Estimation of external gamma doses from deposited radionuclide on inhabited areas of Korea

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Abstract. Studies for understanding gamma external dose from the radionuclide deposited on urban inhabited area have been conducted after Fukushima nuclear accident in Japan. Several months after Fukushima accident, it was needed to evaluate dose reduction factors of the buildings in inhabited area for determining a criterion value for the designation of the intensive contamination survey area. It was known that radiocesium is the major nuclide contributing to ambient dose rates in the area affected by the Fukushima accident. And several experts have studied the distribution of radiocesium inventories on components in urban areas in the evacuation zone affected by the accident to provide the essential parameters for dose evaluation models and to better understand the migration of radiocesium deposited in urban areas. Fukushima accident has showed that the information on the dose reduction factors of the buildings in inhabited area is essential for the selection of the long-term countermeasure. Japan had difficulties in conducting the long-term emergency preparedness due to the lack of the data on the dose reduction factors of the buildings in inhabited area after Fukushima accident. In Korea, the early phase emergency preparedness system against a nuclear accident had been established. But this system is not appropriate for supporting long term emergency preparedness. One of the essential data for establishing site specific long term emergency preparedness system is the dose reduction factors of the buildings in inhabited area. It is because that the biggest contribution on the radiation effect in long term phase is the external gamma dose given from the deposited radionuclide on inhabited area. In this study, the air kerma at various locations inside and outside the 9 cases of Korean domestic buildings were estimated. The evaluation were performed for three radiation source energies of 0.3 MeV, 0.662 MeV and 3.0 MeV.

KEYWORDS: long term phase, inhabited area, air kerma

1 INTRODUCTION

The concept of shielding factor was developed in the United State to predict the radiation effects due to the radioactive fallout deposited on the surface of buildings in 1950s. After Chernobyl accident, German scientists studied the modification of gamma exposure from deposited activity at locations inside and outside of buildings in urban environments using the Monte Carlo method. They evaluated the kinetic energy released per unit mass (kerma) at various locations inside and outside the buildings due to a contamination with unit surface activity for each of the various deposition areas such as walls, windows, roofs, light shafts, paved areas, lawns, and trees [1]. They also estimated the location factors, defined as the ratio of the exposure rate at the respective location and the exposure rate over lawns for different types of deposition and environments of buildings [2].

After the Fukushima accident, in other to assess the impact of the accident and make decisions for protective and remediation actions, comprehensive monitoring data have been obtained by national projects for large-scale environmental monitoring [3,4]. Soon after the accident, in situ measurements were carried out in contaminated areas and dose reduction factors were obtained [5]. Dose reduction factors are useful quantities for the realistic assessment of indoor dose rate in the situation of the deposition on the various surfaces on the environment [6]. About half a year after the Fukushima accident, a criterion value for the designation of the intensive contamination survey area of 0.23 μSv/h was determined on the basis of the dose reduction factor of one- and two- story wood frame homes and the typical pattern of life by the Ministry of environment [7]. No studies on dose reduction factors according to various situations had been conducted until then. Therefore, the factor being expressed as the ratio of the dose inside to that outside the house was not obtained on the basis of Japanese-style houses. And in order to obtain the dose reduction factors for Japanese-style houses, measurements of air dose rates for 192 houses in a less contaminated area (<0.5 μSv/h) of the Fukushima Prefecture in Japan were conducted in both living rooms and/or bedrooms using optically stimulated luminesence (OSL) dosimeters and around the houses via a man-borne survey at intervals of several meters [8]. In any case, the dose reduction factor varies largely according to local conditions. The main reason of the variation is considered to be that the air dose rate could fluctuate according to location, especially in a contaminated area, and it is not easy to select representative locations to calculate the dose reduction factor [9].

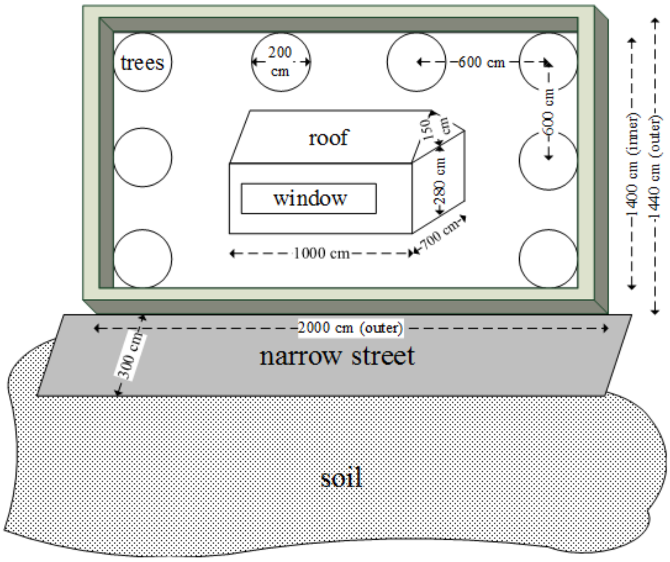
In Korea, an early phase emergency preparedness system against a nuclear accident has been established. The system is designed mainly for supporting the decision making of early countermeasure. And no studies has been conducted for obtaining dose reduction factors for Korean style houses which are essential for long term emergency preparedness. In this study, the air kerma at various locations inside and outside the 9 cases of Korean domestic buildings were estimated. The estimation were performed for three radiation source energies of 0.3 MeV, 0.662 MeV and 3.0 MeV. And the dose reduction factors of the Korean buildings in inhabited area were estimated using a relative source strength based on the experiences of European countries and Japan.

2 MODEL DESCRIPTION

For the estimation of the air kerma at locations inside and outside of Korean style houses, the 9 cases of design were considered. The 9 cases are consists of 3 for single family house (see Figure 1), 3 for multiplex housing (see Figure 2) and 3 for apartment (see Figure 3). According to the 2015 Korea national census on population and housing, the percentage of single family house, multiplex housing and apartment are 60%, 25% and 15%, respectively [10]. In Korea, unlike Japan, most buildings are made of concrete. For the pathway analysis of external gamma exposure, the considered contaminated surfaces are as follows: walls, windows, roofs (for building) and trees, garden, alley way, park (outside of building).

Figure 1 shows the x-y plane view of a single house that was modelled as case 1 for the estimation of the kerma. The height of the fence is 150 cm and the width of the wall and fence is 20 cm. The height of wall of house is 280 cm and 30 % of the front wall is window with 2 cm width. Case 1 is the stand alone house on a filed which is typical in Korean mountainous areas. Case 2 where the houses are arranged in a row, and Case 3 is a model that is repeatedly arranged in a row with narrow paths between houses.

Figure 1: Conceptual model of a single family house (Case 1, 2, and 3)



As shown in Figure 2, the multiplex housing model consists of a semi-basement and four floors above the ground. One layer is 280 cm high and is composed of 20 cm thick concrete between layers. Case 4 is a residential environment in a sparsely populated area. Case 5 is a multiplex housing constructed on a site planned for two rows between a road and a road, such as a detached house in Case 3. Case 6 represents the type of multiplex housing built in an unplanned old town without considering parking or vehicle traffic.

Figure 2: Conceptual model of a multiplex housing (Case 4, 5, and 6)

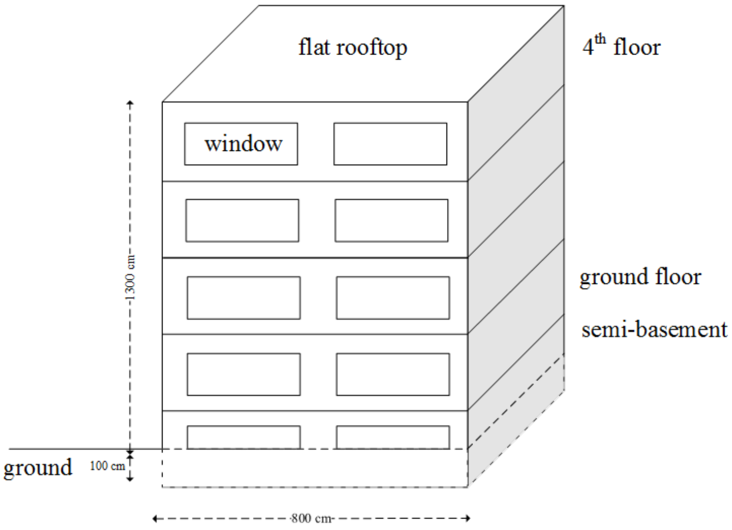
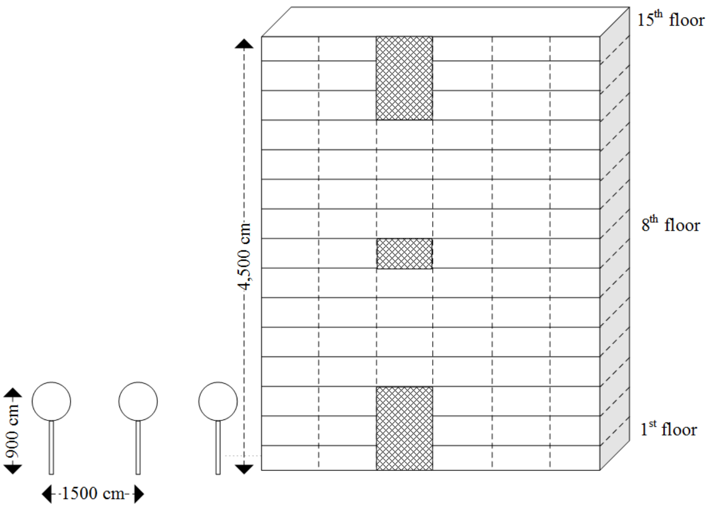


Figure 3 shows the apartment model. One floor of an apartment building consists of 300 cm high and 20 cm thick concrete between the floors. The ceiling of the 15th floor, the highest floor, has the same 20 cm concrete ceiling. The height of the roof of the building is 45 m. One apartment house consists of 9 m in width (x-axis direction) and 9 m in length (y-axis direction), with an area of 81 m^2 per unit. As room six is for one floor, one apartment building is 54 meters wide and 9 meters long. The windows of the apartment are 70 percent of the width of the front wall and consist of about 20 percent of the rear wall. The four corners of the building, which are identical to detached houses and multiplex houses, were designed with concrete columns containing reinforcing bars. The thickness of the columns, walls, and ceilings is assumed to be 20 cm, and the thickness of the windows is assumed to be 2 cm. Cases 7, 8, and 9 are configurations that can be identified in a single complex, unlike detached or multiplex housing.

Figure 3: Conceptual model of an apartment (Case 7, 8, and 9)



3 RESULTS AND DISCUSSION

The amount of radiation exposed to a person as expressed in Eq. 1, is affected by a number of factors such as walls, surrounding trees, and neighbouring houses.

$$D = (Wall + Roof)_{Dwelling\ House} + Trees + Ground(Park) + (Wall + Roof)_{Neighboring\ House} \tag{1}$$

As a dose reduction factor, the DRF is considered as the ratio of doses received internally to external dose. In this study, it is assumed that radiation doses increase linearly in the value of air kerma, and thus DRF is defined as the ratio of air kerma sum as shown in Eq. 2.

$$DRF = \frac{\sum K_{inside}}{\sum K_{outside}} \tag{2}$$

A series of air kerma values for each model were calculated using the MCNP5 Monte Carlo code [11]. For each type of housing, the surface considered as a source may be largely divided into the inside and outside the house. It was assessed based on the assumption that the alleys, roads, and open fields of detached houses or multiplex houses are infinite (radius 300 m). On the other hand, the scope of surface sources for roads, parks, and adjacent complexes was defined in a finite range, considering that the apartment is a downtown area with few open fields and the complexes are set to be blocked. In addition, grounds and trees in the apartment complex were classified as external sources of residence because they were not separated by apartment buildings.
Tables 1 through Table 3 show the values of internal and external kerma for the gamma-ray source with the energy of 0.662 MeV for the most basic type of each representative house. Each kerma value was calculated for each location contaminated by radiation separating the inside and outside the house. There are differences in the subject of contamination by the type of houses. Case 1 showed the highest external kerma value when the open field was contaminated, case 4 showed the highest external kerma value when the road was contaminated, and case 7 showed high value if the complex's ground was contaminated.

Table 1: Kerma on various exposure positions (Case 1, E: 0.662 MeV)

Contaminated Surface		Gamma-ray Energy: 0.662 MeV	
		Internal kerma (pGy/gamma-mm^{-2})	External kerma (pGy/gamma-mm^{-2})
Inside the house	Garden	6.75	3.87
	Window	19.85	2.46
	Wall	7.99	5.23
	Roof	85.49	11.30
	Fence	5.87	3.70
	Tree	19.19	41.85
Outside the house	Narrow path	0.68	221.89
	Open field	18.95	309.08

Table 2: Kerma on various exposure positions (Case 4, E: 0.662 MeV)

Contaminated Surface		Gamma-ray Energy: 0.662 MeV					
		Internal kerma (pGy/gamma-mm^{-2})					External kerma (pGy/gamma-mm^{-2})
		Semi-basement	1st floor	2nd floor	3rd floor	4th floor	
Inside the house	Surrounding ground	2.29	0.04	0.004	0.002	0.001	11.24
	Window	31.35	31.27	31.17	31.46	31.36	174.37
	Wall	7.72	8.04	8.02	8.06	7.45	96.10
	Roof	0.001	0.002	0.002	0.01	0.13	0.06
Outside the house	Ground around neighborhood	0.81	0.03	0.01	0.003	0.001	2.37
	Neighbor's window	8.32	8.59	8.52	8.46	8.56	57.97
	Neighbor's wall	5.71	6.24	6.48	5.94	5.70	38.15
	Neighbor's roof	0.01	0.01	0.01	0.03	0.66	0.29
	Road	15.49	2.82	1.13	0.64	0.49	319.09
	Open field	26.44	14.65	12.86	11.64	9.06	187.26

Table 3: Kerma on various exposure positions (Case 7, E: 0.662 MeV)

Contaminated Surface		Gamma-ray Energy: 0.662 MeV							
		Internal kerma (pGy/gamma-mm^{-2})							External kerma (pGy/gamma-mm^{-2})
		Low floor			Center	High floor			
		1st floor	2nd floor	3rd floor	8th floor	13th floor	14th floor	15th floor	
Inside the house	Window	19.51	20.06	20.19	19.81	19.78	19.66	19.39	119.05
	Wall	4.66	4.73	4.48	4.55	4.42	4.68	4.31	162.84
	Roof	0.005	0.007	0.008	0.01	0.05	0.18	3.61	0.13
Outside the house	Neighbor's window	3.02	3.39	3.48	3.76	3.41	2.80	1.69	10.39
	Neighbor's wall	4.90	4.84	5.06	5.02	4.16	3.16	2.45	17.31
	Neighbor's roof	0.02	0.03	0.02	0.04	1.56	4.87	5.51	0.83
	Complex's ground	13.29	4.74	2.49	0.49	0.22	0.21	0.20	367.95
	Road	8.75	4.58	3.33	0.89	0.38	0.40	0.37	112.03
	Park	9.01	5.78	4.07	2.49	1.42	1.38	0.97	53.36
	Trees in the complex	0.35	1.64	1.45	0.03	0.01	0.01	0.01	0.04
	Roadside trees	0.53	0.54	0.36	0.07	0.03	0.02	0.02	0.05
	Trees in the park	0.66	0.57	0.41	0.12	0.06	0.05	0.05	0.09

After the Fukushima accident, the distribution of ^{137}Cs on components in urban areas has been investigated by many researchers. Relative ^{137}Cs inventory on components such as roofs, walls and windows are needed for the estimation of external dose. There are variations in the values of relative ^{137}Cs inventory on components even if it is the same factor. In this study, the relative source strength of different surfaces of Korean buildings were assumed using the data obtained in Europe and Japan. Table 4 shows the relative source strength of each surface assumed to be appropriate for the real situation in Korea. In the case of grass, radioactive materials are deposited very easily because of the greatest surface roughness. In addition, trees, roofs, and roads have high relative deposition rates because they are good for storing airborne radioactive materials from falling radioactive materials. On the other hand, the materials such as walls and windows are arranged vertically and in planar, so the relative deposition rates are evaluated to be quite low compared to other values.

Table 4: Relative source strength of different surfaces

Surfaces	Relative ^{137}Cs Inventory
Roofs	0.3
Walls	0.02
Windows	0.01
Streets	0.3
Trees	0.5
Lawns	1

Following the recent Fukushima accident, a DRF was calculated for the local environment in Japan [8]. The study is based on light houses and heavy houses, which are made of materials such as wood or thin steel panels, while heavy houses are made of materials such as concrete. The shielding effect of light houses is numerically less shielded than that of heavy houses. When calculating the DRF based on the characteristics of Korean housing, the results were as shown in Table 5. Overall, the value of the results was found to be lower, especially for multiplex housing, which was significantly lower than that of detached houses. In light of these DRF values, Korean houses were generally assessed to have good shielding performance.

Table 5: Dose reduction factors

Cases		**DRF**
Detached House	Case1	0.17
	Case2	0.19
	Case3	0.49
Multiplex House (1st Floor)	Case4	0.05
	Case5	0.02
	Case6	0.02
Apartment (1st Floor)	Case7	0.05
	Case8	0.05
	Case9	0.04

4 CONCLUSION

The biggest contribution on the radiation effects in long-term phase of a nuclear accident is the external gamma-ray doses given from the deposited radionuclides on inhabited area. Dose reduction factor of the buildings arranged in inhabited areas around a nuclear facility is one of the key factors for establishing site-specific long-term emergency preparedness. These factors of the buildings are dependent on the relative source strength of different surfaces. In this study, the relative source strength of different surfaces of Korean buildings were assumed using the data obtained in Europe and Japan. On the other hand, it is necessary to calculate the relative source strength by reflecting the unique environment of Korea in order to increase the accuracy of the dose reduction factor in the future. The dose reduction factors obtained in this study can be used as a basic data for establishing the long-term emergency preparedness in Korea.

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