

Establishment of Selection Criteria and Identification of Target Radionuclides for Off-site Radiation Monitoring Algorithms

Dongseong Shin^a, Seop Hur^{a*}

^aKorea Atomic Energy Research Institute (KAERI), Daejeon 34057, South Korea

*Corresponding author: shur@kaeri.re.kr

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1. Introduction

In the event of a severe nuclear accident, the rapid and accurate identification of radionuclides released into the environment is the most critical factor in determining public protective actions, such as evacuation, sheltering, and the administration of thyroid blocking agents. While current nuclear safety acts and technical standards aim to minimize environmental hazards, the complex mixture of numerous isotopes released during an actual accident poses a significant technical challenge for real-time identification.

In particular, next-generation detection systems based on Silicon Photomultipliers (SiPMs) offer advantages such as miniaturization and low power consumption in extreme environments. However, their inherent sensitivity to temperature fluctuations can lead to gain shifts and degraded energy resolution. To enhance the accuracy and computational efficiency of identification algorithms under these hardware constraints, it is imperative to pre-select core radionuclides that are both metrologically significant and regulatorily critical based on scientific evidence. This study establishes the selection criteria for off-site radionuclides and evaluates their technical validity to optimize monitoring algorithms.

2. Technical Analysis

2.1 Regulatory Guidelines and Standards

Domestic and international regulatory bodies specify reference radionuclides for source term management and environmental impact assessment. NSSC Notice No. 2017-34 utilizes the release frequency of Cs-137 as a key indicator for accident management planning. Similarly, the U.S. NRC's Regulatory Guide 1.183 (Alternative Source Terms) provides release fractions for noble gases, iodine, cesium, and tellurium relative to the core inventory, forming the basis for design-basis accident analysis.

2.2 Evaluation of Accident Source Terms

Historical data from major nuclear accidents provide

essential insights into actual release behavior.

TMI and Chernobyl : While noble gases and iodine were dominant initially, the Chernobyl accident involved a wide range of aerosol-form isotopes such as Cs-137, Te-132, and Ru-103.

Fukushima : The environmental release was dominated by Cesium(Cs-134, 137) and Iodine(I-131), reaffirming the importance of real-time monitoring for high-volatile isotopes.

2.3 Safety Analysis Reports (PSA Level II)

The Level II Probabilistic Safety Assessment (PSA) reports for operating nuclear power plants provide a comprehensive list of isotopes that could potentially be released off-site during containment failure. These reports serve as a robust database that reflects actual core inventories and containment transport behaviors.

3. Filtering of Potential Off-site Radionuclides

3.1 Identification of Potential Isotopes

Based on the analysis, a total of 54 radionuclides were identified as potential candidates for off-site release. These are categorized by their chemical characteristics as follows Table 1.

Table . 1. Summary of Off-site Released Nuclides of NPP Accident.

Category	Selection Criteria	Nuclide	Note
Regulatory Nuclides	TID 14844, RG 1.4& 1.195	I	
	NUREG-1465 & RG 1.183	I, Cs, Te, Ba	
	KINS Notice No. 9	Cs-137	
Overseas Nuclides	Reference Source Term(France)	Xe-133, I-131, Cs-137, Te-132, Sr-90, Ru-106, Pu-239	
Nuclide of Major Accident	Chernobyl	I, Cs, Te, Ru, Mo	
	TMI	Noble Gas, I	
	Fukushima	Noble Gas, Cs, I, Te, Sr	

Safety Analysis for Commercial Reactors	Commercial Reactor FSAR Nuclide	Kr-85m/85/87/88 Xe-133m/133/135m/135/138 I-131/132/133/134/135	
	Level II PSA Result	Co-58/60, Kr-85/85m/87/88 Rb-86, Sr-89/90/91/92 Y-90/91/92/93, Zr-95/97 Nb-95, Mo-99, Tc-99m Ru-103/105/106, Rh-105 Sb-127/129 Te-127/127m/129/131m/132 I-131/132/133/134/135 Xe-133/135, Cs-134/136/137 Ba-139/140, La-140/141/142 Ce-141/143/144, Pr-143 Nd-147, Np-239 Pu-238/239/240/241 Am-241, Cm-242/244	

3.2 Proposed Filtering Process

A 6-step technical filtering process was performed on the 54 candidates to optimize the algorithm:

Gamma Emission : Pure alpha/beta emitters were excluded to focus on gamma-ray spectroscopy (50 isotopes remained).

Half-life Criterion : Isotopes with a half-life of at least 3 hours were selected to ensure sufficient detection time (19 isotopes remained).

Volatility Characteristics : Priority was given to high-volatile (Noble gas, I, Cs, Te, Sb, Rb) and semi-volatile (Ba, Mo) groups (13 isotopes remained).

Measurable Energy Range : Verified the presence of valid gamma peaks within the detector's range of 30 keV to 3 MeV.

Release Amount & Accumulation : Selected 12 isotopes with high total activity (Bq) during accidents or significant long-term accumulation potential.

Resolution & Overlap Analysis : Finalized isotopes based on the detector's Full Width at Half Maximum (FWHM) to avoid peak interference (e.g., Kr-85 vs. Ba-140).

Table . 2. Nuclides that passed the proposed filtering process

Radio nuclide	Gamma Decay	Half-Life	Volatility	Energy Range	Release	Cumulative	Final Passed
Co-58	o	o	o	o		o	o
Co-60	o	o	o	o		o	o
Kr-85	o	o	o	o	o	o	o
Kr-85m	o	o	o	o	o		o
Zr-95	o	o					
Zr-97	o	o					
Nb-95	o	o					
Tc-99m	o	o	o	o			
Ru-103	o	o					
Te-131m	o	o	o	o	o		o
Te-132	o	o	o	o	o		o
I-131	o	o	o	o	o	o	o
I-132	o						

I-133	o	o	o	o	o		o
I-134	o	o	o	o	o		o
Cs-134	o	o	o	o	o		o
Cs-137	o	o	o	o	o	o	o
Ba-140	o	o	o	o	o	o	o
La-140	o	o					
Ce-141	o	o					

4. Result

The following table summarizes the key characteristics of the radionuclides finally selected for the identification algorithm.

Table . 1. Final selected Nuclides

Radionuclide	Half-life	Volatility	Rep. Energy (keV)	Selection Rationale
I-131	8.02 d	High	364.5	Core regulatory isotope; dominant thyroid dose
Cs-137	30.1 y	High	661.7	NSSC Notice indicator; long-term contamination
Kr-85	10.7 y	High	514.0	Representative noble gas; 100% release fraction
Te-132	3.20 d	High	228.2	Significant early-stage activity in major accidents
Co-60	5.27 y	Low	1173.2, 1332.5	High-energy calibration; persistent aerosol

5. Conclusion

Through a systematic evaluation of regulatory requirements and physical constraints, five core radionuclides were selected to optimize off-site radiation monitoring. These results provide the technical foundation for improving the accuracy of identification algorithms in temperature-compensated SiPM systems, ultimately enhancing emergency response capabilities during nuclear accidents.

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