A Methodology for Establishing Residual Radioactive Limits for Subsurface Structures during Nuclear Facility Decommissioning

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***Keywords :** Decommissioning, DCGL, Subsurface structures, RESRAD

1. Introduction

The major milestone in carrying out the decommissioning of nuclear facilities will be the remove of large components such as Reactor Vessel (RV), Reactor Vessel Internal (RVI), and Steam Generator (SG). After these major Systems, Structures, and Components (SSCs) are removed, it is then determined whether the deregulation for reuse of the site and the remaining buildings is possible. The criteria for sites and buildings is usually presented as a dose [1], and in practice, the measurable Derived Concentration Guideline Level (DCGL) for each media corresponding to the dose criteria is utilized. In general, sites and remaining buildings are major release media, and some part of the building is located underground, so if it is determined that they are subject to release media, it will be necessary to calculate DCGL. Therefore, this study intends to discuss the DCGL calculation method for subsurface structures when decommissioning nuclear facilities.

2. Methods and Results

In the case of contaminated structures located below the soil surface layer, it was assumed that they are mainly made of concrete. The underground concrete structure was assumed to be one compartment and as assumed to exist as surface contamination inside the compartment. Since we considered that nuclear facilities containing this compartment remain buried after the site release, contaminations in the compartment must be below the release criteria of the dose. Therefore, it is necessary to calculate how much does the receptors receive after site release from contaminations from subsurface structures, and DCGL corresponding to the dose criteria is calculated based on this process. To do this possible, as an example, the excavation scenario was considered and used for estimating the dose received by the receptor.

2.1 Excavation Scenario

This is a scenario that assumes that surface contamination of concrete structures is transferred to all the contaminated zone of the site by unexpected excavation. The transportation of contamination is converted from surface contamination of subsurface structure to mass contamination of the site contaminated zone by considering the size of the contaminated zone of the target nuclear facility and the thickness of the contaminated zone. The equation that converts surface contamination to mass contamination is as presented below.

$$S_{RC,i} = \frac{C_{RC,i}A_{room}}{\rho_{cntm}A_{cntm}d_{cntm}} \quad \text{Eq. (1)}$$

RC: Remaining concrete
$S_{RC,i}$: *Soil concentration due to room surface contamination (Bq/g)*
$C_{RC,i}$: *Surface contamination of the compartment (Bq/m^2)*
A_{room}: *Surface area of the compartment (m^2)*
ρ_{cntm}: *Density of the contaminated zone (g/m^3)*
A_{cntm}: *Area of contaminated zone (m^2)*
d_{cntm}: *Thickness of contaminated zone (m)*

The RESRAD-ONSITE code can be used to calculate the dose from the concentration (mass concentration) of the contaminated zone [2]. At this point, the dose per unit radioactivity concentration (1 Bq/g) was applied in the RESRAD code. Since the dose result calculated by RESRAD is for mass contamination of the soil, the unit conversion factor of CF is introduced to convert it into a result for surface contamination in the compartment and can be expressed as follows.

$$CF_{RC,i} = \frac{S_{RC,i}}{C_{RC,i}} \quad \text{Eq. (2)}$$

$CF_{RC,i}$: *Conversion factor for surface contamination (Bq/g per Bq/m^2)*
$S_{RC,i}$: *Soil concentration due to room surface contamination (Bq/g)*
$C_{RC,i}$: *Surface contamination of the compartment (Bq/m^2)*

The result from the RESRAD code is dose D (mSv/yr / Bq/g) for soil contaminated zone of 1 Bq/g, and dividing the dose criteria (0.1 mSv/yr) by D yields DCGL (Bq/g). However, since the target media needs DCGLs for the surface contamination limits of underground structures, the above two equations can be applied to make the dose conversion factor of DCF instead of D.

$$DCF_{RC,i} = \frac{D_{RC,i}}{1.0} \times CF_{RC,i} \quad \text{Eq. (3)}$$

$DCF_{RC,i}$: *Dose conversion coefficient per surface contamination of structures in excavation scenario (mSv/yr per 1 Bq/m^2)*
$D_{RC,i}$: *RESRAD code dose result by mass concentration in excavation scenario (mSv/yr per 1 Bq/g)*
1.0: RESRAD concentration of contaminated zone (Ba/g)
$CF_{RC,i}$: *Conversion factor for surface contamination (Bq/g per Bq/m^2)*

Therefore, the final DCGL for the contaminated media subsurface concrete structure can be calculated from the equation below.

$$DCGL_{RC,i} = \frac{0.1}{DCF_{RC,i}} \quad \text{Eq. (4)}$$

$DCGL_{RC,i}$: DCGL of subsurface concrete (Bq/m²)
0.1: Dose criteria by regulation (mSv/yr)
$DCF_{RC,i}$: Dose conversion coefficient per surface contamination of structures in excavation scenario (mSv/yr per 1 Bq/m²)

2.2 Application Example

In order to show and application example with assumed value, the surface contamination of the subsurface structure was applied to an unit concentration of 1 Bq/m^2. The area value was applied to 3.01E+03 m^2 as the related compartment characteristic value, and the area was 9.77E+03 m^2, the thickness was 0.15 m, and the density was assumed 1.56E+06 g/m^3 as the site contamination zone characteristic values. The result of applying Eq. (1) was calculated. By applying unit surface contamination of concrete structure Eq. (2) also can be calculated.

In order to calculate DCF, the dose value of the RESRAD code is required, and in this study, it was assumed that default values of the RESRAD code was applied and shown in the table 1. Co-60 was selected as the radionuclide and the result was applied to the age group.

Table 1: Dose result from example RESRAD

Nuclide	Excavation Scenario (mSv)					
	3 month	Age 1	Age 5	Age 10	Age 15	Adult
Co-60	1.93E+00	1.93E+00	1.92E+00	1.92E+00	1.92E+00	1.91E+00

As shown Eq. (3), the dose conversion factor, DCF, is the value multiplied by CF from the value calculated the RESRAD code presented in Table 1. Then the corresponding DCF can be shown in Table 2.

Table 2: An example of DCF result

Nuclide	Excavation Scenario (mSv)					
	3 month	Age 1	Age 5	Age 10	Age 15	Adult
Co-60	2.55E-06	2.54E-06	2.53E-06	2.53E-06	2.53E-06	2.52E-06

The next step, we applied Eq. (4) to finally derive the DCGL. Since the site reuse criteria is presented 0.1 mSv/yr according to the notification of Nuclear Safety and Security Commission (NSSC), DCGL is derived by dividing it by the DCF value. In this study, an example derivation method was introduced for each age group, and the final DCGL can be select the most conservative value among the group results.

Table 3: An example of DCGL result

Nuclide	Excavation Scenario (mSv)					
	3 month	Age 1	Age 5	Age 10	Age 15	Adult
Co-60	3.86E+04	3.88E+04	3.89E+04	3.90E+04	3.92E+04	3.95E+04

If a media such as structures below surface layer of the site is remaining, most of the contamination will be formed as surface of the concrete. At this time, When RESRAD-ONSITE is used, DCGL basically is calculated in the unit of Bq/g. Since the DCGL we requires a unit of surface contamination of subsurface concrete, the process of converting it inevitably occurs. Therefore, it is necessary to establish a process in which unit radioactive contamination per surface area is evenly distributed to the surface of soil, and then evaluated through the RESRAD code after conversion to contamination per mass unit. In this process, soil contamination per unit mass (S in Eq. (1)), mass contamination conversion factor per surface contamination (CF in Eq. (2)), and dose conversion coefficient (DCF in Eq. (3)) should be reflected.

3. Conclusions

This study discusses how to derive DCGLs, the release criteria for sites and remaining buildings, which is the final stage of decommissioning nuclear facilities. Release criteria is usually presented by regulator in dose, and licensees must derive measurable DCGL values from a practical point of view. In case of general surface soil or remaining buildings, it can be calculated by applying the site characteristic input parameter values relatively easily by using the RESRAD code. However, if there is a structure that will exist in the subsurface area, the method for deriving it may seem rather complicated. Therefore, in this study, a method was discussed as case and DCGL was derived by applying the assume parameter values. As a result, it was confirmed that DCGL could be finally selected in the infant group. Since the results of this study applied the assumed parameter values, it is of great significance to apply complex equations to derive and understand the methodology introduced using RESRAD results in the process rather than giving meaning to the results themselves.

REFERENCES

[1] NSSC, "Criteria for Reuse of Site and Buildings after Completion of Decommissioning of Nuclear Facilities," Notice No. 2021-15, Nuclear Safety and Security Commission, 2021.
[2] ANL User's Manual for RESRAD Version 6, ANL/EAD-4, 2001.