DEVELOPMENT OF PC-BASED RADIOLOGICAL CONSEQUENCE ASSESSMENT TOOL FOR EMERGENCY RESPONSE TO NUCLEAR ACCIDENT IN NORTHEAST ASIA

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Abstract

After Fukushima Daiichi NPP accident, it has been emphasized that fast and reliable dose assessment system for overseas nuclear accident should be established. The purpose of this study is to develop a PC-based radiological consequence assessment tool in Northeast Asia. First, representative reactor types of China, Japan and Taiwan were selected as CPR1000, BWR5 and BWR6, respectively. Selection criteria were number of reactor, power capacity, operating age and geological distance from the Korean Peninsula, which are concerned with accidental effect. For each reactor type, the radiological source-term estimation modules were developed for design basis accident and severe accident models are under development. Also, long-range atmospheric dispersion evaluation module was implemented, and then it was used for sample running. The atmospheric dispersion evaluation module is based on Lagrangian particle model. Now, dose assessment module is being developed and it would consider external and internal exposure pathways. These three modules will be integrated to the PC-based simulation system named NANAS (Northeast Asia Nuclear Accident Simulator) and it would be used as training tool for national emergency response staffs.

1. Introduction

After Fukushima Daiichi NPP accident, there has been a strong demand for dose assessment system to estimate the consequence of nuclear accident in neighboring countries [1]. Moreover, when the overseas nuclear accident occurs, accurate information on the accident should be provided swiftly for emergency response. In case of Korea, neighboring countries such as China, Japan and Taiwan have totally 103 NPPs (containing NPPs under construction). Therefore, the necessity of dose assessment system for overseas nuclear accident has been arising more and more.

The purpose of this study is to develop a PC-based radiological consequence assessment tool in Northeast Asia and assess the consequence of overseas nuclear accident to Korea quickly and exactly. Furthermore, by utilizing the system as a training tool for national emergency response staffs, it could contribute to strengthening the capacity of domestic radiation emergency response.

The simulator system has three main features and calculates in a sequence of steps. These features and steps are: source-term estimation, atmospheric dispersion evaluation and dose assessment

Three features would be programed as a module respectively and they would be integrated as a PC-based simulator system.

2. Representative reactor models

Based on the current status of nuclear reactor, it is intended to choose the representative reactor models of China, Japan and Taiwan. In source-term estimation module, the calculation for each country would be performed to representative reactor models. Most radionuclides of source-term are similar for each reactor model, but time-dependent emission rate and amount of emission could be different based on the release pathway. The representative reactor model should contain the major characteristics of nuclear reactor of each country, and it should consider radiological consequence to Korea. Reactors were classified according to the reactor models, and then the reactors which had the operating period over 20 years, power capacity over 1,000 MWe and geological distance from Korea less than 1,000 km were sorted out.

As of June 2015, China has 26 reactors in operation and 24 reactors under construction. Except one HTGR (High-Temperature Gas-Cooled Reactor), Chinese reactors are PWR (Pressurized Water Reactor). Before applying the four criteria, operating period was excluded for categorizing the reactors since most Chinese reactors have been constructed after 2000 and more than fifty percent of operating reactors are younger than 10 years. As shown in Table 1, CPR1000 took the most of nuclear power reactors with 44% of reactor number. Regarding the power capacity and distance, CPR1000 also took the biggest portion of each criterion, being about 63% of the reactors above 1,000 MWe and about 38% of within 1,000 km from Korea. Therefore, CPR1000 was selected as the representative reactor model in China.

Table 1 Chinese Nuclear Power Plants

Type	Model	No. of Reactor	Criterion A*	Criterion B**	Criterion A & B
HTGR	HTR-PM	1	0	1	0
PWR	M310	4	0	0	0
	CPR-1000	22	22	10	10
	CNP-600	6	0	4	0
	CNP-300	1	0	1	0
	PHWR CANDU 6	2	0	2	0
	VVER V-428	2	2	2	2
	VVER V-428M	2	2	2	2
	AP-1000	4	4	4	4
	EPR-1750	2	2	0	0
	ACPR-1000	3	2	0	0
	Hualong One	1	1	0	0
Total		50	35	26	18

* Criterion A : No. of reactors above 1,000 MWe
** Criterion B : No. of reactors within 1,000 km from Korea

Table 2 shows the categorization of Japanese and Taiwanese nuclear power plants. In case of Japan, BWR5 was a dominant reactor model taking 38% of reactor number. At the same time, BWR5 was accordance with criterion A and B and C. Therefore, BWR5 was chosen as the representative reactor model in Japan. For Taiwan, there are 8 reactors in total and the distance was excluded as a criterion since there is no reactor within 1,000 km from Korea. As a result, BWR6 was selected as the representative reactor model for Taiwan [2].

Table 2 Japanese and Taiwanese Nuclear Power Plants

(A) Japan

Type	Model	No. of Reactor	Criterion A*	Criterion B**	Criterion C***	Criterion A & B & C
PWR	M(2-loop)	5	0	3	5	0
	M(3-loop)	9	0	8	9	0
	M(4-loop)	5	5	5	4	4
	W(4-loop)	2	2	2	2	2
BWR	BWR4	1	0	0	1	0
	BWR5	17	13	10	15	8
	ABWR	6	6	5	0	0
Total		45	26	33	36	14

(B) Taiwan

Type	Model	No. of Reactor	Criterion A*	Criterion C***	Criterion A & C
PWR	W 312	2	0	2	0
BWR	BWR4	2	0	2	0
	BWR6	2	2	2	2
	ABWR	2	2	0	0
Total		8	4	6	2

* Criterion A : No. of reactors above 1,000 MWe
** Criterion B : No. of reactors within 1,000 km from Korea
*** Criterion C : No. of reactors older than 20 years

3. PC-based simulation system

The objective of simulator system is to estimate the radiological source-term of nuclear accident in Northeast Asia region and to perform the dose assessment in Korea. Figure 1 shows the configuration of integrated simulator system. The PC-based simulator is organized by three independent modules (i.e. source-term estimation module, atmospheric dispersion evaluation module and dose assessment module) and database. Each module operates independently, and the output of each module becomes the input of next module. All data necessary for evaluation are managed in system with the format of MS Access. Main screen of NANAS is shown in Figure 2. The program is comprised of three modules, and the calculation could be conducted following the main bar.

The source-term estimation module simulates design basis accident and severe accident, and considers various accident phenomena including loss of coolant accident and steam line break, loss of flow and pump trip, turbine trip, station blackout and loss of load, inadvertent withdraw or insertion of control rod, dilution of boric acid and feedwater transient, steam generator tube rupture, anticipated transient without scram, metal-water reaction and hydrogen generation due to core melting, core debris-concrete reaction in the cavity and etc. The module should reflect design features, and it also have to evaluate the source-term information correctly by simulating behavior characteristics of radionuclides. Output is the release activity of representative radionuclides by nuclide group in IAEA Specific Safety Guide No. SSG-4 such as Xe, I, Cs, Ba, Te, Ru, La, and Ce, and it also contains important radionuclides in accident; Kr, Sr and Pu [3].

The atmospheric dispersion evaluation module evaluates dispersion of radionuclides with three dimensional models which considers terrain effect and uses past or forecast meteorological data. The output of source-term estimation module is the input of this module, and then airborne and ground concentrations are calculated for dose assessment.

The last module is for dose assessment. A methodology in dose assessment module considers all exposure pathways for human; cloudshine, groundshine, inhalation and ingestion. This module uses the output of atmospheric dispersion evaluation module as input and print out exposure dose at interested locations by time.

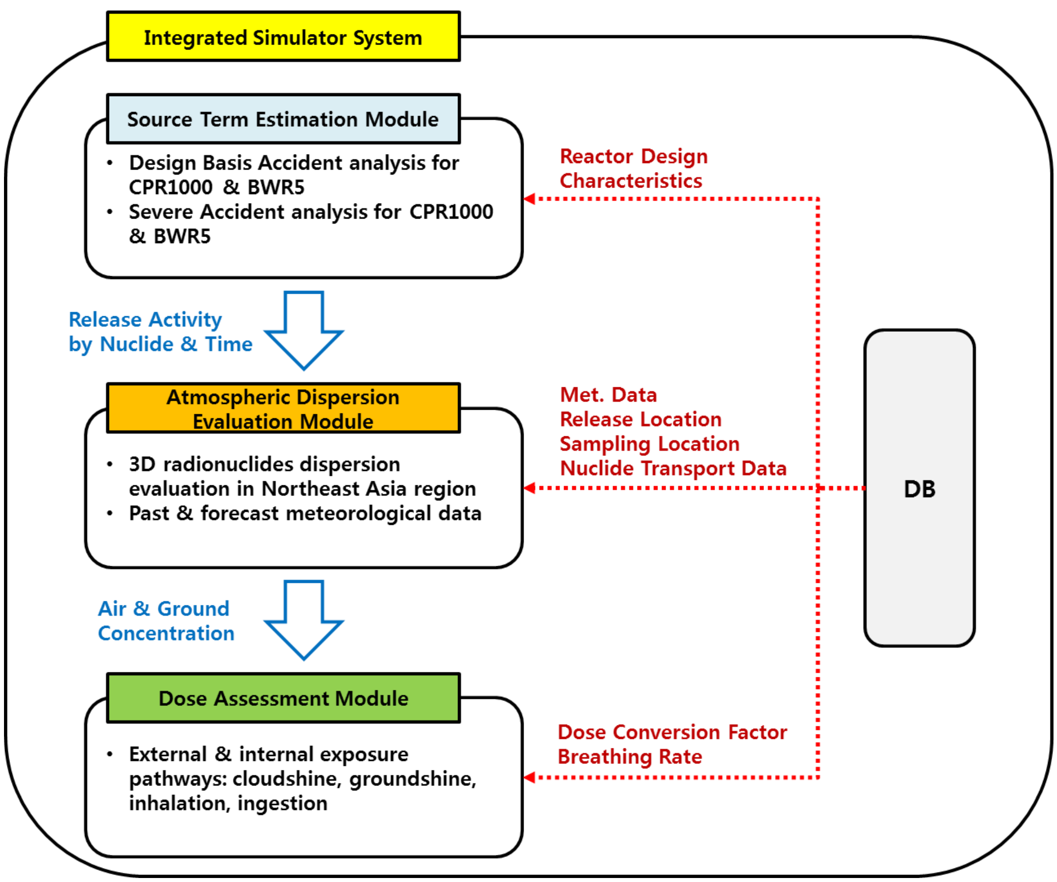


Figure 1 Configuration of Integrated Simulator System

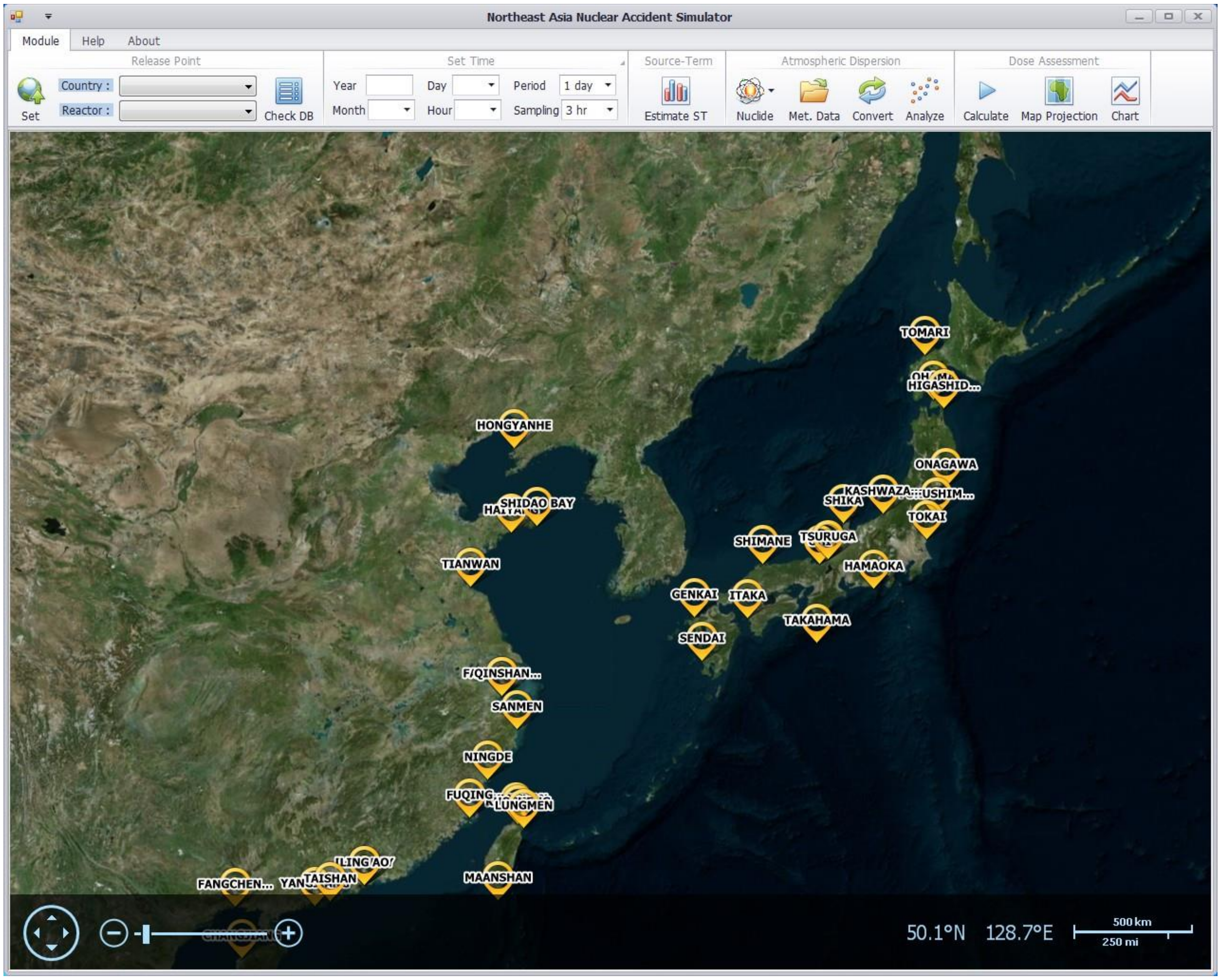


Figure 2 Main Screen of NANAS

4. Results and Discussion

4.1 Source-term estimation module and atmospheric dispersion evaluation module

PCTRAN/CPR1000, PCTRAN/BWR5 and PCTRAN/BWR6 in source-term estimation module are on Microsoft Windows environment. Input and output use the format of MS Office Access database, and the source code is written in Visual Basic 6.0 and .NET.

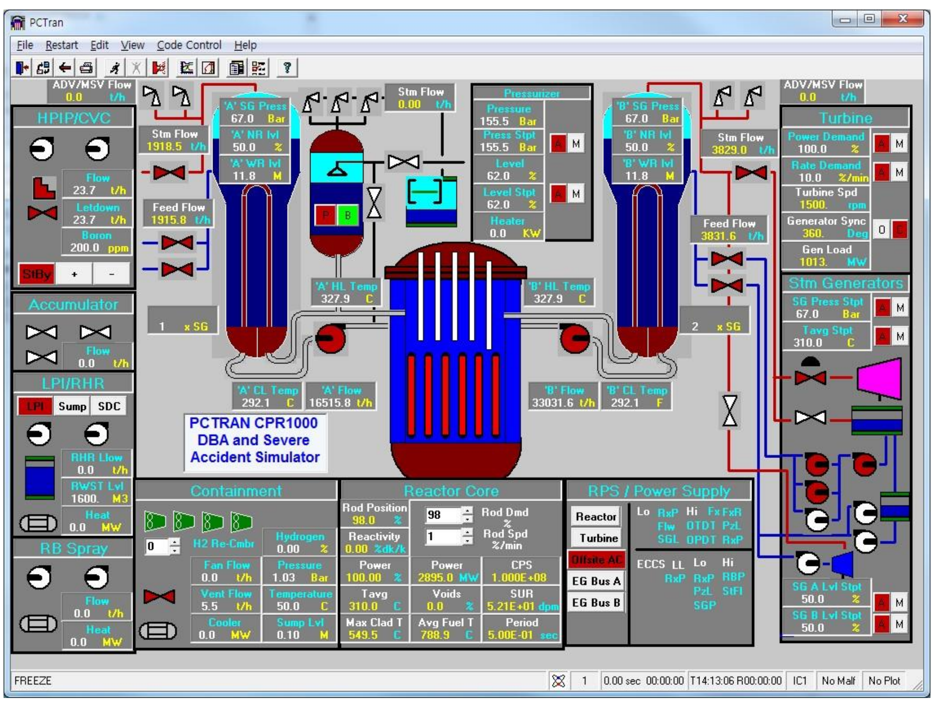
Figure 3 shows the main screen of source-term estimation module. The programs use pull-down menus and mouse interface for usability. Instruments and controls are minimized in order to fit into PC screen and they are controllable from the main screen. Principles and characteristics of reactor are demonstrated on the screen, thus users can watch the change of system intuitionally. Users can control status and failure fraction of all components in the screen. Their status is indicated by color and users can turn them off manually. As a result of simulation, locations of control rod, water level, line breaks or sprays are displayed in the main screen. Red color indicates OPEN or ON and green color indicates CLOSED or OFF [4].

User can also control the speed of simulation up to 16 times of real time. The graph of each operating parameters are shown in real time during or after simulation from the plotting function. After simulation, operating parameters and released activity data are printed out as MS Access format. Therefore, this result can be used as an input of atmospheric dispersion evaluation module.

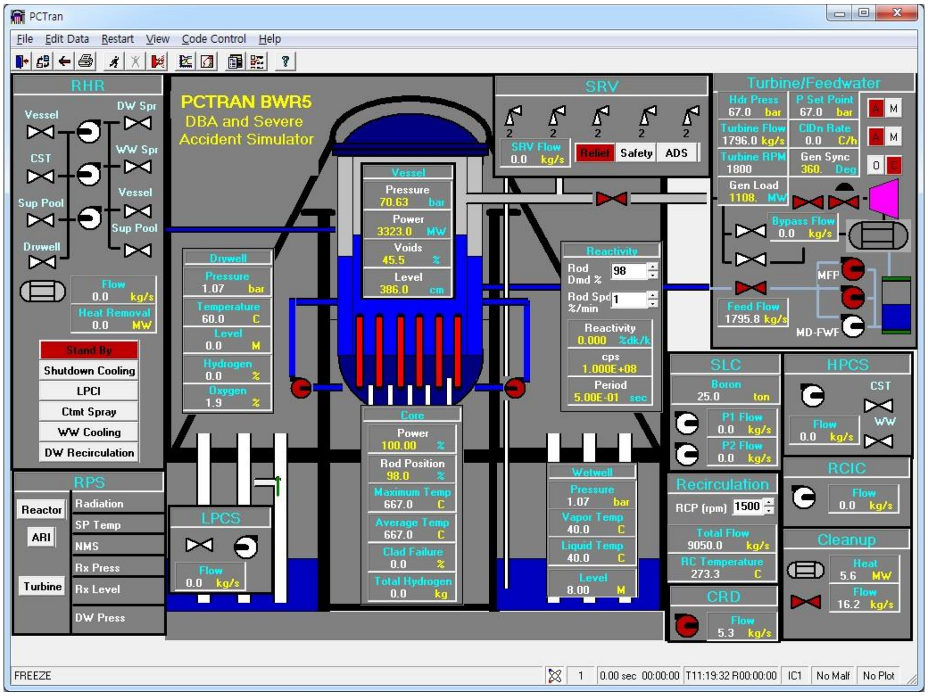
In the atmospheric dispersion evaluation module, the atmospheric dispersion of radionuclides released by the representative reactor is calculated by Lagrangian dispersion model in this study. HYSPLIT (Hybrid Single-Particle Lagrangian Integrated Trajectory) is the main model and is used for long-range dispersion for predicting the impacts to Korea. Additionally, LASAT (Lagrangian Simulation of Aerosol-Transport) is utilized for evaluating a short-range dispersion within 150km from the reactor [5]. The meteorological data are GDAS (Global Data Assimilation System) data from NOAA (National Oceanic and Atmospheric Administration) [6].

The atmospheric dispersion evaluation module uses the output of source-term estimation module which is the amount of radionuclide emission as an input. And then it draws airborne and ground concentrations of radionuclides. Finally, the concentrations are used as an input for the dose assessment module.

(a)



(b)



(c)

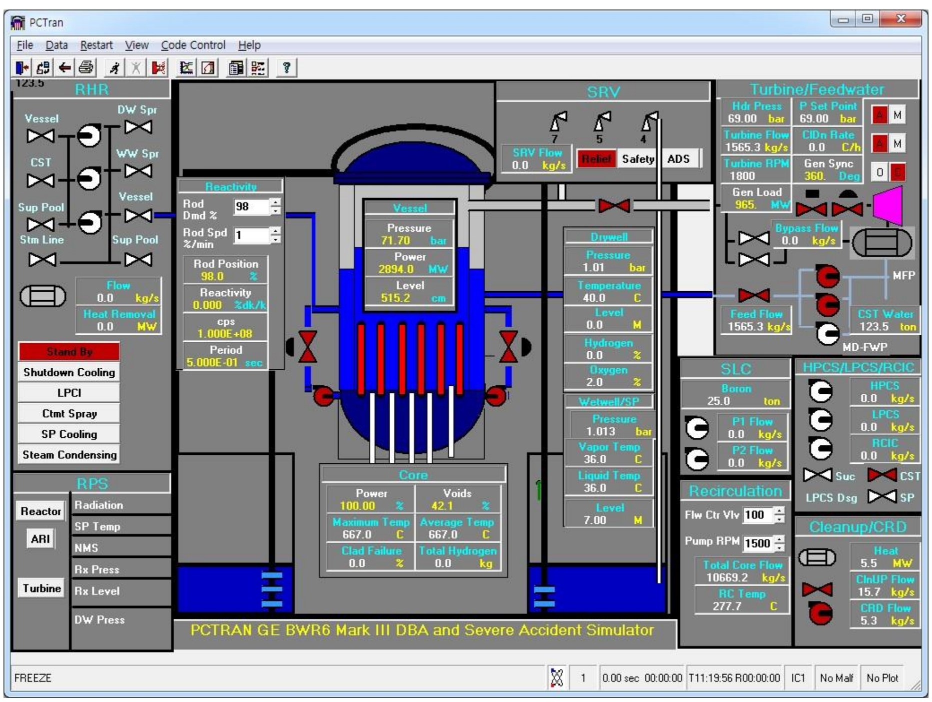


Figure 3 Main Screens of (a) PCTRAN/CPR1000, (b) PCTRAN/BWR5, (c) PCTRAN/BWR6

4.2 Sample running

Sample running was performed concerning with design basis accident of representative reactor model of China and Japan. The purpose was to show the movement of radionuclides from the NPP to environment in accidental circumstance. The object NPPs were Hongyanhe NPP for China and Shimane NPP for Japan respectively because they were the nearest NPP from Korea among the representative NPPs in each country. Exceptionally, for Taiwan, the source term calculation of PCTRAN/BWR6 was only conducted because the meteorological conditions for input data was not yet determined.

The accidental scenario assumed that large break loss of coolant accident happened in Hongyanhe NPP and Shimane NPP, and ^{131}I (particulate) and ^{133}Xe (gas) were generated. It was designed to calculate the dispersion of radionuclides for 72 hours. It was also assumed that the emission of radionuclides lasted for the first 12 hours. The emission rates, which were the result of PCTRAN/CPR1000, PCTRAN/BWR5 and PCTRAN/BWR6, are presented in Table 3.

The emission rates were an input into the atmospheric dispersion evaluation module. For the meteorological data, the most conservative meteorological conditions which let the radionuclides directly go through Korea were chosen. Their periods were from 22 January 2015 to 24 January 2015 for China and from 28 April 2015 to 30 April 2015 for Japan. In dry and wet deposition calculation, ^{131}I was modeled with deposition velocity of 0.001m/s and washout coefficient C_w of 0.00008/s and α_w of 0.8 for calculating washout rate $\Lambda = C_w(\frac{I}{I_o})^{\alpha_w}$ [7,8]. Here, as ^{133}Xe is noble gas, it is excluded for deposition evaluation.

The long-range distributions of ^{131}I and ^{133}Xe are shown in Figure 4 and 5. The airborne concentrations were the average concentration from ground to 100 m height.

Table 3 Emission rate of ^{131}I and ^{133}Xe

Time [hr]	Honyanhe NPP (China)		Shimane NPP (Japan)		Kuoseng NPP (Taiwan)	
	^{131}I [Bq/hr]	^{133}Xe[Bq/hr]	^{131}I [Bq/hr]	^{133}Xe [Bq/hr]	^{131}I [Bq/hr]	^{133}Xe [Bq/hr]
00:00 ~ 03:00	8.3E+08	7.4E+10	7.2E+09	1.5E+11	2.5E+09	1.6E+11
03:00 ~ 06:00	1.4E+09	7.7E+10	7.7E+10	1.0E+12	2.8E+10	1.1E+12
06:00 ~ 09:00	2.2E+09	8.9E+10	2.1E+11	2.7E+12	1.7E+11	2.9E+12
09:00 ~ 12:00	3.2E+09	1.0E+11	5.0E+11	5.2E+12	5.1E+11	5.5E+12
12:00 ~ 72:00	0	0	0	0	0	0

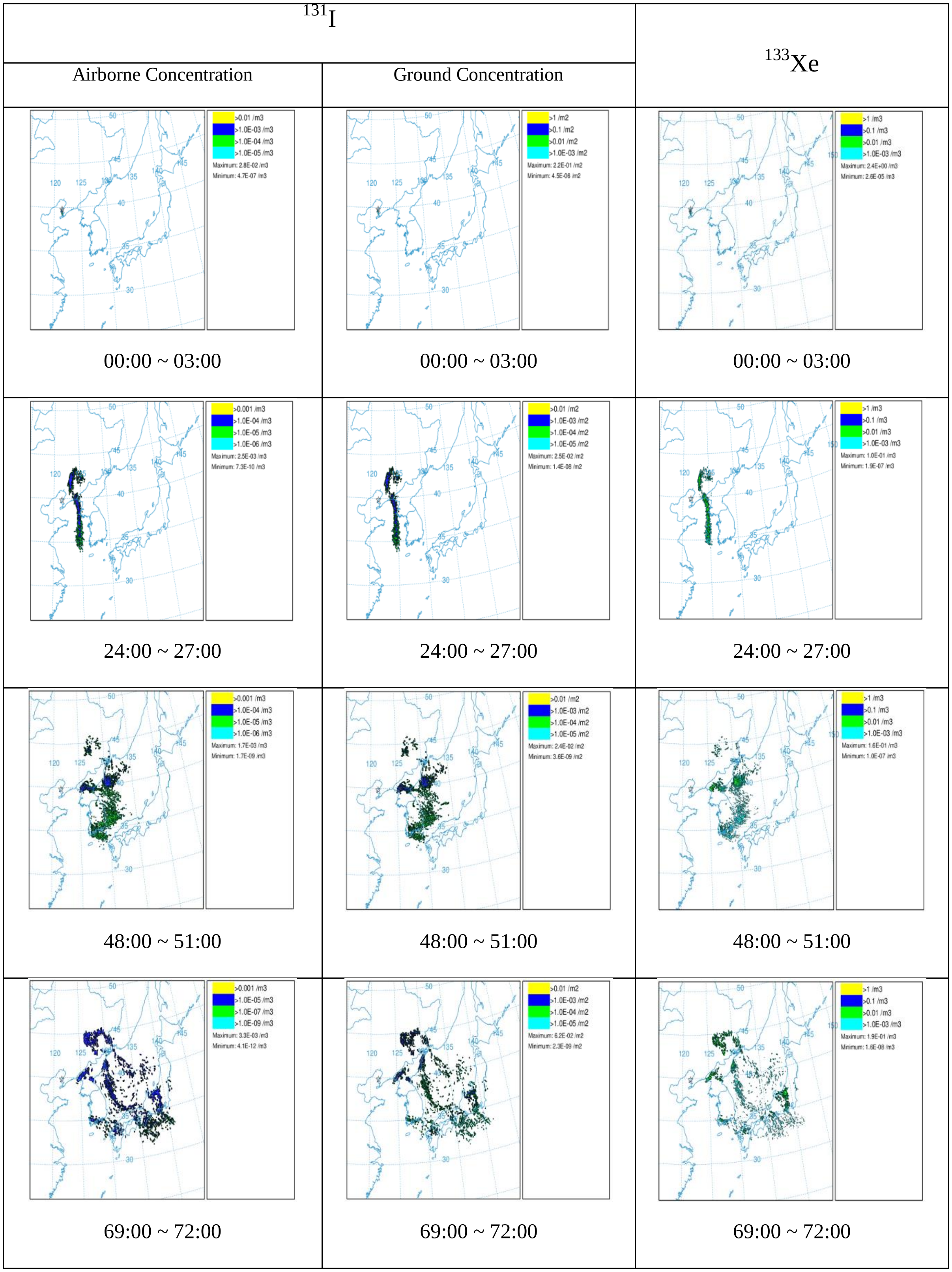


Figure 4 Long-range distributions of ^{131}I and ^{133}Xe from Hongyanhe NPP

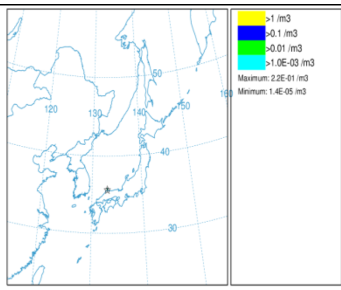
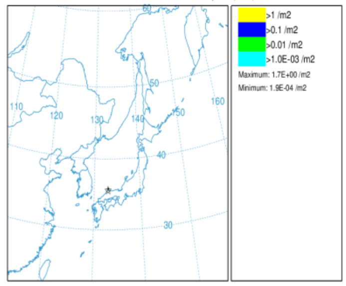
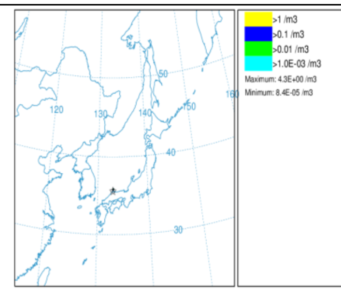
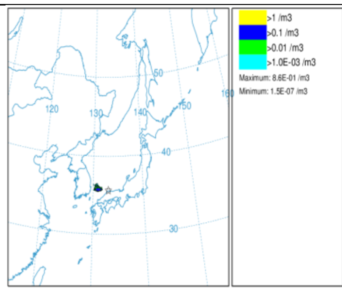
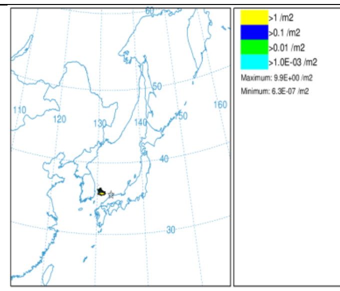
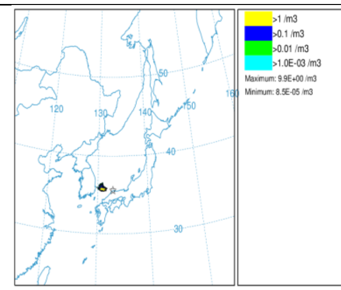
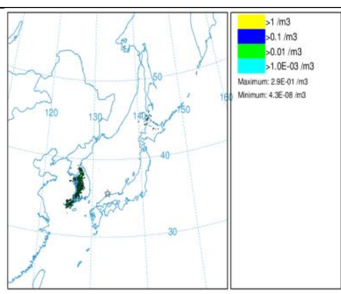
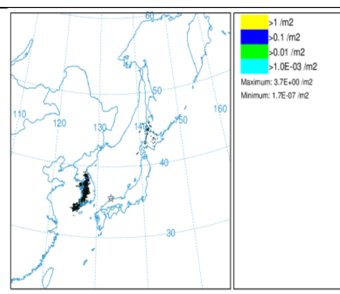
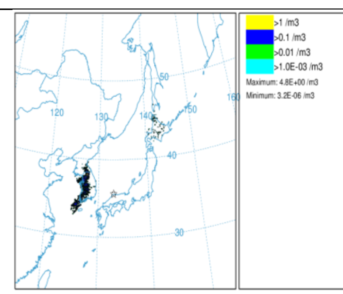
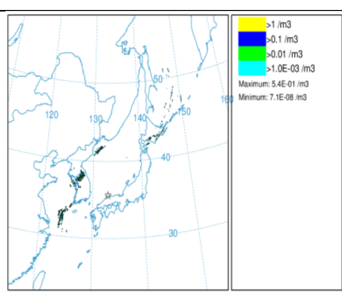
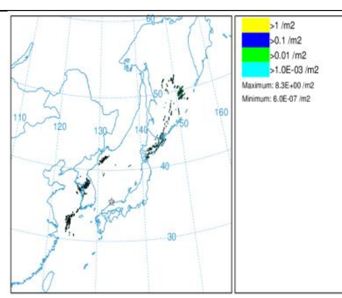
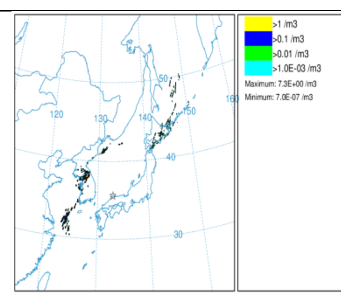
^{131}I		^{133}Xe
Airborne Concentration	Ground Concentration	
 00:00 ~ 03:00	 00:00 ~ 03:00	 00:00 ~ 03:00
 24:00 ~ 27:00	 24:00 ~ 27:00	 24:00 ~ 27:00
 48:00 ~ 51:00	 48:00 ~ 51:00	 48:00 ~ 51:00
 60:00 ~ 63:00	 60:00 ~ 63:00	 60:00 ~ 63:00

Figure 5 Long-range distributions of ^{131}I and ^{133}Xe from Shimane NPP

5. Conclusion

In this study, a PC-based radiological consequence assessment tool for Northeast Asia region is under development. The tool is an integrated system including source-term estimation module, atmospheric dispersion evaluation module and dose assessment module. Based on the representability and accidental consequence of nuclear power plant, the representative reactor models of China, Japan and Taiwan were chosen as CPR1000, BWR5 and BWR6 respectively. For each representative reactor model, the source-term estimation module simulates various accident scenarios of design basis accident and severe accident. Until now, the source-term estimation module has been partially developed for design basis accident of CPR1000 and BWR5. We also performed the atmospheric dispersion evaluation applying Lagrangian particle model. The dose assessment module is now being developed for calculating the exposure dose considering four pathways of cloudshine, groundshine, inhalation and ingestion. In the future, the three modules will be perfectly developed, and then they will be integrated into a simulation system. The system could be used as an educating and training tool for national emergency response staff.

6. Acknowledgements

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