A Study on the Deriving Methodologies for Optimizing Worker Exposure in Radioactive Waste Treatment Facilities

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1. Introduction

Radiocarbon (C-14), the focus of this study, is a typical volatile nuclide found in nuclear facilities and radioactive material handling workplaces. It can be released as a gas or exist in organic form, leading to internal and external exposures through inhalation, ingestion, and other pathways. Therefore, to effectively manage exposure in C-14 handling facilities, it is crucial to analyze worker exposure pathways and develop optimization strategies to minimize radiation exposure [1][2].

In this study, we analyze the exposure path of C-14 workers based on the principle of exposure minimization for ALARA in a radiation protection environment, and build a schematic diagram of exposure management. We also develop a checklist for exposure optimization and propose a methodology to improve the efficiency of radiation exposure management in C-14 handling facilities and increase the radiation safety of workers based on it.

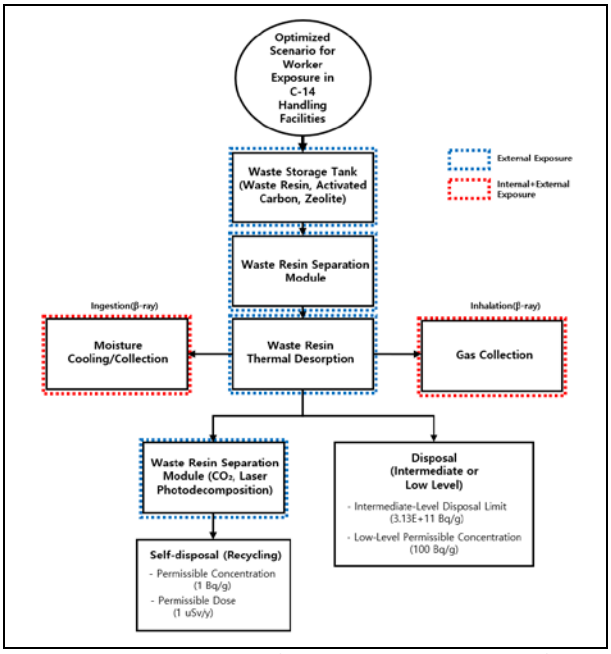
2. Methods

2.1 C-14 Source term characteristics

Table 1. shows the Source term properties of C-14. The radiotoxicity of C-14 is reported to be 6.36E-12 Sv/Bq (0.023 mrem/μCi) for inhaled $^{14}CO_2$ and 5.64E-10 Sv/Bq (2.09 mrem/μCi) for inhaled or ingested organic compounds, with the main affected organs being adipose tissue (for most labeled compounds) and bone tissue (for some carbonate-labeled compounds) [3]. This means that in the body, C-14 can accumulate in certain tissues or persist for long periods of time in metabolic processes, potentially resulting in radiation effects from long-term internal exposure. Therefore, appropriate safety measures that take into account the main routes of radiation exposure are essential. In this study, we analyzed the exposure pathways of C-14 workers to identify the main pathways that are likely to be exposed during work and conceptualized them as shown in Fig 1.

"Table 1. C-14 Source term data" [3]

	value	
Radiation	Beta (100% abundance)	
Energy	Max 156 Kev	
	Average 49 Kev	
Half-life	Physical	5730 y
	Biological	12 d
	Effective	Bound: 12 d
		Unbound: 40 d
Specific Activity	4.46 Ci/g [0.165 TBq/g] max	
Beta Range	Air	24 cm
	Water/Tissue	0.28 mm
	Plastic	0.25 mm

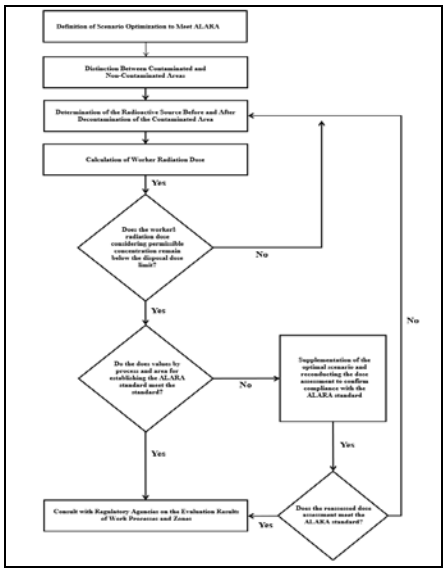


"Figure 1. Conceptualization of exposure pathways in terms of C-14 handling facility worker exposure management."

2.2 C-14 Schematic diagram of exposure management

Based on the ALARA (As Low As Reasonably Achievable) principle, a schematic diagram to minimize the exposure of workers was derived as shown in Fig. 2, and the exposure reduction strategy was systematically presented. The main criteria for exposure optimization

are classification of contaminated and non-contaminated areas, source term, and calculation of exposure dose[4][5][6]. In order to improve the reliability of worker dose calculation results, it is important to satisfy ALARA standards. The structure as shown in Fig. 2 is intended to be used as a basic concept for optimizing the worker dose assessment according to the site situation.



"Fig 2. Exposure management schematic diagram"

2.3 Checklist for optimizing C-14 exposure

It is important from the perspective of radiation safety to evaluate the exposure potential of each work process in advance and to systematically apply exposure prevention measures to reduce exposure. In this study, we developed a checklist for optimizing exposure as shown in Table 2.

"Table 2. Checklist for optimizing radiation exposure scenarios"

	Check list	Optimization judgment
1	Does the work process involve internal or external exposure risk?	Derive contaminated/non-contaminated workpaths and scenarios
2	Does the output of the work process meet radiological regulatory requirements for disposal or self-disposal?	Working Dose Limits, Allowable Concentrations, and Disposal Limits
3	Is there a potential for leakage or ingress of radioactive materials in the work process?	Storage cylinder specifications and device durability by work process
4	Is there any secondary radioactive waste generation?	Characterization and performance evaluation of adsorbent types
5	Is there a potential for contamination of the work process and work area?	Consider potential exposures under normal and abnormal scenarios

Checklists such as Table 2 can be used as a basis for determining the likelihood of exposure to actual radiation/environmental hazards and are linked to the derivation of possible exposure scenarios.

3. Conclusion

In this study, a methodology for reducing the exposure of C-14 workers was established by integrating the exposure path analysis, exposure management schematic diagram, and checklist for optimizing the exposure. In addition, the reliability of the study was enhanced by considering the gaseous radioactive waste discharge standards and related regulations of domestic nuclear facilities. Based on this, we plan to build a scenario of worker exposure in an environment utilizing C-14 and evaluate it in the future. This is expected to help systematically manage radiation exposure in C-14 handling workplaces and enhance radiation safety for workers.

4. Ackonwledements

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5. Reference

[1] H. P. Kim, "A Study on the Public Exposure due to Carbon-14 Release to the Environment from Korean Nuclear Power Plants", M.S. thesis, Dept. of Nuclear Eng., Chosun Univ., Gwangju, South Korea, 2024.
[2] J. H. Ji, E. O. Koh, E. S. Jung, D. W. Kang, and M. C. Kim, "Assessment of C-14 discharge through liquid waste of NPP," in Proc. Korean Nuclear Society Spring Meeting, 2001.
[3] National Council on Radiation Protection and Measurements (NCRP), "Nuclide Safety Data Sheet: Carbon-14", NCRP Report, 2018.
[4] United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), "Sources, Effects and Risks of Ionizing Radiation": UNSCEAR 2013 Report, Volume I. United Nations, New York, 2014.
[5] International Commission on Radiological Protection (ICRP), "Application of the Commission's Recommendations to the Protection of Individuals Living in Long Term Contaminated Territories After a Nuclear Accident or a Radiation Emergency", ICRP Publication 111.
[6] P. Croüail, T. Schneider, J.-C. Gariel, M. Tsubokura, W. Naito, M. Orita, and N. Takamura, "Analysis of the modalities of return of populations to the contaminated territories following the accident at the Fukushima power plant," *Radioprotection*, vol. 55, no. 2, pp. 79–93, 2020.