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Determination of Derived Concentration Level of Radionuclides in Soil Based on the ICRP-60 Recommendation

Hai Yong Jung and Kun Jai Lee

Korea Advanced Institute of Science and Technology (KAIST)
373-1 Kusong-dong, Yusong-gu, Taejon, South Korea 305-701

Abstract

Determination of a policy for decommissioning nuclear facilities requires establishing a relationship between potential dose to an individual and the radioactive contaminant existing on the surface soil of the site. Dose assessment of residual radioactivity in soil is, therefore, important to make the guideline and to evaluate the post-decontamination radiological effects. It is an activity of radionuclides in soil that is the significant factor of the decontamination. Allowable residual contamination level in soil has been estimated using dose assessment methodology with radiation exposure pathway. First of all, three pathways of external, inhalation and ingestion have been modeled in order to evaluate the radiation dose from the contaminated soil and the radiation dose has been derived based on the ICRP's new radiation protection concepts. Many models and methodologies currently used to calculate the dose are based on the ICRP 26. However, since the ICRP 60 published in 1990 have many significant differences in radiation protection, the modified dose assessment model adopting the new recommendation is required. In this study, new conversion coefficients have been introduced to evaluate radiation dose from the contaminated soil. Effective dose based on new dose conversion coefficients for some key radionuclides has been calculated with Korean data and compared with the result based on old coefficients and with other study's result. There are differences between the result of this study and that of other references, since it seems that the change of dose conversion coefficients could affect the total dose and ARCL.

INTRODUCTION

Nuclear facilities should be decommissioned after their lifetime and the surface soil of their site has the possibility to be contaminated by radioactive materials. If the surface soil of the site is contaminated by radionuclides during operation and decommissioning, it should be decontaminated. Determination of a policy for decommissioning nuclear facilities requires establishing a relationship between potential doses to an individual and the radioactive contaminant existing on the surface and in the soil. Regulation guides for decommissioning of the site are based on the radiological dose assessment of residual radioactivity in soil. Dose assessment of residual radioactivity in soil is, therefore, important to make the guideline and to evaluate the post-decontamination radiological effects. However, the existing dose assessment model and data are based on the ICRP Recommendation 26 that must be substituted by ICRP 60 (1,2).

In this study, therefore, allowable residual contamination level (ARCL) in soil is calculated with dose assessment model and data based on the ICRP's new radiation protection concepts. ARCL varies with the scenario for site reuse, so the site reuse scenario should be fixed first and foremost.

New conversion coefficients have been used to evaluate radiation dose from the contaminated soil. ARCL of radionuclides in soil have been calculated in considering the unrestricted site reuse scenario and with conversion coefficients based on ICRP 60 and Korean data (for example, food consumption rate and other parameters related with soil).

DOSE ASSESSMENT MODEL

Dose assessment models can be divided into three exposure pathways: external, inhalation and ingestion pathways. Each pathway has a sub-pathway. Particularly the ingestion pathway could be broken into according to the food consumption type. Each pathway has the model for radiation exposure dose and radiation conversion coefficients.

External Exposure

External exposure to residual radiation in soil is mainly made by a photon. A concept of external exposure from soil is illustrated in Fig. 1, in which the phantom is exposed to the horizontal, rotational (ROT) beam 1m above the soil (3).

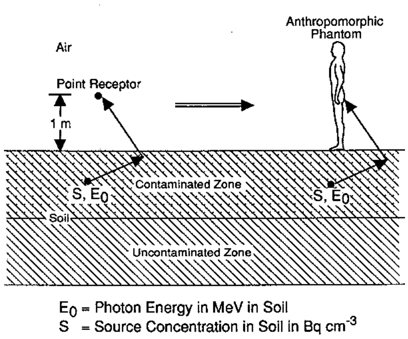

Fig. 1. Scematic illustation of external exposure from soil.

Effective dose rate by external exposure to residual radiation in soil consists of exposure period (T) and radionuclide concentration in soil (Ci) and dose conversion coefficient (DF).

$$D_{ext,i} = T \cdot C_i \cdot DF_{ext,i} \qquad \text{(Eq.1)}$$

where

D_{ext} = effective dose from external exposure (Sv) ;

DF_{inh} = dose conversion coeff. (Sv y^{-1} per Bq cm^{-3}) ;

T = exposure period (y);

C_i = concentration of radionuclides in soil (Bq cm^{-3}) ;

In external exposure, conversion coefficients in ICRP 51 based on ICRP 26's concepts have been used for calculation of effective dose rate by external exposure for a long time. In this study, new conversion coefficients of ICRP 74 published in 1995 and based on the new ICRP 60's concepts, have been used for calculation. (4,5)

Conversion coefficients for residual radioactivity of external exposure to soil, which has been calculated using coefficients in ICRP 74, are presented in Table I. Dose conversion coefficients in Table I are given for photon energy between 0.01 and 10 MeV in assuming a infinite ground volume (i.e., with infinite source thickness).

Table I. Effective dose conversion coefficients for external exposure in soil based on ICRP 74.

Photon Energy (MeV)	Air-absorbed dose	Conversion factor	Effective dose conversion coefficient
	Infinite volume sources Gy yr^{-1} / Bq cm^{-3}	Sv Gy^{-1}	Infinite volume sources Sv yr^{-1} / Bq cm^{-3}
1.00E-02	1.09E-06	0.00326	4.25E-09
1.50E-02	3.29E-06	0.0153	7.57E-08
2.00E-02	5.29E-06	0.0462	3.44E-07
3.00E-02	8.99E-06	0.1910	2.07E-06
4.00E-02	1.35E-05	0.4260	6.26E-06
5.00E-02	2.04E-05	0.6610	1.40E-05
6.00E-02	3.05E-05	0.8280	2.53E-05
8.00E-02	6.39E-05	0.9610	6.10E-05
1.00E-01	1.04E-04	0.9600	1.00E-04
1.50E-01	2.14E-04	0.8920	1.91E-04
2.00E-01	3.33E-04	0.8540	2.84E-04
3.00E-01	6.00E-04	0.8240	4.96E-04
4.00E-01	8.73E-04	0.8140	7.16E-04
5.00E-01	1.07E-03	0.8120	8.82E-04
6.00E-01	1.31E-03	0.8140	1.08E-03
8.00E-01	1.87E-03	0.8210	1.56E-03
1.00E+00	2.29E-03	0.8310	1.92E-03
1.50E+00	3.55E-03	0.8510	3.04E-03
2.00E+00	4.96E-03	0.8710	4.34E-03
3.00E+00	6.99E-03	0.8900	6.30E-03
4.00E+00	8.86E-03	0.9090	8.12E-03
5.00E+00	1.11E-02	0.9170	1.04E-02
6.00E+00	1.30E-02	0.9250	1.23E-02
8.00E+00	1.73E-02	0.9280	1.68E-02
1.00E+01	2.18E-02	0.9410	2.16E-02

Inhalation Exposure

Inhalation of raionuclides in soil can occur from inhalation of dust, radon, radon decay products, and other gaseous airborne radionuclides. Inhalation dose in soil occurs mainly due to the resuspension of radionuclides in the surface of the soil. Inhalation dose is related with the human respiratory tract model that simulates the real human respiratory organ. The respiratory tract model in ICRP Publication 30 has been used to calculate the inhalation dose in many dose assessments over the past decade (6). However, ICRP 30 has been replaced by new respiratory tract for inhalation dose assessment in ICRP 66 published in 1993 (7). Recently, inhalation dose coefficients based on the new tract model in ICRP 66, especially for public, are suggested in Publication 68 and 71 (8,9). The assessment for inhalation dose should be considered in view of new respiratory model and new conversion coefficients since this difference may have an affect on the dose assessment (10). The comparison between new and old dose coefficients for the important radionuclides is presented in Table II. Dose coefficients of ICRP 68 based on ICRP 66 are lower than those based on ICRP 30 except some radionuclides. Calculation of effective dose rate by inhalation should make it possible to look into the effects according to the change of dose conversion coefficients.

Effective dose rate by inhalation can be calculated from the simple product of dose coefficients, annual breathing rate and radionuclide concentration in air. Thus,

$$D_{inh} = DF_{inh} \cdot U_b \cdot C_{ai} \qquad \text{(Eq.2)}$$

$$C_{ai} = A \cdot C_{si} \cdot \frac{1}{\rho} \qquad \text{(Eq.3)}$$

where

D_{inh} = effective dose rate from inhalation (Sv y^{-1}) ;

DF_{inh} = conversion coeff. for inhalation (Sv Bq^{-1}) ;

U_b = annual breathing rate (m^3 y^{-1}) ;

C_{ai} = concentration of radionuclides in air (Bq cm^{-3}) ;

C_{si} = concentration of radionuclides in soil (Bq cm^{-3}) ;

A = mass loading coefficient by suspension (g cm^{-3}) ;

ρ = the soil density (g cm^{-3}).

Inhalation Dose has been obtained with conversion coefficients of ICRP 68 adopted from ICRP 66's new respiratory model based on ICRP 60.

Ingestion Exposure

Ingestion dose is made when food produced on the contaminated soil is eaten by human beings. The ingestion of food can be broken into six major types of food : plant, meat, milk, fish, drinking water, and soil (11). Equations for calculating the effective dose for these food products are described below.

$$\begin{aligned} D_{ing} &= \sum DF_{ing} \cdot U_f \cdot \left(C_p + C_a \right) \\ C_p &= B_p \cdot C_s \\ C_a &= F_a \cdot U_a \cdot C_p \\ &= F_a \cdot U_a \cdot \left(B_p \cdot C_s \right) \end{aligned} \qquad \text{(Eq.4)}$$

where,

D_{ing} = effective dose rate from ingestion (Sv y^{-1}) ,

DF_{ing} = conversion coeff. for ingestion (Sv Bq^{-1}) ,

U = food consumption rate (kg y^{-1}) ,

C_p = concentration of radionuclides in plant (Bq kg^{-1}) ,

C_a = concentration of radio. in animal food (Bq kg^{-1}) ,

C_s = concentration of radionuclides in soil (Bq kg^{-1}).

B_p = Transfer coefficients of nuclides from soil to plant (Bq kg^{-1}-wet wt per Bq kg^{-1}-soil)

F_a = Transfer coefficients for animal food. (d kg^{-1}).

Dose conversion coefficients for ingestion have been obtained with conversion coefficients of ICRP 68 adopted from ICRP 66's new model based on ICRP 60 in the same manner of inhalation dose.

Table II. Inhalation effective dose conversion coefficients

	ICRP 68	ICRP 30	NUREG/CR-5512	RESRAD
Mn^{54}	1.50E-06	1.70E-06	1.81E-06	1.73E-06
Co^{60}	2.90E-05	4.10E-05	5.91E-05	4.05E-05
Sr^{90}	1.50E-04	3.40E-04	3.51E-04	3.51E-04
Cs^{134}	6.80E-06	1.30E-05	1.25E-05	1.27E-05
Cs^{137}	4.80E-06	8.70E-06	8.63E-06	8.65E-06
U^{235}	7.70E-03	3.20E-02	3.32E-02	3.24E-02
U^{238}	7.30E-03	3.20E-02	3.20E-02	3.24E-02
Pu^{238}	4.30E-02	1.20E-01	1.06E-01	1.24E-01
Pu^{239}	4.70E-02	1.20E-01	1.16E-01	1.38E-01
Am^{241}	3.90E-02	1.20E-01	1.20E-01	1.41E-01

Table III. Ingestion effective dose conversion coefficients

	ICRP 68	ICRP 30	NUREG/CR-5512	RESRAD
Co^{60}	3.40E-06	7.00E-06	7.28E-06	7.03E-06
Sr^{90}	2.80E-05	4.00E-05	3.85E-05	3.78E-05
Cs^{134}	1.90E-05	2.00E-05	1.98E-05	2.00E-05
Cs^{137}	1.30E-05	1.40E-05	1.35E-05	1.35E-05
U^{235}	4.60E-05	6.90E-05	7.19E-05	6.76E-05
U^{238}	4.40E-05	6.90E-05	6.88E-05	6.76E-05
Pu^{238}	2.30E-04	9.30E-04	8.65E-04	1.03E-03
Pu^{239}	2.50E-04	9.60E-04	9.56E-04	1.16E-03
Am^{241}	2.00E-04	9.80E-04	9.84E-04	1.22E-03

CALCULATION AND RESULTS

ARCL can be obtained through the dose assessment depending on the site reuse scenario and the dose exposure pathway. Dose limit for site reuse is usually determined by regulation bodies and can be changed according to the site reuse objective, which should be fixed after examining characteristics of the site (12).

First, the site reuse scenario or objective should be set up and dose limit would be fixed after the determination of its characteristic. Regulation agency, for example, NRC or DOE, has the dose limit for site restoration and the limit is currently from 0.25 mSv/yr to 0.3 mSv/yr for the unrestricted use scenario (13). In this study, dose limit for the site reuse has chosen 0.3mSv/yr for the unrestricted use. Since it is assumed that the site could be available for unrestricted use, all major pathway that potentially contributes to dose should be considered. The pathways include consumption of food grown on the contamination soil, surface exposure, inhalation of resuspended radioactive soil. In detail, pathway consists of six parts: external exposure, inhalation and ingestion of plants, meat, milk, soil. Six major pathways are assumed as Table IV. ARCL could be calculated, therefore, from the dose obtained through the methodology considering dose limit and exposure pathway.

Korean specific data has been used for the calculation of the actual dose and contamination level. Table V lists values for several parameters that are independent of radionuclides. Sources of these data are obtained from the Korea National Statistical Office ' 96 & ' 97 (14).

Nine radionuclides have been selected for ARCL after considering many options such as half-life, emission energy, dose conversion coefficients.

Table VI lists nine radionuclides and their effective dose conversion coefficients according to the pathway such as direct exposure to γ radiation, inhalation, and ingestion from soil surfaces. The direct exposure, inhalation, and ingestion conversion coefficient values for all of the radionuclides listed in the table are based on the most recent models of the ICRP .

Table IV. Radiation exposure pathway

Exposure pathway		Unrestricted reuse
External	Direct	O
Inhalation	Radionuclide Dust	O
Ingestion	Plant	O
	Meat	O
	Milk	O
	Soil	O

Table V. Values for pre-determined parameters.

Consumption of plant	315.3 kg/yr
Consumption of meat	29.3 kg/yr
Consumption of milk	23.4 l/yr
Consumption of fodder by animal	15.6 kg/d
Consumption of soil	36.5 g/yr
Breathing rate	7400 m^3/yr
Resuspension rate	1.0E-7 kg/m^3
Soil density	1.2 g/cm^3

Table VI. Effective dose conversion coefficients of each radionuclides.

Nuclides	External (mSv/yr per Bq/cm^3)	Inhalation (mSv / Bq)	Ingestion (mSv / Bq)
Co^{60}	5.28E00	2.90E-05	3.40E-06
Sr^{90}	-	1.50E-04	2.80E-05
Cs^{134}	3.26E00	6.80E-06	1.90E-05
Cs^{137}	9.96E-01	4.80E-06	1.30E-05
U^{235}	1.47E-01	7.70E-03	4.60E-05
U^{238}	-	7.30E-03	4.40E-05
Pu^{238}	-	4.30E-02	2.30E-04
Pu^{239}	-	4.70E-02	2.50E-04
Am^{241}	5.39E-03	3.90E-02	2.00E-04

With the data and assumptions described above, the ARCL is estimated with the radiation dose from the radioactive nuclides in soil. Table VII lists the portions of dose of each radionuclides according to the pathway. Dose from Co^{60}, Cs^{134}, and Cs^{137} come mostly from the external exposure and radiation dose in case of Sr^{90} has mainly come through ingestion pathway. In case of Pu and its isotopes, most radiation doses might be due to inhalation and ingestion pathway.

Maximum acceptable soil concentration for selected radionuclides with the six pathways, 0.3 mSv/yr dose limit, and other parameters for Korea are listed in Table VIII. These guidelines are based on the dose limits proposed by regulatory agency (DOE) and obtained with the Korean specific data. Acceptable soil contamination level listed in Table VIII has been calculated with the new ICRP model and has compared with values of other references. The values of other references are based on Till and Moore(15), Lee and Kim(16), and DOE (RESRAD)’ results. (17).

All data in the case of RESRAD except for conversion coefficients are same with data of this work so that the results can be showed the differences between conversion coefficients based on ICRP 60 and those based on other methodology.

Soil concentrations in this work are relatively higher than the values derived from other references. The higher concentration for most nuclides has presumably originated from the reduction of total radiation dose. Since conversion coefficients of new model become lower than old coefficients, total dose calculated through pathway seems to be lower. Therefore, since total dose is lower than the allowable dose limit, the acceptable concentration is higher than before. In case of U and Pu, the great increase of concentration compared with other values is likely caused by a great difference of inhalation and ingestion dose conversion coefficients. Since inhalation and ingestion conversion coefficients of Pu and its isotope from ICRP 68 are lower than the other models, therefore, the results of Pu might be much more influenced by the conversion coefficients of new model than the other nuclides.

Table VII. Portion of dose from pathway (%)

Nuclide	External	Inhalation	Ingestion
Co^{60}	99.5	-	0.5
Sr^{90}	-	-	100
Cs^{134}	92.4	-	7.6
Cs^{137}	84.6	-	15.4
U^{235}	81.6	2.6	15.8
U^{238}	-	14.3	85.7
Pu^{238}	-	68.1	31.9
Pu^{239}	-	68.3	31.7
Am^{241}	11.3	50.3	38.4

Table VIII. Acceptable concentration calculated using ICRP 60 new model for a limit (0.3mSv/yr) (Bq/g).

Nuclide	This work	Till and Moore	Lee and Kim	RESRAD
Co^{60}	0.047	0.074	0.050	0.116
Sr^{90}	0.056	0.33	0.058	0.145
Cs^{134}	0.071	-	0.076	0.174
Cs^{137}	0.21	0.30	0.201	0.439
U^{235}	1.39	1.2	0.736	1.913
U^{238}	7.96	2.7	4.422	5.324
Pu^{238}	6.39	4.3	2.848	1.968
Pu^{239}	5.86	-	2.727	1.783
Am^{241}	5.24	3.3	1.803	1.671

CONCLUSSION

Until now, the acceptable concentration of radionuclides in soil has been estimated with the new ICRP 60 model. As the above results, ARCL for the selected radionuclides are two or three times higher than other reference's result. It could be suggested that there are the effects on the total radiation dose and ARCL according to the change of dose conversion coefficients.

ARCL estimated shows that many previous dose assessment methodologies may be revised with the new guideline because they may have the possibility to overestimate the total dose and to represent a more conservative guideline. It is suggested that more study about coefficients and dose models should be followed to get more precise ARCL

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