Radiation Safety Assessment for Decontamination and Reuse of RI Utilization Facilities Using the RESRAD-BUILD Code

Ji Hyeong Lee, Chul Heo, Seungmin Lee *
Korea Institute of Nuclear Nonproliferation and Control., 1418, Yuseong-daero, Yuseong-gu, Daejeon
**Corresponding author: seungmin@kinac.re.kr*

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1. Introduction

RI utilization facilities have experienced a notable increase, with an annual growth rate of 3.4%, from 43,254 locations in 2015 to 49,391 in 2019 [1]. This surge underscores the necessity for comprehensive research on safety evaluations and regulatory considerations for the decontamination, dismantling, and reuse of these expanding RI utilization institutions.

To ensure such facilities' safe dismantling and reuse, adherence to the criteria outlined in the Nuclear Safety Act and guidelines issued by the Nuclear Safety and Security Commission is imperative. Consequently, this study conducts a detailed radiation safety assessment for dismantling laboratories handling uranium, leading to the determination of Derived Concentration Guideline Levels (DCGLs). Furthermore, employing the RESRAD–BUILD code, this research aims to identify the primary dose pathways for workers and develop strategies to reduce occupational doses.[2] This is achieved through a sensitivity analysis of dose based on various scenarios, thus providing a framework for minimizing radiation risk to workers in the context of dismantling and reusing RI facilities.

2. Methods

2.1 Nuclear Material Storage Room on the Basement Floor 1 of the Hwaam

In this study, for objective analysis, data from facilities such as the Nuclear Material Storage Room located on the basement floor 1 of the KINAC (in Hwaam-dong) will be utilized [3].

Fig. 1. Floor plan of nuclear material storage room

For a conservative analysis, the quantity of the source material was set to the maximum capacity that can be stored in the containment vessel.

Table I: Quantity of source [3]

Types	State	Storage Quantity
Nuclear material storage room		
U 6% less	UO_2, U_3O_8	25kg
U 0.72%	UO_2, U_3O_8	2kg
U 0.72% less	UO_2, U_3O_8	1kg
U 20% less	UO_2, U_3O_8	0.5kg
Pu	Metal, Liquid	1.5g

The nuclear material storage room previously served as a laboratory that utilized nuclear fuel materials. Consequently, it is expected to contain trace amounts of uranium contamination on the fume hoods, exhaust systems, and walls. Therefore, the surface contamination concentration was measured using a survey meter (RADEYE B20-ER) using the following formula.

$$(1)\quad Bq/m^2 = \frac{CPS - CPS_{background}}{Area} \times \frac{1}{Efficiency}$$

The results indicated a measurement of 116 Bp/m^2 at surface and 131Bq/m^3 at hood. Furthermore, a conservative assessment was conducted assuming that surface contamination was uniformly distributed across all six walls, i.e., throughout the entire room.

2.2 RESRAD-BUILD Code

The RESRAD code is designed for evaluating radiation safety and DCGLs concerning residual radioactivity in areas contaminated. And it was developed by the Argonne National Laboratory (ANL). The RESRAD suite encompasses a variety of family codes tailored for specific assessment needs: “Onsite” for evaluating the safety of sites where radioactive waste is buried, and “Build” for evaluating the safety of buildings contaminated with radioactive materials. This study incorporates the ICRP 107 Data as the Dose

Conversion Factor (DCF) within the RESRAD-BUILD code. [4]

Table II: Control Factors for decontamination workers [5]

Factor	Default	Decontamination
Deposition Velocity	0.00039	0.0027
Resuspension rate	0.5E-6	1.4E-5
Breathing rate	18	46
indirect ingestion rate	0.0001	0.00029
Air Release Fraction	0.1	1

The decontamination process was adjusted for factors as outlined in Table II.

2.3 Parameters

The actual source material is stored in cabinet, but for this analysis, the cabinet was conceptualized as another room, referred to as Room 1, while the workspace for personnel was designated as Room 2. Considering occasional visitors, a corridor-like Room 3 was added to the model.

Thus, fig. 2 states that the situation was modeled with three rooms, and it was assumed that there was no air movement between Room 1 and Room 2. Rooms 2 and 3 had an air flow of 76 m³/h between them.

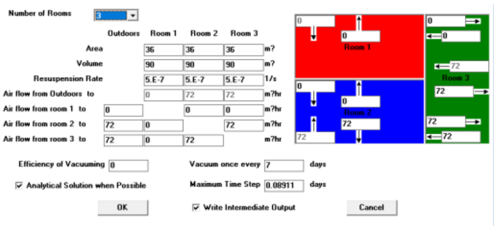

Fig. 2 Building parameters in RESRAD-BUILD

Fig. 3 illustrates the positions and characteristics of the sources and receptors throughout the building. Receptor1 represents the decontamination workers, while receptors 2 and 3 are assumed to be security guards and other employees. The features of the sources are summarized in Table III below.

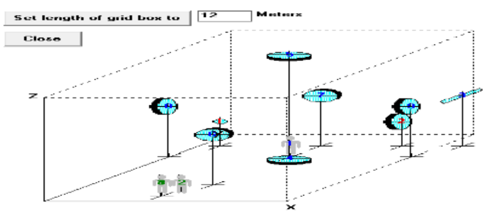

Fig. 3 Source parameter in RESRAD-BUILD

Table III: Summery of sources

No	Source	type
1	source material within the cabinet	Point
2	contamination source in the fume hood	Volume
3	contamination source in the exhaust system	Line
4~9	contamination source on the wall surface	Area

Sources 1 and 2 are assumed to be shielded by 3 mm of Iron (7.6g/cm^3) from individual 1, while sources 3 to 9 are shielded by 15 cm of concrete (2.4g/cm^3) exposed individuals 2 and 3.

3. Result

3.1 Occupational Dose

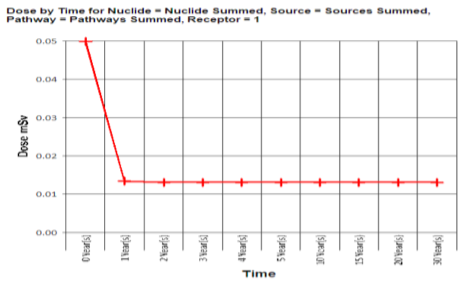

Fig. 4 Output of occupational dose (receptor 1)

At the fig. 4, the total dose for workers was 0.05 mSv/yr, and from Year 1 to Year 30, the total dose approximately amounted to 0.0168 mSv/yr annually. The dose was predominantly due to Source 1. Additionally, the dose remains almost constant after the initial year due to the presence of short-lived radionuclides in the decay chains of U-235/238 and Pu. Specifically, a dose of 6.48E-03 mSv/yr was recorded for Th-234 (T1/2=25.52 hours), and a dose of 9.51E-05 mSv/yr was recorded for Th-231 (T1/2=24.1 days).

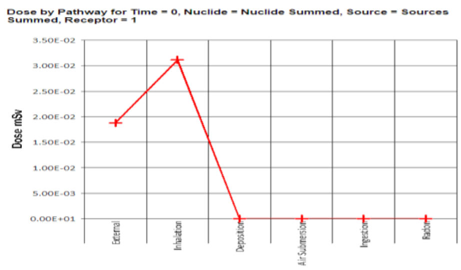

Fig. 5 Output of dose for each pathway

Additionally, fig. 5 states that the main dose pathways include both external and inhalation. A dose from inhalation exists due to the contamination source on the wall surfaces, it is minimal, amounting to 0.0311 mSv/yr. Therefore, inhalation dose is the dominant pathway, and reducing external & inhalation dose can significantly decrease the overall dose received by individuals.

3.2 Sensitivity Analysis

It has been determined that the main dose pathways for workers include both external and internal dose. Consequently, sensitivity analyses were performed on factors such as work duration and workers' breathing rates. Distance and shielding were excluded because they do not significantly affect the total dose. [6]

3.2.1 Time

The work-time ratio for decontamination workers is set at 0.25 (6 hours). Consequently, the work time was adjusted to twice and half its original duration, followed by a sensitivity analysis to assess the impact of these changes.

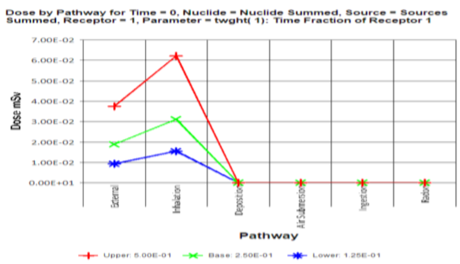

Fig. 6 Output of sensitivity analysis on time

As a result of fig. 6, adjusting the work time, the dose from external dose decreased from 0.188 mSv/yr to 0.0094 mSv/yr. And the dose from inhalation decreased from 0.0311 mSv/yr to 0.0155 mSv/yr. The doses from both dose pathways decreased by approximately 50%.

3.2.2 Breathing rate

The breathing rate of decontamination worker is 46 m³/h. Therefore, it was assumed that auxiliary tools such as work masks are used to regulate the breathing rate of the workers.

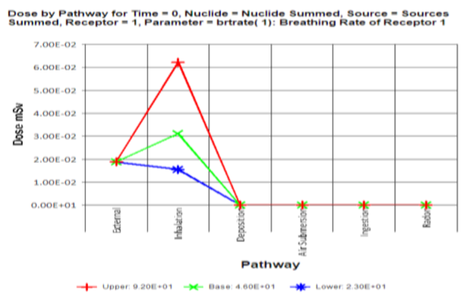

Fig. 7 Output of sensitivity analysis for breathing rate

As a result of regulating the breathing rate(fig, 7), the dose due to external dose decreased by 0.25% compared to the original. Additionally, the dose due to inhalation was reduced by approximately 50%, from 0.0311mSv/yr to 0.0155 mSv/yr.

3.3 Without decontamination Scenario

RECYCLE must be used to evaluate radiation exposure due to the reuse of metal waste, such as experimental equipment. Still, since this service is not currently supported, the total dose was assessed using BUILD. [7]

Considering that the dose for decontamination workers is 0.05mSv/yr, the necessity for decontamination work may not be high.

Therefore, a scenario was assumed where the space is repurposed for a different type of laboratory without undergoing decontamination work. Additionally, the factors listed in Table II were set as the default.

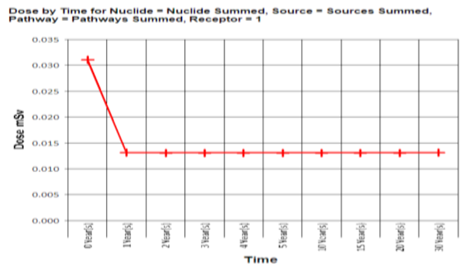

Fig. 8 Output of dose without decontamination scenario

As a result of fig. 8, a dose of receptor1 is 0.0310 mSv/yr. This indicates that the difference in dose is minimal, amounting to 0.019 mSv/yr.

3.4 DCGL

DCGL is the radionuclide-specific concentration limits applied to reuse sites or buildings after decommissioning. These values are derived from an annual dose limit of 0.1 mSv/yr. Therefore, in this study, DCGL was derived using the equation below.

$$(2)\ DSR = \frac{Total\ dose\ rate\left(\frac{mSv}{yr}\right)}{Contamination\ Contentration\left(\frac{Bq}{m^2}\right)}\ [8]$$

$$(3)\ DCGL(Bq/m^2) = \frac{Dose\ Criterion(mSv/yr)}{DSR(\mathrm{mSv/yr}/Bq/m^2)}$$

$$(4)\ \sum_{i=1}^{n}\frac{C_i}{DCGL_i} \le 1$$

$C_i = radioactive\ concentration\ of\ nuclide\ i$

the results were $DCGL_{U\text{-}235}$=10.50Bq/m² and $DCGL_{U\text{-}238}$=222.36Bq/m².

4. Conclusion

Among the sensitivity analyses conducted, the most significant variation was observed in the workers' operational hours. Hence, it becomes imperative to augment the workforce to diminish the workload per individual.

Nonetheless, the total dose resulting from repurposing the laboratory without decontamination amounted to 0.05 mSv/yr for total receptors. This dose is safer than the site release standard of 0.1 mSv/yr.

The DCGL for surface contamination in the laboratory is determined to be 232 Bq/m^2. This signifies that if the surface contamination in the said laboratory is maintained at or below 232 Bq/m^2, the resulting annual dose will be less than 0.1 mSv/yr.

In the RESRAD-BUILD code, it is impossible to precisely adjust the locations of the rooms or their detailed settings. Furthermore, since cabinets were designated as separate rooms, there is a risk associated with factors that could not be controlled. Therefore, future experiments aim to incorporate corrections for these conditions to achieve more accurate results.

It is hoped that this research will serve as valuable assessment material for the facility’s safe reuse or site release evaluation.

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