A Sensitivity Study on Effective Protection Measures for Consequence Analysis

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Abstract: When a severe accident occurs in a nuclear power plant, early public protection measures are the best response to reduce the health effect of residents. Sheltering and evacuation are considered for residents as the early public protection measures. The evacuation before plume arrival is the most effective measure. It is actually difficult for all residents to evacuate before plume arrival because the distance between nuclear power plants and residential area is closer in Korea than other countries. And, the sheltering is also the effective measure, resulting in less substantial exposure. WinMACCS 3.10, the graphical user interface of representative level 3 PSA (Probabilistic Safety Assessment) code, can evaluate the effectiveness of these two public protection measures. The purpose of this work is to gain insight into the importance of variables in emergency response modeling and to understand the relevance between derived variables. Thus, the variables in WinMACCS affecting emergency response modeling were derived and sensitivity analysis was performed for these variables. In addition, not all possible uncertain input parameters were included. We expect that the results in this work might be useful information to establish emergency response model in WinMACCS, and it might provide a technical basis for future work.

Keywords: Public Protection Measure, Level 3 PSA, Sensitivity Analysis

1. INTRODUCTION

When a severe accident occurs in a nuclear power plant, early public protection measures, such as sheltering and evacuation, are the best response to reduce the health effect of residents, because the emergency response is expected to be effective prior to the onset of environmental release. The evacuation before plume arrival is the most effective measure. Also, the sheltering is the effective measure in specific conditions, resulting in less substantial exposure. These two measures can be modeled in WinMACCS, the graphical user interface of representative level 3 PSA code.

This study was conducted because of a curiosity how important uncertain variables of early public protection measures could affect consequence. Thus, the variables in WinMACCS, affecting related to emergency response model in the early module, are derived and sensitivity analysis was performed for these variables. In addition, not all possible uncertain variables were included. Rather, key parameters were carefully chosen. The major objective of this study is to gain insights into variables of emergency response model.

This paper is divided into five sections. The first section demonstrates emergency phase in WinMACCS and its parameters. The second section presents the basic characteristic of selected source terms. The third section presents the variables in the base model. The fourth section presents the sensitivity analysis and its results. In addition, the fifth section presents the conclusion and limitation of this study.

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2. ANALYSIS AND RESULT

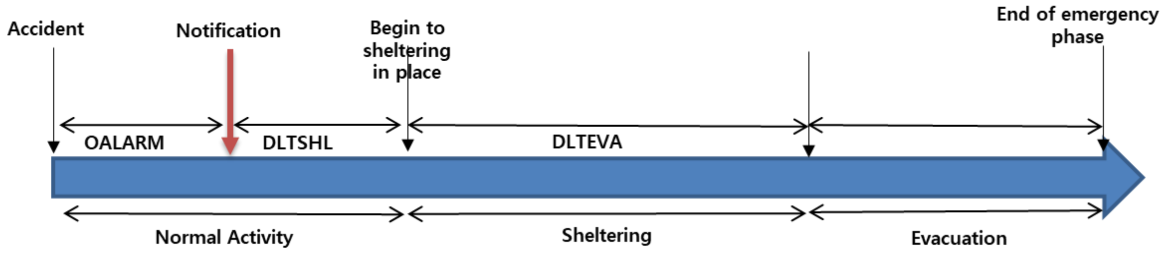
2.1. Emergency Phase in WinMACCS

WinMACCS is divided into three primary modules: ATMOS, EARLY, and CHRONC. ATMOS performs all of the calculations pertaining to atmospheric transport, dispersion, and deposition, as well as the radioactive decay that occurs prior to release and while the material is in the atmosphere. EARLY performs all of the calculations pertaining to the emergency phase. The emergency phase begins, at each successive downwind distance point, when the first plume of the release arrives. The duration of the emergency phase is specified by the user, and usually set a week. The exposure pathways considered during this period are as follow [1].

(1) Direct external exposure to radioactive material in the plume (cloudshine)
(2) Internal exposure from inhalation of radionuclides in the cloud (cloud inhalation)
(3) External exposure to radioactive material deposited on the ground (groundshine)
(4) Inhalation of resuspended material (resuspension inhalation)
(5) Skin dose from material deposited on the skin

The emergency phase is divided into four periods. The first period is from the accident point to notification time for the public protection measure. The second period is from the notification time to beginning of sheltering. Shielding factors of normal activity are applied into public during this period. In other words, it is the period when everyone returns to the house or other places. The third period is the period of sheltering indoors. Shielding factors of sheltering are applied into public during this period. The fourth period is the time to leave the building after the sheltering, and evacuate outside the EPZ (Emergency Planning Zone) boundary. At this time, shielding factors of evacuation are applied. The entire timeline of the emergency phase is shown in Figure 1.

Figure 1: Entire Timeline of Emergency Phase in WinMACCS



OALARM is the time at which notification is given to off-site emergency response officials to initiate protective measures for the surrounding population. This time is a function of the accident sequence. It is measured from accident initiation (shutdown time) and is given in units of seconds [2].

DLTSHL is the delay time to take shelter and DLTEVA is the delay time to evacuate. For each distance ring in the shelter/evacuate region, these two parameters must be defined for resident individuals. When DLTSHL is specified as 0, sheltering will occur with no delay (that is, immediately) at that distance. When DLTEVA is specified as 0, evacuation will occur with no additional delay (that is, there is no shelter period at that distance) [1].

2.2. Source Term

A brief description of the source terms in this study is provided in Table 1. We carefully choose the bypass accident scenarios. Reactor type, representative initiating event, release time, core uncover time, and release fraction after 72 hours is given in Table 1.

Table 1: General Characteristics of Source Term Release Scenarios

	Source term 1	Source term 2
Reactor type	OPR1000: Pressurized Water Reactor with 1000MWe	
Representative initiating event	ISLOCA	SGTR
Release time (s)	4275	11252
Core uncovery time	3422	9359
Release fraction after 72 hours	Xe: 100%, Cs: 69.8%, I: 81.4%	Xe: 94.3%, Cs: 21.1%, I: 37%

2.3. Base Model

In this section, input variables in the base model, closely related to the public protection measure, are described. In Korea, EPZ boundary, 8 to 10km, was changed to PAZ (Precautionary Action Zone) and UPZ (Urgent Protective action planning Zone) in accordance with the IAEA requirements [3].

In Korea, EPZ is divided into PAZ (Precautionary Action Zone) within 3~5km and UPZ (Urgent Protective action planning Zone) within 20~30km. The PAZ is the area for which arrangements shall be made with the goal of taking precautionary urgent protective actions, before or shortly after the release of radioactive material begins. The UPZ is the area for which arrangement shall be made for urgent protective action to be taken promptly and conditionally in accordance with radioactive level. [4]. And, in the emergency response model in WinMACCS, it is hard to simulate conditional protective measures, such as sheltering and evacuation excluding relocation, depending on radioactive level.

Only sheltering and radial evacuation are applied to the population within 20km as early public protection measures in the base model. People outside 20km were not considered in the base model. The input parameters in Table 2, except for source term, are applied into two scenarios.

Table 2: Input Data in Early Module

Input parameter	Value			Description
LASMOV	27(30km)			Outer boundary at which evacuees are assumed to disappear from the early health effects model and receive no further dose
ESPEED	5.5m/s(20km/h)			Evacuation speed.
	Evacuation	Normal Activity	Sheltering	
CSFACT	1	0.7	0.62	Cloudshine shielding factor
GSHFAC	1	0.3	0.11	Groundshine shielding factor
PROTIN	0.98	0.46	0.33	Inhalation protection factor
SKPFAC	0.98	0.46	0.33	Skin protection factor
BRRATE	2.14e-4			Breathing rate

LASMOV is outermost boundary in the early module. The plume disappears at this boundary and the exposure calculation in the early module ends as soon as evacuees reach LASMOV. In this study, LASMOV was set to 30 km conservatively to reflect the domestic situation. ESPEED is evacuation speed. ESPEED should be set differently for each cohort and throughout the evacuation period. It should be derived from Evacuation Time Estimate (ETE) analysis. However, it was not performed because of the limited scope in this work. Hence, it was conservatively set at 20 km/h (5.5 m/s) in this study. CSFACT and GSHFAC are cloudshine shielding factor and groundshine shielding factor, respectively. And, CSFACT and GSHFAC were derived using domestic statistical data. PROTIN and SKPFAC, are respiratory protection factor and skin protection factor, respectively. The input data is the value used in SOARCA project [5]. BRRATE is the long-term average respiration rate. It was derived using domestic statistical data.

DLTEVA and DLTSHL used in our base model are described in Table 3.

Table 3: Delay Time to Shelter and Evacuate

Input parameter	Value		Description
DLTSHL(s)	Within 5km	3600	The delay from the OALARM to the start of sheltering. During this duration, normal activity shielding factors are applied.
	5-8km	4200	
	8-11km	4800	
	11-14km	5400	
	14-17km	6000	
	17-20km	6600	
DLTEVA	0-20km	3600	The delay from the beginning of the sheltering period to the beginning of evacuation. During this duration, sheltering shielding factors are applied.

2.4. Sensitivity Analysis

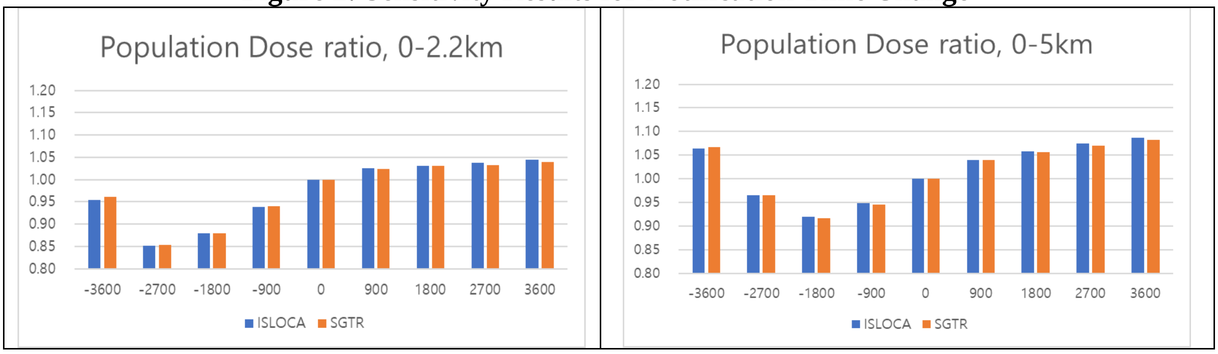
After the notification delay time, people will receive a dose corrected for the normal activity shielding factor during DLTSHL time, receive a dose corrected for the sheltering shielding factor for the DLTEVA time, and then evacuate. Sensitivity analysis was performed by changing the OALARM time only as shown in the following Table 4 to see the influence of the notification delay time.

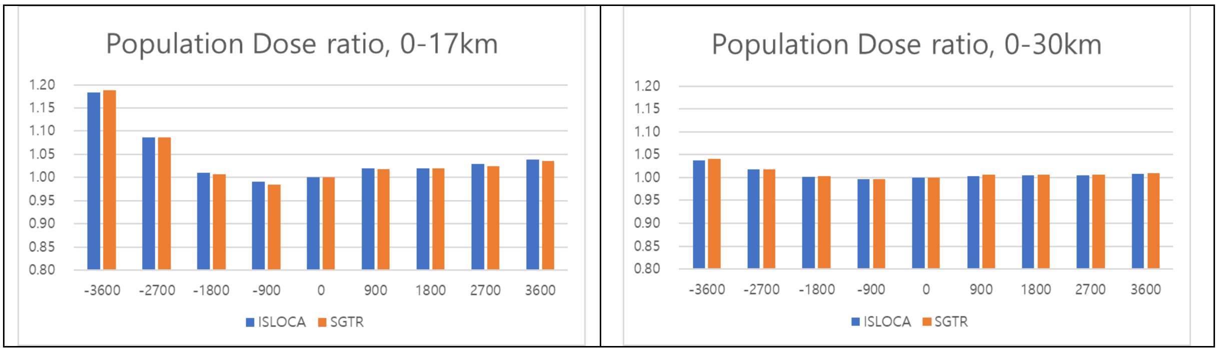
Table 4: Notification Time Change

OALARM	-3600	-2700	-1800	-900	Release time	+900	+1800	+2700	+3600
ISLOCA	675	1575	2475	3375	4275	5175	6075	6975	7875
SGTR	7652	8552	9452	10352	11252	12152	13052	13952	14852

Sensitivity analysis was performed on 10 cases with OALARM from -60 to +60 minutes based on release time. When the OALARM is same as the release time, the population dose is presented as 1.0. The ratio of the dose for each case is shown in the following Figure 2.

Figure 2: Sensitivity Results for Notification Time Change





In general, the shorter the notification time, the sooner the public protection measures will be taken. It is expected that the population dose will decrease. It can be seen in Figure 2 that the population dose is likely to increase monotone as the notification time increases, but not at all conditions except the notification time are the same. In the 0-2.2 km results, the population dose if the notification time is earlier than release time. However, an hour early notification results in greater population dose than 45 minutes early notification. Residents who are notified 2 hours early within 2.2km evacuate 15 minutes early. The people eventually reach the plume because the evacuation speed is faster than average wind speed. Thus, the people are additionally affected by cloudshine. As the distance increases, the population increases exponentially as shown in the following Table 5, and the tendency of change in the graph is the same, but it eventually converges to 1.0.

Table 5: Population within Each Distance

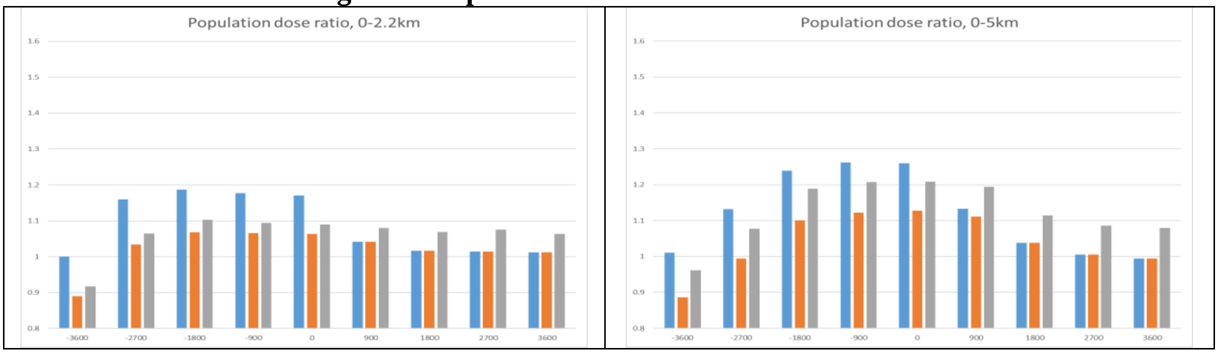
Distance(km)	0-2.2	0-5	0-17	0-30
Population	1219	5683	224610	3208667

The above results led us to be curious about the population within 20 km in front of and behind the tail of plume. The DLTEVA time was set for each sector by comparing the time at which the tail reaches the midpoint of each sector with the average wind speed and the total delay time to evacuate at each sector. The three scenarios are as follows,

Scenario 1: Evacuation five minutes before the tail of plume reaches the midpoints of each sector.
Scenario 2: Evacuation five minutes after the tail of plume reaches the midpoints of each sector.
Scenario 3: Scenario 2 + half of evacuation speed

To add the description of three scenarios, scenario 1 (blue graph) is to evacuate under the plume. Scenario 2 (red graph) is to evacuate behind the plume tail. Scenario 3 (gray graph) is to evacuate with slower speed than scenario 2. The results are shown in Figure 3 and 4.

Figure 3: Population Dose Results for ISLOCA



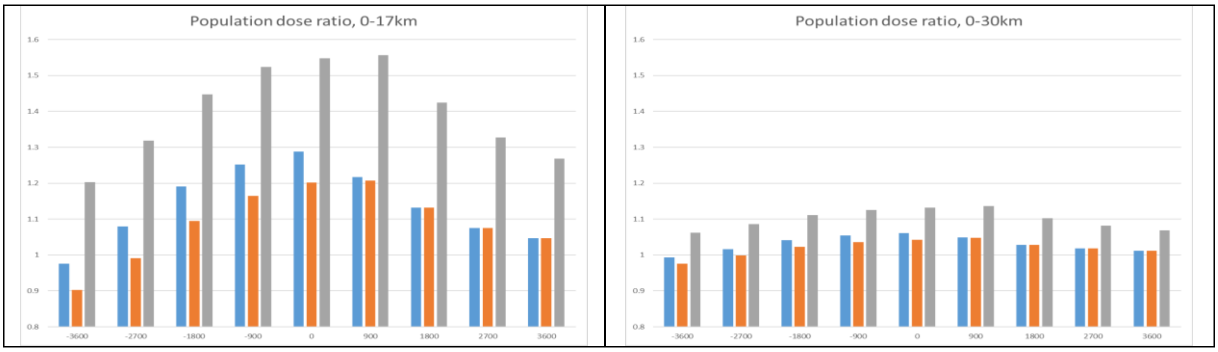
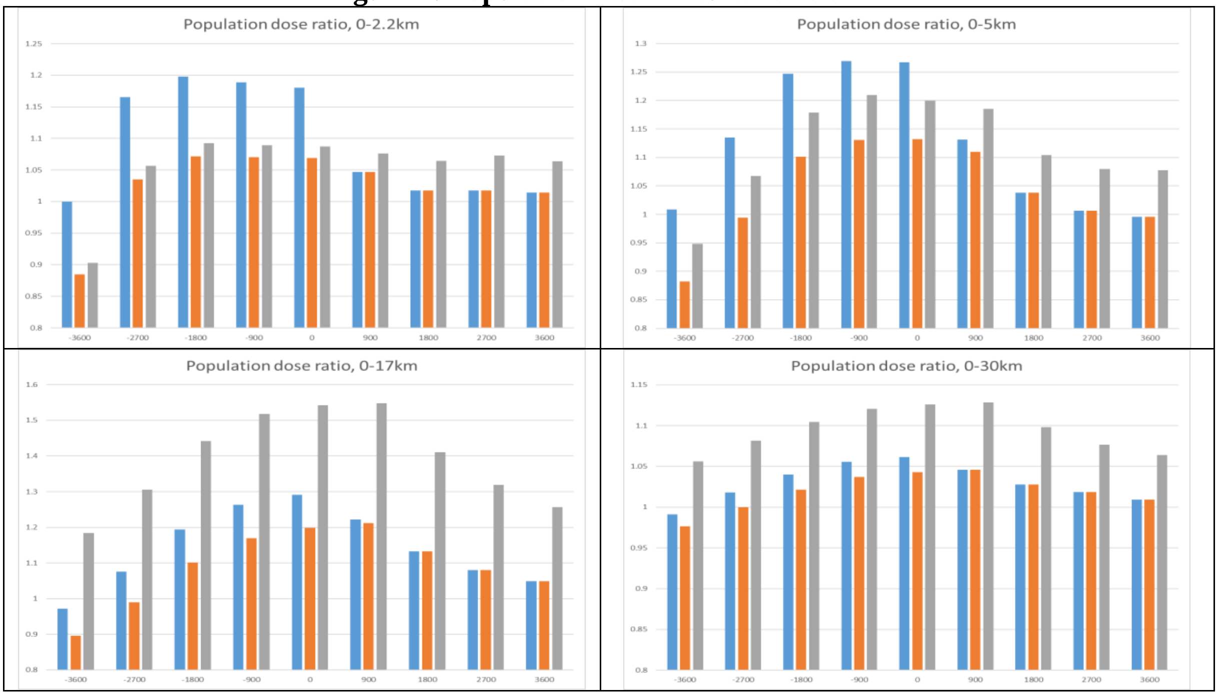


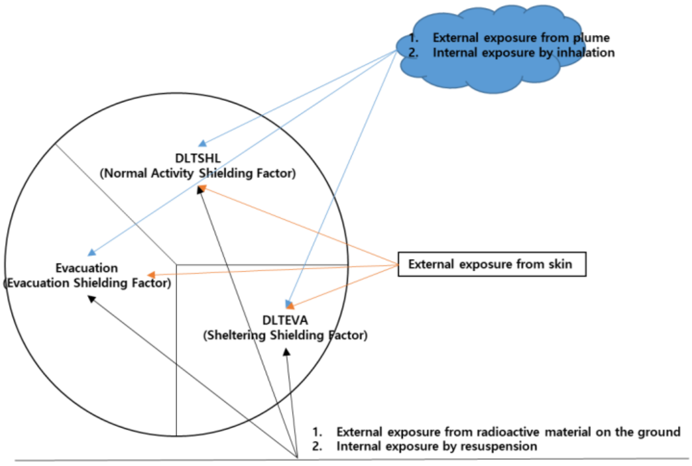
Figure 4: Population Dose Results for SGTR



The graph trends by distance and scenario are similar. In the 0-2.2 and 0-5 km results, it is advantageous in terms of public dose to evacuate after the plume has passed if it is notified faster than the release time. If the notification time is later than the release time, the scenarios 1 and 2 become equal because the plume has already passed. Therefore, in this case, scenario 3 becomes the most disadvantageous. In the 0-17 km and 0-30 km results, scenario 3 is the most disadvantageous due to the exponential population growth, regardless of the time of notification. However, the trends of Scenario 1 and 2 are similar to the previous two cases.

Therefore, we could find the fact that it is most advantageous to complete the evacuation before release of the plume or, if the plume has passed, to evacuate at the maximum speed that will not enter the plume. The insight obtained from the two previous sensitivity analyzes is as follows. To model an optimal emergency response scenario, the total public dose (size of cake) should be reduced. If the size can not be reduced, the dose is simply divided by the exposure path. It is described in Figure 5.

Figure 5: All Exposure Path Way

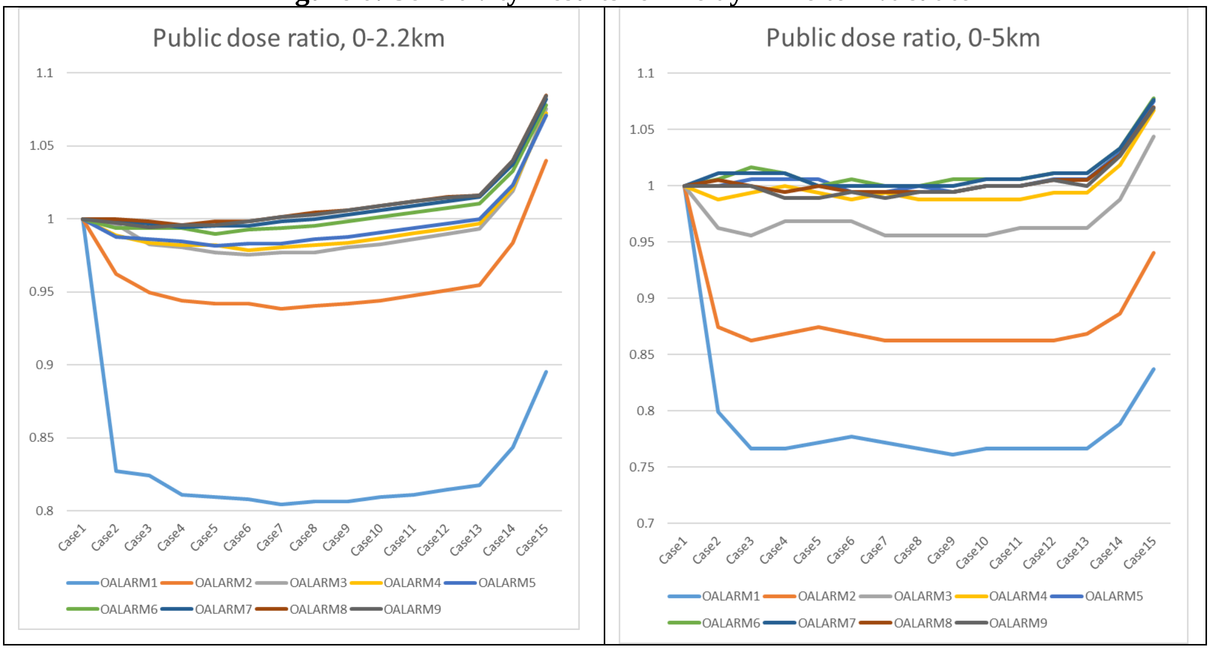


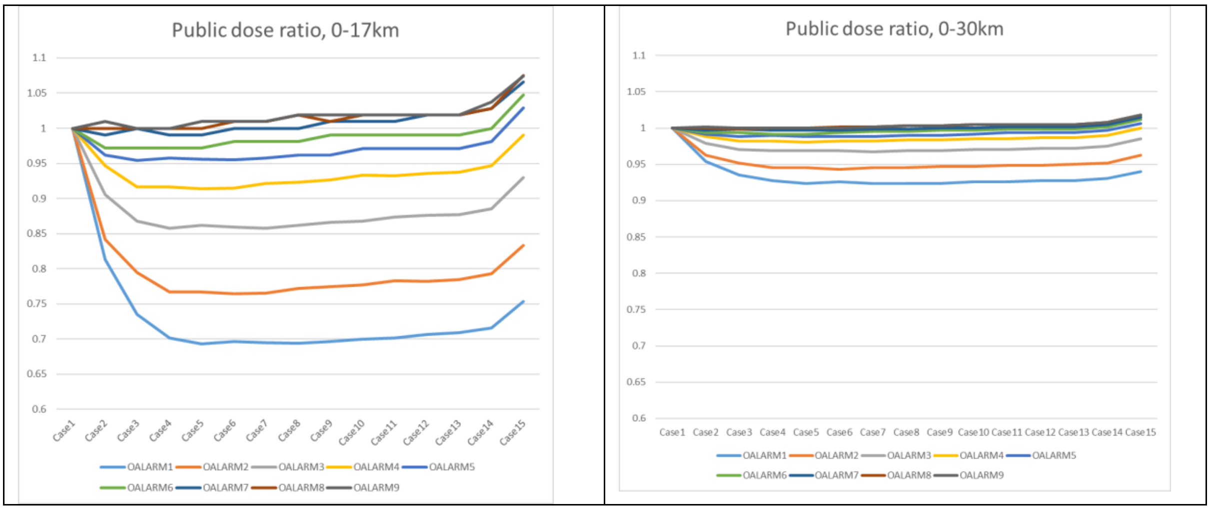
We had to consider how much sheltering time should be beneficial. To investigate the effect of sheltering time, sensitivity analysis was performed by increasing the DLTEVA of all sectors comparing to the base case (DLTEVA = 3600). The DLTEVA values for each case are shown in Table 6. Since the trends of the ISLOCA and SGTR result graphs are similar, only the result graph for ISLOCA is shown in Figure 6.

Table 6: Delay Time to Evacuate

Case	1(BASE)	2	3	4	5	6	7	8
DLTEVA	1h	1h30m	2h	2h30m	3h	3h30m	4h	4h30m
Case	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**-**
DLTEVA	5h	5h30m	6h	6h30m	7h	12h	24h	

Figure 6: Sensitivity Results for Delay Time to Evacuate





The graph has a U-shape. The shorter the notification time, the greater the dose reduction due to the longer sheltering time. It means that the response scenario could be beneficial in terms of population dose when all populations are sheltered until all plumes pass. And, there are small fluctuations in the graphs. It is caused by competition between the dose increase for the population entering the plume and dose reduction by sheltering. And, if sheltering lasts, population dose will eventually increase due to groundshine exposure pathway.

3. CONCLUSION AND LIMITATION

3.1 Conclusion

When massive radioactive materials release into the environment, early public protection measures are very critical for public to reduce the health effect. Sheltering and evacuation are considered as the early protection measures. However, in real situation, it is difficult to evacuate all residents in EPZ perfectly due to various and unpredictable variables. Hence, it is important to identify the key factors that affect the most realistic and effective early public protection measures and their impacts. From this point of view, in this study, we conducted several sensitivity analyzes for important variables and scenarios using WinMACCS 3.10. We could find the fact that the public dose can be increased unexpectedly if only the notification time is reduced. Also, it is the most advantageous response scenario to evacuate before the plume arrives if it is notified quickly or to evacuate at the maximum speed that does not exceeds the speed of plume tail if the plume has passed.

In conclusion, it is hard to find optimal and realistic public protection measures for reducing health effects. However, we can improve the current emergency preparedness plan with detailed and various simulations. The results of simulations would be useful not to analysis consequences underestimated or overestimated, and to improve the current emergency preparedness plan using its results. Therefore, we hope that this study would be used as an infrastructure technology for improvement of the public protection measures presented in the radiation emergency plan.

3.2 Limitation

In order to construct a more realistic and conservative model, the following improvements is needed. It is necessary to analyze the characteristics of various cohorts, and reflect it in the emergency response model. In this study, we used DLTSHL for 1 hour within 5km and extended time in 5-20km. It did not reflect the real situation. Hence, we need to Evacuation Time Estimate such as questionnaires for trip generation time and traffic simulation code for base evacuation speed. Finally, for the more realistic analysis, study should be re-conducted in consideration of multi-source terms.

Acknowledgements

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