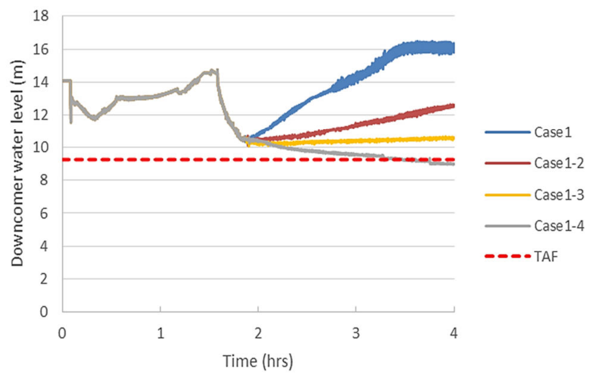

Fig. 7 The water level results for the sensitivity study of the required raw water injection

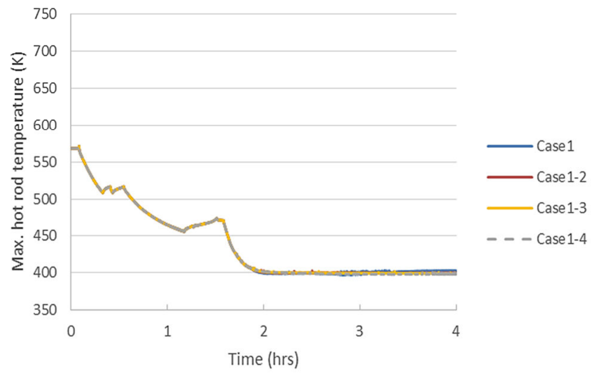

Fig. 8 The PCT results for the sensitivity study of the required raw water injection

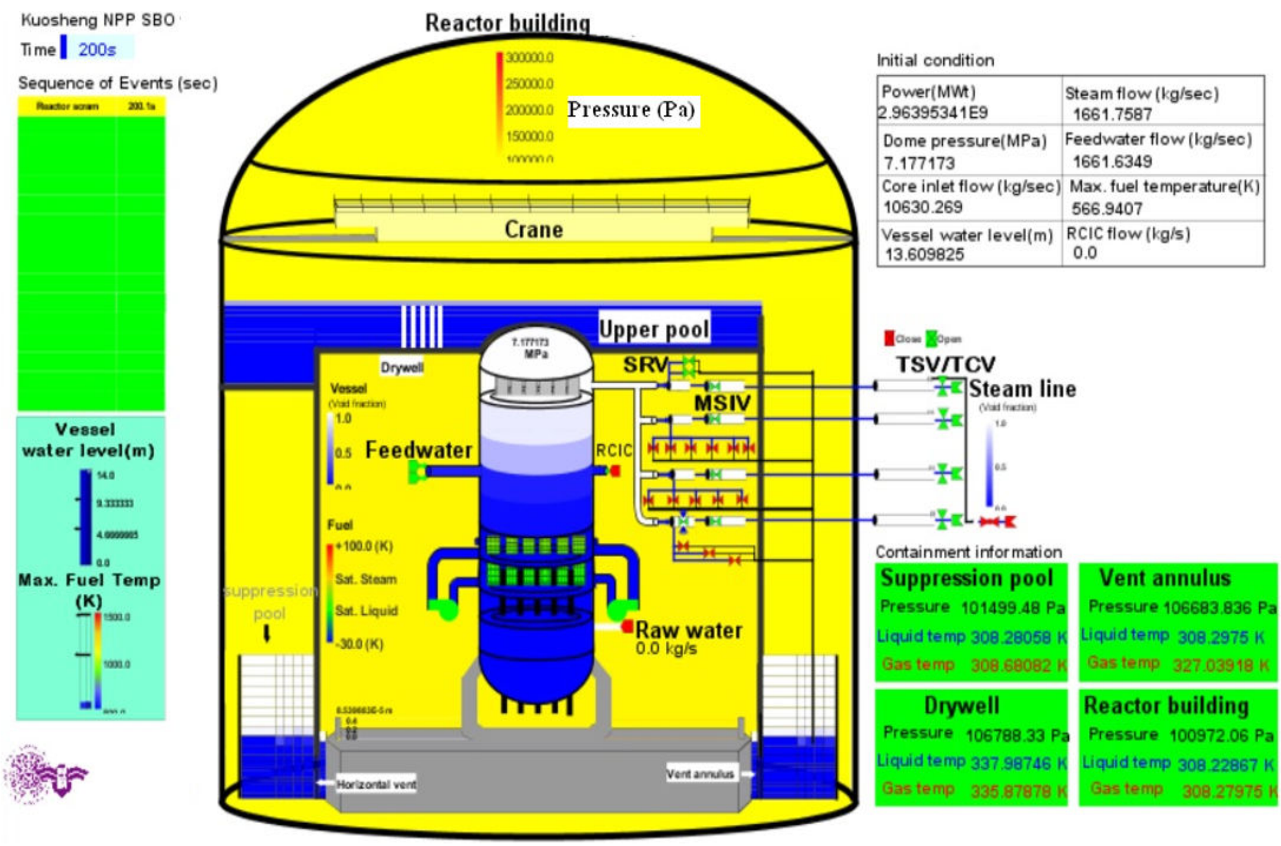

Fig. 9 The animation model of Kuosheng NPP

IV. Conclusion

By using TRACE and SNAP code, this study established the model to estimate the effectiveness of URG for Kuosheng NPP. The results of TRACE present that the URG can keep the PCT below the criteria 1088.7 K under Fukushima-like conditions. It depicted that Kuosheng NPP was at the safe situation. On the sensitivity study of the depressurization and low pressure water injection of URG, the summary is as:

- When the depressurization was performed, the PCT went up faster than no depressurization for no water injection cases.
- For Case 1 and 6 (the controlled and fully depressurization case), the water level dropping was lower than Case 3 and 4 (only fully depressurization case). This implied that the PCT go up faster for only fully depressurization case.
- The required raw water injection must be larger than 16.4 kg/sec based on the analysis results.

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