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DETERMINATION OF ALLOWABLE RESIDUAL CONTAMINATION LEVELS OF RADIONUCLIDES IN SOIL CONSIDERING ICRP RECOMMENDATION 60

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Abstract

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 dose to an individual and the radioactive contaminant existing on the surface soil of the site. Regulation guides of the site remediation 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. It is an activity of radionuclides in soil that is the significant factor of the decontamination.

In this study, 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 calculated 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 (for example, food consumption rate and other parameters related with soil) and compared with the result based on old coefficients and with other study's result.

Allowable Residual Contamination Levels (ARCL) of radionuclides in soil have been calculated with the presumed unrestricted use scenario and 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

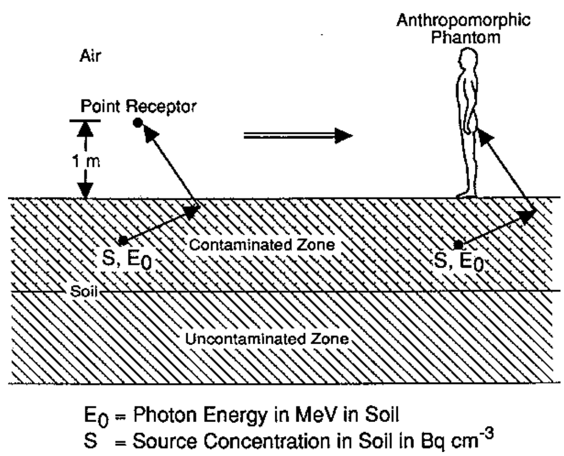

Fig. 1. Scematic illustation of external exposure from soil.

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).

Effective dose rate by external exposure to residual radiation in soil can be calculated by exposure period (T) and radionuclide concentration in soil (Ci) and dose conversion coefficient (DF), such as

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

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}) ;

For 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 the calculation. (4,5)

Conversion coefficients for external exposure due to residual radioactivity of 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 dose through radionuclides in soil can occur by inhalation of dust, radon, radon decay products, and other gaseous airborne radionuclides. Inhalation dose by soil can occur mainly due to the resuspension of radionuclides at the surface of the soil. Inhalation dose is estimated 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 for many dose assessment cases over the past decade (6). However, ICRP 30 has been replaced by the new respiratory tract model 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 ICRP Publications 68 and 71 (8,9). The assessment for inhalation dose should be reassessed in view of the new respiratory model and new conversion coefficients since this difference may have an significant effect on the dose assessment (10). The comparison between the new and old dose coefficients for the some important radionuclides is presented in Table II. Most dose coefficients of ICRP 68 based on ICRP 66 are generally lower than those based on ICRP 30 except some radionuclides. The calculation of effective dose rate by the inhalation should make it possible to identify 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 concentrations 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}).

So for our case, inhalation dose has been obtained with the conversion coefficients of ICRP 68 adopted from ICRP 66's new respiratory model based on ICRP 60.

Ingestion Exposure

Dose by ingestion occurs when food produced on the contaminated soil is consumed by human beings. The ingestion of food has been 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.

Table II. Inhalation effective dose conversion coefficients

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

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

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 radionuclides 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.

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 the site reuse is usually determined by regulatory bodies and can be changed depending on the site reuse objective, which could 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. Regulatory agency, for example, NRC or DOE, set the dose limit for site restoration and the limit is currently set 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 been chosen as 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 the dose should be considered. The pathways include consumption of food grown on the contamination soil, surface exposure, and inhalation of resuspended radioactive soil. In detail, these pathways consist of six parts: external exposure, inhalation and ingestion of plants, meat, milk, and soil. Six major pathways are shown at Table IV. ARCL could be calculated, therefore, from the dose calculated through the methodology with these dose limit and exposure pathways.

Korean specific data has been used for the calculation of the actual dose and contamination level.

Table III. Ingestion effective dose conversion coefficients

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

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 lists default 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 important parameters such as half-life, emission energy, dose conversion coefficients.

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 lists nine radionuclides and their effective dose conversion coefficients for 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 VI. Effective dose conversion coefficients of each radionuclides.

Nuclides	External (mSv/yr per Bq/cm^3)	Inhalation (mSv / Bq)	Ingestion (mSv / Bq)
^{60}Co	5.28E00	2.90E-05	3.40E-06
^{90}Sr	-	1.50E-04	2.80E-05
^{134}Cs	3.26E00	6.80E-06	1.90E-05
^{137}Cs	9.96E-01	4.80E-06	1.30E-05
^{235}U	1.47E-01	7.70E-03	4.60E-05
^{238}U	-	7.30E-03	4.40E-05
^{238}Pu	-	4.30E-02	2.30E-04
^{239}Pu	-	4.70E-02	2.50E-04
^{241}Am	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 by each radionuclides according to the different pathway. Dose due to ^{60}Co, ^{134}Cs, and ^{137}Cs come mostly from the external exposure and radiation dose by ^{90}Sr has mainly come through ingestion pathway. In case of Pu and its isotopes, most of the radiation doses might be due to both inhalation and ingestion pathway.

Maximum acceptable soil concentrations for the pre-selected radionuclides of the six pathways with 0.3 mSv/yr dose limit, and other parameters for Korea are calculated and listed in Table VIII. These guidelines are based on the dose limits proposed by DOE and obtained with the specific data for Korea. Acceptable soil contamination level listed in Table VIII has been calculated with the new ICRP model and has compared with that 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 of RESRAD except for the conversion coefficients are same of this work so that the results can be compared and showed the differences due to the modifications of conversion coefficients based on ICRP 60 and those based on the old methodology.

Table VII. Portion of dose from pathway (%)

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

Soil concentrations in this work are relatively higher than the those of 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 the old coefficients, total dose calculated through all the pathways 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 most of increase of concentrations compared with other results is likely caused by great differences of inhalation and ingestion dose conversion coefficients. Since inhalation and ingestion conversion coefficients of Pu and its isotope from ICRP 68 are lower than that of the other models, therefore, the results of Pu might be much more affected by the new conversion coefficients of our model than the other nuclides.

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

CONCLUSSION

The acceptable concentration of some important radionuclides in soil has been estimated with the new ICRP 60 model. ARCL for the selected radionuclides are two or three times higher than the previous result. It could be suggested that these are due to the effects on the total radiation dose and ARCL because of the change of dose conversion coefficients.

Estimated ARCL shows that many previous dose assessment methodologies should be revised and adjusted with the new guidelines because of the possibility of overestimating the total dose and consequently representing a more conservative guideline. It is suggested that more detailed study about the coefficients and dose models should be followed to get the more precise ARCL

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