ISSN:1738-6764, eISSN:2093-7504

Using RESRAD-BUILD for Potential Radiation Dose Estimation the Korea Research Reactor-1 When It Opens to the Public as a Memorial Hall

Sangbok Lee [1], Yongsu Yoon [2] and Sungchul Kim [3,*]

[1] Department of Radioactivity Test & Analysis center, Sunkwang T&S, Department of Radiological Science, Graduate school of Gachon University; Ph.D course student; lsbguy87@gmail.com
[2] Department of Health Sciences Kyushu University, JAPAN; Assistant Professor, yoonys@med.kyushu-u.ac.jp
[3] Department of Radiological Science, Graduate school of Gachon University; Professor, ksc@gachon.ac.kr
* Correspondence

https://doi.org/10.5392/IJoC.2020.16.2.102

Manuscript Received 23 October 2019; Received 22 June 2020; Accepted 23 June 2020

Abstract: *The purpose of this study was to estimate and analyze the potential radiation dose that the future visitors and the cleaning staff will be exposed to when the KRR-1 reactor is converted into a memorial hall. The radiation doses were estimated using the RESRAD-BUILD software, where case, building, receptor, shielding, and source parameters were applied as the input data. Also, the basic data for the assessment of the radiation doses were determined in an indirect manner using the data on the waste generated during the decommissioning process of the reactor. The assessment results indicate that the potential radiation dose to the visitors and the cleaning staff will be less than 1 mSv, the annual dose limit for the general public. However, if anyone for a significant period of time is close to the reactor, the overall dose will increase. The radiation dose for the future visitors and the cleaning staff was determined to be lower than the annual dose limit for the general public. Given such a risk, systematic measures, such as periodic monitoring or limiting hours, are imperative.*

Keywords: RESRAD-BUILD; research reactor; potential radiation dose; annual dose limit; memorial hall

1. Introduction

Korea Research Reactor-1 (KRR-1; TRIGA Mark-II) was Korea's first nuclear reactor. It was established after a 1955 proposal by the USA to build a nuclear research reactor in Korea for peace purposes. The reactor began operation on March 19th, 1962. The capacity of this research reactor was initially 100 kW, but it was later extended to 250 kW. For 33 years, the reactor fully accomplished its intended missions before its operation came to an end in 1995 [1]. Since 1996, the Specialized Committee on the Use and the Development of Nuclear Energy has been pushing forward its initiative to decommission the research reactor with the ultimate aim of converting it into a memorial hall because of its educational and historical value as the country's first nuclear reactor [2]. Among the decommissioning methods for nuclear power plants and nuclear-related facilities, the immediate dismantling method involves structures and facilities of the target facility and waste therefrom being decontaminated and dismantled immediately after the shut-off of the facility so that the radiation dose is reduced to below the given limit. Alternatively, the deferred dismantling method is an approach based on the theory that radioactive substances have their own characteristic decay constants and half-life periods, so they naturally decay over time. With this method, it takes almost 100 years to fully decommission and restore a facility. Therefore, it is clear that the deferred dismantling method is not suitable for KRR-1 given its intended use [3]. In Korea, many nuclear power plants are due for decommissioning, starting with the Kori-1 reactor [4]. With this in mind, the present study largely focuses on estimating and analyzing the potential radiation dose that might occur when KRR-1 is converted into a memorial hall so that the resulting data can be used as a basis for future radiation dose evaluation. More specifically, this study aims to assess the safety of future visitors and staff (especially those who will spend longer periods of time near the nuclear reactors, i.e., the cleaning staff) at the memorial hall when it opens [5]. To this end, the potential radiation dose will be estimated to assess any risks. Given the lack of existing research on radiation dose evaluation, the present study will provide valuable basic research data for the estimation of future radiation doses.

2. Materials and Methods

KRR-1 has been designated as a cultural asset, so it is difficult to collect samples from it. Also, among the radioactive waste generated during the initial decommissioning process, the waste subjected to permanent disposal has the highest radiation dose. In the present study, the basic data used was onsite data obtained from 516 drums of waste that were delivered from KRR-1 to the radioactive waste disposal site in Gyeongju in 2015.

The evaluation of the residual radioactivity was conducted as follows: the 2015 data, which was obtained at the time of disposal, were subjected to radioactive decay revision in 2018. Based on the revised data, the potential radiation dose to future visitors and cleaning staff as of 2023, i.e., the year the memorial hall will open, was estimated using the RESRAD-BUILD software (Ver 3.0, United States, Argonne National Laboratory) [6, 7] as shown in Fig. 1.

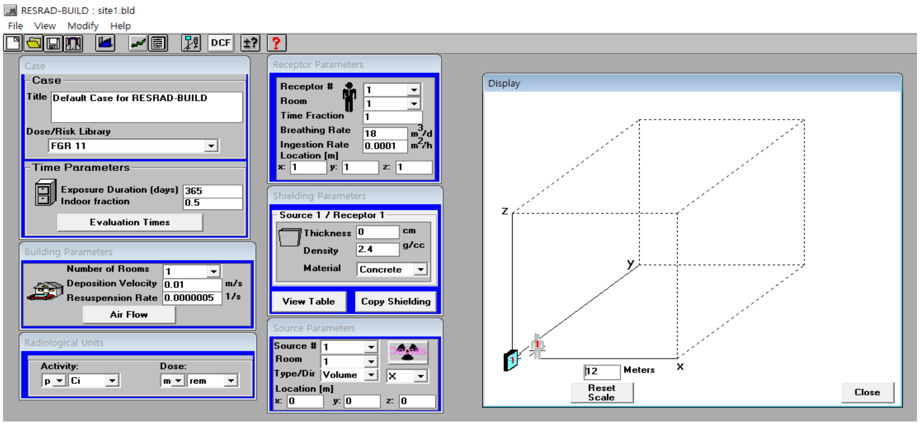

Figure 1. Main Scenario of the RESRAD-BUILD Software

2.1 Case Parameter

The analysis was conducted separately for visitors and cleaning staff, and the dose/risk factor was set to 17. Given that the number of the target radioactive waste nuclides for evaluation is 10 (with the exception of tritium), the dose/risk factor 17 is a conservative figure that also considers the number of daughter nuclides [7]. It was assumed that the visitors spent two hours per day touring the memorial hall, their exposure period was set to one day, and the indoor fraction was set to 0.083. For the cleaning staff, their annual average working days were estimated to be 249 using Eq. 1 [8], and their indoor fraction was set to 0.042, which assumes that they stay indoors for one hour per day, as shown in Fig. 2.

$$Working\ days = [\ 365.25days/1year \times \frac{5}{7}\ ] - Number\ of\ Actual\ holidays \quad \text{Eq. 1.}$$

On the case parameter input page of the RESRAD-BUILD software, the dose estimation time was set to five years. The rationale behind this setting is that, as it currently stands, the demolition of the remaining facilities of this research reactor will be completed by 2021, which will be followed by a preparation period for deregulating the facility site and converting the reactor into a memorial hall. In this regard, the opening year of the memorial hall was set to 2023.

2.2 Build Parameters

Assuming that the reactor room of KRR-1 is converted into a memorial hall, the number of rooms was set to one, and the degree of deposition and resuspension rate of the radioactive nuclides were set as the program defaults. The area and height data were estimated based on measured blueprints (22.5x16.05x15.6 m^3). Considering the large area of the reactor room, it was reasoned that the performance of the supply and exhaust fans set in the reactor room was lower than the default value, so the building exchange rate was set to 0.8 (Fig. 3).

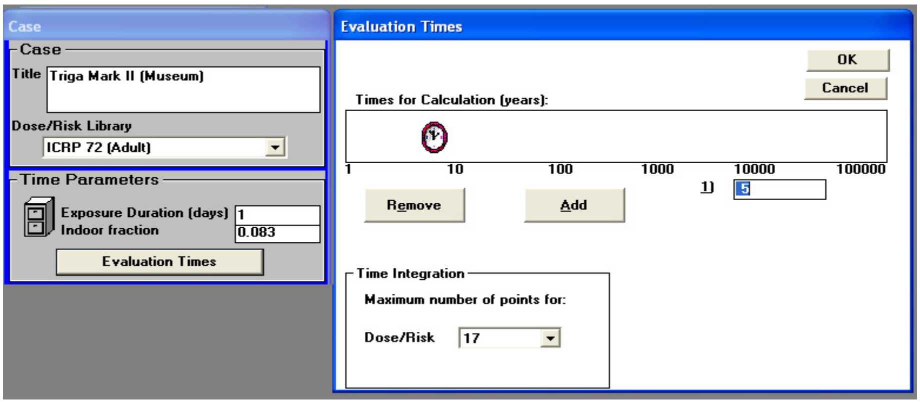

Figure 2. Case Parameters

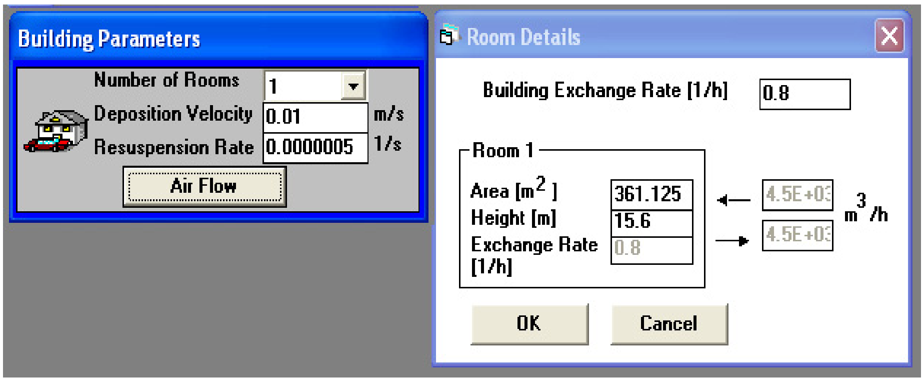

Figure 3. Building Parameters

2.3. Receptor Parameters

The nearest visitor-accessible location to the KRR-1 model is approximately 50 cm away from the centerline of the model, and the cleaning staff are expected to cover the entire area of the model. Thus, as a conservative approach, the location of the cleaning staff was set to be the same as that for the visitors, i.e., the nearest location to the KRR-1 model as shown in Fig. 4.

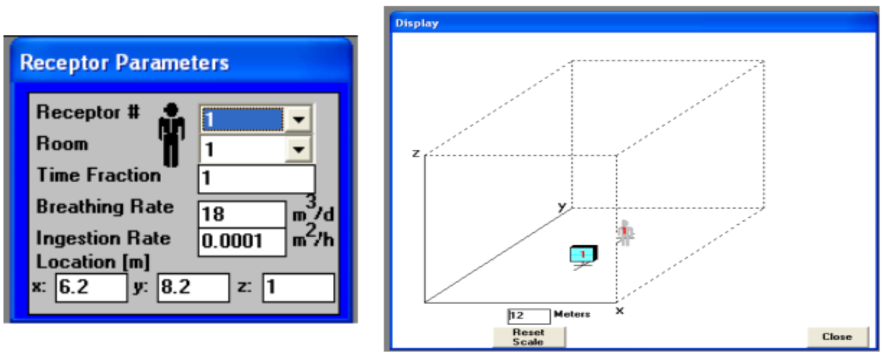

Figure 4. Receptor Parameters for the Visitors and Cleaning Staff

2.4 Shielding Parameters

Considering that the entire space of the memorial hall, including the reactor building, is a concrete structure, the concrete density was set as the default of 2.4 g/cc. At this point, the KRR-1 model was set as Source 1, and the thickness of the shielding wall was set to 0 cm.

2.5. Source Parameters

Source parameters were determined based on the nuclide analysis data of the radioactive waste delivered to the disposal site in November 2015; as a result, the decay time was estimated at 1156 days as of November 2018 (see Eq. 2 and Table 1). Considering that the half-life period of the tritium is 12.3 days and that the decommissioning of the reactor core of KRR-1 was completed in 2011, it can be reasoned that the tritium no longer remains in 2018, so this nuclide was excluded from the evaluation (Fig. 5).

$$After\,the\,Calibration\,(Bq/g) = Rawdata \times \exp\left(\frac{\ln 2}{365.24 \times half\,life}\right) \times Decay\,time \qquad \text{Eq. 2.}$$

Table 1. Input Data for the Source Parameters

Unit: Bq/g

Nucilde	Calibration	Nucilde	Calibration
C-14	8.40E+00	Sr-90	1.22E+01
Fe-55	1.28E+02	Cs-134	3.14E+01
Ni-59	1.41E+01	Cs-137	8.05E-02
Co-60	6.07E+02	Eu-152	1.36E+00
Ni-63	2.78E+02	Eu-154	5.93E+00

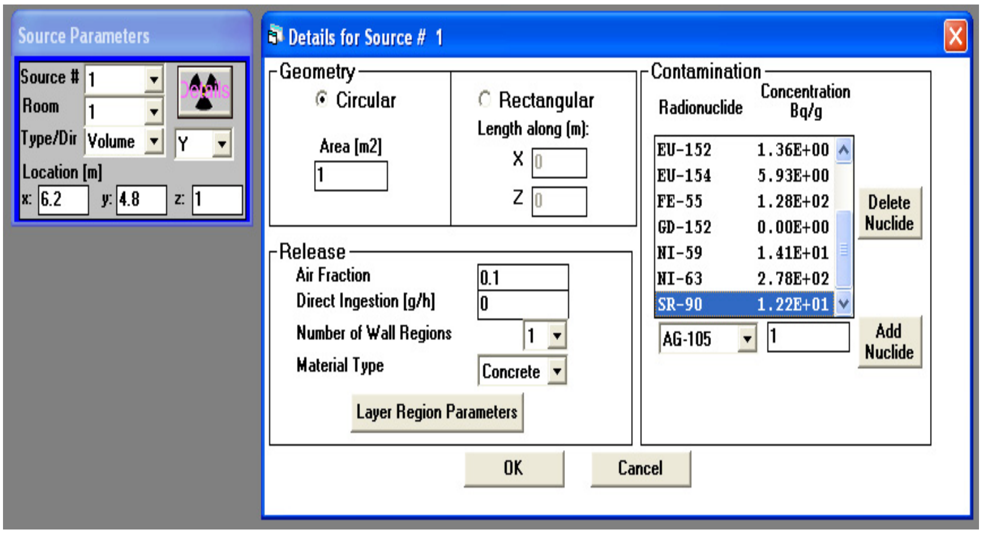

Figure 5. Source Parameters

3. Results

3.1. Estimation of Radiation Dose to Visitors

The external radiation dose to the visitors was estimated to be 6.14 μSv as of November 2018, and this figure was estimated to be 3.12 μSv as of the opening year of 2023; both figures are below 100 μSv, i.e., which is the minimum requirement for the deregulation of nuclear facilities. All other results, which consider additional exposure pathways, such as breathing, also satisfied the related requirements. The nuclide-specific radiation dose evaluation results showed that the strongest radiation source as of 2023 will be Co-60, i.e., 3.06 μSv (see Table 2 and 3).

Table 2. Estimated Radiation Dose to Visitors according to Exposure Pathway

Unit : μSv

Year	External	Deposition	Immersion	Inhalation	Radon	Ingestion
2018	6.14E+00	4.88E-08	2.96E-10	3.25E-08	-	1.15E-08
2023	3.12E+00	2.48E-08	1.51E-10	1.82E-08	-	6.01E-09

Table 3. Estimated Radiation Dose to Visitors according to Radioactive Nuclide

Unit : μSv

Nuclide	2018 year	2023 year	Nuclide	2018 year	2023 year
Co-60	5.91E+00	3.06E+00	C-14	6.57E-08	6.56E-08
Cs-134	1.94E--01	3.61E-02	Ni-63	4.67E-10	4.51E-10
Eu-154	2.84E-02	1.91E-02	Fe-55	1.13E-10	3.12E-11
Eu-152	6.03E-03	4.64E-03	Ni-59	9.88E-12	9.88E-12
Cs-137	1.89E-04	1.69E-04	Gd-152	6.25E-25	2.01E-21
Sr-90	1.95E-04	1.73E-04			

3.2. Estimation of Radiation Dose to Cleaning Staff

For the cleaning staff, the radiation dose as of 2023 was estimated to be 73.1 μSv. The nuclide-specific radiation dose evaluation results showed that the strongest radiation source will be Co-60, i.e., 70.6 μSv (Table 4 and 5).

Table 4. Estimated Radiation Dose to Cleaning Staff according to Exposure Pathway

Unit : μSv

Year	External	Deposition	Immersion	Inhalation	Radon	Ingestion
2018	7.31E+01	5.87E-06	3.56E-08	2.12E-06	-	7.68E-07
2023	3.72E+01	2.99E-06	1.82E-08	1.18E-06	-	3.95E-07

Table 5. Estimated Radiation Dose to Cleaning Staff according to Radioactive Nuclide

Unit : μSv

Nuclide	2018 year	2023 year	Nuclide	2018 year	2023 year
Co-60	7.06E+01	3.66E+01	C-14	6.56E-07	6.55E-07
Cs-134	2.11E+00	3.93E-01	Ni-63	6.66E-08	6.43E-08
Eu-154	3.40E-01	2.29E-01	Fe-55	1.84E-08	5.10E-09
Eu-152	7.24E-02	5.58E-02	Ni-59	1.41E-09	1.41E-09
Cs-137	2.16E-03	1.92E-03	Gd-152	5.63E-21	7.79E-20
Sr-90	2.38E-03	2.11E-03			

4. Discussion

The present study estimated and analyzed the potential radiation dose to any future visitors and cleaning staff at KRR-1, which was Korea's first nuclear research reactor, when it is converted into a memorial hall. The RESRAD-BUILD software applied in the evaluation is widely used in radioactivity evaluation of building materials [9] and radiation dose evaluation during the decommissioning of a nuclear reactor [10]. Globally, a total of 19 nuclear power plants have been decommissioned, and among them, 15 belong to the US. The decommissioned US nuclear plants are currently used for various purposes, such as power generation, green areas, and for educational purposes. In Japan and Germany, all decommissioned nuclear plants are used as green areas [11]. However, given the particular situation of KRR-1, which is to be converted into a memorial hall that can accommodate the general public, more attention has to be paid to radiation exposure risks. Assuming that the opening year of the memorial hall will be 2023, the potential radiation dose to any visitors who spend two hours touring the hall was estimated to be 3.12 μSv/yr, while the potential radiation dose to cleaning staff who spend one hour a day cleaning the hall was estimated at 73.1 μSv/yr. Both figures are lower than the annual dose limit for the general public of 1 mSv/yr. These figures were even lower than 0.19 mSv/yr, which was the minimum requirement for the opening of the Connecticut Yankee Nuclear Power Plant to the general public; the Connecticut Yankee Nuclear Power Plant was, recently decommissioned and converted into green areas in the US [11, 12]. However, if the cleaning staff work for a longer period of time near the center of the reactor room, their overall dose will increase. Given such a risk, systematic measures, such as limited working hours, are deemed to be necessary. It is important to note that the US is the most experienced country in terms of decommissioning nuclear power plants. Considering Korea's lack of existing research data on decommissioning nuclear facilities, the upcoming decommissioning of some of the country's nuclear reactors whose intended service time has been reached, such as the Kori-1 reactor and the Wolsong-1 reactor, will provide a great deal of valuable data and information that will help advance the country's decommissioning technology. Despite the limitations of this study, the memorial project of the research reactor is a project designated as a cultural asset. In addition, this study is valuable in that it is estimated indirectly based on nuclide data obtained from waste generated during the KRR-1 decomposition process in the absence of basic data to evaluate them.

There are several studies in which dose assessment for the dismantling of nuclear power plants was evaluated using RESRAD programs [13-15]. There studies simulated as a supplementary indicator for calculating the grade of each site or building by deriving the concentration of DCGL for each radionuclide in order to establish a decommissioning plan. It is significant that it was modeled as a RESRAD-BUILD.

The major findings of the present study will serve as a basis for the future study of radiation exposure when the memorial hall is finally opened to the public.

5. Conclusions

The potential radiation dose to any future visitors and cleaning staff that might occur when KRR-1 is opened to the public as a memorial hall in 2023 was estimated to be 3.12 μSv/yr and 73.1 μSv/yr, respectively. Both figures are lower than the annual dose limit of 1 mSv for the general public. However, if the cleaning staff work for a longer period of time, the overall dose will increase. Given such a risk, systematic measures, such as minimizing working hours near the center of the reactor room where exposure will be highest, implementing a work schedule where they only work every other day, or continuously monitoring their radiation doses, are considered to be very crucial.

Conflicts of Interest: The authors declare no conflict of interest.

References

[1] D. H. Seo, "TRIGA-Mark II. Operating & Decommissioning project for TRIGA MARK II of 33 years," Nuclear Industry, vol. 15, no. 11, pp. 48-52, 1995, Accessed: Jun. 10, 2019. [Online] Available: http://www.ndsl.kr/ndsl/commons/util/ndslOriginalView.do?cn=JAKO199572621734735&oCn=JAKO199572621734735&dbt=JAKO&journal=NJOU00290803

[2] K. J. Jung, "Decontamination and Decommissioning Project of the KRR 1＆2 Research Reactors," Korea Atomic Energy Research Institute, Rep. RR-2182, 2002. Accessed: Jun. 10, 2019. [Online] Available: http://www.ndsl.kr/ndsl/commons/util/ndslOriginalView.do

[3] H. K. Kim and Y. J. Kim, "Seeking Principles for a Korean Nuclear Decommissioning System from a Comparative Perspective," Journal of International Area Studies, vol. 19, no. 1, pp. 3-32, 2015. Accessed: Jun. 10, 2019. [Online] Available: file:///C:/Users/GC/AppData/Local/Microsoft/Windows/INetCache/IE/O11UR4XT/KCI_FI001985262.pdf

[4] H. J. Lee, S. W. Ji, W. J. Kim, T. G. Do, D. Y. Kim, and K. P. Kim, "Study of Decommissioning Organization and Target Doses for Management of Radiation Exposure to Workers at Nuclear Facilities," J. Radiat. Ind., vol. 12, no. 1, pp. 89-96, 2018. Accessed: Jun. 10, 2019. [Online] Available: https://www.ksri.kr/0304/view/page/13/id/3463

[5] ICRP Publication 103, "The 2007 Recommendations of the international commission on radiological protection," 2007. Accessed: Jun. 10, 2019. [Online] Available: http://www.icrp.org/publication.asp?id=ICRP%20Publication%20103

[6] Argonne National Laboratory, Development of Probabilistic RESRAD 6.0 and RESRAD-BUILD 3.0 Computer Codes, EAD/TM-98, 2000. Accessed: Jun. 10, 2019. [Online] Available: https://resrad.evs.anl.gov/docs/NUREG_6697.pdf

[7] Argonne National Laboratory, User's Manual for RESRAD- BUILD Version 3.0, EAD/03-1, 2003. Accessed: Jun. 10, 2019. [Online] Available: https://resrad.evs.anl.gov/docs/ANL-EAD-03-1.pdf

[8] Rancho Seco, Compliance With the Radiological. Chapter 6, License Termination, 2008. Accessed: Jun. 10, 2019. [Online] Available: https://www.nrc.gov/docs/ML0819/ML081990517.pdf

[9] S. Pepin, "Use of NORM-containing products in construction Using RESRAD-BUILD to assess the external dose from the natural radioactivity of building materials," Construction and Building Materials, vol. 168, pp. 1003-1007, Apr. 2018, doi: https://doi.org/10.1016/j.conbuildmat.2018.02.015.

[10] S. B. Hong, K. W. Lee, J. H. Park, and U. S. Chung, "Application of MARSSIM for Final Status Survey of the Decommissioning Project," Journal of the Korean Radioactive Waste Society, vol. 9, no. 2, pp. 107-111, 2011, doi: http://dx.doi.org/10.7733/jkrws.2011.9.2.107.

[11] S. B. Hong, "A Study on the Optimization Method for Decommissioning Site Remediation," Ph.D. Dept. of Nuclear Engineering, Kyung Hee University, Korea, 2016.

[12] J. Samseth, A. Banford, B. Metcalf. M. Cantone, P. Lietava, H. Peimani, and A. Szilagyi, Closing and Decommissioning Nuclear Power Reactor, UNEP Year Book, pp. 35-49, 2012. Accessed: Jun. 10, 2019. [Online] Available: https://pdfs.semanticscholar.org/e595/96bd6e90a9382dfbab9b22b0d8b512f18879.pdf

[13] S. J. Park, J. Byon, D. H. Ban, S. Lee, W. Sohn, and S. Ahn, "Derivation of preliminary derived concentration guideline level (DCGL) by reuse scenario for Kori Unit 1 using RESRAD-BUILD," Nuclear Engineering and Technology, vol. 52, no. 6, pp. 1231-1242, Jun. 2019, doi: https://doi.org/10.1016/j.net.2019.11.032.

[14] S. Y. Cho, Y. S. Kim, D. W. Park, and C. J. Park, "A study on DCGL determination and the classification of contaminated areas for preliminary decommission planning of KEPCO-NF nuclear fuel fabrication facility," Nuclear Engineering and Technology, vol. 51, no. 8, pp. 1951-1956, Dec. 2019, doi: https://doi.org/10.1016/j.net.2019.06.012.

[15] S. Kamboj, Y. Charley, and R. Johnson, "Development of DCGLs by using both probabilistic and deterministic analysis in RESRAD and RESRAD-OFFSITE codes," Journal of the Health Physics Society, vol. 104, pp. 68-75, May. 2013, doi: 10.1097/HP.0b013e318286cb20.