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ENHANCING DETECTION OF NUCLEAR AND OTHER RADIOACTIVE MATERIAL (NRM) USING RADIOISOTOPE IDENTIFICATION DEVICE: A CASE STUDY IN GHANA

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Abstract

To ensure the safety and security of Nuclear and Other Radioactive Material (NRM) under regulatory control, and to mitigate the risks associated with illicit trafficking and potential malicious activities, an assessment was undertaken to evaluate the detection of NRM in imported cargo transiting through Ghana's sole international airport. In the absence of a radiation portal monitor, a Radioisotope Identification Device (RID) was utilised for the screening process. A total of 648 containers were examined, of which 62 were determined to contain radioisotopes with the recorded equivalent dose rates ranging from 0.029 µSv/h to 0.417 µSv/h. Although the RID is a less optimal tool than radiation portal monitors for comprehensive cargo screening, its application, however, confirmed the presence of radiation in air cargo shipments. These findings raise concerns regarding the potential for illegal or illicit trafficking of NRM at Kotoka International Airport.

Introduction

The International Atomic Energy Agency (IAEA) and other international organisations have over the years raised concerns about the illegal movement of Nuclear and other Radioactive Material (NRM) which has become a global nuclear security problem, and one that exists in Africa, Broodryk and Stott (2011); Institute for Security Studies (2011). The increasing civilian and industrial uses, coupled with the persistent intent of certain terrorist groups to exploit these materials for malicious purposes, has compelled states to adopt preventive measures to restrict their unauthorized entry into public domain by using radiation detection devices, James Martin Center for Non-proliferation Studies (2015). Mandatory inspections carried out by national Nuclear Regulatory Authorities are often insufficient to comprehensively monitor and control the the transboundary and domestic movement of high-risk materials. The maritime domain presents significant challenges in detecting NRM due to the magnitude and pace of global trade flows, Downes et al. (2019), facilitating an estimated 90% of trade through shipping, International Chamber of Shipping (2018). Containerization, which has expanded significantly since the 1980s, has resulted in more than 43 million containers currently in circulation worldwide, Organisation for Economic Co-Operation and Development (2016). Even though the maritime supply chain presents a huge and growing cargo stream, identifying NRM presents an acute challenge giving that as little as a few kilograms of such materials could present substantial security threats, Budget Shipping Containers (2016) and Fias et al. (2008). Thus, rapid and easy identification of NRM was essential to avoid the disruption of the flow of legitimate commerce. Effective detection must therefore balance the need to monitor and interdict these materials and other illegal imports given resource constraints including unavailability of Front-Line Officers (FLOs), Potter et al. (2004). To address these challenges, emphasis has been placed on the use of detection technologies capable of scanning large volumes of cargo to identify the physical signatures of these materials. Passive radiation detection devices are generally used measure gamma and/or neutron emissions arising from radioactive decay, The Guardian (2012) and Weltz et al. (2015). These detectors vary in sensitivity and portability, with greater effectiveness when deployed in combination, Podgorsak et al. (2005). Fixed Radiation Portal Monitors (RPMs) and Mobile Detection Vans (MDVs) enable non-intrusive inspection of containers without disrupting trade flows, typically within a two-minute interval. Such detection systems could trigger alarms categorised as false, innocent, or non-innocent depending on whether the detected radiation originated from background fluctuations, legitimately declared sources, or materials out of regulatory control, United States of America, Department of Homeland Security (2010). Confirmatory assessment was typically performed with handheld Radioisotope Identification Devices (RIDs), capable of identifying specific isotopes for medical, industrial, or Naturally Occurring Radioactive Materials (NORMs), Boeck (2006), Medalia (2010), Department of Homeland Security (2015) and Pellens (2010). In Ghana, there are no Radiation Portal Monitors currently deployed at border points, limiting the effectiveness of destination inspection for detecting illicit NRM. Alternatively, RIDs intended for secondary inspection and Personnel Identification Devices (Pagers) are employed although their use as a primary detector was hindered by time constraints constraints and reluctance among customs and front-line officers (IAEA Nuclear Security Series, 2013a).

The present study investigates the possibility of NRM entering Ghana through import cargo at Kotoka International Airport (KIA) without detection. The assessment was performed using a RID to evaluate the presence of radioisotopes in cargo that had already undergone scanning by existing inspection system. The findings aim to inform policy and operational strategies for strengthening detection capabilities and reducing the risks associated with uncontrolled NRM.

Materials and Methods

Location

The location of data collection was the Kotoka International Airport cargo village where cargo arriving at the airport are sent for inspection (i.e., scanning to identify the content of the cargo as specified in the manifest or cargo documentation).
The Kotoka International Airport (KIA) was the only international airport in the country. It was one of the destinations for the imports and exports, Wikipedia (2021). The cargo village of the airport has a scanning system which scans pallets of cargo. The scanning system utilises an x-ray technology to identify the images of commodities or items contained in a cargo just like taking a chest x-ray scan for medical diagnosis, and it only identifies the images of the commodity(ies) in the container. This inspection procedure does not in any way consider the detection of NRM transported in and out of or through the airport, Ghana Ports and Harbours Authority (2021).

Radioisotope Identification Device (RID)

The device employed for radiation detection and data collection in this study was the Radioisotope Identification Device (RID), commonly referred to as the IdentiFinder. As shown in Figure 1, the IdentiFinder was a portable radiation detection instrument capable of measuring equivalent dose (µSv) and equivalent dose rate (µSv/h). The device was designed to detect the presence of a radiological source, produce an alarm as proximity to the source increases, and identify the source by class and specific radionuclide as pre-installed in its internal library. The IdentiFinder has an energy resolution specified at the 662 keV gamma line of Cs-137. It was capable of recording gamma-ray energies within the range of 20–3,000 keV. The device operates reliably across a temperature range of –15 °C to +55 °C and has a total weight of less than 1.25 kg.
The RID estimates the Equivalent Dose Rate (H) as follows:

$$H = D_m \cdot Q \tag{1}$$

where
- D_m was the absorbed dose to the material
- Q was the quality factor or the radiation weighting factor (W_R)
- standard W_R for gamma rays was unity (1)
- W_R for neutron was ten (10)

The absorbed dose was defined as the measure of the amount of radiation energy absorbed per unit mass and expressed as follows, United States Nuclear Regulatory Commission (2011):

Figure 1. IdentiFinder

$$D_m = D_{\text{air}} \cdot X \frac{(\mu_{en}/\rho)_{\text{material}}}{(\mu_{en}/\rho)_{\text{air}}} \tag{2}$$

where:
- D_m was the absorbed dose to the specified material (μSv, μSv/h).
- X was the exposure or exposure rate (R/hr).
- $(\mu_{en}/\rho)_{\text{material}}$ was the mass energy absorption coefficient for the specified material at the photon energy of interest.
- $(\mu_{en}/\rho)_{\text{air}}$ was the mass energy absorption coefficient for air at the photon energy of interest.

The IdentiFinder can detect both gamma and neutron radiations from environmental background and potential sources. The device operates in three primary modes: equivalent dose rate mode, finder mode, and identify mode.
In the equivalent dose rate mode, the instrument measures the ambient equivalent dose rate irrespective of the presence of a source, thereby serving as a survey meter for radiation safety assessments. This was the most easily and rapidly accessible mode.
The finder mode was employed for source localisation within a designated area. The detector enables the user to pinpoint the approximate location of a radiological source. Audible and vibration alarms are activated to assist in detection while minimising the risk of overexposure.
The identify mode was utilised once a source has been located, allowing the radionuclide to be characterised. Identification was performed by matching the detected spectral signature against the nuclide library stored in the IdentiFinder. The display provides the confidence level of identification, the classification of the nuclide by application (e.g., medical, industrial, or naturally occurring), and the specific isotope detected. The internal nuclide library data of the "FLIR" RID used for the purpose of this study was tabulated in Table 5.
The IdentiFinder also incorporates an advanced mode, that

allows for the configuration of additional operational settings. These include calibration of the device prior to use, adjustment of date and time, display of battery status and power source information, as well as access to spectral data from saved measurements, Rees (2018).

Methodology

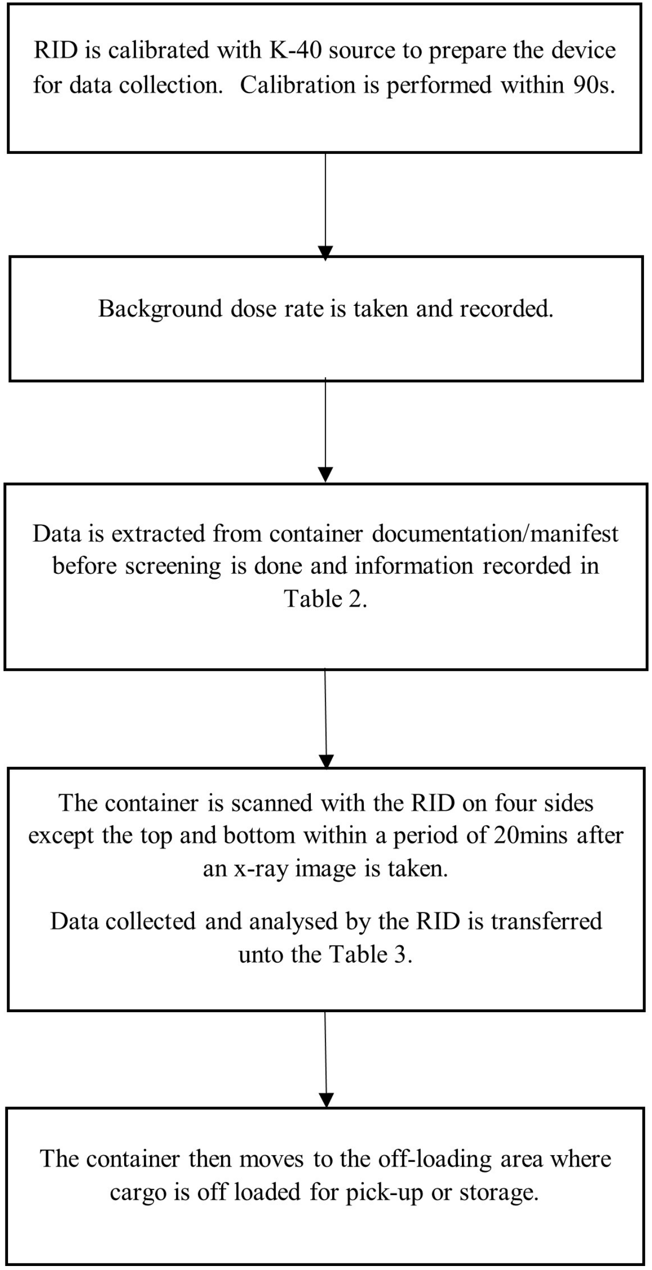
The investigation of radiation presence in each cargo was carried out by using the RID to take measurement on each container for approximately 20 minutes (20mins). Measurements were taken across four surfaces of each container except for the top and bottom surfaces. Measurement or data were taken after the RID was calibrated and background equivalent dose rate reading taken away from the operation station. Equivalent dose rate measurements were taken after the cargo had been scanned using the x-ray inspection system.

The data sheet in Table 2 attached in appendix, presents the summary of cargo information collected during the assessment from each assessed cargo documentation/manifest.

Each cargo entry was assigned a Serial Number to ensure traceability and ease of reference. The Commodity Number corresponds to the unique identifier used by the cargo operator and customs system to distinguish individual consignments within a container. The Container Type field specifies the physical dimension/unit used for transport, providing context for cargo configuration. The Harmonized System (HS) Code was included to classify commodities according to international customs standards, enabling cross-referencing with regulatory requirements and facilitating risk-based screening (WCO HS classification handbook, nd). The Commodity column describes the nature of the goods transported, while the Weight (kg) indicates the declared mass of the cargo, which was relevant for assessing compliance with transport limits. The Commodity Comment field captures possible additional observations made during assessment, including cargo homogeneity or heterogeneity, and any notable features that may influence radiation detection outcomes. The Origin column records the origin of the cargo as obtained from the cargo manifest, supporting provenance verification and assisting in identifying trade routes relevant to safety and security analysis.

The process of data collection was elaborated in the field activity process flow chart.

Field Activity Process Flow Chart



RID is calibrated with K-40 source to prepare the device for data collection. Calibration is performed within 90s.

Background dose rate is taken and recorded.

Data is extracted from container documentation/manifest before screening is done and information recorded in Table 2.

The container is scanned with the RID on four sides except the top and bottom within a period of 20mins after an x-ray image is taken.

Data collected and analysed by the RID is transferred unto the Table 3.

The container then moves to the off-loading area where cargo is off loaded for pick-up or storage.

Results and Discussion

Results

At the completion of data collection, equivalent dose-rate measurements were obtained for 648 containers. The average background radiation level was 0.03 µSv/h. Across all containers, the mean equivalent dose rate was 0.1029 µSv/h, with a standard deviation of 0.0672 µSv/h, indicating moderate variability consistent with heterogeneous cargo composition. The distribution was slightly right skewed due to a small number of elevated readings. The minimum recorded value (0.03 µSv/h) corresponded to background radiation, while the maximum value (0.44 µSv/h) was observed in a container identified as containing Thorium-232/Uranium-232 (Th-232/U-232) enriched commodities. The overall range of 0.41 µSv/h reflects the presence of both low-activity and moderately elevated NORM-associated materials within the sampled cargo stream. The results of the assessment are presented graphically in Figure 2 and Figure 3. All 648 containers exhibited detectable levels of radiation, as illustrated in Figure 2. Of these, the RID successfully identified isotopes in 62 containers (9.57%), a total of 194 containers (29.94%) produced readings associated with "unknown isotopes," meaning the device detected radiation signatures not contained in its internal library. For

Table 1. RID Specification

Category	Specification
Detectors	
Gamma: NaI	Crystal size 35 mm × 51 mm
Neutrons: ^{3}He Proportional Counter Tube	15 mm × 54 mm; net: 14 mm × 29 mm; 8 atm
Gamma (High Dose Rate)	Geiger-Müller detector
GPS	12-channel SiRF III receiver
Calibration (external source)	40K; Startup time: ≈320 s
Performance	
Energy Range (Gamma)	20 keV – 3 MeV
Throughput	>150 kcps
Max. Input Count Rate	300 kcps
Sensitivity (137Cs)	>500 cps per µSv/h
Corrections	Real-time linearization of gamma spectrum
Gamma Spectrum	1024 channels; 3 MeV
Dose Rate Range	0.000 µSv/h – 10.00 mSv/h
Scintillator	0.000 µSv/h – 500 µSv/h
Geiger-Müller Detector	100 µSv/h – 10 mSv/h
Overload	10 mSv/h – 1 Sv/h
Dose Rate Accuracy (137Cs)	±30 %
Dose Range	0.000 µSv – 1 Sv
Neutron Sensitivity	2.6 cps/nv
Stabilisation	LED; ±1 % for temperature change rate of <0.5 °C (0.9 °F)/min
Nuclide Identification	According to ANSI N42.34
Typical Resolution	≤8 % FWHM at 662 keV at 20 °C (68 °F) ambient temperature
Physical	
Dimensions (W × D × H)	248 mm × 93 mm × 75 mm
Weight	1200 g including batteries
Housing Material	Aluminium
Environmental	
Operating Temperature	-20 °C – +55 °C
Relative Humidity	10 % – 80 %, non-condensing

Table 2. Data collection sheet for manifest information

Serial No.	Commodity number	Container type	HS code	Commodity	Weight (Kg)	Commodity comment	Origin
		20 footer				back middle front	
		40 footer				back middle front	

392 containers (60.49%), the device returned an "insufficient counts" message, indicating that the emitted radiation was either below the RID's pre-set detection threshold or attenuated by shielding. A further 13 containers (2%) were found to contain more than one isotope, reflecting mixed cargo compositions. This was consistent with the RID's isotope distribution trends, where materials containing K-40, identified as the most frequently detected isotope, produced dose-rates ranging between 0.03 µSv/h and 0.23 µSv/h, consistent with established radiation signatures of NORM-rich commodities such as ceramics, fertilizers, and processed foods.

Assessment outcomes were initially categorized into three risk levels namely low, medium, and high risk based on isotope identification and regulatory significance.

Low-Risk Category

Containers with background dose rate levels and those identified (by both instrument and document verification) as containing Naturally Occurring Radioactive Material (NORM),

Table 3. Data collection sheet for RID information

Serial number of RID	Background measurement	Doserate Measurement (µSv/h)	Radionuclide	Radionuclide ID

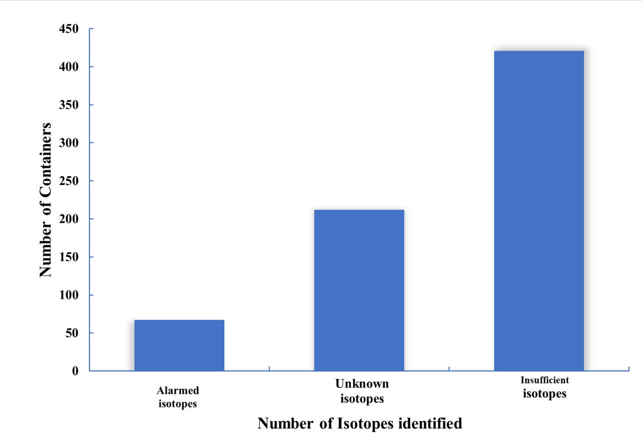


Figure 2. Representation of results from data collected.

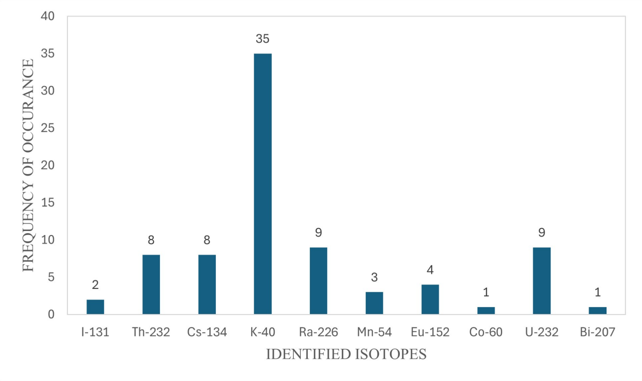


Figure 3. Identified isotopes and their frequency of occurrence.

were categorised as being of low security risk (Pellens, 2010). This category included containers in which isotopes such as Potassium-40 (K-40) were confidently identified. Containers identified with insufficient counts results that clustered around background levels were also considered as being of low security risk where dose rates did not exceed expected natural variation and commodity type was consistent with low emission potential (e.g., HDPE products, used clothing, automobile parts, frozen goods).

Medium-Risk Category

These are containers that yielded "unknown isotope" results or "insufficient counts" at dose rates measurably above background were classified as medium risk due to unresolved characterization.

Although the dose rates were generally only slightly elevated above background, the inability to confidently identify the radionuclide introduces uncertainty.

High-Risk Category

Containers within this category are those in which regulated and anthropogenic isotopes were positively identified, irrespective of dose rate magnitude. The RID successfully detected and identified isotopes and anthropogenic radionuclides of regulatory concern such as Cobalt-60 (Co-60), Cesium-134 (Cs-134), Iodine-131 (I-131), and Europium-152 (Eu-152) due to their association with industrial and medical activities. Also, containers containing multiple isotopes (13 containers; 2%) were included in this category where the isotope profile suggested mixed or regulated material streams.

Observational trends also showed that "unknown isotopes" were generally associated with commodities such as alcoholic beverages, detergents, toiletries, and mixed light-metal goods. These containers often produced dose-rates slightly above background but below the device's threshold for confident isotope identification and classification. Conversely, "insufficient counts" results clustered around lower dose-rates levels, particularly for materials such as HDPE, used clothing, automobile parts, and frozen goods, which are more likely to attenuate radiation or produce negligible emissions.

There are several types of air cargo containers used for transporting commodities, however, containers assessed in this study were PGA containers, commonly known as the 20-foot air cargo pallet, with dimensions of 96 × 238.5 inches. These containers are constructed from lightweight aluminium, providing insignificant shielding capability and therefore offering very low potential to conceal nuclear material or other radioactive materials. The allowable weight range for each container was between 7000kg to 13,600kg. During the assessment, 50 containers representing 7.72% exceeded the allowed weight limit, an occurrence deemed acceptable by the Port Authorities given the total number of containers evaluated. The remaining 598 containers representing 92.28% fell within the permissible weight range.

Most of the containers held heterogeneous cargo, although the exact quantities and item breakdown could not be fully determined. This was because the assessment team had limited access to cargo manifests or documentations due to unavailability and confidentiality protocols. As per the classification by Port Authorities, a container was classified as heterogeneous when it contains multiple items within a specific category; a food product classified cargo container holds cereals, assorted beverages, and canned products. In contrast, a container was considered homogeneous when it carries only one type of commodity, such as a food product cargo container consisting solely of beverages.

Table 4. Commodities and corresponding identified isotopes

Code	Isotopes identified	Usage identified by RID	Container Size (inches)	Weight of container (Kg)	Average Equivalent Dose rate (µSv/h)
RG_20_001	I-131, K-40	Medical	20	13000	0.055
RG_20_002	Th-232/U-232	NORM	20	11820	0.072
RG_20_003	K-40	NORM	20	12100	0.149
RG_20_004	K-40	NORM	20	16100	0.068
RG_20_005	K-40	NORM	20	13200	0.029
RG_20_006	K-40	NORM	20	13212	0.030
RG_20_007	Cs-134	Industrial	20	13170	0.072
RG_20_008	Eu-152	Industrial	20	11150	0.059
RG_20_009	K-40, Th-232/U-232	NORM	20	11170	0.069
RG_20_010	K-40	NORM	20	12340	0.083
FL_20_001	Ra-226, K-40	NORM	20	13390	0.129
FL_20_002	K-40	NORM	20	11128	0.171
FL_20_003	K-40	NORM	20	12320	0.147
FL_20_004	K-40	NORM	20	12732	0.160
FL_20_005	K-40	NORM	20	11000	0.130
FL_20_006	K-40	NORM	20	13117	0.195
FL_20_007	K-40	NORM	20	11400	0.172
FL_20_008	K-40	NORM	20	11455	0.062
FL_20_009	K-40	NORM	20	11512	0.095
FL_20_010	Cs-134, K-40	Industrial, NORM	20	11443	0.109
FL_20_011	K-40, Ra-226	NORM	20	12550	0.156
FL_20_012	Ra-226	NORM	20	12468	0.095
FL_20_013	K-40	NORM	20	12550	0.109
FL_20_014	K-40	NORM	20	11443	0.107
FL_40_015	K-40	NORM	20	11621	0.225
FL_40_016	Th-232/U-232 K-20	NORM	20	11918	0.140
FL_40_017	K-40	NORM	20	10659	0.168
NA_20_001	Cs-134, U-232	Industrial, Nuclear	20	-	0.083
NA_40_002	Cs-134	Industrial	20	-	0.073
NA_20_003	Th-232/U-232, Mn-54	NORM, Industrial	20	-	0.131
NA_20_004	Ra-226	NORM	20	-	0.159
NA_20_005	K-40	NORM	20	-	0.066
NA_20_006	K-40	NORM	20	-	0.098
NA_20_007	Cs-134	Industrial	20	-	0.103
NA_40_008	Th-232/U-232, K-40	NORM	20	-	0.066
NA_20_009	Eu-152	Industrial	20	-	0.060
NA_20_010	K-40	NORM	20	-	0.088
NA_20_011	Cs-134	Industrial	20	-	0.072
TG_20_001	Cs-134	Industrial	20	13170	0.068
TG_20_002	Th-232/U-232	NORM	20	13150	0.168
TG_20_003	I-131, K-40	Medical	20	13170	0.069
PB_40_001	K-40	NORM	20	12591	0.050
PB_40_002	Eu-152	Industrial	20	11270	0.057
FT_40_001	Ra-226	NORM	20	12015	0.417
FT_40_002	Ra-226	NORM	20	13895	0.350
AC_20_001	Th-232/U-232	NORM	20	12880	0.439
AC_40_002	Ra-226	NORM	20	13840	0.142
Ch_40_001	Mn-54	Industrial	20	12340	0.077
SW_40_001	K-40	NORM	20	11900	0.142
KW_40_001	Th-232/U-232, K-40	NORM	20	11670	0.072
CF_40_001	Ra-226	NORM	20	13040	0.068
UB_40_001	K-40	NORM	20	12462	0.092
SF_40_001	Mn-54	Industrial	20	10160	0.060
RS_20_001	Ra-226	NORM	20	7448	0.159
CS_40_001	Cs-134	Industrial	20	11460	0.062
PP_40_001	Eu-152	Industrial	20	10669	0.068
CB_40_001	Co-60	NORM	20	13380	0.059
AP_40_001	K-40	NORM	20	12784	0.071
FP_20_001	K-40	NORM	20	13900	0.050
MB_40_001	K-40	NORM	20	13845	0.097
EW_40_001	Eu-152	Industrial	20	10223	0.119
BP_20_001	K-40, Bi-207	NORM	20	13751	0.052

Discussion

Statistical Discussion

These statistical patterns reveal that while some dose-rate variations correspond to well-known NORM sources tabulated in Table 4, a significant portion of the dataset falls into ambiguous or unclassified categories. This underscores operational challenges in discriminating benign NORM signatures from potentially malicious ones that may have been shielded or concealed, iterating the importance of reliable detection systems and proper alarm adjudication procedures.

Isotopes Identification

The isotope distribution illustrated in Figure 3 and Table 4, shows a clear dominance of Naturally Occurring Radioactive Material (NORM), with K-40 appearing in 35 out of the 62 identified cases, making it by far the dominant isotope. This pattern aligns with the dose-rate ranges observed during the assessment, where moderate increases above background levels were frequently associated with cargo types known to contain K-40, such as ceramics, fertilizers, grains, processed foods, and certain construction materials. The relatively higher dose-rates for these containers, when compared with others, are consistent with the natural gamma emissions typical of K-40. Other NORM-related isotopes, including Thorium-232 (Th-232) and Cesium-134 (Cs-134), were each detected eight times, while Uranium-232 (U-232) and Radium-226 (Ra-226) appeared nine times. Their presence indicates the movement of materials containing trace radioactive constituents, potentially from industrial sources such as mineral ores, scrap metal, and processed consumer goods. These isotopes generally produced dose-rates moderately above background but below the higher levels associated with K-40, suggesting lower activity concentrations or greater attenuation within the cargo. Anthropogenic isotopes including I-131, Mn-54, Eu-152, Co-60, and Bi-207 occurred at much lower frequencies (between 1 and 4 detections each), with their limited appearance reflecting in the dose-rate measurements. The low dose-rates of these isotopes, especially I-131 and Co-60 may possibly be due to shielding, low quantities, or decay depending on the age of the source. These isotopes are frequently associated with medical, calibration, or industrial radiography uses, and their low detection frequency (shown in Figure 3 and Table 4) suggests minimal movement of such regulated materials through the assessed cargo.

Overall, the distribution pattern demonstrates a predominance of NORM-bearing materials, characterized by noticeable but not alarming elevations in dose-rate values. The comparatively low representation of high-risk anthropogenic isotopes, combined with the significant presence of ambiguous “unknown” signatures in the wider dataset, highlights operational challenges in distinguishing benign NORM signals from potentially masked or shielded radioactive sources.

Isotopes such as K-40, Th-232, and Ra-226 are naturally NORMs found in a wide range of commodities including ceramics, fertilizers, minerals, building materials, and metal alloys. Their presence in imported goods was to be expected, often and generally of low risk to security. Although NORMs could generate routine radiation alarms and may contribute to elevated dose-rate readings, these detections are typically innocent and relate to safety awareness than to security threats. Conversely, industrial and medical isotopes such as Co-60, Cs-134, I-131, and Eu-152 identified carry greater regulatory and security significance. These isotopes are associated with regulated or controlled applications including industrial radiography, sterilization, medical diagnostics, cancer therapy, and research, and transported under strict regulatory oversight. Their presence in cargo should always be declared and traceable through proper documentation. Undeclared or unexpected detection of these isotopes raises potential security concerns relating to loss of regulatory control, improper disposal, illicit trafficking, or deliberate concealment and requiring investigation.

The high proportion of containers flagged by the RID as containing "unknown isotopes", representing 29.94% and those yielding “insufficient counts”, representing 60.49% reflects both technical and operational limitations that directly affect the reliability and sensitive nature of radiation detection during cargo screening operations.

Technical Factors associated with the "Unknown Isotopes" Results

An "unknown isotope" designation occurs when the RID detects a radiation signature but was unable to match the energy peaks to isotope entries in its internal isotope library as seen in Table 5, technical reasons explaining this outcome includes:

- **Library limitations:** Some NORM variants, industrial alloys, or composite materials emit gamma energies not included in the detector’s library, leading to ambiguous classification.
- **Mixed or overlapping spectra:** Heterogeneous cargo may contain multiple radioactive components whose combined spectra prevent a clear match.
- **Low signal-to-noise ratio:** Weak emissions superimposing background radiation may distort peak structures, making algorithmic identification difficult.
- **Interference from shielding materials:** Light to moderate shielding (e.g., metals, plastics, or packaging layers) could attenuate characteristic peaks, resulting in shifted energy signatures.

A typical scenario was that of a container carrying mixed industrial goods including a small sealed radioactive source embedded within metal components. The overlapping spectral signatures (emanating from the mixed industrial goods and) and partial shielding (emanating from the metal components) could prevent the RID from confidently identifying the radionuclide, resulting in an “unknown isotope” classification. In such cases, the inability to characterize the source introduces uncertainty that requires further inspection or secondary detection methods.

Technical Factors associated with the "Insufficient Counts" Results

The “insufficient counts” message appears when the detector cannot collect enough gamma-ray events within the acquisition period to generate a statistically meaningful spectrum. Possible reasons include:

- **Very low-activity materials:** Some cargo emits radiation just above background, yielding minimal counts insufficient to associate with any energy peak irrespective of the duration for counting.
- **Excessive shielding:** Dense materials (e.g. frozen goods with high water content) could absorb or scatter gamma

Table 5. RID pre-installed library of Isotopes

Category of Radioisotope	Radioisotopes
1. Test Sources for inspectors	Ba-140, Cd-115, Ce-141, Ce-144, I-132, La-140, Mo-190, Nb-95, Nd-147, Pr-144, Nuc Pu, Ru-103, Sb-125, Te-132, Xe-131m, Med Xe-131, Xe-133m, Xe135, Zr-95, Med I-131, Tc-99m, Ga-67
2. Special nuclear materials	U-233, U-235, Pu-239
3. Sources for customs usage	Med Xe-133, Med I-131, Med Tc99m, Med Ga-67, Med In-111, Med Pd-103, Med Tl-201, Am-241, Ba-133, Bi-207, Co-57, Co-60, Cs-134, Cs-137, Eu-152, K-40, Mn-54, Na-22, Ra-226, Th-232, U-238, Pu-239, U-233, U-235, Np-237
4. Sources for medical usage	Ga-67, Tc-99m, Pd-103, In-111, I-123, I-125, I-131, Tl-201
5. Industrial usage	Ag-110m, Bi-207, Cd-109, Cr-51, Na-22, Co-57, Co-57, Co-58, Co-60, Ba-133, Cs-134, Cs-137, Cs-137, Eu-152, Eu-155, Fe-59, K-40, Mn-54, Se-75, Ir-192, Ra-226, Th-232, Am-241, U-238, Zn-65
6. Security concerned radioisotopes	Nuc Pu, Med Xe-133, Med I-131, Med Tc-99m, Ga-67, Med I-123, Med I-125, Med In-111, Med Tl-201, Am-241, Ba-133, Bi-207, Co-57, Co-60, Cs-134, Cs-137, Eu-152, Ir-192, K-40, Mn-54, Na-22, Ra-226, Se-75, Th-232, Nuc U-238, Nuc U-233, Nuc U-235, Nuc Pu, DU-238, Nuc Np-237, Nuc Pu-240

emissions, preventing detection.

- **Short acquisition time:** Time-limited measurements, which was common in high-throughput port environments may not allow sufficient accumulation of counts, particularly for marginal emitters.

For instance, a malicious actor attempting to transport a small radioactive source could conceal it within a dense cargo or packaging materials to attenuate emissions. The resulting low photon counts may cause the detector to return an "insufficient counts" message, potentially leading to the cargo being incorrectly assumed to be benign.

Operationally, “insufficient count” results reduce the sensitivity of the inspection process, increasing the risk of undetected or poorly characterized radioactive sources. Containers producing low-count spectra may be incorrectly assumed to be benign, thus, creating a vulnerability that could be exploited by malicious actors who rely on shielding and dilution strategies to obscure such materials. Additionally, repeated "insufficient count" outcomes diminish confidence in the detection system and may lead frontline officers to underestimate risks associated with poorly characterized cargo.

Nuclear Security Implications of the Assessment Outcomes

The distribution of detection outcomes illustrated in Figure 2 reveals a significant concentration of radiation alarms that could not be conclusively resolved during assessment or selected cargo screening. Relatively, only a small proportion of the total containers assessed resulted in positively identified (alarmed) isotopes, while a much larger share produced “unknown isotope” and “insufficient isotope” outcomes.

From a nuclear security perspective, these findings are significant in that, all detections were undeclared radioactive materials in cargo manifests, implying that the radiation alarms cannot be dismissed as innocent or expected. While a proportion of the alarms may be attributable to Naturally Occurring Radioactive Materials (NORMs), the inability to confidently identify or characterize most radiation signatures elevates the proportion of potentially “non-innocent” detections. Containers producing “unknown” or “insufficient count” results represent a security blind spot where radioactive sources whether shielded or mixed with legitimate cargo could evade effective regulatory control.

Operationally, the absence of modern detection systems to support security measures to yield quality outcomes places a substantial burden on Ghana’s frontline cargo screening system. Radiation detection instruments that frequently return inconclusive results reduce confidence in alarm adjudication, increase inspection delays, and may contribute to alarm fatigue among officers (Transactions of the American Nuclear Society, 2015). Over time, the risks of unresolved alarms normalize thereby weakening the deterrent effect of radiation screening and increasing the likelihood of malicious actors exploiting system limitations.

From a policy standpoint, the findings underscore the need for an improved detection infrastructure, and clearly defined alarm adjudication protocols within Ghana’s nuclear security architecture. Strengthening inter-agency coordination between relevant stakeholders; including the Nuclear Regulatory Authority, Ghana Revenue Authority, Customs Division, Port Authorities, and Security Agencies, was critical to ensuring accurate and adequate; primary and secondary, screening rather than routine clearance (IAEA Nuclear Security Series, 2013b).

Additionally, the results support the adoption of a risk-informed screening framework, majority of containers fall within the low-to-medium-risk spectrum; however, nearly 40% of detections (unknown isotope and elevated insufficient-count

Table 6. Summary of Detection Outcomes and related Nuclear Security Significance

Detection Outcome	Number of Containers	Percentage (%)	Typical Technical Explanation	Nuclear Security Significance	Operational Implication
Identified Isotopes	62	9.57%	Clear gamma spectra matched to RID isotope library; often associated with NORM-containing commodities such as ceramics, fertilizers, and food products.	Low to Moderate Risk depending on isotope type; NORM generally benign but anthropogenic isotopes would require regulatory verification.	Requires documentation checks and confirmation that the material is legitimately declared and authorized.
Unknown Isotopes	194	29.94%	Radiation detected but energy peaks not matched in the RID isotope library due to mixed spectra shielding, or library limitations.	Medium Risk, Unresolved Detection. Potential for shielded or mixed radioactive sources concealed within legitimate cargo.	Requires secondary inspection, longer acquisition time, or higher-resolution detection systems.
Insufficient Counts	392	60.49%	Radiation signals too weak to generate statistically meaningful spectra; may result from low activity, shielding, dense cargo, or limited acquisition time.	Medium Risk, Detection Blind Spot. Low-count signals could mask small or shielded radioactive sources.	Requires improved detection infrastructure, extended scanning, or additional detection technologies.
Multiple Isotopes Detected	13	2%	Mixed cargo compositions producing overlapping radiation signatures.	Moderate to High Risk depending on isotope type and regulatory Control status.	Requires detailed cargo verification and regulatory review.

cases combined) required further characterization beyond initial screening. The low-risk categorised containers represent alarms that could be rapidly adjudicated with minimal security concern once NORM characteristics are confirmed. While unknown and insufficient-count alarms are systematically treated as medium to higher-risk until resolved. Although some elevated readings were attributable to NORM (e.g., Th-232/U-232 enriched commodities), the regulatory importance of anthropogenic radionuclides warrants heightened security attention, documentation verification, and potential interagency coordination.

Key Security Insight

The technical detection outcome and their nuclear security significance and operational implications have been summarised in Table 6. The table highlights, over 90% of detection outcomes were not conclusively resolved at the point of screening, creating a substantial proportion of uncertain or potentially non-innocent alarms. In the absence of declared radioactive materials in cargo manifests, these unresolved detections represent a significant nuclear security concern, emphasizing the need for improved detection infrastructure for Ghana's Cargo Controls.

Conclusion

NORMs represent a frequent but largely benign component of cargo movements, while industrial and medical isotopes represent infrequent but high-consequence detections requiring rigorous verification. The detection of these two categories correctly was therefore essential for effective alarm adjudication, risk prioritization, and the overall strengthening of transport safety and nuclear security frameworks.

From the result discussed, illicit trafficking of nuclear and other radioactive material (NRM) through the airport was one that cannot be overlooked. It was informative from the assessment that any form of NRM could make its way into or transit the country illegally without being detected, thus destination inspection infrastructure and measures employed at the airport need to be improved to prevent a conducive environment for illicit trafficking of NRM.

Recommendations

To improve nuclear security detection and the effectiveness of destination inspection, the following recommendations are proposed.

Policy-Level Priorities

- Establishing of standardized national protocols for alarm adjudication, escalation, and reporting, aligned with IAEA Nuclear Security Series (NSS) 15 (Nuclear Security Recommendations on Nuclear and Other Radioactive Material out of Regulatory Control) and 23-G (Guidance on Nuclear Security Systems and Measures for the Detection of Nuclear and Other Radioactive Material out of Regulatory Control).
- Enhancing interagency coordination between Ghana Revenue Authority (GRA) Customs Division, the Nuclear Regulatory Authority (NRA), Port Securities, and Law Enforcement to addressing compliance gaps in inspection processes, the need for regulatory frameworks that mandate transparency and accountability in cargo handling and enable rapid, coordinated responses to unresolved alarms.

Technology Priorities

- Upgrading RIDs with expanded isotope libraries, improved sensitivity, and enhanced shielding detection capabilities.
- Investing in complementary detection systems such as neutron detectors, gamma spectroscopy, and mobile detection platforms to address RID limitations.
- Deploying data fusion and AI-based analytics to cross-check alarm data with cargo manifests, reducing false alarms and streamlining decision-making.

Training and Capacity-Building Priorities

- Providing specialized and continuous training for frontline officers (FLOs), customs officers and security personnel particularly in the effective use of radiation detection device and in adjudicating alarms, interpreting Radiation Portal Monitors (RPM) and RID data, especially for ambiguous results.
- Conducting regular field exercises simulating shielded source scenarios to test system performance and operator readiness.
- Developing national and regional reach-back capabilities, where technical experts could remotely support frontline officers in analysing complex alarms.

Investment in Fixed Radiation Portal Monitors (RPMs)

- Prioritizing the installation of fixed RPMs at high-throughput cargo entry/exit points to enable non-intrusive, automatic scanning of large container volumes.
- Ensuring sustainable investment by allocating funds for RPM lifecycle management which must cover calibration, maintenance, spare parts, and software upgrades.
- Link RPM networks to centralized databases to enable real-time monitoring, alarm adjudication, and reach-back support for unresolved cases.

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Declaration of interest statement

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