Establishment and Application of Control Room Habitability Methodology for Maanshan Nuclear Power Plant

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Abstract

In this study, we focus on the establishment and application of the control room habitability methodology for Maanshan PWR Nuclear Power Plant (NPP) by using RADTRAD and HABIT codes. Therefore, there are two steps in this study. The first step is to use RADTRAD and HABIT codes to establish the analysis methodology. We use the Final Safety Analysis Report (FSAR) and other data for Maanshan NPP as the input data in the RADTRAD and HABIT models. Second, we use these models to evaluate the control room habitability for the LOCA and CO_2 storage burst cases. The analysis results of RADTRAD for the LOCA case are similar to FSAR data. The HABIT results for the CO_2 storage burst case are below the R.G. 1.78 failure criteria. The above results indicate that Maanshan NPP habitability can be maintained.

1. Introduction

Maanshan nuclear power plant is located in the south of Taiwan. The type of reactor is Pressurized Water Reactor (PWR). The nuclear steam supply system of the nuclear plant includes the reactor, auxiliary equipment and the reactor coolant system (RCS), etc. The RCS contains three loops. Each loop contains a reactor coolant pump (RCP) and a steam generator. The hot side of the secondary loop is equipped with a pressurizer to adjust the pressure of the RCS circuit.

The safety analysis of nuclear power plants is a very important assessment, especially after the Fukushima accident in Japan. The safety requirements of nuclear power plants are increasing in Taiwan. National Tsing Hua University in 2016 joined the RAMP (Radiological Protection Computer Code Analysis and Maintenance Program) led by US NRC. The RAMP program's main research area is to focus on radiation dose assessment, control room habitability, nuclear power plant decommissioning and so on. RADTRAD and HABIT are both codes included in RAMP. RADTRAD can perform the dose calculations for the radioactive materials migration and removal. HABIT can calculate toxic chemicals concentration for the habitability of the control room.

Therefore, this study uses the RADTRAD and HABIT codes to establish the analysis methodology for the evaluation of the Maanshan control room habitability. This control room habitability evaluation has two parts: the radiation dose assessment for the DBA LOCA case and the chemical concentration assessment for the CO_2 storage burst case.

2. Analysis of case and model description

2.1 Analysis program

2.1.1 SNAP

The Symbolic Nuclear Analysis Package (SNAP) consists of a suite of integrated applications designed to simplify the process of performing engineering analysis. SNAP is built on the Common Application Framework for Engineering Analysis (CAFEAN) which provides a highly flexible framework for creating and editing input for engineering analysis codes as well as extensive functionality for submitting, monitoring, and interacting with the codes. SNAP is developed by Applied Programming Technology (APT), Inc. and is sponsored by the NRC. It provides the RADTRAD user with a graphical user interface with pre– and post–processor capabilities allowing users to develop RADTRAD input decks.

2.1.2 RADTRAD

RADTRAD (RADionuclide, Transport, Removal and Dose Estimation Computer Code) is one of the RAMP codes. RADTRAD can be used for the calculation of transport and removal of radionuclides and dose at Exclusion Area Boundary (EAB), Low Population Zone (LPZ), and the control room.

2.1.3 HABIT

HABIT V2.0 is a package of computer codes designed to assist in the evaluation of Light-Water Reactor (LWR) control room habitability in the event of accidental spills of toxic chemicals. It consists of a number of program modules and produces files containing tabular output that can be printed, viewed, or imported into spreadsheet programs for further applications. HABIT V2.0 also implements a heavy-gas dispersion model, unifies input screen of EXTRAN, DEGADIS and SLAB, and incorporates Bitter Mc-Quaid calculation to determine which model needs to run and provide plotting the concentration versus time outputs.

2.2 Description of cases

2.2.1 LOCA case

In the FSAR of Maanshan nuclear power plant, the LOCA case is assumed that a RCS pipe ruptures. Additionally, the radionuclides are assumed to release from the containment. The related assumptions are as follows:

1. The reactor core equilibrium noble gas and iodine inventories are based on long-term operation at 2900 MW.
2. When the accident occurs, 100% noble gas is released into the containment and is immediately leaking from the containment to the atmospheric environment.
3. When the accident occurs, 25% radioactive iodine inventory is released into the containment, and immediately leak from the containment to the atmospheric environment.
4. For the iodine fission product inventory released to the containment, 91% is elemental iodine, 5% is particulate iodine, and 4% is organic iodine.
5. Credit for iodine removal by the containment spray system is simulated in this case.
6. The control room filter efficiency is 99% for iodine.

2.2.2 CO_2 storage burst case

Assuming that the CO_2 storage tank in Maanshan nuclear power plant is exploded, the CO_2 is released to the atmosphere by a large amount and is affected by the atmospheric environment and spread to the control room. The air intake of the control room may inhale air with carbon dioxide, so if too much inhalation of carbon dioxide, it may cause damage to the staff in the control room. Therefore, we use HABIT to analyze the case according to RG 1.78.

2.3 Models establishment

2.3.1 RADTRAD/SNAP model

Maanshan Nuclear Power Plant model is shown in Figure 1. The reference is from the FSAR Chapter 15 of Maanshan Nuclear Power Plant[3]. Block 1 is the simulated atmospheric environment region, block 2 is the unsprayed region of the containment, and block 3 is the spray region of the containment. The junctions between the blocks are simulated for their exchange or leakage. The region of the containment was divided into sprayed region (81%) and unsprayed region (19%). The exchange rate is 33000cfm between the two regions. Assuming that the leakage rate of the containment is 0.1 vol% / day (0 to 1 day); 0.05 vol% / day (1 to 30 days) for a total of 720 hours. In addition, TID-14844 is selected as the radiation source in this model, the other important input data [3] as shown in Table 1 to Table 4.

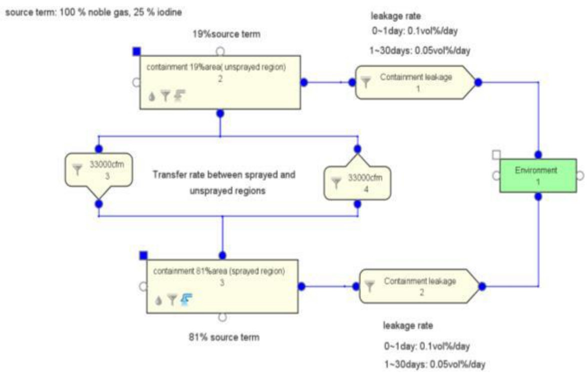

Figure 1: RADTRAD / SNAP model of Maanshan nuclear power plant

Table 1: χ / Q value

Time Period	X/Q (s/m^3)	
	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 2: DCF values

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}

Table 3: nuclear stock inventory

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}

Table 4: Respiratory rate

Time after Accident	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}

2.3.2 HABIT model

The methodology established in this study is shown in Figure 2. First, we collect and investigate the relevant information of Maanshan nuclear power plant, such as: chemical species in and out of power plant, location, inventory, weather and other information, and the reference data used in this study is from Maanshan nuclear power plant information, manual and FSAR report [3] - [6]. These chemicals are then screened according to rule of R.G. 1.78[6]. R.G. 1.78 sets the rules mainly based on the location of chemicals, distance, inventory, etc. The chemicals screened out means that does not cause harm to the control room. The chemicals that are not screened out may cause harm to the control room and need further analysis by HABIT.

R.G. 1.78 can be divided into two types of stationary sources and mobile sources, stationary sources are usually chemical storage tanks or a small amount of chemicals in bottle or barrow in laboratories, mobile sources are usually trucks, Train, boat, etc. loaded with chemicals, as follows:

<u>screening criteria for stationary sources:</u>

- Chemicals stored or situated at distances greater than 8 km from the plant need not be considered
- If sources of hazardous chemicals such within a 8-km radius of the plant, and in quantities less than a given toxicity limit and stable meteorological conditions, these sources need not be considered in the evaluation of control room habitability.
- Any hazardous chemical stored onsite within 500 m of the control room in a quantity greater than 45 kg should be considered for control room habitability evaluation.
- Small quantities for laboratory use, 9.07 kg or less, are exempt.

<u>screening criteria for mobile sources</u>

- If hazardous chemicals outside a 8-km radius of a nuclear power plant, the shipments need not be considered for further evaluation.
- If the shipments are within a 8-km radius of a nuclear power plant, estimates of the frequencies of these shipments should be considered in the evaluation of control room habitability. Shipments are defined as being frequent if there are 10 total shipments per year for truck traffic, 30 per year for rail traffic, or 50 per year for barge traffic.
- Frequent shipments need not be considered in the analysis if the quantity of hazardous chemicals is less than the quantity shown in R.G. 1.78

The inventory of carbon dioxide in this case is 45,000 kg and its distance is less than 0.5 km.

According to R.G. 1.78, it could not be screened out, so it need further analysis in HABIT, Table 5 lists the parameter value of this case in HABIT.

HABIT 2.0 is used in this study, HABIT operation screen is shown in Figure 3. HABIT is divided into two sub-modules which are EXTRAN and CHEM. HABIT first performs EXTRAN. After EXTRAN calculation is completed, HABIT then performs CHEM calculation. EXTRAN calculates the concentration of chemicals at the air intake of the control room which diffuse through the atmospheric environment when the gaseous or liquid chemical explodes or leaks, as shown in Figure 4. EXTRAN use mass balance equation, energy balance equation and puff diffusion model to calculate which is based on the property and inventory of chemicals, combined with the conditions of the atmospheric environment. According to the results calculated by EXTRAN, CHEM uses this result, combined with the relevant information of the control room (such as the flow rate of the inlet and the volume of the control room). The mass balance equation is used to calculate the concentration of the air into the control room. As shown in Figure 5. As HABIT calculation is completed, it will automatically display the file and the data output as text files, as shown in Figure 6.

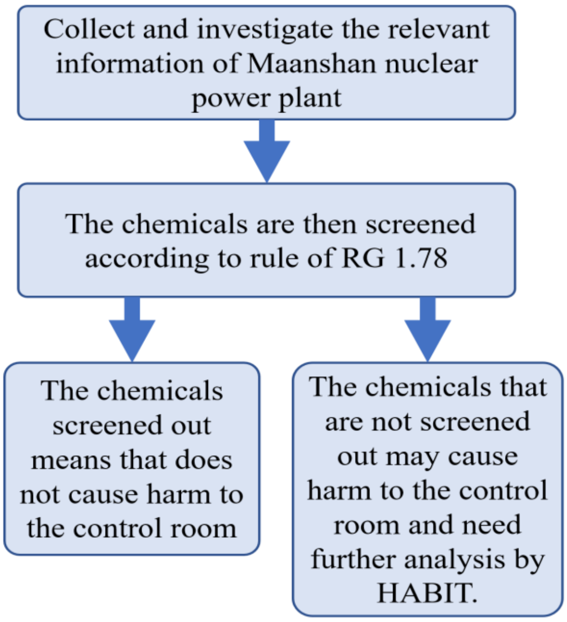

Figure 2: flow chart of Methodology

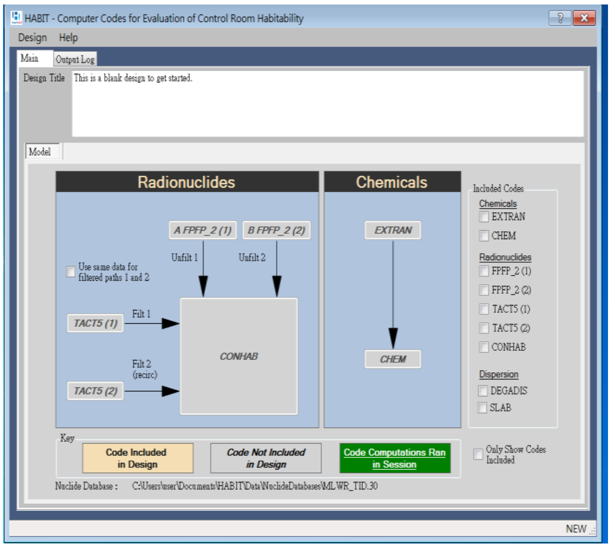

Figure 3: settings of HABIT

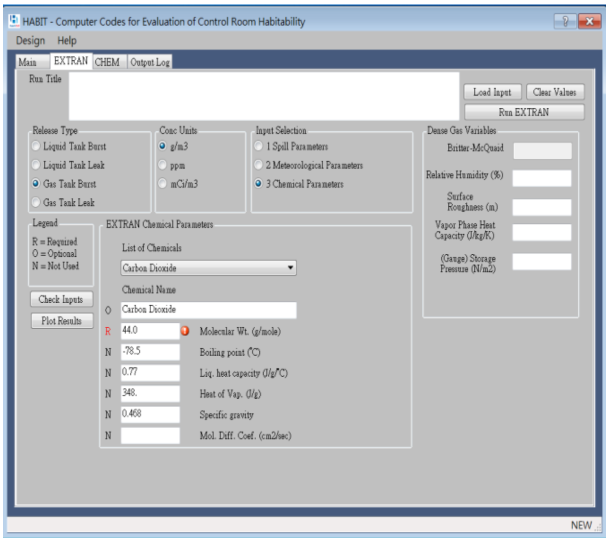

Figure 4: settings of EXTRAN

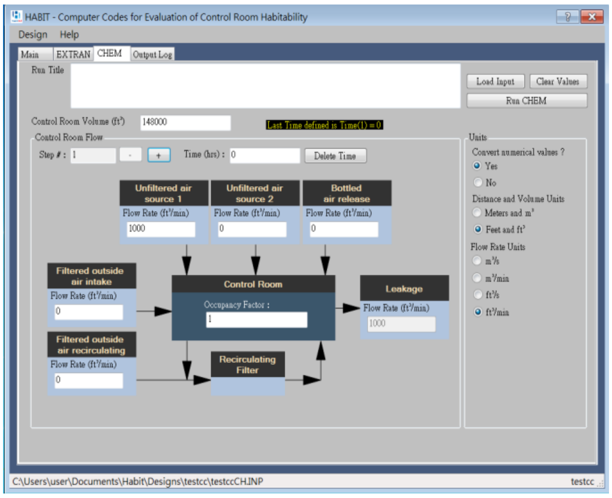

Figure 5: settings of CHEM

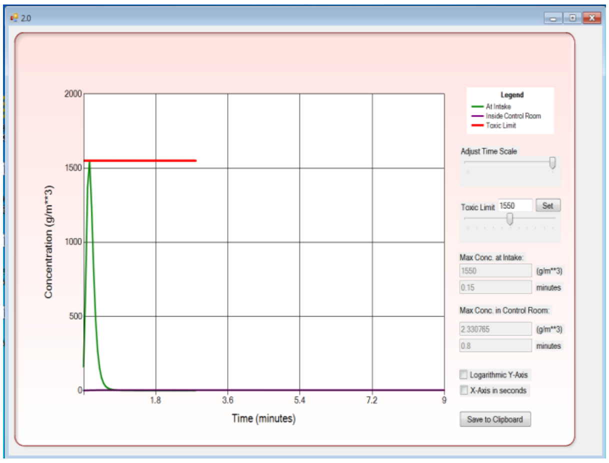

Figure 6: HABIT analysis results

Table 5: Input parameters in HABIT

Parameters	Values
CO_2 initial mass (kg)	45000
CO_2 storage temperature(℃)	-16.67
Wind speed(m/s)	3.11
Atmospheric stability class	F
Air temperature(℃)	37.2
Control room volume (ft^3)	73169
Control room intake flow rate(ft^3/min)	1000

3. Analysis results and discussion

3.1 RADTRAD / SNAP analysis results

According to FSAR 15.0 [3], the results of the calculated dose shall comply with the criteria in 10 CFR 100.11:

For the EAB:

- A total radiation dose to the whole body is below 250 mSv.
- A total radiation dose to the thyroid from iodine exposure is below 3000 mSv within 2 hours after the accident.

For the LPZ:

- A total radiation dose to the whole body is below 250 mSv.
- A total radiation dose to the thyroid from iodine exposure is below 3000 mSv during the entire period of radioactive cloud passage.

Figure 7 shows the output of RADTRAD. The results of the calculation at EAB and at LPZ are shown in the figure. Table 6 and Table 7 show the comparison of the analysis results of RADTRAD/SNAP model of Maanshan nuclear power plant at EAB and LPZ with the FSAR and the regulatory limits. From the table, we can see that the analysis dose at EAB and LPZ are similar with the data in the FSAR, and are lower than the regulatory limits.

The RADTRAD/SNAP model has a certain degree of credibility according to the comparison results. In addition, Table 6 and Table 7 shows that although the results of RADTRAD analysis and FSAR data are similar, there are some numerical differences. The difference may come from two aspects:

1. Differences are between FSAR analysis model or code and RADTRAD. However, FSAR did not describe its analysis model or code in detail. Therefore, we cannot confirm it.
2. Some parameter values are not included in FSAR. For example, FSAR does not specify the stop time of the containment spray system, and this parameter may affect the analysis results.

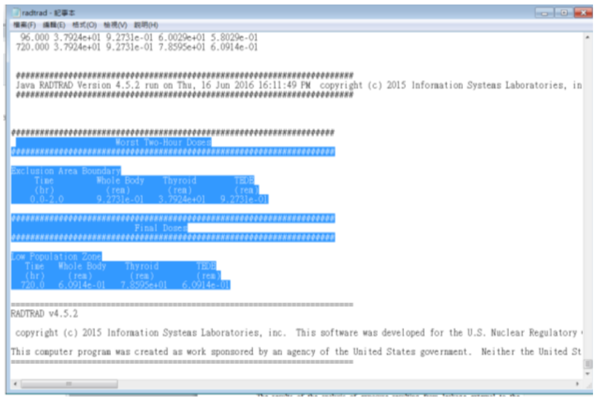

Figure 7: RADTRAD result data

Table 6: analysis dose at EAB of Maanshan nuclear power plant

EAB	FSAR	RADTRAD	Regulatory limits
Whole body dose(mSv)	9.9	9.273	250
Thyroid dose(mSv)	469	379.24	3000

Table 7: analysis dose at LPZ of Maanshan nuclear power plant

LPZ	FSAR	RADTRAD	Regulatory limits
Whole body dose (mSv)	5.94	6.0914	250
Thyroid dose (mSv)	629	785.95	3000

3.2 HABIT analysis results

The analysis results of the HABIT are shown in Table 8. The maximum concentration appears at 1.25 minutes after the explosion, which is 3.166 g / m^3. According to RG 1.78 [6], the limit concentration of carbon dioxide is 7.36 g / m^3. The result of HABIT is less than this limit, which means the concentration of carbon dioxide in this case does not harm the personnel in the control room.

Table 8: HABIT analysis results for CO_2 storage tank explosion case of Maanshan nuclear power plant

	Time (min)	Concentration (g/m^3)
HABIT	1.25	3.166
R.G. 1.78 limits		7.36

4. Conclusion

This study used the RADTRAD, SNAP, and HABIT codes to establish the methodology for control room habitability. The RADTRAD/SNAP model was successfully established by referring to the FSAR and data of Maanshan nuclear power plant and the RADTRAD manual. And this model was used to analyze the "release from the containment" case of LOCA. The RADTRAD analysis result shows that the dose at EAB and LPZ are similar to the FSAR data and both are lower than the regulatory limits. The above comparison shows that we have established the RADTRAD / SNAP model of Maanshan nuclear power plant with a certain degree of credibility. This model will apply to the researches related to radiation dose of Maanshan nuclear power plant in the future, such as LOCA ESF leakage. Based on the above experience and methods, we will proceed to perform the establishment and application of RADTRAD/SNAP models for the other nuclear power plants in Taiwan.

On the other hand, the HABIT model was successfully established by referring to the FSAR and data of Maanshan nuclear power plant and the HABIT manual. This model was used to analyze the "CO_2 storage tank explosion" case. The HABIT analysis result shows that the chemical concentration is lower than the limits of R.G. 1.78, which means the habitability of control room would be maintained. This model will apply to the researches related to the habitability of control room of Maanshan nuclear power plant in the future. In addition, based on the above experience and methods, we will proceed to perform the establishment and application of analysis methodology of HABIT models for the other nuclear power plants in Taiwan.

5. References

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