COMPARISON OF THE CONSEQUENCES BETWEEN SHELTERING AND EVACUATION DURING HYPOTHETICAL NUCLEAR EMERGENCY SITUATION

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There has been a simple question of curiosity which action scenario would be a better one among successful evacuation, successful sheltering and unsuccessful evacuation in emergency phase of nuclear plant accidents. To obtain insights into answering the foregoing question, dose assessment including typical emergency actions were performed for three representative severe accident scenarios (early, intermediate, and late release). It has been found that unsuccessful evacuation with very low evacuation speed in early release scenario could lead to adverse effect due to long-duration outdoor exposure to relatively high dose. It has been also found that to last sheltering too long time cannot be a good solution even though appropriate sheltering in early phase may helpful when adequate fast evacuation speed is not guaranteed. This study emphasizes the importance of successful evacuation ensuring adequately fast evacuation speed. In addition, appropriate initial sheltering in the EPZ could help emergency response especially in high-dose and early release scenario, if adequately fast evacuation speed is not guaranteed. Evacuation speed and shielding / exposure factors are regarded as the most important factors to be examined in further study.

I. INTRODUCTION

Though it cannot be simply answered, there is a simple question of curiosity which scenario would be a better scenario among the success of evacuation or successful sheltering when nuclear emergency situation happens. In addition, it is wondered how the offsite consequences would be influenced when evacuation is unsuccessful due to traffic jam, failure of roads and buildings by earthquake or tsunami, public panic, and etc. Preliminary investigation giving an insight for answering this question has been performed in this study. Representative scenarios of source term and emergency responses were selected and applied for the analyses and the results were compared to obtain the insight about countermeasures in emergency situations.

II. METHOD

II.A. Source Term

Three source term release scenarios representing early, intermediate, and late releases, which were obtained by performing Level 2 PSA of the reference plant (Korean PWR with 1,000 MWe) were selected for the present analysis. As initial conditions of the dose assessment, typical characteristics of each Source Term Category (STC) for the aforementioned three scenarios are summarized in Table I.

Modular Accident Analysis Program Version 5 (MAAP5)[1] was used to calculate release amounts and fractions of radionuclides for the early, intermediate, and late release scenarios. MELCOR Accident Consequence Code System 2 (MACCS2)[2] was employed for performing dose assessment. Due to the different composition of radionuclide groups between MAAP5 and MACCS2, conversion of source term is necessary procedure as preprocess. Conversion from the results of MAAP5 into MACCS2 input was performed by using the source term conversion module of Korea Off-site Consequence Analysis code package (KOSCA-SOURCE)[3]. Fig. 1 shows the source term conversion of early release scenario by using KOSCA-SOURCE.

TABLE I. Characteristics of Early, Intermediate, and Late Release

	Early Release	Intermediate Release	Late Release
Reactor Type	Korean PWR with 1,000 MWe		
Source Term Category	STC-19	STC-04	STC-14
Initiating Event	LOOP	TLOCCW	TLOCCW
Major Events	NOTISO	ECF, LEAK	LCF, RUPTURE
Delay Time of Release	2.25 hours	19.25 hours	48 hours
Release Fractions after 72 hours	- Xe: 100% - CsI: 31%	- Xe: 98.7% - CsI: 3.67%	- Xe: 100% - CsI: 0.994%

II.B. Meteorological and Population Data

Annual meteorological data of the reference plant site was converted into MACCS2 input format by using the meteorological data conversion module of KOSCA-MACCS2 (KOSCA-METEO)[3]. Sector population and land fraction data of the reference plant site was calculated by population and land fraction calculation module of KOSCA-MACCS2 (KOSCA-POP)[3] using 2010 census data and recent geographic map of the administrative district. Example calculation of sector population is shown in Fig. 1.

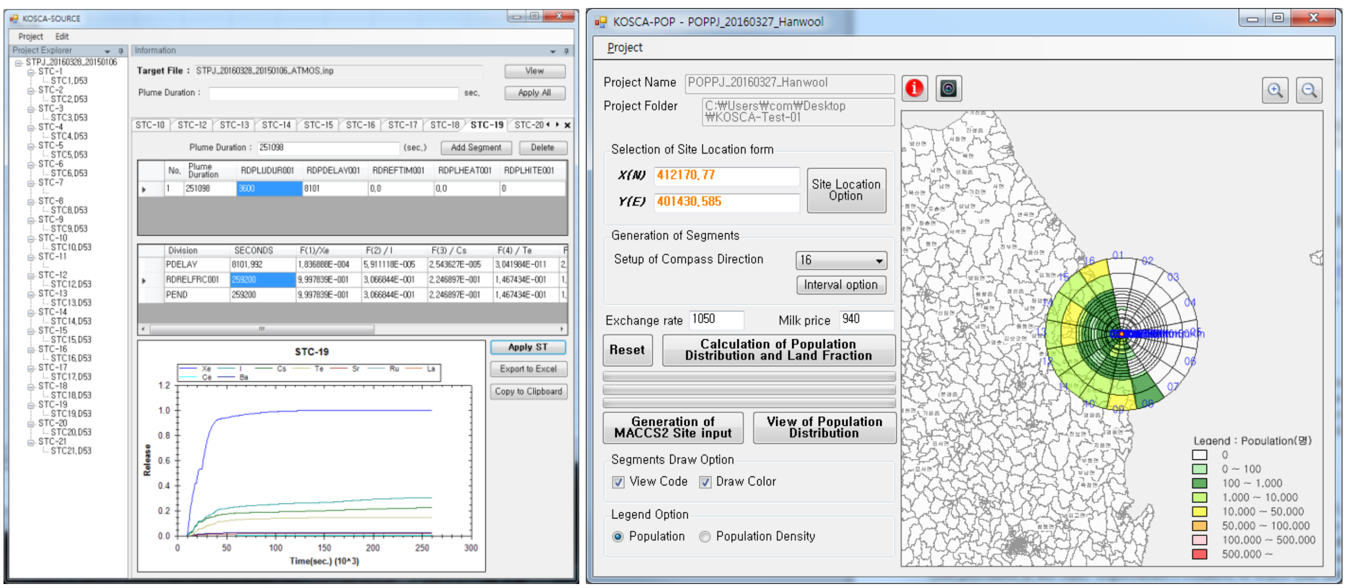

Fig. 1. Example of the Source Conversion from the Result of MAAP5 into MACCS2 Input Using KOSCA-SOURCE (Left-hand) and the Sector Population Calculation Using KOSCA-POP (Right-hand)

II.C. Emergency Response Scenario

Total one-week of emergency phase was considered in this study following the typical way has been performed in MACCS analysis. Modeling of emergency response has been conducted by EARLY module of MACCS. Long-term phase including the exposure by ingestion pathway was excluded because only differences originated from different emergency response actions such as sheltering and evacuation are more concerned and focused in this study. Therefore, only the effect of exposures during the emergency phase (one-week) is the part of interest in this study and the effect of exposures in further duration is beyond the scope of this study. In addition, only dose was estimated excluding frequency of each scenario.

II.C.1. Successful Sheltering Scenario

Every population is assumed to shelter for whole emergency phase (a week) after 1 hour delay of offsite alarm and 2 hours' delay of sheltering. Shielding and exposure factors of cloud shine, ground shine, protection for inhalation, and skin protection were referred to the data of Surry site used in State-of-the-Art Reactor Consequence Analyses (SOARCA)[4] and are listed in Table II. Three kinds of activity types were considered in SOARCA such as evacuee while moving, normal activity in sheltering/evacuation zone, and sheltered activity. Each activity type has different shielding and exposure factors. When people await evacuation, they are assumed to be carrying out normal activity and then sheltering. The shielding factors for normal activity or sheltering are applied to them during these periods. They become evacuees after the starting of moving and shielding factors of evacuation is applied to them during evacuation period[2].

Two kinds of response actions without conducting evacuation have been examined:
1. Normal activity in sheltering/evacuation zone without any mitigative action, and
2. Sheltered activity in sheltering/evacuation zone without evacuation.

TABLE II. Shielding and Exposure Factors of Surry Site[4]

	Evacuation	Normal Activity	Sheltering
Cloud Shielding Factor	1	0.68	0.6
Ground Shielding Factor	0.5	0.26	0.2
Inhalation Protection Factor	0.98	0.46	0.33
Skin Protection Factor	0.98	0.46	0.33

The shielding and exposure factors of normal activity are applied when ‘no evacuation’ option is chosen in MACCS (the first scenario). Therefore, shielding and exposure factors of normal activity were changed to the factors for sheltering in Table 2 when performing the analysis assuming sheltered activity (the second scenario).

II.C.2. Successful Evacuation Scenario

Duration and speed of each phase in successful evacuation scenario have been established referring to the report of development of evacuation time estimation methodologies within EPZ[5]. In this scenario, evacuation of sheltered public starts in 45 minutes after the sheltering. Initial and middle evacuation phase last 30 minutes and 105 minutes respectively and then late evacuation phase follows.

TABLE III. Evacuation Speed of Vehicle in Reference Site by Weather Conditions[5]

	Daytime		Night	
	Normal weather	Adverse weather	Normal weather	Adverse weather
Free velocity on the road (mile/hr)	30	15	25	12.5

Evacuation speeds of a vehicle in reference site by weather conditions are presented in Table III. Compared to the free velocity in normal weather, 50% slower speed has been decided as the free velocity in adverse weather conservatively. Daytime velocity of a vehicle in normal weather (30 miles per hour) was adopted as the evacuation speed for the initial and late evacuation phase and night velocity of a vehicle in adverse weather (12.5 miles per hour) was applied as the evacuation speed for the middle evacuation phase since intense traffic jam is expected during the middle evacuation phase.

II.C.3. Unsuccessful Evacuation Scenario

In this scenario, evacuation is assumed to be unsuccessful due to traffic jam, failure of building and road by earthquake or tsunami, panic of public, and etc. Same period for preparing the evacuation used in successful evacuation scenario applies this scenario too. Walking evacuation with 1.46 m/s of evacuation speed[6] was assumed as unsuccessful evacuation situation and longer duration of evacuation which incurs longer-term outdoor exposure due to slow evacuation speed is predicted in this scenario. In other word, even though identical shielding and exposure factors were used in both successful and unsuccessful scenario, duration of outdoor exposure is longer in latter scenario due to unsuccessful evacuation.

Comparing to the normal activity without sheltering and evacuation, population dose within 5 km / 30 km of each scenario have been calculated normalized to the population dose of normal activity. Y-axis of the results have no unit because the result from normal activity was set up as unit value (green colored) and the other results were normalized. Distances for dose assessments were set up as 5 km and 30 km respectively, referring to the largest area of precautionary action zone (PAZ) and urgent protective action planning zone (UPZ) of Korea.

For every scenario, dose-dependent relocation was considered referring to the values used for Surry site in SOARCA[4].

III. RESULT AND DISCUSSION

III.A. Early Release Scenario

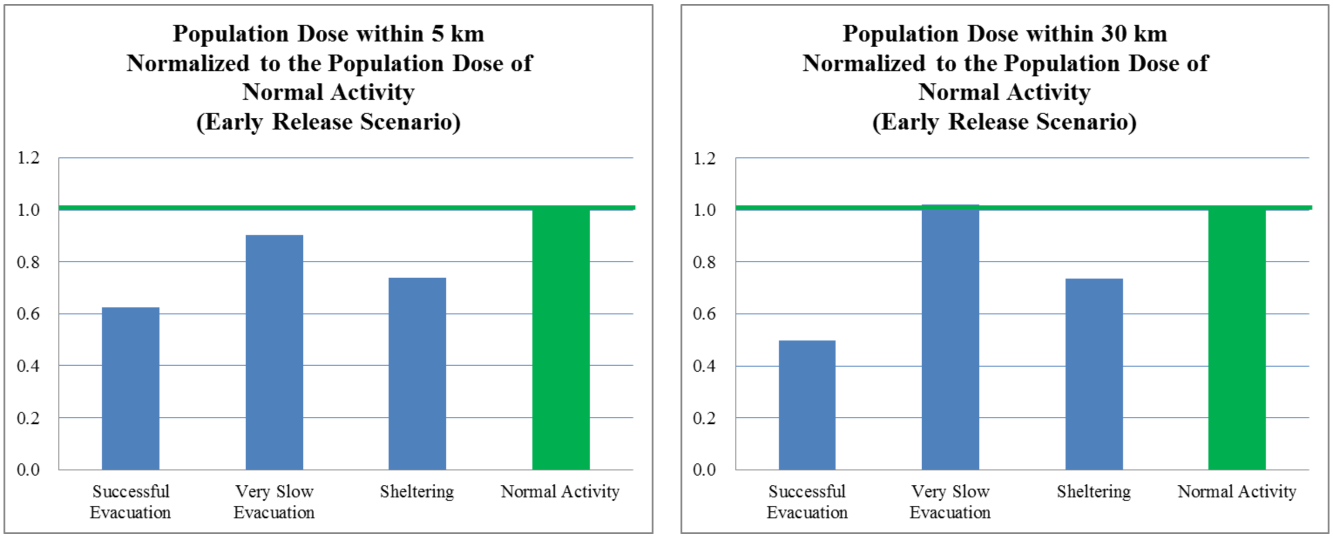

Fig. 2. Population Dose within 5 km (Left-hand) and Population Dose within 30 km (Right-hand)
Normalized to the Population Dose of Normal Activity in Early Release Scenario (Including Relocation)

Every mitigative action assumed in this study has been found to be safer than normal activity in emergency zone, excluding very slow evacuation in the early release scenario especially when we consider the population dose in the UPZ. It has been found that a very unsuccessful mitigative action can lead to worse consequence due to long-duration outdoor exposure to high dose in the early release scenario. The results emphasize the importance of evacuation speed related with the degree of success of the evacuation and it would be regarded more serious in the early release scenario.

III.B. Intermediate and Late Release Scenario

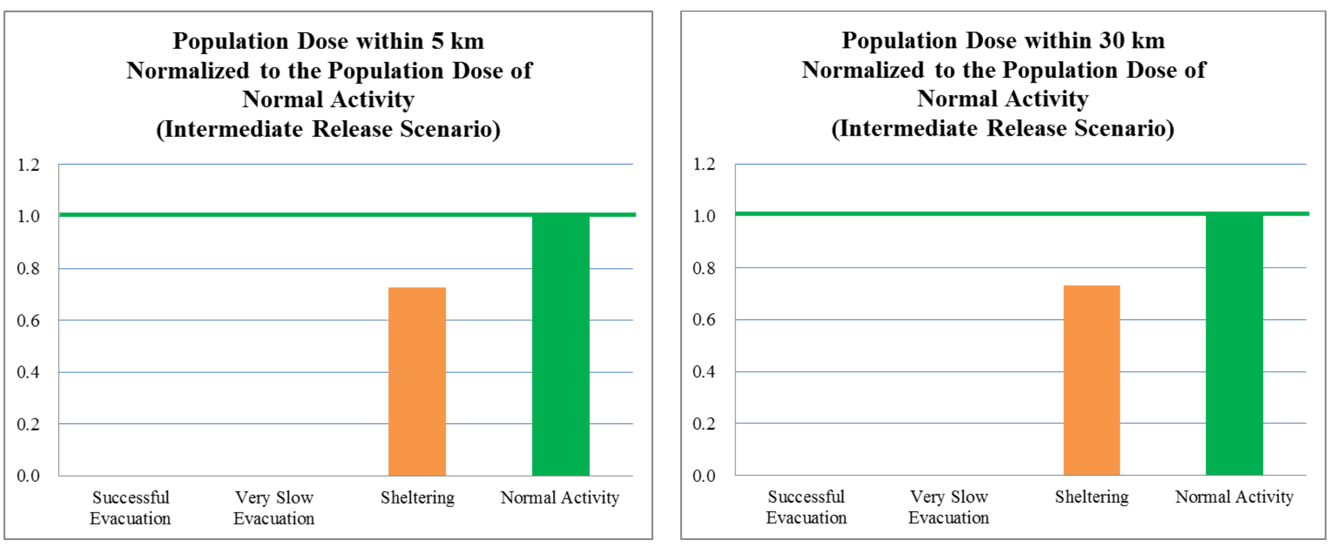

Fig. 3. Population Dose within 5 km (Left-hand) and Population Dose within 30 km (Right-hand)
Normalized to the Population Dose of Normal Activity in Intermediate Release Scenario (Including Relocation)

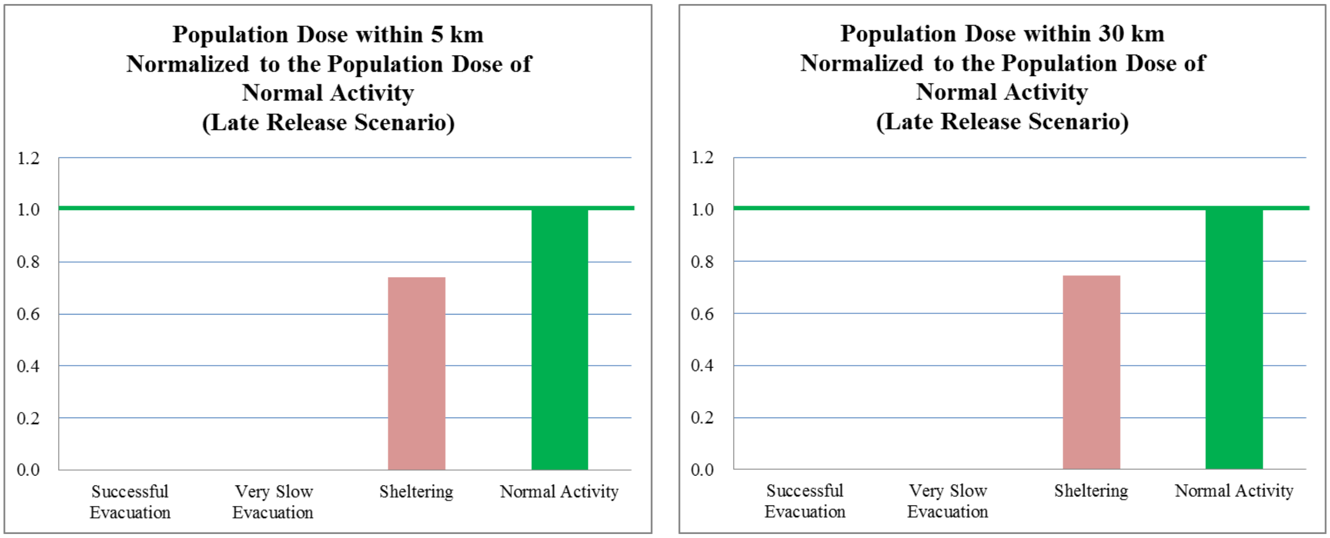

Fig. 4. Population Dose within 5 km (Left-hand) and Population Dose within 30 km (Right-hand) Normalized to the Population Dose of Normal Activity in Late Release Scenario (Including Relocation)

Evacuation has been regarded as a better option than sheltering in both intermediate and late release scenario, even in the case of slow evacuation. It is owing to relatively adequate time for evacuation before release of the source and plume arrival. In addition, release amount of radionuclides in intermediate and late release scenario considered in this study are much lower than that of early release scenario. If evacuation is conducted, zero dose in emergency phase is expected in both intermediate and late release scenario because public evacuate from PAZ and UPZ prior to the plume arrival.

III.C. Results without Dose-dependent Relocation

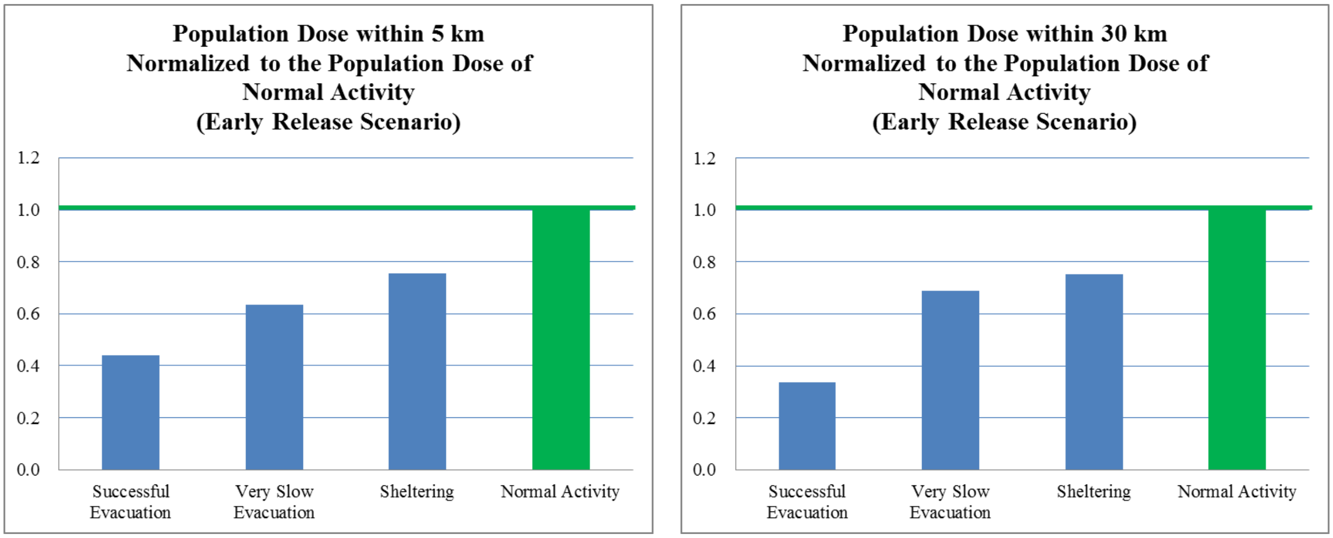

Fig. 5. Population Dose within 5 km (Left-hand) and Population Dose within 30 km (Right-hand) Normalized to the Population Dose of Normal Activity in Early Release Scenario (Excluding Relocation)

When dose-dependent relocation is not included as additional mitigative action, sheltering could not be a better solution than evacuation in any release scenario, because evacuees stay in EPZ and are exposed for whole period of emergency phase. This results means that to last sheltering too long time cannot be a good solution even though appropriate sheltering in early phase may helpful when adequate fast evacuation speed is not guaranteed.

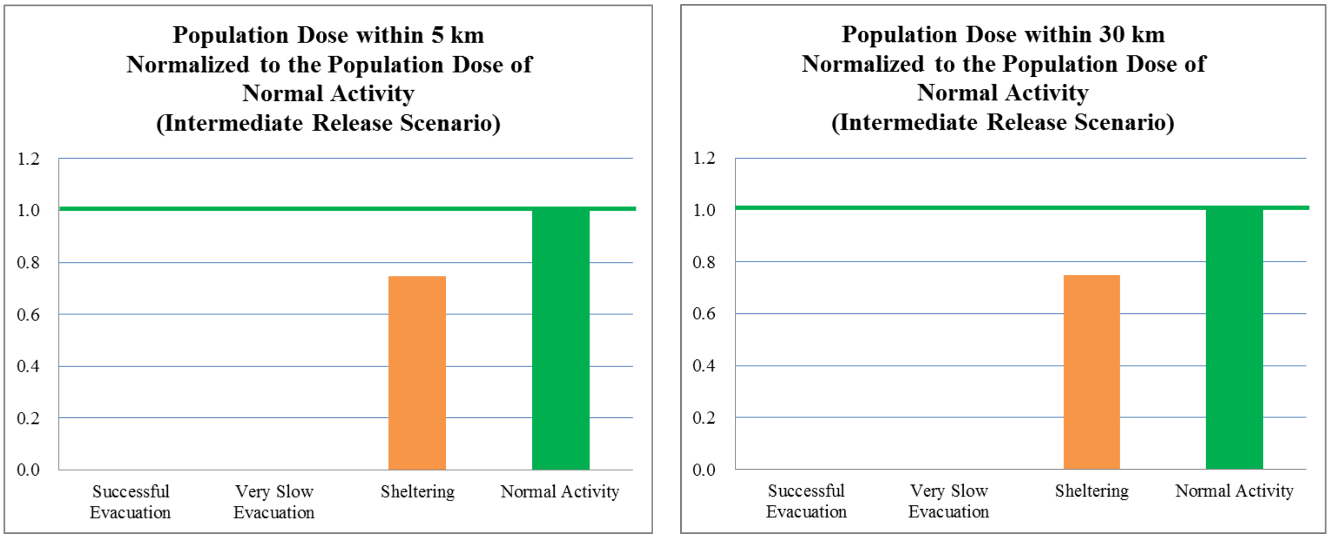

Fig. 6. Population Dose within 5 km (Left-hand) and Population Dose within 30 km (Right-hand) Normalized to the Population Dose of Normal Activity in Intermediate Release Scenario (Excluding Relocation)

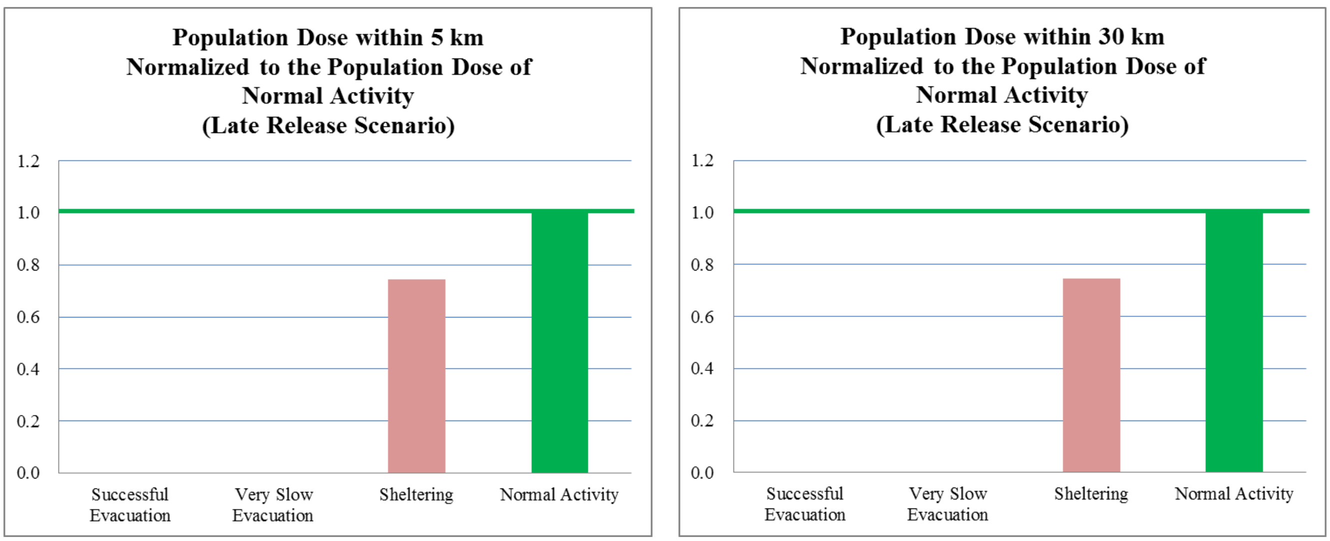

Fig. 7. Population Dose within 5 km (Left-hand) and Population Dose within 30 km (Right-hand) Normalized to the Population Dose of Normal Activity in Late Release Scenario (Excluding Relocation)

IV. CONCLUSION

Various kinds of emergency response options have been considered in this study with the early, intermediate, and late source release scenario. Conducting an evacuation has been found to be the best option in almost every scenario. However, it has been found that evacuation with very slow speed can make worse effect especially in early release scenario due to long-duration outdoor exposure to relatively high dose. Even though situations are possibly different up to the evacuation speed, it has been found that appropriate initial sheltering in the EPZ could help emergency response especially in high dose and early release scenario, if adequately fast evacuation speed is not guaranteed.

The importance of successful evacuation ensuring fast evacuation speed is emphasized in this study. In other word, emergency preparedness is very important such as developing well-established strategy, providing steady education and training, constructing the infrastructure to response the emergency situation, and so on.

Sensitivity analyses using evacuation speed, release duration, and shielding/exposure factors can be performed as further studies.

V. LIMITATIONS OF THE STUDY

Only three kinds of source release scenarios such as early, intermediate, and late release were taken into account in this study as the representative scenarios. More various scenarios having different characteristics of release should be assessed in further study. Every amount of radionuclides calculated for 72 hours accident progression was assumed to release to the environment in the first one hour in this study conservatively. Further study with more realistic source release model should be carried out and be compared to the results estimated in this study. Frequencies of each source release scenario have not been considered in this study and it should be noted that only consequence analysis was performed rather than risk analysis taking into account both consequence and frequency. This is a possible further study as well.

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