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Evaluation of the External Exposure Dose in Decontamination Works on Contaminated Residential Area

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1. Introduction

After the accident of a nuclear power plant releasing radioactive materials into the environment, one of the most important thing is the expeditious and efficient recovery strategy for the early return to minimize potential damages. The restoration activity requires to establish the full-scale decontamination procedure by appropriately arranging workforce in the contaminated residential areas. However, the formulation of decontamination plans faces difficulties in allocating the specific remediation task to the workers who may have potential risks with the significant radiation exposure. In the stage of the decontamination planning; therefore, the maximum exposure dose and the working time of workers need to be determined considering the dose criteria and the reference level proposed by ICRP [1].

Many researches have shown the analytical results on the external doses of workers in the specific facilities based on the total amount of radiation doses during the operation time. However, the prediction of the external dose of workers for hypothetical nuclear accidents differ on the actual circumstances such as the structural geometry of the contaminated area and the nuclear properties of the radiation source.

This study suggests the methodology of the external dose evaluation for the workforce considering the properties of decontamination methods based on the source regions. The gamma-ray doses were derived with the kerma of the reference calculation domain for the domestic residential environment, and with the workforce needed determined by the decontamination project of the Fukushima NPP accident [2].

2. Materials and Methods

To establish a methodology determining the total exposure dose and work hours of the workforce needed in the virtual decontamination planning, the reference computational model was designed with the representative properties of domestic residential environments. **Figure 1** shows the conceptual model of a single unit house and its three types of arrays (CASE-I, -II, and –III). It is divided from the outside by the fence which is surrounded with trees. It is assumed that each surface of residential environment is contaminated with the activity of unity ($Bq \cdot m^{-2}$) by the gamma-ray sources with the energy of 0.3 MeV, 0.662 MeV, and 3 MeV.

The regions of gamma-ray source are chosen to be the garden, windows, walls, roofs, fences, and trees for the internal area with the index of (A) to (F), and to be the neighbor's garden, walls, roofs, trees, narrow paths, open field, alleys, and roads for the external area with the index of (I) to (P), respectively. A series of the calculations for the kerma were performed by MCNP5 [3], and the detector volume is 1 m^3 and the detection point was set to 1 m above from the surface.

The external exposure dose to gamma-rays of decontamination workers may be derived from the kerma considering the workforces along with various work methods.

$$D_i = k_i \cdot A_i \cdot WF_i \cdot DCF \qquad (1)$$

where,

D_i : External dose for the decontamination workforce ($man \cdot Sv \cdot m^{-2}$)

k_i : Kerma on the object i contaminated by gamma-ray ($pGy / gamma - mm^{-2}$)

A_i : Activity on the object i ($Bq \cdot m^{-2}$)

WF_i : Workforce needed for the decontamination work of the object i ($man \cdot days \cdot m^{-2}$)

DCF : Kerma to dose conversion factor

As presented in **Table 1**, the workforce demanded for the decontamination work of the reference model was determined based on the data for the decontamination plan from the nuclear accident in Fukushima.

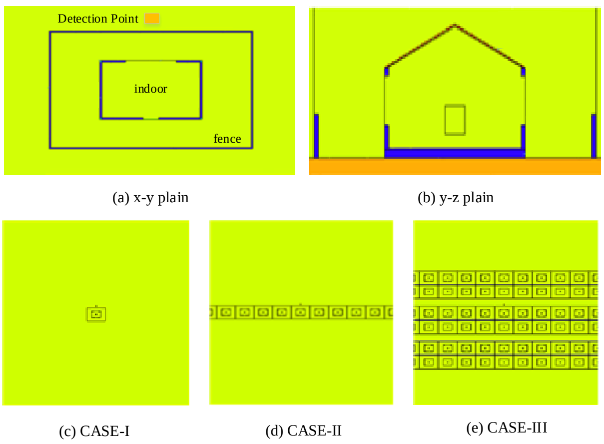

Fig. 1. Configuration of the Conceptual Model and the Arrays of Unit Geometry (MCNP5)

Table 1. Workforce needed for the decontamination work of the individual object of the reference model [$man \cdot days \cdot m^{-2}$]

γ-Source Position		WF	Source Position		WF
INT	(A) garden	0.2319	EXT	(I) neighbor garden	0.2319
	(B) window	0.0409		(J) neighbor wall	0.0409
	(C) wall	0.0409		(K) neighbor roof	0.0532
	(D) roof	0.0532		(L) neighbor tree	0.0484
	(E) fence	0.0409		(M) narrow path	0.0162
	(F) tree	0.0484		(N) open field	0.2356
	-			(O) alley	0.0162
	-			(P) road	0.0147

The work conditions include the site situations, material properties, and surface conditions of the objects to be decontaminated.

3. Results and Discussion

The kerma for three kinds of energies of gamma-rays were calculated using the MCNP5 code. **Table 2** shows the relative contributions of kerma value for each source domain on the total amount of kerma. With the results obtained the calculation set, it can be found that the source on the internal trees with the relatively low energy gamma-rays (0.3 MeV and 0.662 MeV) largely contribute to the total kerma value. However, the high-energy gamma-ray (3 MeV) is more uniformly distributed due to its longer mean free path depending on the material and the photon energy. In the case of the external area, the effects of the neighbors on the contribution to the total kerma are negligibly small, but the ground sources including narrow paths, open fields, alleys, and roads contribute to the kerma in the detector region.

The external exposure doses for the decontamination workers were derived from the kerma and the workforces for the individual objects as tabulated in **Figure 2**. The color map from blue (minimum) to red (maximum) presents the magnitude of the external dose expected to be exposed from the decontamination work.

γ-Source Position		CASE-I			CASE-II			CASE-III		
		0.3 MeV	0.662 MeV	3 MeV	0.3 MeV	0.662 MeV	3 MeV	0.3 MeV	0.662 MeV	3 MeV
INT	A	1.94E-14	6.20E-14	6.88E-13	1.94E-14	1.94E-14	6.87E-13	1.94E-14	6.22E-14	6.88E-13
	B	2.94E-15	6.96E-15	3.29E-14	2.94E-15	2.94E-15	3.29E-14	2.94E-15	6.99E-15	3.29E-14
	C	6.62E-15	1.48E-14	6.76E-14	6.62E-15	6.62E-15	6.76E-14	6.65E-15	1.49E-14	6.77E-14
	D	1.83E-14	4.15E-14	1.48E-13	1.85E-14	1.85E-14	1.49E-13	1.86E-14	4.25E-14	1.51E-13
	E	2.63E-15	1.05E-14	1.13E-13	2.63E-15	2.63E-15	1.13E-13	2.66E-15	1.05E-14	1.13E-13
	F	6.42E-14	1.40E-13	4.45E-13	6.42E-14	1.40E-13	4.45E-13	6.44E-14	1.40E-13	4.46E-13
EXT	I				8.02E-15	9.14E-15	9.94E-15	3.90E-14	5.80E-14	3.17E-13
	J				3.14E-15	5.54E-15	1.62E-14	8.06E-15	1.45E-14	4.87E-14
	K				5.25E-15	1.10E-14	3.69E-14	8.60E-15	2.15E-14	1.01E-13
	L				1.61E-14	3.41E-14	1.10E-13	5.69E-15	1.20E-14	3.73E-14
	M	1.18E-13	2.49E-13	7.31E-13						
	N	2.26E-12	5.03E-12	1.66E-11	2.56E-12	5.47E-12	1.74E-11			
	O				1.19E-13	2.49E-13	7.31E-13			
	P							1.22E-13	2.59E-13	7.70E-13

Fig. 2. The External Exposure Doses for the Decontamination Workforce ($man \cdot Sv \cdot m^{-2}$)

As a result, the worker dose is not linearly related with the kerma contributions. It shows that the worker dose may be differ depending on the work characteristics and work hours, even though it is basically based on kerma value. The most severe work is evaluated as the one on the open field which requires the longest working hours and without any shielding material surrounding the source region. On the other hand, the work in the internal garden has the relatively minor effect on the exposure dose, even though it requires very long working hours similar to that in open field.

Table 2. The relative contribution of gamma-ray source for each domain on the total kerma in the detector region [%]

γ-Source Position		CASE-I			CASE-II			CASE-III		
		0.3 MeV	0.662 MeV	3 MeV	0.3 MeV	0.662 MeV	3 MeV	0.3 MeV	0.662 MeV	3 MeV
INT	(A) garden	4.07	5.66	14.70	4.07	2.31	14.69	4.05	5.64	14.67
	(B) window	3.50	3.60	3.99	3.50	1.98	3.98	3.48	3.59	3.98
	(C) wall	7.88	7.65	8.20	7.87	4.47	8.19	7.87	7.63	8.18
	(D) roof	16.80	16.52	13.84	16.91	9.60	13.88	16.95	16.81	14.01
	(E) fence	3.13	5.41	13.63	3.13	1.77	13.63	3.15	5.39	13.61
	(F) tree	64.61	61.18	45.65	64.53	79.87	45.62	64.50	60.95	45.55
EXT	(I) neighbor garden				0.18	0.10	0.04	1.88	1.33	2.38
	(J) neighbor wall				0.41	0.34	0.32	2.21	1.88	2.07
	(K) neighbor roof				0.53	0.52	0.57	1.81	2.14	3.31
	(L) neighbor tree				1.77	1.78	1.86	1.32	1.31	1.34
	(M) narrow path	43.18	41.79	38.94						
	(N) open field	56.82	58.21	61.06	58.03	58.59	60.33			
	(O) alley				39.08	38.67	36.88			
	(P) road							92.79	93.34	90.90

4. Conclusion

To establish the methodology of determining the external dose for the decontamination workers, the kerma for the separated gamma-ray source regions were calculated by the Monte Carlo method. With the data obtained from the decontamination plan in Fukushima, the workforce depending on the decontamination work properties was determined for the reference domain of the domestic residential environments.

The worker dose is shown not to be linearly related with the kerma contributions. The worker dose differs depending on the work characteristics and work hours, even though it is basically based on the kerma value.

With the methodology provided by this study, it would be easy to develop a strategy that the radiation effect of workers could be minimized by achieving the possibly low exposure considering the reference level or the dose constraints proposed by ICRP.

The build-up of additional data sets for the other reference models of the domestic environments are currently in progress; therefore, this work would contribute to preparations to establish the decontamination work planning against a potential nuclear accident.

REFERENCES

[1] ICRP, Application of the Commission's Recommendations for the Protection of People in Emergency Exposure Situations, International Commission on Radiological Protection (ICRP) Publication 109, 2009.
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[3] T. E. Booth et al, MCNP – A General Monte Carlo N-Particle Transport Code, Version 5, LA-CP-03-0245, Los Alamos National Laboratory, 2003.