Proceedings of the Korean Nuclear Society Autumn Meeting
Seoul, Korea, October 1998

Dose Assessment for Potential External Exposure from Residual Photon Emitters in Soil

Hai Yong Jung and Kun Jai Lee

Korea Advanced Institute of Science and Technology
Department of Nuclear Engineering
373-1 Kusong-dong, Yusong-gu
Taejon, Korea 305-701

Gye Nam Kim and Dong Gyu Lee and Byung Jik Lee and Won Zin Oh

Korea Atomic Energy Research Institute
150 Dukjin-dong, Yusong-gu
Taejon, Korea 305-353

Abstract

It has been known that residual photon emitters have an influence on the worker and public during decommissioning. Therefore, dose assessments have to be accomplished for external exposure from residual photon emitters in soil. Many models and methodologies of external dose assessment that have been used currently are based on the ICRP 26 and the conversion coefficient of ICRP 51. The ICRP 60 published in 1990, however, have many significant differences in radiation protection and the ICRP has presented the new conversion coefficients for external radiation protection in ICRP 74 according to ICRP 60.

In this study, estimates of the air-absorbed dose were converted into the effective dose. The effective dose is based on the concept of weighted organ doses, as recommended by the ICRP. The ICRP's latest conversion coefficients were used to transform point air-absorbed doses into effective doses. Conversion coefficients based on the ICRP 74 have a tendency to decrease compared with that based on ICRP 51. Finally, the effective dose based on new dose conversion coefficients about some radionuclides have been calculated and compared with the result based on old coefficients.

I. Introduction

Nuclear facilities have to be decommissioned after their life time and the surface soil of their site have the possibility to be contaminated by radioactivity materials. Determination of a policy for decommissioning nuclear facilities requires establishing a relationship between potential dose to an individual and the radioactive contaminant existing on surface and in soil. Dose assessment of residual radioactivity in soil is important to make the guideline and to evaluate the post-decontamination radiological impact. For the purpose of developing radiological release level of site or evaluating radiological dose of public after decommissioning, many agencies have studied methodology and model of dose assessment

The radiological dose assessment methodology of decommissioning has to determine the exposure pathway to evaluate the dose of residual radioactivity. The exposure pathway is divided to three main pathway of external, inhalation and ingestion and two pathways of inhalation and ingestion have some detail pathways. The model or methodology which is able to calculate all pathways and variables are needed to evaluate the total system of radiological dose for decommissioning.

In 1990, new recommendation on radiation protection standards was developed by ICRP to take into account new biological information related to the detriment associated with radiation exposure[1]. Adoption of these recommendations needed a revision of the Commission's secondary limits related with radiation protection. For external radiation protection, conversion coefficients of ICRP 51 based on ICRP 26's concepts have been used for a long time[2]. To meet the new ICRP 60's concepts, the ICRP 74 that has the new conversion coefficients was published in 1995[3].

The main objective of this study is to illustrate methodologies for calculating the external dose from residual photon emitters in soil and to compare the difference between results based on the ICRP 51 and results based on the ICRP 74. In this study, external radiation exposure is focused on the evaluation of the radiation dose for exposure from residual photon emitters in soil as the first step of a total evaluation system. The dose conversion coefficient of effective dose using ICRP 74 was smaller than that of ICRP51, and this fact is reasonable respect to other study[4]. Consequently, committed effective dose of residual radioactivity was known to be decreased.

II. Calculation of Dose Conversion Factors and Effective Dose

Dose conversion factors have been studied and calculated for a long time by many researchers [5][6]. Especially, the conversion factor for external dose is various in accordance with its source, geometry and source existing material [7]. To calculate this various external dose conversion coefficients, the model based on computerized method is needed, which is complex and difficult. In this study, the main objective is not to calculate the air-absorbed dose of photon emitters in soil but to investigate the influence of the different dose conversion coefficients according to ICRP 51 and 74. The air-absorbed dose of photon emitters in soil in this study is quoted from S. Y. Chen, who has calculated it using the Monte Carlo Method in 1991[5].

The schematic of dose from photon emitters in soil is illustrated in Figure 1. On the basis of the configuration illustrated in Figure 1, the objective of calculations in S.Y. Chen's study is to obtain the air-absorbed dose responses for plane surface photon sources and infinite volume sources in soil. The air-absorbed doses are calculated for a point receptor located 1 m above the ground. In his study, such doses are then converted into the effective dose using the ICRP 54 conversion factors based on an anthropomophic phantom, as shown in Figure 1.

The effective dose can be calculated by employing methods that are used to derive the air-absorbed dose, with the incorporation of conversion coefficient R, by which an air-absorbed dose is converted into the effective dose. Thus:

$$\tilde{H}(r,T,E_0)=\int_{E_0}K\left[\frac{m_{en}(E)}{r}\right]E\Phi(r,T,E_0)R(E)dE\ , \tag{1}$$

where

$\left[\frac{m_{en}(E)}{r}\right]$ = mass energy-absorption coefficient of air in $\mathrm{cm^2g^{-1}}$;

E = incident photon energy at the receptor in MeV ;

$\Phi(r,T,E_0)$ = energy-differential photon flux in photons $\mathrm{cm^{-2}MeV^{-1}s^{-1}}$ at the receptor ;

R(E) = ICRP conversion coefficients for converting the air-absorbed dose into the effective dose equivalent expressed in Sv $\mathrm{Gy^{-1}}$; and

K = a constant equal to 5.04×10^{-3} (Gy g $\mathrm{MeV^{-1}}$ s $\mathrm{y^{-1}}$ $\mathrm{cm^3Bq^{-1}}$).

In this calculation, R(E) has been selected at an appropriate incident orientation on the receptor and a ROT(Rotational geometry) beam orientation is assumed for calculation. The air-absorbed doses that are calculated in Chen's study are listed in Table 1. The air-absorbed dose results are presented in Table 1 for photon energy between 0.01 and 10 MeV for sources uniformly distributed over a ground surface (i.e., with zero source thickness) and a ground infinite volume (i.e., with infinite source thickness).

As described in previous chapter, the preliminary results of conversion coefficients used in this paper are based on the air-absorbed dose of Table 1 that was calculated using a Monte Carlo algorithm by Chen. The air-absorbed dose (Gy $\mathrm{y^{-1}}$ per Bq $\mathrm{cm^{-2}}$ and Gy $\mathrm{y^{-1}}$ per Bq $\mathrm{cm^{-2}}$) is converted to effective dose multiplied by conversion coefficients of effective dose to air-absorbed dose (Sv $\mathrm{Gy^{-1}}$). Conversion coefficients of effective dose to air-absorbed dose (Sv $\mathrm{Gy^{-1}}$) are different in ICRP 51 and ICRP 74. Table 2 shows the result which taken into account the new coefficients of ICRP 74. The conversion coefficients for residual radioactivity of photon emitters in soil has been calculated using the conversion coefficients of effective dose to air-absorbed dose in ICRP 74 and presented in Table 2.

Effective doses have been calculated using conversion coefficients of Table 2 in case of infinite volume source. For calculating of effective doses of some radionuclides in soil, four reference radionuclides are selected. Four radionuclides considered and their physical half-lives are listed in Table 3. The initial activity of radionuclides in soil was assumption as 100 $\mathrm{pCi/cm^3}$ and the duration of exposure is one hundred years.

III. Results and Discussion

The dose conversion coefficients of photon emitters in soil that ware calculated in this study are smaller than Chen's coefficients. This tendency is illustrated in Figure 2 and Figure3. In ICRP 60, the organ weighting factors is different with that of ICRP 26, therefore the conversion coefficients of effective dose to air-absorbed dose have been changed in ICRP 74. Thus, results in Table 2, Figure 2 and Figure 3 show the tendency of decreasing effective dose.

Committed effective doses of four radionuclides during 100 years have been calculated using conversion coefficients of photon emitters in soil, which is calculated considering conversion coefficients of effective dose to air-absorbed dose in ICRP 74. The results of committed effective doses are illustrated in Figure 4 to Figure 7, which is the assessment of effective dose for the radionuclides in soil that has an initial activity of 100 pCi considering the external exposure pathway. In this study, the shield factor or occupancy factor is not considered, therefore the amount of committed effective dose is very high. The value of result in committed effective dose is not significant because many assumptions have been used for calculating and main objectives of this study are to illustrate the influence on the dose assessment of the different dose conversion coefficients between ICRP 51 and ICRP 74. And other objective is to present the model of dose assessment of external photon emitters in soil. In actual state, if many conditions are considered in calculating the committed dose, the value of dose became lower.

The methodology of this study shows the assessment of dose for photon emitters in soil, therefore this methodology has the ability to be applied to evaluate the radiological dose assessment for decommissioning or for contaminated soil surface. The results of this study also have presented the new conversion coefficients of photon emitters in soil, which is calculated with consideration of ICRP 60.

Acknowledgement

This work was performed as part of Nuclear Fuel Cycle Radwaste Treatment R&D Project of KAERI in the Nuclear R&D Program by MOST.

References

1. International Commission on Radiological Protection. *"1990 recommendations of the International Commission on Radiological Protection."*, Oxford, Pergamon Press, ICRP Publication 60, 1991
2. International Commission on Radiological Protection. "Data for use in protection against external radiation.", Oxford, Pergamon Press, ICRP Publication 51, 1987
3. International Commission on Radiological Protection. "Conversion Coefficients for Use in Radiological Protection against External Radiation.", Oxford, Pergamon Press, ICRP Publication 74, 1995
4. M. Zankl, N. Petoussi, and G. Drexler, *"Effective Dose and Effective Dose Equivalent – The Impact of The New ICRP Definition for External Photon Irradiation."*, Health Physics Vol. 62 No. 5, 395-399, 1992
5. S. Y. Chen, *" Calculation of Effective Dose-Equivalent Responses for External Exposure from Residual Photon Emitters in Soil."*, Health Physics Vol. 60, No. 3, pp. 411-426, 1991
6. D. C. Kocher and A. L. Sjoreen, *"Dose-Conversion Factors for External Exposure to Photon Emitters in Soil."*, Health Physics Vol. 48, No. 2, pp. 193-205, 1985
7. International Commission on Radiological Protection. *"Recommendations of the International Commission on Radiological Protection."*, Oxford, Pergamon Press, ICRP Publication 26, 1977

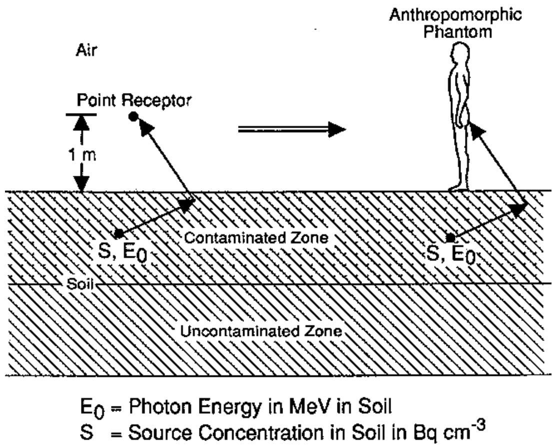

Figure 1. The schematic of dose from photon emitters in soil

Table 1. Air-absorbed dose and effective dose equivalent for plane surface photon sources and infinite volume source in soil based on ICRP 51.

Source Photon Energy (MeV)	**Air-absorbed dose**		**Conversion coefficient** (ICRP51) Sv Gy^{-1}	**Effective dose equivalent**	
	Plane surface sources Gy yr^{-1} / Bq cm^{-2}	Infinite volume sources Gy yr^{-1} / Bq cm^{-3}		Plane surface source Sv yr^{-1} / Bq cm^{-2}	Infinite volume sources Sv yr^{-1} / Bq cm^{-3}
1.00E-02	**5.34E-05**	**1.09E-06**	**0.0039**	**2.08E-07**	**4.25E-09**
1.50E-02	6.71E-05	3.29E-06	0.023	1.54E-06	7.57E-08
2.00E-02	5.76E-05	5.29E-06	0.065	3.74E-06	3.44E-07
3.00E-02	3.87E-05	8.99E-06	0.230	8.90E-06	2.07E-06
4.00E-02	2.93E-05	1.35E-05	0.464	1.36E-05	6.26E-06
5.00E-02	2.45E-05	2.04E-05	0.687	1.68E-05	1.40E-05
6.00E-02	2.38E-05	3.05E-05	0.830	1.98E-05	2.53E-05
8.00E-02	2.74E-05	6.39E-05	0.954	2.61E-05	6.10E-05
1.00E-01	**3.40E-05**	**1.04E-04**	**0.962**	**3.27E-05**	**1.00E-04**
1.50E-01	5.34E-05	2.14E-04	0.891	4.76E-05	1.91E-04
2.00E-01	7.45E-05	3.33E-04	0.854	6.36E-05	2.84E-04
3.00E-01	1.12E-04	6.00E-04	0.826	9.25E-05	4.96E-04
4.00E-01	1.57E-04	8.73E-04	0.820	1.29E-04	7.16E-04
5.00E-01	1.92E-04	1.07E-03	0.824	1.58E-04	8.82E-04
6.00E-01	2.33E-04	1.31E-03	0.824	1.92E-04	1.08E-03
8.00E-01	2.90E-04	1.87E-03	0.832	2.41E-04	1.56E-03
1.00E+00	**3.75E-04**	**2.29E-03**	**0.839**	**3.15E-04**	**1.92E-03**
1.50E+00	5.07E-04	3.55E-03	0.856	4.34E-04	3.04E-03
2.00E+00	6.12E-04	4.96E-03	0.875	5.36E-04	4.34E-03
3.00E+00	9.14E-04	6.99E-03	0.902	8.24E-04	6.30E-03
4.00E+00	9.90E-04	8.86E-03	0.917	9.08E-04	8.12E-03
5.00E+00	1.28E-03	1.11E-02	0.935	1.20E-03	1.04E-02
6.00E+00	1.38E-03	1.30E-02	0.943	1.30E-03	1.23E-02
8.00E+00	1.75E-03	1.73E-02	0.969	1.70E-03	1.68E-02
1.00E+01	**2.15E-03**	**2.18E-02**	**0.991**	**2.13E-03**	**2.16E-02**

Source : References 2.

Table 2. Effective dose equivalent for plane surface photon sources and infinite volume source in soil based on ICRP 74.

Source Photon Energy (MeV)	**Conversion coefficient** (ICRP74) Sv Gy^{-1}	**Effective dose***		**Ratio of effective dose** ICRP 74 / ICRP 51
		Plane surface source Sv yr^{-1} / Bq cm^{-2}	Infinite volume sources Sv yr^{-1} / Bq cm^{-3}	
1.00E-02	**0.00326**	**1.74E-07**	**3.55E-09**	**0.8359**
1.50E-02	0.0153	1.03E-06	5.03E-08	0.6652
2.00E-02	0.0462	2.66E-06	2.44E-07	0.7108
3.00E-02	0.1910	7.39E-06	1.72E-06	0.8304
4.00E-02	0.4260	1.25E-05	5.75E-06	0.9181
5.00E-02	0.6610	1.62E-05	1.35E-05	0.9622
6.00E-02	0.8280	1.97E-05	2.53E-05	0.9976
8.00E-02	0.9610	2.63E-05	6.14E-05	1.0073
1.00E-01	**0.9600**	**3.26E-05**	**9.98E-05**	**0.9979**
1.50E-01	0.8920	4.76E-05	1.91E-04	1.0011
2.00E-01	0.8540	6.36E-05	2.84E-04	1.0000
3.00E-01	0.8240	9.23E-05	4.94E-04	0.9976
4.00E-01	0.8140	1.28E-04	7.11E-04	0.9927
5.00E-01	0.8120	1.56E-04	8.69E-04	0.9854
6.00E-01	0.8140	1.90E-04	1.07E-03	0.9879
8.00E-01	0.8210	2.38E-04	1.54E-03	0.9868
1.00E+00	**0.8310**	**3.12E-04**	**1.90E-03**	**0.9905**
1.50E+00	0.8510	4.31E-04	3.02E-03	0.9942
2.00E+00	0.8710	5.33E-04	4.32E-03	0.9954
3.00E+00	0.8900	8.13E-04	6.22E-03	0.9867
4.00E+00	0.9090	9.00E-04	8.05E-03	0.9913
5.00E+00	0.9170	1.17E-03	1.02E-02	0.9807
6.00E+00	0.9250	1.28E-03	1.20E-02	0.9809
8.00E+00	0.9280	1.62E-03	1.61E-02	0.9577
1.00E+01	**0.9410**	**2.02E-03**	**2.05E-02**	**0.9495**

* Air-absorbed doses in Table 1 have been used to calculate effective dose

Table 3. Radionuclides considered in the effective dose calculation.

Radionuclides	Half-life (yr)
Co^{60}	5.3×10^{0}
Zn^{65}	6.7×10^{-1}
Nb^{94}	2.0×10^{4}
Cs^{137}	30×10^{1}

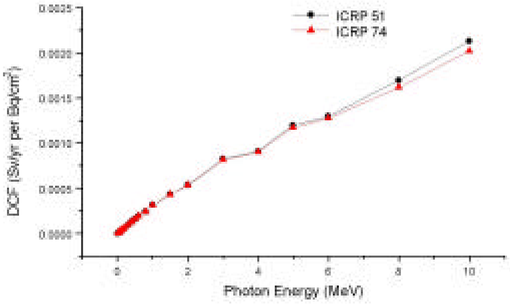

Figure 2. DCF of infinite plane source

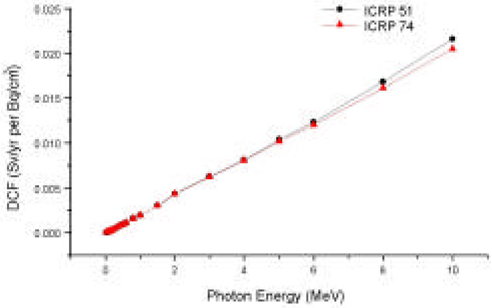

Figure 3. DCF of volume source

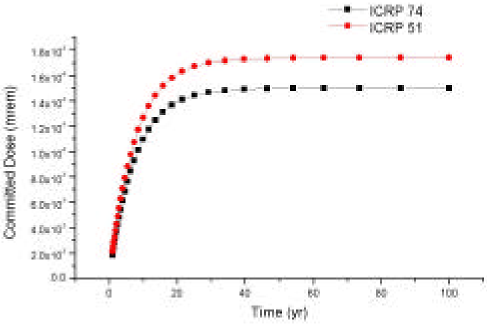

Figure 4. Committed dose of Co^{60}.

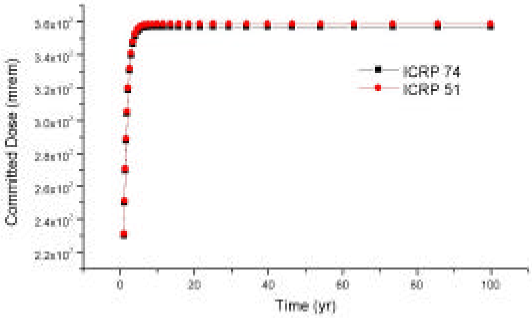

Figure 5. Committed dose of Zn^{65}.

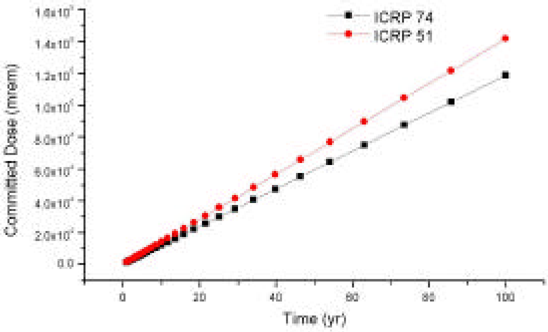

Figure 6. Committed dose of Nb^{94}.

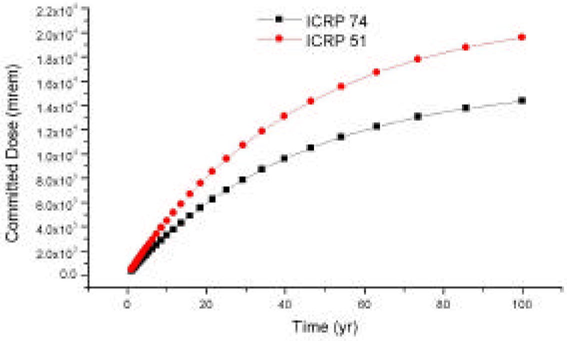

Figure 7. Committed dose of Cs^{137}.