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Assessment of radioactive material in imported air freight: Findings and security implications

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Abstract

Ensuring the effective control of the movement of nuclear material and other radioactive material in air freight is essential in the strengthening a states' nuclear security regime. Thus, the study assessed the presence of radioactive material in imported air freight processed through the Kotoka International Airport (KIA) in Ghana. In the absence of Radiation Portal Monitors (RPMs), a Radioisotope Identification Device (RIID) was deployed to screen 897 air freight containers. Radioisotopes were detected in 198 containers with measured averaged equivalent dose rates ranging from 0.059±0.005 µSv/h to 0.427±0.013 µSv/h. The obliviousness of Frontline Officers (FLOs) about the presence of radioisotopes in the commodities highlights potential gaps in cargo documentation and radiation security awareness, suggesting the possibility of unauthorized movement of radioactive material. The findings underscore the need to upgrade detection infrastructure, enhance frontline officers' capabilities and improve inter-agency coordination to support an effective nuclear security regime.

Keywords: Radiation Detection; Nuclear Security; Illicit Trafficking; Air Freight Screening; Radiation Identification Device (RIID); Ghana

1. Introduction

Several international bodies have raised concerns about the illegal movement of nuclear material and other radioactive material (RN materials) which has become a global nuclear security challenge with Africa being no exception [1, 2] The increasing use of RN materials in medicine, industry and research combined with the intent of some terrorist groups to employ such materials for malicious purposes has heightened the urgency in countries to strengthen measures to prevent RN materials from entering their public domain. Thereby protecting their citizens and securing their borders by using radiation detection equipment. Competent Authorities mandatory inspections are often insufficient to effectively monitor and control all RN materials within their territories.

The maritime environment is also associated with significant challenges in the detection of RN materials due to the vast volume and rapid pace of global trade. The international shipping industry handles an estimated 90 % of global trade [3, 4]. In recent decades, increased trade has been due to the widespread use of containerisation with approximately 43 million containers in global circulation (European Conference of Ministers of Transport [5]. Despite such growth, the detection of RN materials remains an acute challenge even though just a few kilograms could pose a significant threat [6, 7].

In addition to RN materials, other contrabands such as narcotics, weapons and explosives are also trafficked through maritime channels thus, a rapid and accurate identification is essential to avoid disruption of legitimate trade. Consequently, the need to detect RN materials and other illicit goods with limited resources remains a challenge [8].

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The difficulties in using profiling tools to identify suspicious consignments containing RN materials has resulted in the use of modern detection systems capable of scanning a significant proportion of cargo for physical signatures of RN materials. These systems typically employ passive radiation detectors that measure gamma and/or neutron emissions associated with radioactive decay [9, 10].

Radiation detection systems are critical equipment for identifying and measuring radioactivity in cargo and among pedestrians. They differ in sensitivity and portability and are mostly effective when used in combination, enabling them to distinguish between various RN materials [11]. Thus, in a heterogenous container containing general goods, legitimate and illegitimate RN materials, an effective detection system must be sufficiently sensitive to measure the amount of radiation and identify the different radiations emitters [12].

Radiation Portal Monitors (RPM) or a Mobile Detection Vans (MDV) are commonly used at ports. Typically, they are used to scan cargo containers for the presence of radiation (gamma and/or neutrons) without altering the physical or chemical characteristics of the cargo. When the presence of radiation is detection and the dose rates exceeds preset thresholds and/or neutrons are detected, the systems trigger an alarm [13]. Three (3) possible alarms may be triggered, including:

- A false alarm, caused by system malfunction or a temporary background radiation fluctuation.
- An innocent alarm, triggered by legitimate Naturally Occurring Radioactive Material (NORM) or regulated radioactive sources
- A non-innocent alarm, caused by radioactive material outside of regulatory control, including orphan sources or trafficked RN materials [14].

Front-Line Officers (FLOs) are government security personnel including customs officers, border guards, police officers, immigration officers, and other officials who carry out activities at points of entry/exit, major public venues, or other locations where they may detect RN materials. FLOs assigned the detection responsibilities at borders assess alarms by examining both the total radiation response and the cargo's radiation profile [15].

Handheld Radioisotope Identification Device (RIIDs) are used to confirm alarms, identifying the specific radioisotope(s) present in the cargo [13]. Although, RIIDs are typically employed for confirmatory inspection (secondary inspection) they can also be used as primary detection tools in the absence of an RPM or MDV for the purposes of radiation detection [14, 16].

In Ghana, the currently available radiation detection system consists primarily of handheld radiation detection devices, thus, a shortfall in a comprehensive destination inspection. RIIDs are time-consuming to use, custom officers and FLOs are often reluctant to rely on them as primary detection tools due to the potential impact on daily inspection targets. As a result, initial screening for RN materials does not occur systematically, increasing the likelihood that radioactive materials may enter the country outside regulatory control.

This study investigates the presence of radioactive material in imported air freight entering Ghana through KIA and provides empirical data on radiation detections with the available detection infrastructure. The findings reveal vulnerabilities in current detection measures employed at the KIA cargo village and highlight the need for improved equipment, enhanced training, and strengthened inter-agency coordination to support Ghana's nuclear security infrastructure.

2. Materials and Method

2.1. Location and Equipment

The Kotoka International Airport Cargo Village was the location for data collection and the RIID manufactured by FLIR with serial number 101099001120 was the detection device employed.

The study was conducted at the Cargo Village of Kotoka International Airport (KIA), Ghana's primary hub for processing, storing, and handling air freight. The facility operates under the Ghana Airports Company Limited (GACL) and hosts multiple border and security agencies including the Customs Division of the Ghana Revenue Authority, freight forwarders, ground handlers, and national security entities. These institutions collectively form an integrated system responsible for cargo inspection, regulatory compliance, and border security oversight [17].

The Cargo village is designed to accommodate high cargo volumes through dedicated warehouses, temperature-controlled storage facilities, dedicated spaces and offices for inspection and documentation. Its operation forms a critical component of Ghana's national detection architecture for identifying contraband and hazardous materials including RN materials [18].

Radiation detection was performed by the team using a FLIR-manufactured Radioisotope Identification Device (RIID) with serial number 101099001120. The device was calibrated in accordance with the manufacturer's specifications prior to deployment. Table 1 summarises the technical specifications of the RIID model used.

Table 1 Specification of the RIID

Energy resolution by the gamma-line	662 keV (Cs-137)
Range of recorded gamma-ray energy	20–3,000 keV
Operating temperature range	−15 to +550 °C
Weight	Less than 1.25 kg

Figure 1 Radioisotope Identification Device (RIID)

As shown in Figure 1, the RIID is a portable detection tool capable of measuring equivalent dose (Sv) and equivalent dose rate (Sv/h) within a specified area, locating a radioactive source through increasing alarm intensity as proximity increases, and identifying a radiation source by isotope and category.

The RIID estimates the Equivalent Dose Rate (H) as follows [19]:

$$H = D_m . Q \qquad \ldots\ldots\ldots \qquad (1)$$

where D_m is the absorbed dose to the material and

Q is the quality factor or the radiation weighting factor (W_R)

The standard W_R for gamma rays is unity (1); W_R for neutron is ten (10).

The absorbed dose is defined as the measure of the amount of radiation energy absorbed per unit mass and expressed as follows:

$$D_m = D_{air}.X\frac{(\mu_{en}/\rho)material}{(\mu_{en}/\rho)air} \quad \text{..........} \quad (2)$$

$D_{material}$ is the absorbed dose to the specified material (Sv, Sv/h).
X is the exposure or exposure rate (R/hr).
$(\mu_{en}/\rho)_{material}$ is the mass energy absorption coefficient for the specified material at the photon energy of interest.
$(\mu_{en}/\rho)_{air}$ is the mass energy absorption coefficient for air at the photon energy of interest.

2.1.1. RIID Functionality and Operating Modes

The RIID detects gamma radiation and/or neutron originating from both the surrounding environment and radioactive source [20]. The technical specifications of the RIID are presented in Table 1. The RIID operates in three (3) primary modes namely:

The equivalent dose rate mode: a mode in which the device measures the average ambient equivalent dose rate independent of the presence of a radioactive source. It functions similarly to a survey meter and is typically the quickest and easiest mode to access. The measurement range spans from 10 nSv/h to 1 Sv/h, allowing for rapid safety assessments of radiological conditions.

The finder mode: the RIID in this mode, is used to locate a radioactive source within a defined area. As the detector approaches the source, it triggers an increasingly audible and vibration alarm, enabling the operator to determine the source location while minimizing the potential for overexposure.

The identify mode: once a radioactive source is located, the RIID is switched into this mode to determine the specific radionuclide present. Identification is performed by comparing the measured spectrum with the instrument's internal isotope library. The resulting screen display provides the identification certainty (expressed numerically), the radioactive source (isotope name), and its classification according to its approved usage [20].

There is also the advance mode where configuration settings on the device can be done and modified. These settings include the calibration before use, the date and time, battery life and power source information as well as spectral information on save data [20].

3. Methodology

Radiation assessments were conducted on air freights as they arrived at the screening area using the calibrated RIID. Prior to measurements, an averaged background equivalent dose rate reading was taken at a location further away from the cargo village. For each freight, measurements were taken over a 120-second (120s) interval across all four (4) sides of the freight container: the rear, the front, and both lateral sides. This approach ensured comprehensive surface coverage and increased the likelihood of detecting any gamma- or neutron-emitting materials within the freight.

The data collection process followed standardized recording procedures, and the templates used during field measurements are presented in Tables 2 and 3.

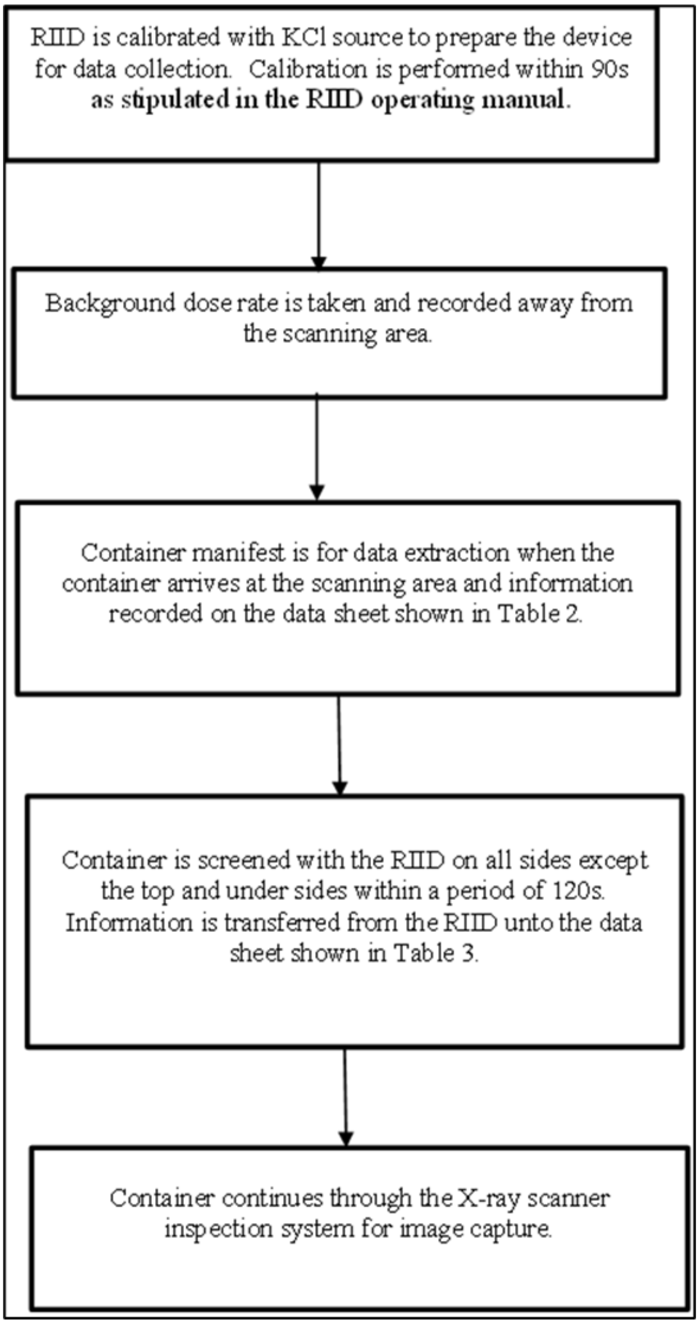

Figure 2 Field Activity Process Chat

4. Results

A total of eight hundred and ninety-seven (897) air freight containers were assessed using the Radioisotope Identification Device (RIID). An average background radiation measurement taken before measurement commenced was recorded as ambient equivalent dose rate of 0.03±0.00 µSv/h. All containers were heterogenous and recorded some level of measurable radiation as shown in Figure 3 below.

4.1. Detection Outcomes

As part of the eight hundred and ninety-seven (897) containers screened, one hundred and ninety-eight (198) containers representing 22.10% contained radioisotopes that the RIID successfully identified.

Two hundred and ninety-four (294) containers representing 32.80% displayed unknown isotopes, meaning the detected radiation signatures were not represented in the RIID's isotope library.

Four hundred and five (405) containers represented 45.10% produced “insufficient counts,” suggesting radiation levels below the RIID’s detection threshold or the presence of significant shielding.

The equivalent dose rate measurements across all containers ranged from 0.059±0.005 μSv/h to 0.427±0.013 μSv/h, with a measurement uncertainty of less than ±10%, consistent with typical RIID performance specifications.

4.2. Identified Radioisotopes

Among the 198 containers with identifiable radioisotopes, Potassium-40 (K-40) was the most frequently detected radioisotope and was classified by the RIID as a Naturally Occurring Radioactive Material (NORM). A graphical representation of identified radioisotopes is shown in Figure 4 below. These findings align with the known presence of NORM in certain agricultural, industrial, and consumer goods.

Commodity associated with the identified radioisotopes in imported goods include but not limited to the following.

- Food products and beverages
- Ceramics and tiles
- Fertilizers
- Industrial metals and metal components
- Cosmetic and pharmaceutical raw materials

4.3. Unknown Radioisotopes

The appearance of unknown radioisotopes in certain goods is notable, given that such commodities are not typically associated with radiological signatures. This may indicate either uncommon NORM distributions or the presence of radioisotopes not stored in the RIID database, an operational limitation with potential security implications.

Containers flagged with unknown radioisotopes included commodities such as:

Alcoholic beverages and food items

- Detergents and toiletries
- Metal accessories (e.g., door locks, poles, drilling tools, welding rods)
- Electrical components
- Sewing machines and light machinery

4.4. Insufficient Counts

Low count rates were likely due to very weak emissions or extensive shielding, preventing the RIID from acquiring adequate spectral data.

Commodities associated with insufficient count readings included:

- Furniture
- Used clothing and bags
- High-density polyethylene (HDPE) products
- Aluminium foil
- Automotive parts
- Electrical appliances
- Glassware
- Cosmetics
- Frozen foods

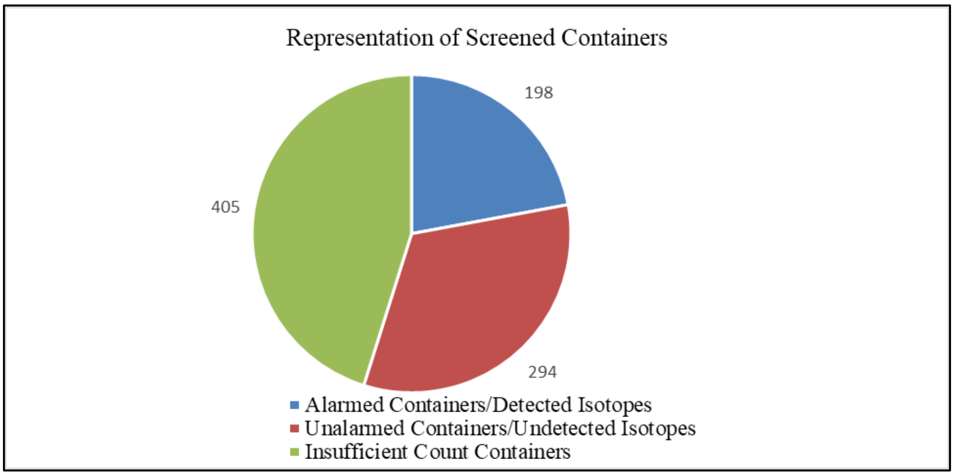

Figure 3 A Graphical Representation of Screened Air Freight Containers

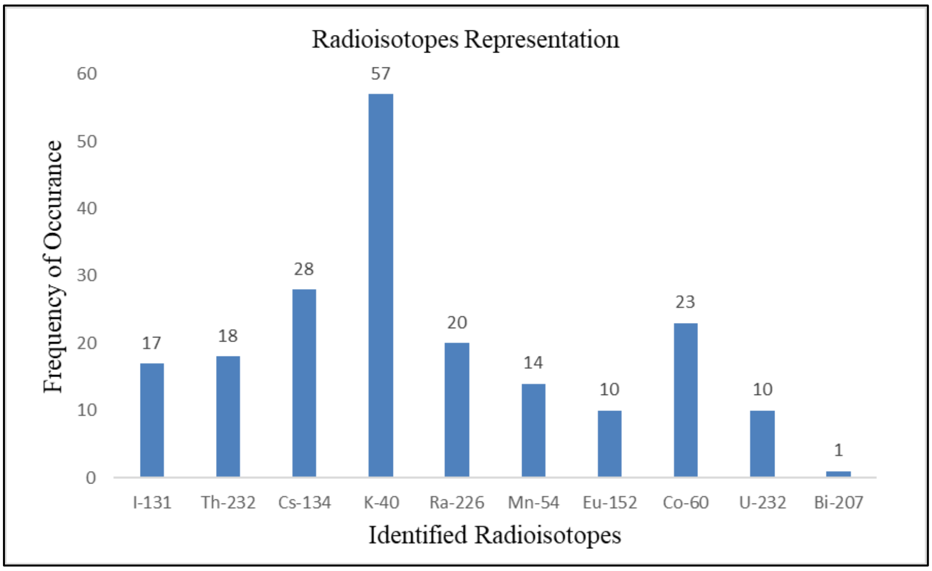

Figure 4 A Graphical Representation of Identified Radioisotopes

5. Discussion

5.1. Detection Outcome

The distribution of radioisotopes detected, illustrated in the results (Figure 3) demonstrates a trend of different radionuclide occurrence across the assessed freights. Potassium-40 (K-40) recorded the highest frequency of detection (57 occurrences), a trend that was expected, given its natural presence in a wide range of materials, including ceramics, fertilizers, and certain food products [21, 22]. This also suggest that a substantial proportion of alarmed cargo relates to Naturally Occurring Radioactive Materials (NORM), underscoring the importance of differentiating benign NORM signatures from potential security-relevant sources to avoid operational inefficiencies.

Cesium-134 (Cs-134), Radium-226 (Ra-226), Cobalt-60 (Co-60), and Iodine-131 (I-131) were also prominent, with their frequencies of detection/occurrence ranging from 17 to 28. These isotopes are commonly associated with medical, industrial, and environmental sources. Their presence indicates legitimate movement of regulated radioactive materials but there is the need for continuous oversight to ensure compliance with licensing and transportation requirements. Especially for Cs-134 and Co-60 sources used widely in industrial radiography, sterilisation, and calibration, where lapses in control can have significant safety and security implications.

The detection of Europium-152 (Eu-152) and Uranium-232 (U-232), though less frequent (10 occurrences each), are of interest due to their relevance to industrial applications. U-232 has a potential connection to legacy nuclear material, even though the frequencies observed with these two radioisotopes do not suggest systematic movement of sensitive materials.

The least detected radioisotope is Bi-207 with an occurrence frequency of unity (1). Such an isolated detection may represent a benign occurrence but requires a careful review to determine whether it arises from legitimate source or signal anomalies requiring follow-up.

Overall, the detection outcomes reflect the effectiveness of the deployed radiation detection and identification system in capturing a broad spectrum of isotopes transiting through a monitored location. However, the prevalence of NORM-related alarms highlights the need for refined alarm-resolution protocols, continuous frontline officer training, and enhanced system to minimize false positives.

5.2. Comparison with IAEA findings

IAEA technical guidance and coordinated research projects on border monitoring repeatedly note that a high fraction of portal-monitor alarms is attributable to NORM or medical/industrial sources legitimately in commerce, rather than to attempts to move nuclear materials illicitly. This international experience explains why K-40 is often the single most frequent signature encountered in operational deployments, and why detection systems and operational procedures must be tuned to distinguish benign NORM signatures from security-relevant anomalies [23, 24].

The relatively high frequencies of occurrence of Cs-134 (28) and Co-60 (23) are consistent with international reports that indicate industrial and medical radionuclides appear repeatedly in cargo streams as calibrated sources, irradiators, radiopharmaceuticals or contaminated scrap and thus show up in the IAEA's Incident and Trafficking Database (ITDB). The ITDB documents confirmed incidents involving Co-60 and Cs-137 among the most frequently reported orphan or uncontrolled sources even though such incidents remain far fewer than routine NORM alarms; that pattern fits the distribution in Figure 5.[25].

5.3. Potential for Illicit Trafficking and Smuggling

The presence of Cs-134, Co-60, Eu-152, and Mn-54 reflects materials commonly used in industrial applications, research, and radiological equipment. These radioisotopes are of interest from a nuclear security perspective because their potential diversion malicious use in devices for radiological dispersion (RDDs).

While the graph shows only moderate frequencies ranging between 10 and 28 detections, several considerations increase the potential for illicit trafficking and smuggling including:

- The inconsistent cargo declarations can allow regulated radioactive materials to be concealed within legitimate shipments. If such materials appear without accompanying documentation, these occurrences may indicate attempts to move sources covertly.
- Gaps in systematic screening can lead to some cargo streams not undergoing full inspection, potentially creating pathways for no detection.
- Orphan sources (these are previously licensed radioactive materials that have become uncontrolled) pose a significant threat due to their unpredictability and the difficulty in tracing their origin. They can be unintentionally mixed with scrap metal, recycled materials, or machinery being transported across borders.
- The single but notable detection of Bi-207, an isotope rarely associated with routine commerce, raises the possibility of an abandoned or a mismanaged source finding its way into cargo streams.
- Moderate levels of Ra-226 and Eu-152 correlate with disused industrial gauges, density meters or calibration sources that may have been discarded improperly.

5.4. Potential for Unintentional Movement of NORM

The high frequency of Potassium-40 (K-40) detections (57 occurrences) overwhelmingly indicates the movement of NORM-containing goods such as fertilizers, ceramics, food products, or raw minerals. Similarly, isotopes like Ra-226 and Th-232 may have originate from natural deposits or processed materials.

Substantial transboundary movement of NORM reflects the common presence of K-40 in everyday commodities.

5.5. Security Vulnerabilities

The detection outcome reveals several security vulnerabilities within the current monitoring system; the distribution also highlights gaps that could undermine nuclear security objectives.

- Screening activities rely largely on handheld radiation detection devices; thus, cargo screening is selective; only a fraction is assessed.
- The presence medical and industrial isotopes point to the movement of regulated sources and technologically enhanced NORM. Thus, their interpretation and classification require strong technical competence. Without adequate training, officers may close cases prematurely without escalating suspicious findings to the regulatory authority.
- Inconsistent or incomplete documentation may complicate verification process thus, forcing officers to rely solely on instrument readings rather than cross-checking shipment manifests. This increases the risk of both missed threats and unnecessary alarms.

Limitation of the Study

The detection outcomes provide valuable insight but are shaped substantially by the RIID sensitivity limits, the absence of continuous monitoring infrastructure and time constraints inherent in the operational environment. These limitations suggest that the findings reflect radiological profile spectrum during the time of assessment and not the general radiological profile presence in air freight movements.

6. Conclusion

The assessment of air cargo entering Ghana revealed a measurable presence of radioisotopes within import consignments. Approximately 22% of the screened freights registered detectable levels of radioactive material, underscoring the potential risks associated with RN Materials being out of regulatory control. These findings highlight the persistent vulnerabilities that exist within cargo movement pathways and the need for strengthened national nuclear security measures.

In the absence of fixed radiation detection systems at border points, the use of a Radioisotope Identifier Device (RIID) proved essential in identifying materials of regulatory concern. The study therefore demonstrates the critical role of frontline detection capabilities in safeguarding against illicit trafficking, accidental movement of orphan sources, and unintentional transport of NORM. Strengthening these detection systems, supported by coordinated institutional frameworks and enhanced technical expertise, remains vital for ensuring the safe and secure management of nuclear and radioactive materials across Ghana's borders.

The pattern of radioisotope detections, ranging from high-frequency naturally occurring radionuclides such as K-40 to moderate detections of industrial and medical isotopes like Cs-134, Co-60, I-131, and Ra-226, provides important insights into the radiological threats and operational gaps within the current air freights monitoring system. The detection outcomes highlight several areas where targeted policy interventions can strengthen national radiation protection and nuclear security frameworks. These include but not limited to the following.

Need for Better Detection Infrastructure

The fact that detections were dominated by strong, easy-to-identify radionuclides (e.g., K-40) while more complex or shielded signatures appeared infrequently suggests limitations in the current instrumentation and screening coverage.

Policy implications include:

- Investment in Radiation Portal Monitors (RPMs): The reliance on handheld Radiation Identification Devices (RIIDs) means screening is selective rather than comprehensive. Deploying fixed RPMs would enable continuous scanning, improving the probability of detecting illicit or concealed radioactive materials.
- Upgrading spectrometric capabilities: Higher-resolution gamma spectrometry systems would enhance the ability to distinguish between NORM, industrial sources, and potential illicit materials. This is particularly relevant given the moderate frequencies of Cs-134, Eu-152, and Mn-54, which can be difficult to identify with low-performance devices.

- Establishing a national radiological detection team: Integrating border, port, and inland checkpoint detection systems would create an end-to-end monitoring architecture capable of tracking radioactive material movements more accurately.
- The detection profile, therefore, underscores the need for enhanced infrastructure to ensure that all air freights, not just a sampled subset, are systematically assessed.

6.1. Coordinated Border Security Mechanisms

The presence of regulated isotopes in routine cargo (such as Co-60, I-131, and Ra-226) and isolated detections of less common radionuclides (such as Bi-207) indicates that multiple agencies interact with radiological materials across the supply chain. This creates challenges that require coordinated policy responses.

Policy implications include:

- Strengthening interagency information-sharing: The Customs Division of the Ghana Revenue authority, the Nuclear Regulatory Authority, port operators, health agencies, and national security secretariate must share detection data in real time. Coordinated responses are critical when unexpected isotopes are detected or when documentation is incomplete.
- Developing standardized cargo documentation requirements: Inconsistent or inaccurate documentation complicates threat assessment. Harmonized paperwork and mandatory declaration of radiological materials would reduce uncertainty and help identify anomalies more efficiently.
- Creating a unified national incident response framework: Shared protocols for escalation, particularly for detections involving industrial isotopes that could indicate orphan sources would ensure consistent handling across different border points.
- The detection outcomes thus highlight the importance of interagency cooperation to manage routine detections while rapidly responding to those that may indicate security risks.

6.2. Improved Training for Officers

The identification of multiple medical and industrial isotopes in the dataset shows that frontline officers encounter varied radiological signatures requiring technical interpretation. High counts of K-40 also suggest that officers are frequently required to distinguish between NORM and potentially risky materials.

Policy implications include:

- Enhanced radiological literacy: Officers need deeper understanding of gamma signatures, shielding effects, isotope decay characteristics, and common cargo associations to make accurate judgments in the field.
- Scenario-based training: Regular exercises involving mock cargo with mixed isotopes would improve officers' ability to differentiate between harmless and suspicious detections.
- Improved alarm-resolution protocols: Officers must be trained to follow structured assessment steps to reduce unnecessary delays from false positives while ensuring that genuine threats are escalated appropriately.
- Certification programs for radiation detection personnel: Formal training and competency standards would improve detection accuracy across all border points in the country.
- The variation in detected isotopes and the need to interpret both common and unusual signatures demonstrates that skilled personnel are a critical component of an effective national detection strategy.
- Together, these policy measures will strengthen national capabilities to prevent illicit trafficking, manage orphan sources, and safely handle NORM movements while maintaining smooth trade operations.

Compliance with ethical standards

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Disclosure of conflict of interest

Etornam Ann Mensah, Kwame Appiah, Nelson Agbemava, Cyril Cyrus Arwui and Ernest Beinpuo declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

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