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Using SNAP and RADTRAD to Establish the Analysis Model for Maanshan PWR Plant

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***Abstract*—**In this study, we focus on the establishment of the analysis model for Maanshan PWR nuclear power plant (NPP) by using RADTRAD and SNAP codes with the FSAR, manuals, and other data. In order to evaluate the cumulative dose at the Exclusion Area Boundary (EAB) and Low Population Zone (LPZ) outer boundary, Maanshan NPP RADTRAD/SNAP model was used to perform the analysis of the DBA LOCA case. The analysis results of RADTRAD were similar to FSAR data. These analysis results were lower than the failure criteria of 10 CFR 100.11 (a total radiation dose to the whole body, 250 mSv; a total radiation dose to the thyroid from iodine exposure, 3000 mSv).

***Keywords*—**RADionuclide, transport, removal, and dose estimation, RADTRAD, symbolic nuclear analysis package, SNAP, dose, PWR.

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I. Introduction

MAANSHAN PWR plant is a NPP located in Hengchun Town, Pingtung County, Taiwan, operated by Taiwan Power Company. The type of reactor is a light water type PWR, is also the only use of this type of NPP in Taiwan. The systems of the NPP are designed and manufactured by Westinghouse, which includes the reactor and its ancillary equipment and the Reactor Coolant System (RCS). The RCS has three loops, each containing one Reactor Coolant Pump (RCP), a steam generator. In addition, only one loop is equipped with a pressurizer to adjust the pressure of the RCS loops.

The safety analysis is a very important assessment, especially after the Fukushima accident in Japan. The NPPs safety requirements are increasing and Taiwan is also in line with the world trend. Taiwan pays more attention to the NPPs safety, especially in the radiation dose assessment. Tsing-Hua University in 2016 joined the U.S. NRC led by the Radiological protection computer code Analysis and Maintenance Program (RAMP) international cooperation program, and the program's main research area is to focus on radiation dose assessment, control room habitability, NPPs decommission, and so on. RADTRAD (RADionuclide, Transport, Removal and Dose Estimation Computer Code) is one of the programs developed in the RAMP that can be used for the calculation of transport and removal of radionuclides and dose at selected receptors such as EAB, LPZ outer boundary, and the control room in the NPP. Maanshan NPP EAB boundary is in the Unit 1 or Unit 2 around the center of the containment, the radius of 1 km radius of the circumferential position, LPZ boundary is the radius distance 2.5 km of the circumferential location, the Emergency Planning Zone (EPZ) is the NPP as the center, the radius of 8 km radius of the location, the relative position shown in Fig. 1. Therefore, this study uses the RADTRAD code, with its graphical interface program Symbolic Nuclear Analysis Package (SNAP), reference to the FSAR data and other related data 1-6, to establish Maanshan NPP RADTRAD/SNAP model and its application to the radiation dose assessment of the Design Basis Accident (DBA) and Loss-of-Coolant Accident (LOCA) cases which release from the containment.

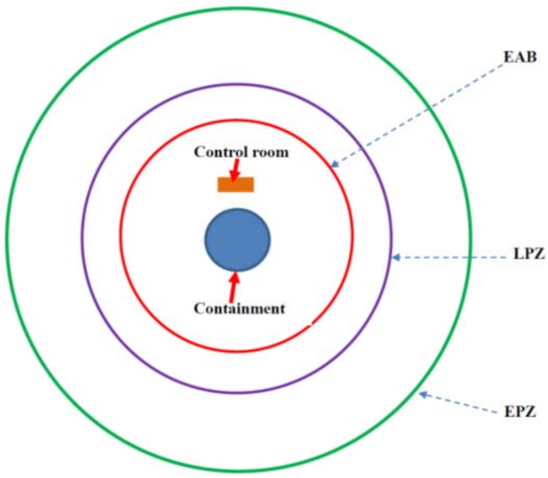

Fig. 1 The position for EAB, LPZ, EPZ

II. The Description of the Codes, Model and Case

The RADTRAD program used in this study was version 4.5.3 and the SNAP program was version 2.4.3. RADTRAD is developed by the Sandia National Laboratory (SNL). RADTRAD can calculate radionuclides transport and removal and estimate dose at selected receptors, including EAB, LPZ outer boundary, and the control room in the NPP. The RADTRAD program can use the TID-14844 or NUREG-1465 source term [1], or the user-defined form data. All nuclides can be grouped according to their chemical and transport similarities in RADTRAD. They are divided into four groups: noble gases, elemental iodine, organic iodine, and aerosols. Removal mechanisms in RADTRAD include: spray, natural deposition, leakage, filtration, and so on. Additionally, the

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atmospheric dispersion factor (χ/Q), breathing rate (BR), and dose conversion factor (DCF) are the input data in RADTRAD.

SNAP is the advanced graphical interface program, and users can directly use the SNAP window to create the components and establish models as shown in Figs. 2 and 3.

In the Maanshan NPP FSAR [2], the DBA LOCA case is assumed that a RCS pipe ruptures. And the sequence of LOCA is presented in Fig. 4, which is from FSAR [2]. In addition, the radionuclides are assumed to release from the containment in this case. The related assumptions are as follows:

- The reactor core equilibrium noble gas and iodine inventories are based on long-term operation at 104.5% of the rated core power level of 2775 MWt which is 2900 MWt.
- When the accident occurs, 100% of noble gas is released into the containment and is immediately leaking from the containment to the atmospheric environment.
- When the accident occurs, 25% of radioactive iodine inventory is released into the containment, and immediately leak from the containment to the atmospheric environment.
- Of the iodine fission product inventory released to the containment, 91% is in the form of elemental iodine, 5% is in the form of particulate iodine, and 4% is in the form of organic iodine.
- Credit for iodine removal by the containment spray system is simulated in this case.

TABLE I
THE VALUES OF X/Q (S/M^3) [2]

Time Period	EAB	LPZ
0 to 2 hours	2.47×10^{-4}	7.22×10^{-5}
2 to 8 hours	---	4.58×10^{-5}
8 to 24 hours	---	3.05×10^{-5}
1 to 4 days	---	1.63×10^{-5}
4 to 30 days	---	6.66×10^{-6}

TABLE II
THE VALUES OF DCF [2]

Isotope	Whole Body Gamma DCF rem-m^3 /Ci-sec
I-131	8.72×10^{-2}
I-132	5.13×10^{-1}
I-133	1.55×10^{-1}
I-134	5.32×10^{-1}
I-135	4.21×10^{-1}
Kr-83m	5.02×10^{-6}
Kr-85	5.25×10^{-4}
Kr-85m	3.72×10^{-2}
Kr-87	1.87×10^{2}
Kr-88	4.64×10^{-1}
Kr-89	5.25×10^{-1}
Xe-131m	2.92×10^{-3}
Xe-133m	8.0×10^{-3}
Xe-133	9.33×10^{-3}
Xe-135m	9.92×10^{-2}
Xe-135	5.72×10^{-2}
Xe-137	4.53×10^{-2}
Xe-138	2.81×10^{-1}

Maanshan NPP RADTRAD/SNAP model was shown in Fig. 3. The model establishment is based on the FSAR chapter 15 [2]. It can be seen from Fig. 3 that it is divided into three blocks: block 2 is the unsprayed area of the containment, block 3 is the sprayed area of the containment, and block 1 is the atmospheric environment area. The objects that are connected between the blocks are simulated for their flow pathway or leakage. In this mode, the NPP power is set at 2900 MWt, and the area of the containment is divided into sprayed zones (81%) and unsprayed zones (19%), and the intercrossing rate is simulated by 33,000 cfm transfer rates between the two regions. The leakage rate of the containment is assumed to be 0.1 vol.% / day (0 to 1 day); 0.05 vol.% / day (1 to 30 days) for a total of 720 hours. In addition, in this mode, TID-14844 radiation source term is selected, and the other more important input data are shown in Tables I-IV.

TABLE III
THE VALUES OF BREATHING RATE [2]

Time after Accident	Breathing rate m^3 /s
0 to 8 hours	3.47×10^{-4}
8 to 24 hours	1.75×10^{-4}
1 to 30 days	2.32×10^{-4}

TABLE IV
THE VALUES OF INVENTORY [2]

Parameter	Value (Ci)
I-131	2.0×10^{7}
I-132	2.9×10^{7}
I-133	4.2×10^{7}
I-134	4.5×10^{7}
I-135	3.9×10^{7}
Xe-131m	5.6×10^{5}
Xe-133m	2.3×10^{7}
Xe-133	1.6×10^{8}
Xe-135m	3.3×10^{7}
Xe-135	3.4×10^{7}
Xe-138	1.4×10^{8}
Kr-83m	9.9×10^{6}
Kr-85m	2.2×10^{7}
Kr-85	5.2×10^{5}
Kr-87	4.1×10^{7}
Kr-88	5.8×10^{7}
Kr-89	7.2×10^{7}

III. RESULTS

According to Maanshan NPP FSAR chapter 15.0 [2], the results of the NPP dose calculation shall comply with the acceptance criteria specified in 10 CFR 100.11 [7]:

- For EAB, a total radiation dose to the whole body is less than 250 mSv, and a total radiation dose to the thyroid from iodine exposure is less than 3000 mSv within two hours after the accident.
- For LPZ outer boundary, a total radiation dose to the whole body is less than 250 mSv, and a total radiation dose to the thyroid from iodine exposure is less than 3000 mSv during the entire period of radioactive cloud passage.

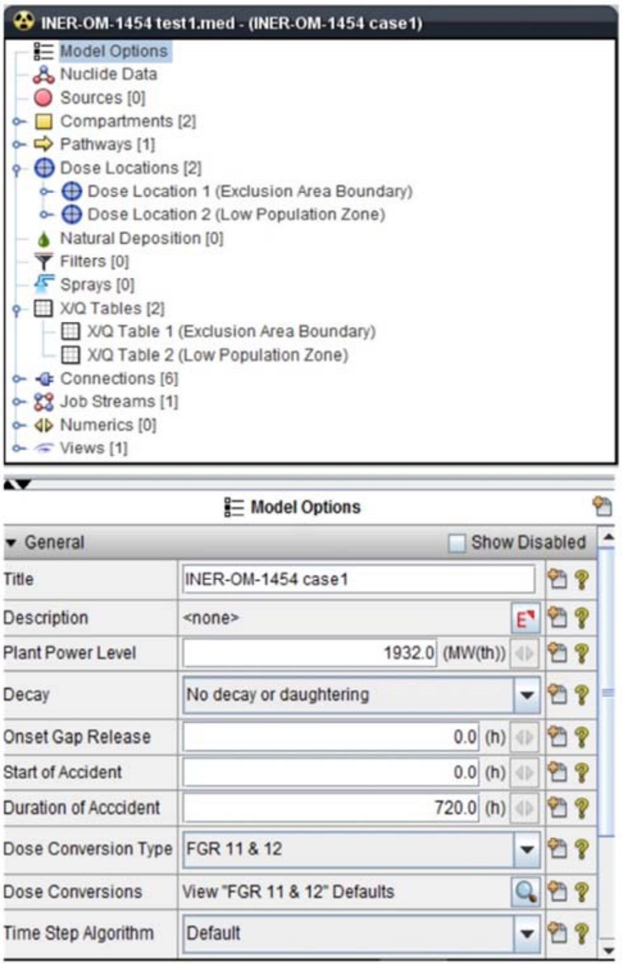

Fig. 2 The RADTRAD/SNAP screen

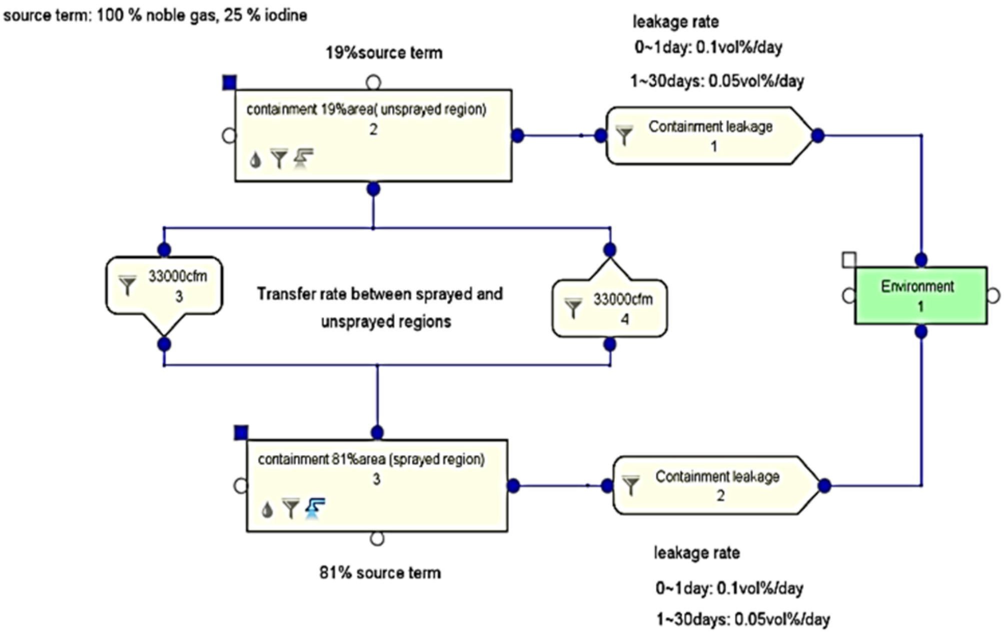

Fig. 3 Maanshan NPP RADTRAD/SNAP model

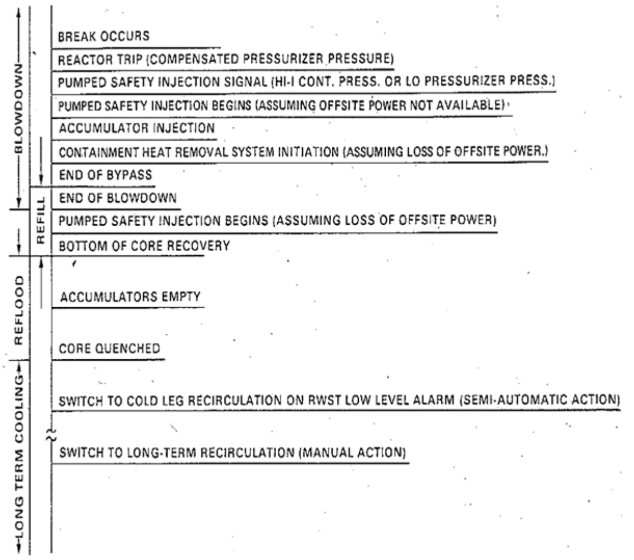

Fig. 4 The sequence of LOCA [2]

In this study, the radiation dose assessment of the DBA LOCA case was calculated using the RADTRAD/SNAP model of Maanshan NPP. The description and assumptions of this case are in Section II.

Fig. 5 shows the output file of RADTRAD. The results of the predictions of the EAB and LPZ outer boundary are presented in this figure. Therefore, the RADTRAD results, failure criteria, EAB and LPZ outer boundary positions are clearly shown in Fig. 6. Tables V and VI present the comparison of the results of the dose analysis with the FSAR [2] and 10 CFR 100.11 [7] failure criteria for the EAB and LPZ outer boundary. From the tables, it can be seen that RADTRAD EAB and LPZ dose analysis results are similar with the FSAR data. Additionally, these results are lower than the 10 CFR 100.11 [7] failure criteria. The above comparison indicates that we have established a Maanshan NPP RADTRAD/SNAP model which has a certain degree of credibility.

TABLE V
THE RESULTS OF RADTRAD FOR EAB

	FSAR	RADTRAD	Failure criteria
a total radiation dose to the whole body (mSv)	9.9	9.27	250
a total radiation dose to the thyroid from iodine exposure (mSv)	469	379.24	3000

Fig. 5 shows the output file of RADTRAD. The results of the predictions of the EAB and LPZ outer boundary are presented in this figure. Therefore, the RADTRAD results, failure criteria, EAB and LPZ outer boundary positions are clearly shown in Fig. 6. Tables V and VI present the comparison of the results of the dose analysis with the FSAR [2] and 10 CFR 100.11 [7] failure criteria for the EAB and LPZ outer boundary. From the tables, it can be seen that RADTRAD EAB and LPZ dose analysis results are similar with the FSAR data. Additionally, these results are lower than the 10 CFR 100.11 [7] failure criteria. The above comparison indicates that we have established a Maanshan NPP RADTRAD/SNAP model which has a certain degree of credibility.

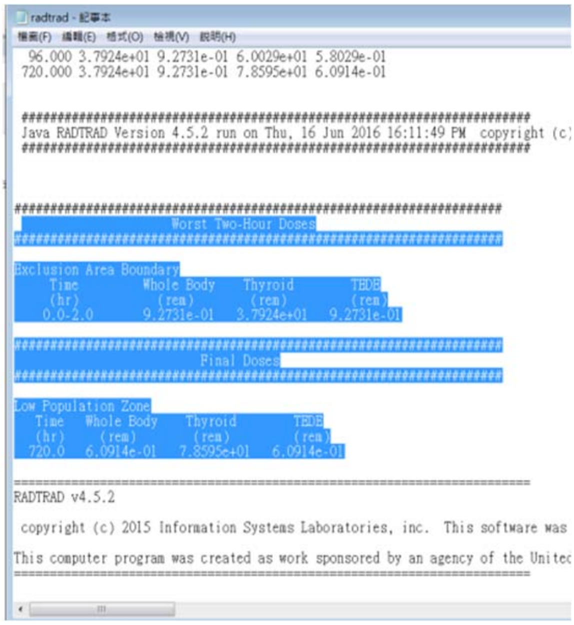

Fig. 5 The output file of RADTRAD

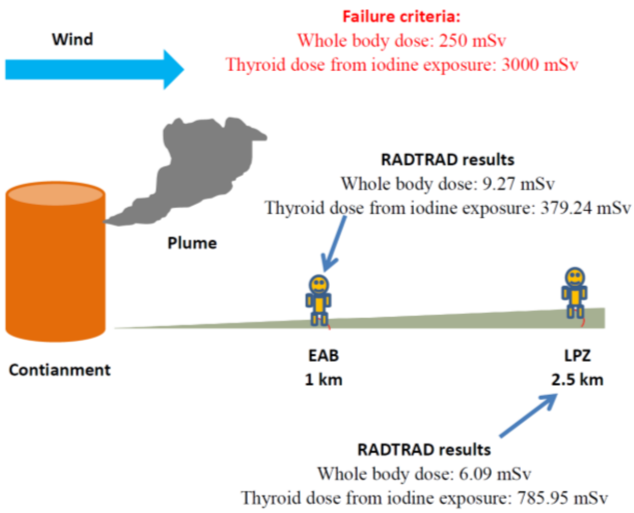

Fig. 6 The results of RADTRAD

TABLE VI
THE RESULTS OF RADTRAD FOR LPZ OUTER BOUNDARY

	FSAR	RADTRAD	Failure criteria
a total radiation dose to the whole body (mSv)	5.94	6.09	250
a total radiation dose to the thyroid from iodine exposure (mSv)	629	785.95	3000

IV. CONCLUSION

Using RADTRAD and SNAP codes with FSAR, manuals, and other data [1]-[6] to develop and establish the analysis model for Maanshan NPP is the main purpose of this research. This RADTRAD/SNAP model performed the analysis of the

DBA LOCA case and calculated the cumulative dose at the EAB and LPZ outer boundary. The RADTRAD analysis results were consistent with FSAR data. It implied that this model had a seemly accuracy. In addition, the results were lower than the failure criteria of 10 CFR 100.11 [7] (a total radiation dose to the whole body, 250 mSv; a total radiation dose to the thyroid from iodine exposure, 3000 mSv). Based on the above comparison results, this RADTRAD/SNAP model will be applied to perform the transients' dose analysis for Maanshan NPP in the future.

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