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Original article

Status of Development and Production of Certified Reference Materials for Radioactivity in Korea

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ABSTRACT This study provides a comprehensive analysis of the utilization, demand, development, and production systems for certified reference materials (CRMs) related to radioactivity in Korea, focusing on various industrial sectors. Radioactivity CRMs are essential for ensuring the reliability of measurements in applications such as radiation detection, environmental monitoring, radiopharmaceutical quantification, nuclear facility decommissioning, and radioactive waste management. These materials are crucial for maintaining radiation safety standards and quality control. Currently, the Korea Research Institute of Standards and Science (KRISS) is the only institution responsible for developing and distributing radioactivity CRMs in Korea. Since the mid-1990s, KRISS has gradually expanded its CRM production to meet the needs of various industries. Initially, the focus was on radionuclides such as ^{60}Co and ^{137}Cs, but over time, the range has broadened to include medical radioisotopes, radionuclides for environmental analysis, and mixed gamma-emitting sources. KRISS supplies radioactivity CRMs in several forms, including liquid sources, point sources, mixed gamma-emitting sources, and solid matrix materials. Each CRM has detailed specifications outlining the radiation type, primary radionuclides, physical form, and activity range. Notably, mixed gamma-emitting CRMs are widely used for energy and efficiency calibration of high-purity germanium detectors in medical institutions, environmental monitoring facilities, and nuclear industries. These CRMs contain radionuclides such as ^{241}Am, ^{109}Cd, ^{57}Co, ^{139}Ce, ^{51}Cr, ^{113}Sn, ^{85}Sr, ^{137}Cs, ^{60}Co, and ^{88}Y, covering a broad spectrum of gamma energies. However, the distribution of radioactivity CRMs currently occurs only twice a year, which poses challenges in meeting the rising demands across various sectors. There is an urgent need for more flexible supply schedules and a diversification of CRM types. The findings of this study are intended to serve as foundational data for future policy development and strategic planning regarding CRM utilization in industry and research sectors.

Key words: Radioactivity, Certified reference material, Radiation measurement, Radionuclide

1. Introduction

Following the Fukushima Daiichi nuclear power plant accident, public concerns about radiation safety have significantly increased in Korea. Notably, the discharge of treated radioactive liquids into the ocean has led to heightened demands for accurate and reliable radiation measurements of imported seafood and other products from Japan [1]. In response, efforts to enhance the accuracy and reliability of radiation monitoring through the use of certified reference materials (CRMs) for radioactivity have intensified. Calibrating radiation measurement instruments with these CRMs is essential for ensuring high precision and reliability in measurements. Therefore, establishing standardized references using CRMs is crucial for boosting measurement credibility.

The demand for radioactivity CRMs within Korea's nuclear industry has steadily grown. Specifically, nuclear power plants use whole-body counters (WBCs) to monitor the internal exposure of radiation workers, resulting in a consistent need for CRMs to calibrate these instruments [2]. Additionally, periodic environmental radiation monitoring is performed to assess the release of radioactive effluents from nuclear facilities into nearby

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areas, which requires high-purity germanium (HPGe) detectors. Consequently, the necessity for CRMs to calibrate HPGe detectors has also increased.

In the medical sector, CRMs are increasingly used to ensure the reliability and traceability of nuclear medicine diagnostics. The Ministry of Food and Drug Safety conducts annual inspections of radiation measurements in medical institutions that use radiation-emitting diagnostic and therapeutic devices, relying on CRMs sourced from certified standard material producers [3-5]. Furthermore, as medical devices age and their service life is extended, the need for CRM-based performance verification and maintenance has risen steadily.

These examples illustrate that the utilization and demand for radioactivity CRMs in Korea have consistently increased across various industries. However, the production of radioactivity CRMs and reference materials (RMs) in Korea remains insufficient to meet this growing demand. This study analyzes the current status of the application, demand, development, and production of radioactivity CRMs in Korea through a comprehensive review of literature and reports, providing essential insights into the future development of CRM-related infrastructure.

2. Materials and Methods

A reference material (RM) is defined as a material or substance with sufficiently homogeneous and well-characterized properties [6]. It is used for calibrating equipment, evaluating measurement methods, or assigning values to material properties. A CRM is a type of RM that comes with a certificate issued by an accredited body. This certificate provides one or more specified property values along with associated uncertainties and establishes traceability through valid procedures [7].

Radioactivity CRMs are specifically utilized to calibrate radiation measurement instruments, ensuring accurate and reliable results. In Korea, the Korea Research Institute of Standards and Science (KRISS) is currently the only institution supplying radioactivity CRMs. According to Article 4, Paragraph 2 of the Framework Act on National Standards, universities, research institutions, enterprises, and public organizations are required to actively participate in the development of national standards and work towards their effective utilization [6]. As a result, RMs can be developed and produced not only by KRISS but also by universities, research institutes, and industries.

The purpose of this national standard framework is to promote diversity and quality in RM production and to invigorate standard-based research activities at the national level. KRISS serves a role similar to that of the National Institute of Standards and Technology (NIST) in the United States, acting as the sole institution responsible for the development and dissemination of radioactivity CRMs in Korea. NIST is internationally recognized as a leading standards organization, developing and distributing CRMs used across various industries and research fields while actively participating in international standardization efforts. NIST refers to its certified materials as standard reference materials (SRMs) [8].

Similarly, KRISS establishes and maintains national measurement standards and develops CRMs across multiple fields, including radioactivity, which are distributed to the research and industrial sectors in Korea. Furthermore, KRISS ensures that its developed CRMs maintain international traceability and collaborates with overseas standards organizations, such as NIST, to comply with global standard systems. This collaboration enhances the reliability of CRMs produced in Korea and ensures consistency and compatibility with international measurement standards.

This study investigates the current status of the development and production of radioactivity CRMs in Korea by analyzing CRM development and production reports published by KRISS, the sole producer of radioactivity CRMs in the country. In particular, the KRISS CRM catalog—an official document summarizing the types, characteristics, and applicable fields of CRMs developed and distributed by KRISS—was used to identify the range of radioactivity CRMs currently available in Korea [9]. Additionally, KRISS has published a series of reports (1995-2005) detailing the background of CRM development and the methodologies for measuring radioactivity associated with these materials [10-16]. This study also reviewed these reports to explore the historical development and production status of radioactivity CRMs in Korea.

3. Results and Discussion

3.1. Usage scope and demand status of radioactivity certified reference materials in Korea

Radioactivity CRMs are crucial for ensuring the accuracy and reliability of radiation measurements across various industrial and analytical fields. This study investigates the use of radioactivity CRMs in major industries in Korea and examines the associated demand structure. Radiation measurement and environmental radioactivity monitoring involve the quantitative analysis of radio-

Table 1. Certified values and uncertainties for KRISS mixed gamma-emitting radionuclide CRMs

Radionuclide	Half-life		Main Gamma Energy			Activity		
	Half-life (d)	Uncertainties[1] (d)	Energy (keV)	Emission Probability[2] (%)	Emission Probability Uncertainties[3] (%)	Activity (Bq)	Absolute Uncertainty[4] (Bq)	Relative Uncertainty[5] (%)
^{241}Am	158004	±219	59.54	35.92	±0.17	877	±35	4.0
^{109}Cd	416.9	±0.4	88.03	3.66	±0.05	4294	±180	4.2
^{57}Co	271.81	±0.04	122.06	85.49	±0.14	255	±11	4.3
			136.47	10.71	±0.15			
^{139}Ce	137.641	±0.02	165.86	79.90	±0.04	247.3	±9.9	4.0
^{51}Cr	27.704	±0.004	320.08	9.89	±0.02	26341	±1100	4.2
^{113}Sn	115.09	±0.03	391.70	64.97	±0.17	627	±25	4.0
^{85}Sr	64.850	±0.007	514.00	98.5	±0.4	851	±34	4.0
^{137}Cs	10963.8	±8.0	661.66	85.01	±0.20	400	±16	4.0
^{60}Co	1925.23	±0.29	1173.23	99.85	±0.03	610	±25	4.1
			1332.49	99.9826	±0.0006			
^{88}Y	106.63	±0.05	898.04	93.7	±0.3	1267	±51	4.0
			1836.07	99.346	±0.025			

[1]Uncertainty associated with the measured half-life (Unit: Day)
[2]The probability of gamma-ray emission from a radionuclide at the specified energy
[3]The measurement uncertainty associated with the gamma-ray emission probability at the specified energy (the specified probability value± uncertainty), representing the reliability of the measurement
[4]Uncertainty associated with the measured radioactivity (Unit: Bq)
[5]Relative uncertainty (%) of the measured radioactivity, indicating the accuracy of the measurement by comparing the absolute uncertainty to the total measured value

nuclides present in environmental media such as air, water, soil, and marine environments to assess radiation safety. These activities include monitoring natural background radiation, conducting environmental assessments around nuclear power plants, and performing emergency monitoring of radioactive material releases. The radionuclides typically monitored in environmental samples include ^{137}Cs, ^{90}Sr, ^{131}I, ^{40}K, and ^{60}Co [17]. High-sensitivity radiation detection equipment, particularly HPGe detectors, is predominantly used in these analyses due to their capability for high-resolution gamma spectrometry. Ensuring the accuracy and reliability of measurement results requires periodic calibration and performance verification of this equipment, for which radioactivity CRMs are indispensable.

Radioactivity CRMs provide critical information, including the type of radiation, radioactivity concentration, gamma energy, and peak intensity of radionuclides, all with certified traceability and uncertainty. They serve as references for instrument calibration, which is essential for precise radiation measurement. Calibration of instruments, such as HPGe detectors, involves accurately identifying and quantifying gamma peaks corresponding to radionuclides such as ^{137}Cs, ^{60}Co, and ^{152}Eu across the energy spectrum. By comparing measured values against the certified values provided by radioactivity CRMs, calibration of energy scales and counting efficiencies can be achieved. Calibration CRMs for HPGe detectors typically consist of a mixture of radionuclides, including ^{241}Am, ^{109}Cd, ^{57}Co, ^{139}Ce, ^{51}Cr, ^{113}Sn, ^{85}Sr, ^{137}Cs, ^{60}Co, ^{88}Y, which are supplied by KRISS [18]. An example of a KRISS mixed gamma-emitting CRM is presented in Table 1, which includes certified radionuclides with details such as half-lives, principal gamma-ray energies, emission probabilities, certified radioactivity values, and associated uncertainties [19]. The uncertainty in half-life indicates the uncertainty of the measured half-life (in days). The emission probability and its uncertainty reflect the likelihood of gamma-ray emission at a specific energy and the associated measurement uncertainty, serving as indicators of result reliability. Absolute uncertainty denotes the uncertainty of the measured radioactivity (in Bq), while relative uncertainty expresses this value as a percentage of the measured radioactivity, indicating the measurement's accuracy. The gamma-emitting radionuclides contained in the CRM exhibit a wide range of half-lives and gamma-ray energies. High-resolution detectors like HPGe can differentiate subtle spectral differences.

Table 2. Major application fields of radioactivity CRMs

Industrial Sector	Measurement Instrument	CRM Type	Purpose of Use
Environmental Monitoring	HPGe detector	Mixed gamma-emitting CRM	Calibration of energy and detection efficiency
Medical Field	Dose calibrator, SPECT, PET	Liquid source CRM	Calibration of diagnostic devices
Nuclear Decommissioning	Portable gamma spectrometer, HPGe	Solid matrix CRM, mixed gamma source CRM	Waste classification, material clearance

However, without proper calibration, measured values may not accurately reflect the characteristics of the radionuclides. Therefore, regular calibration using CRMs is critical for maintaining measurement accuracy, ensuring reliability in radiation analysis, and complying with legal standards.

Radioactivity CRMs play a vital role beyond simple calibration tasks. In quality control processes, they are essential for method validation, ensuring that analytical procedures yield accurate and reliable results. For example, when analyzing radioactive nuclides in soil samples, using CRMs that contain the same radionuclides at similar concentrations helps verify the entire analysis process. Significant deviations between measured values and certified values may indicate potential errors in sample preparation, measurement, or calculations, prompting necessary corrective actions. Moreover, radioactivity CRMs are regularly employed within laboratory quality control systems to maintain consistency through statistical quality control tools. They are also utilized in proficiency tests and inter-laboratory comparison studies to ensure result comparability and international traceability.

In medical and pharmaceutical applications, radioactivity CRMs are extensively used in radiation-based diagnostics and treatments. Their major applications include quality control of radiopharmaceuticals, dose assessments for patients, and calibration and verification of radiation-based medical equipment. Given the direct implications for patient safety, precise calibration and accuracy verification using radioactivity CRMs are essential. Additionally, radioactivity CRMs are used in imaging techniques such as positron emission tomography (PET) and single-photon emission computed tomography (SPECT) for measuring radiopharmaceutical activity and calibrating equipment. When analyzing human biological samples, such as blood or urine, for radionuclide concentrations, CRMs serve as reference standards to ensure measurement traceability and accuracy.

In the field of nuclear power plant decommissioning and radioactive waste management, the use of radioactivity CRMs is essential. Decommissioning activities necessitate the analysis of radioactive contamination in various materials, such as structural components, piping, concrete, and soil. Accurate identification and quantification of radionuclides are crucial for waste classification and obtaining disposal licenses, with radioactivity CRMs playing a key role in ensuring measurement reliability. Solid matrix CRMs containing radionuclides like ^{60}Co and ^{137}Cs are used to simulate waste matrices and assess the response characteristics of measurement instruments [20]. These CRMs ensure traceability and consistency in analytical results, thereby supporting regulatory compliance, technical documentation, and safety assessments. The use of radioactivity CRMs is vital for the safe and effective handling of radiation and radioactive materials, significantly enhancing the reliability and accuracy of radiation-related activities. Following the discharge of treated liquids from the Fukushima Daiichi nuclear power plant, there has been an increased interest in monitoring radiation in daily life, which has further driven the demand for reliable radiation measurements. As a result, the demand for radioactivity CRMs continues to rise across multiple sectors, including radiation measurement, environmental radioactivity monitoring, calibration of medical devices, nuclear facility decommissioning, and medical applications. Table 2 summarizes the major application fields of radioactivity CRMs, along with the corresponding measurement instruments, CRM types, and purposes of use.

In Korea, the demand for radioactivity CRMs was indirectly assessed using national statistical data from Statistics Korea, as no official direct surveys on CRM demand have been conducted. The primary drivers of this demand are the calibration requirements for radioisotope production devices and radiation generators. Table 3 presents the overall trends in the utilization of radioisotopes and radiation generators in Korea from 2016 to 2022 [21]. During this period, the number of user institutions increased by 19.5%, growing from 45,261 in 2016 to 54,081 in 2022. Furthermore, the total distribution volume—encompassing imports, production, and exports—rose by 107.3%, from 1.4415 trillion KRW in 2016 to 2.9886 trillion KRW in 2022. The overall economic scale of radiation technology utilization expanded by 24%, increasing from 17.1457 trillion KRW in 2016 to 21.2832 trillion KRW in 2022.

Table 3. Trends in the use of radioisotopes and radiation generators in Korea (2016–2022)

Category	Fields	2016	2017	2018	2019	2020	2021	2022
Number of User Institutions (units)	Total	45,261	46,634	48,182	49,391	51,100	52,814	54,081
	Industrial Sector	5,470	5,862	6,372	6,696	6,885	7,262	7,308
	Medical Sector	35,319	36,258	37,038	38,061	39,098	40,054	41,050
	Animal Hospital	2,657	2,623	2,948	2,782	3,037	3,384	3,567
	Educational, Research, Public Institutions	1,461	1,526	1,548	1,618	1,651	1,682	1,707
	Others (Sales/Production)	354	365	394	405	429	432	449
Number of Employees (persons)	Total	126,102	131,417	138,718	146,195	150,840	158,133	163,477
	Industrial Sector	34,645	28,998	30,333	31,202	32,390	32,936	32,755
	Medical Sector	80,115	89,996	94,935	100,627	104,250	108,691	113,092
	Animal Hospital	3,446	3,677	4,554	5,733	6,037	6,587	7,344
	Educational/Research/Public Institutions	7,896	8,746	8,896	8,633	8,163	9,919	10,286
Economic Scale of Radiation Technology Utilization (billion KRW)	Total	171,457	190,689	208,557	203,167	214,872	224,283	212,832
	Industrial Sector	124,421	142,108	155,226	144,732	151,390	155,393	151,005
	Non-Destructive Testing Sector	1,727	1,303	1,567	2,357	2,421	1,400	1,554
	Radiation Sterilization Sector	232	249	286	333	378	331	352
	Medical Sector	40,657	42,520	47,153	51,575	56,423	62,795	55,518
	Agricultural Sector	4,420	4,509	4,325	4,168	4,260	4,364	4,402

Table 4. History of the development of radioactivity CRMs by KRISS

Year	Developed Radionuclides	Form	Main purpose
1995	^{60}Co, ^{113}Ba, ^{134}Cs, ^{137}Cs	Point source, Liquid source	Improve the calibration accuracy for basic gamma-emitting radionuclides
1999	Standard Source Development (Marinelli beaker)	Marinelli beaker	Improve the accuracy of environmental radioactivity measurements and correct gamma-ray detection efficiency
2000	^{152}Eu, ^{88}Y, ^{51}Cr	Liquid source, Point source	Improve calibration accuracy across a wide range of gamma-ray energies
2001	^{89}Sr, ^{125}I	Electrodeposited Source	Establish the foundation for developing radioactivity CRMs for alpha- and beta-emitting radionuclides
2002	^{51}Cr, ^{22}Na, ^{131}I, ^{133}Ba, ^{90}Sr	Liquid Source, Point Source	Expand the variety of radioactivity CRMs for environmental and medical applications
2003	^{57}Co, ^{133}Ba, ^{137}Cs, ^{152}Eu	Liquid Source, Point Source	Develop radioactivity CRMs for calibration of medical radioisotope measuring equipment
2004	^{60}Co, ^{134}Cs, ^{67}Ga, ^{241}Am	Liquid Source, Point Source	Improve calibration precision for medical RI measurement systems
2005	^{111}In, ^{68}Ge, ^{238}Pu	Liquid Source, Point Source	Enhance calibration accuracy for nuclear decommissioning and radioactive waste management

3.2. Current status of development and production of radioactivity certified reference materials in Korea

Radioactivity CRMs are essential for accurate analysis in a variety of industries, including radiation measurement, healthcare, and the decommissioning of nuclear power plants. They play a crucial role in ensuring the reliability of measurement values. Radioactivity CRMs are used in several fields, such as calibrating radiation measurement instruments, analyzing environmental radioactivity, measuring pharmaceutical radioisotopes, and managing waste. The accuracy of radiation measurement results is directly tied to national health and safety, environmental protection, and the technological reliability of radiation-related industries. Therefore, securing a stable supply of radioactivity CRMs is strategically important at the national level. In Korea, KRISS is the only institution that develops and produces radioactivity CRMs, while the remaining demand is met through imports. According to Article 4, Paragraph 3 of the National Standards Framework Act, universities, research institutes, companies, and public institutions are all required to actively participate in the development of national standards and make every effort to utilize the results effectively [6]. This means that various institutions in Korea that meet legal and technical criteria can engage in the development of radioactivity CRMs.

Since the mid-1990s, KRISS has played a crucial role in developing CRMs tailored for various industries in Korea. This initiative is a fundamental aspect of the national standards system. KRISS has created a variety of CRMs, including those for radioactivity, to enhance and refine national standards for measurement technology, thereby contributing to international competitiveness and the advancement of science, technology, and industry. Over time, the objectives of CRM development and target nuclides have expanded. Initially, the focus was on relatively common gamma-ray emitting radionuclides, such as ^{60}Co and ^{137}Cs. Subsequently, KRISS broadened its efforts to include CRMs for medical radioisotopes and environmental sample analysis. A summary of KRISS's main development activities from 1995 to 2005 is provided in Table 4 [10-16].

The development of radioactivity CRMs has significantly improved the accuracy of radiation measurement and measurement technologies in Korea. These materials are particularly vital for calibrating devices used for diagnosis and treatment involving radioisotopes in medical institutions. In recent years, KRISS has relied on imported raw materials from international reference material production facilities, followed by quantification, aliquoting, and certification processes within Korea. However, importing these raw materials poses risks of disruption or delays due to changes in the international supply chain, export-import regulations, and nuclear safety agreements. Restrictions on the importation of specific radionuclides could significantly hinder the reliability of radiation measurements in Korea.

Recently, the Korea Atomic Energy Research Institute (KAERI) established a joint research facility utilizing the HANARO research reactor to enhance CRM production [22]. In connection with HANARO, KAERI signed a memorandum of understanding (MOU) with KRISS to jointly operate this facility. If KAERI can secure a stable supply of raw materials through its radioisotope production and analysis technologies, a circular production system for radioactivity CRM manufacturing in Korea could be established in partnership with KRISS. This collaborative framework is expected to yield both technical synergy and strategic benefits, such as enhancing the stability of CRM supplies in Korea, diversifying the available radionuclides, and creating a solid foundation for emergency preparedness.

Currently, KRISS is the sole distributor of radioactivity CRMs in Korea. A catalog of available products, which includes solution sources, point sources, mixed gamma-emitting sources, and other types of CRMs, is published by KRISS [9]. Distribution occurs twice a year, in February and August-September, through a formal application process. Table 5 presents representative radioactivity CRMs offered by KRISS [9]. Specifically, mixed gamma-emitting CRMs, optimized for calibrating HPGe detectors, are extensively used by medical institutions and radiation measurement laboratories. The currently available mixed gamma-emitting CRMs primarily include radionuclides such as ^{241}Am, ^{109}Cd, ^{57}Co, ^{51}Cr, ^{113}Sn, ^{85}Sr, ^{137}Cs, ^{60}Co, and ^{88}Y. These CRMs are offered in various formats, including capsule-type sources and Marinelli beaker formats, and across a wide range of activity levels, from 10^2 to 10^7 Bq. This wide variety allows users to select products based on their specific measurement needs. These radioactivity CRMs are practically applied in areas such as energy and efficiency calibration of radiation detectors, environmental and medical sample analyses, and industrial radiation measurements.

NIST in the United States provides a diverse range of SRMs for radioactivity. These radioactivity SRMs quantitatively characterize radionuclide concentrations and their associated uncertainties, and they are tailored to meet various industrial applications, including radiopharmaceuticals, environmental samples, and biological materials. NIST offers radioactivity SRMs in multiple formats, including solid, liquid, and matrix-based forms, to sup-

Table 5. Main radioactivity CRMs provided by KRISS

Category	Form/Size	Radiation Type	Major Radionuclides	Activity Range
Liquid Source	Liquid source in designated container (10 mL)	Gamma	^{22}Na	10^2-10^5 Bq
Liquid Source	Liquid source in designated container (10 mL)	Gamma	^{88}Y	10^2-10^5 Bq
Liquid Source	Liquid source in designated container (10 mL)	Gamma	^{111m}In	10^2-10^5 Bq
Point Source	Capsule (diameter ≤7 mm)	Gamma	^{22}Na	10^2-10^5 Bq
Point Source	Capsule (diameter ≤7 mm)	Gamma	^{131}I	10^2-10^5 Bq
Point Source	Capsule (diameter ≤7 mm)	Gamma	^{241}Am	10^2-10^5 Bq
Mixed Gamma-Emitting Source	1 L Gas Marinelli Beaker (1 M HCl)	Gamma	^{241}Am, ^{109}Cd, ^{57}Co, ^{139}Ce,	10^2-10^5 Bq
Mixed Gamma-Emitting Source	Charcoal Filter Type, 45 mL (1 M HCl)	Gamma	^{51}Cr, ^{113}Sn,	10^2-10^5 Bq
Mixed Gamma-Emitting Source	Liquid source in 20 mL cylindrical plastic container (1 M HCl)	Gamma	^{85}Sr, ^{137}Cs, ^{60}Co, ^{88}Y	10^2-10^5 Bq
Other CRM	20 mL LSC vial solution	Beta	^{90}Sr	10^2-10^5 Bq
Other CRM	20 mL LSC vial solution	Alpha, Gamma	^{226}Ra, ^{210}Pb	10^2-10^5 Bq
Other CRM	20 mL LSC vial solution	Alpha, Gamma	^{222}Ra, ^{222}Rn	10^2-10^5 Bq

Table 6. Radioactivity SRMs provided by NIST

Category	Form/Size	Radiation Type	SRM Number (Major Radionuclides)	Activity Range
Liquid Source	5 mL Ampoule	Gamma	SRM 4401L (^{131}I), SRM 4410H (^{99m}Tc), SRM 4427L (^{90}Y)	5-150 MBq
Liquid Source	5 mL Ampoule	Gamma	SRM 4417L (^{111}In), SRM 4404L (^{201}Tl), SRM 4416L (^{67}Ga)	3-60 MBq
Liquid Source	5 mL Ampoule	Gamma	SRM 4415L (^{133}Xe), SRM 4407L (^{125}I), SRM 4412L (^{99}Mo)	0.3-5 MBq
Liquid Source	5 mL Ampoule	Gamma	SRM 4233f (^{137}Cs)	0.1-10 MBq
Solid Matrix	Ocean Shellfish, Seaweed (150-300 g)	Gamma, Alpha, Beta	SRM 4357 (^{210}Pb), SRM 4358 (^{226}Ra), SRM 4359 (^{228}Th), SRM 4360 (^{228}Ra), SRM 4361 (^{232}Th), SRM 4362 (^{238}U)	0.1-10 kBq
Solid Matrix	Rocky Flats Soil, Freshwater Lake Sediment (45-85 g)	Gamma, Alpha, Beta	SRM 4355 (^{90}Sr), SRM 4356 (^{243}CM, ^{244}Cm), SRM 4357 (^{154}Eu), SRM 4358 (^{60}Co)	0.1-10 kBq
Solid Matrix	River Sediment, Human Lung (25-300 g)	Gamma, Alpha, Beta	SRM 4350B (^{137}Cs), SRM 4351 (^{241}Am), SRM 4352 (^{152}Eu), SRM 4353 (^{238}Pu), SRM 4354 (^{239}Pu, ^{240}Pu)	0.1-10 kBq

port not only instrument calibration but also analytical method validation and the development of laboratory quality systems. Each radioactivity SRM is assigned a unique identification number, and accompanying documentation includes certification dates, measurement uncertainties, and recommended storage conditions to help users conduct reliable analyses [8]. Table 6 provides a summary of representative radioactivity SRMs offered by NIST [8,23-25]. These SRMs include various radionuclides that emit gamma rays, alpha particles, and beta particles, and they are available in both liquid and solid matrix formats. They are designed for a wide range of experimental and analytical applications, including radiation detector calibration, environmental radioactivity analysis, radionuclide identification, and analytical method validation. Notably, the radioactivity SRM of ^{137}Cs is widely used for calibrating gamma-ray spectrometry systems, allowing for precise energy and efficiency calibration during gamma-ray peak analysis.

4. Conclusion

This study thoroughly examined the scope of application, demand status, development, and production system of radioactivity CRMs in Korea. Radioactivity CRMs are crucial throughout the entire process of radioactivity analysis, including the calibration of radiation measuring instruments, validation of analytical methods, and implementation of quality control measures. The demand for these materials continues to grow across various sectors, particularly in environmental radioactivity monitoring, the medical field, nuclear power plant decommissioning, and radioactive waste management.

KRISS is the sole institution responsible for developing and distributing radioactivity CRMs in Korea. KRISS has created and supplied a variety of radioactivity CRMs to enhance the precision of measurement systems in the country and to strengthen international credibility. Among these, mixed gamma-emitting radioactivity CRMs serve as key calibration standards, optimized for energy and detection efficiency calibration of HPGe detectors. These CRMs, which include major gamma-emitting radionuclides such as ^{241}Am, ^{60}Co, and ^{137}Cs, are widely used in industrial sites and research institutions. They are designed to cover a broad range of gamma-ray energies, significantly contributing to improved accuracy in radiation measurement systems. However, the regular supply of radioactivity CRMs is currently limited to twice a year, and the available range of products is insufficient to fully meet the practical needs of industries and research sectors. Additionally, most raw materials for radioactivity CRMs are imported from overseas, raising concerns about supply stability and sustainability. Therefore, systematic strategies are urgently needed to enhance the supply infrastructure in Korea. This includes diversifying the types of radioactivity CRM products, introducing more flexible supply schedules, and stabilizing the procurement of raw materials.

Radioactivity CRMs are essential for ensuring the reliability and precision of radiation measurements. Continuous improvements to the overall supply system are vital to support the future expansion of radioactivity CRM utilization in Korea. These efforts are expected to significantly contribute to advancing the reliability of radiation-related analyses and elevating the overall standards of quality control in radiation measurement activities.

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References

1. Choi WS, Kong TY, Kim HG, Lee EJ, Kim SJ, Son JH, Song CJ, Kim HP and Jeong CK. 2023. The regulatory system for imported-cargo radiation monitoring in Korea and a proposal for its improvement, *Nuclear Engineering and Technology*, **55**(1):1-11. https://doi.org/10.1016/j.net.2022.08.025.
2. Kong TY and Kim HG. 2009. Improvement to whole-body counting procedures at nuclear power plants, Radiation Protection Dosimetry, **133**(2):89-96. https://doi.org/10.1093/rpd/ncp014.
3. Medical Service Act. 2023. Act No. 19421.
4. Regulation on Safety Control of Radiation-Emitting Medical Devices. 2024. Ordinance of the Ministry of Health and Welfare, Act No. 1068.
5. Standards for Safety of Electrical and Mechanical Medical Devices. 2020. Ordinance of the Ministry of Health and Welfare, No. 20220-29.
6. Framework Act on National Standards 2018. Act No. 15643.
7. KS A ISO Guide 35:2017. Reference materials—Guidance for characterization and assessment of homogeneity and stability, International Organization for Standardization (ISO).
8. National Institute of Standard and Technology (NIST). 2025. NIST Standard Reference Materials 2025 Catalog.
9. Korea Research Institute of Standards and Science (KRISS). 2022. Certified Reference Materials Catalog.
10. Korea Research Institute of Standards and Science (KRISS). 1999. Development and Distribution of Certified Reference Materials, KRISS/IR-2000-008.
11. Korea Research Institute of Standards and Science (KRISS). 2000. Development and Dissemination of Certified Reference Materials, KRISS/IR-2001-003. (in Korean)

12. Korea Research Institute of Standards and Science (KRISS). 2001. Establishment of National Reference Materials Production System, KRISS/IR-2002-006. (in Korean)
13. Korea Research Institute of Standards and Science (KRISS). 2002. Establishment of National Reference Materials Production System, KRISS/IR-2003-004. (in Korean)
14. Korea Research Institute of Standards and Science (KRISS). 2003. Development and Dissemination of Certified Reference Materials, KRISS/IR-2004-011. (in Korean)
15. Korea Research Institute of Standards and Science (KRISS). 2004. Development and Dissemination of Certified Reference Materials, KRISS/IR-2005-002. (in Korean)
16. Korea Research Institute of Standards and Science (KRISS). 2005. Development and Dissemination of Certified Reference Materials, KRISS/IR-2005-048. (in Korean)
17. Nuclear Regulatory Commission (NRC). 2022. Environmental Monitoring Report.
18. Vukanac Ivana. 2021. Preparation and validation of laboratory radioactive standards for experimental calibration in gamma ray spectrometry. *Radiation Physics and Chemistry* **183**:109407.
19. Korea Research Institute of Standards and Science (KRISS). 2005. Certificate of Certified Reference Material for Mixed Gamma-Emitting Radionuclides.
20. Lee MJ, Lee SH and Jung Y. 2022. Development of concrete reference material for quality assurance/quality control of gamma radioactivity measurement for nuclear power plant decommissioning waste. *Journal of Environmental Radioactivity* **255**:107031.
21. Ministry of Science and ICT (MSIT). 2022. Survey on the Utilization Status of Radiation and Radioisotopes. Comprehensive Statistics on the Use of Radioisotopes and Radiation Generators (accessed on 2025-04-03).
22. Korea Atomic Energy Research Institute (KAERI). 2016. Collaboration for Research and Development of Certified Reference Materials at Government-Funded Research Institutes. Available online: https://www.kaeri.re.kr/rcus/board/view?pageNum=84&rowCnt=10&no1=571&linkId=6111&menuId=MENU00326&schType=0&schText=&boardStyle=Text&categoryId=&continent=&country=&schYear (accessed on 2025-04-07).
23. National Institute of Standards and Technology (NIST). 2023. SRM 205.4—Radioactive Solutions, Gaithersburg, MD, USA.
24. National Institute of Standards and Technology (NIST). 2023. SRM 205.5—Radiopharmaceuticals (solution and gaseous forms), Gaithersburg, MD, USA.
25. National Institute of Standards and Technology (NIST). 2022. SRM 205.11—Radioactive Natural Matrix Materials (powder form), NIST SRM Catalog, Gaithersburg, MD, USA.