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Application of area monitors and scintillating detectors in the development of CBRN defense reconnaissance vehicles

Silva[a,b] T.M.S., Lobato[b] A.C.L., Mendonça[b] A.K.F., Azevedo[b] A.M., Pontes[b] C.C.C., Cardoso[b] D.O., Silva[b] M.P.C.S., Salazar[b] A.P., Vasconcelos[b] V.C., Nunes[b] W.V.

[a] *Instituto de Defesa Química, Biológica, Radiológica e Nuclear (IDQBRN) / Seção de Defesa Radiológica e Nuclear (SDRN). Avenida das Américas, 28.705 – Guaratiba. 23020-470. Rio de Janeiro - RJ - Brasil.*

[b] *Instituto Militar de Engenharia (IME) / Seção de Engenharia Nuclear (SE/07). Praça Gen. Tibúrcio, 80 – Urca. 22290-270. Rio de Janeiro - RJ - Brasil.*

thiago.medeiros@eb.mil.br

ABSTRACT

This study describes the use of ionizing radiation detectors in a Brazilian Army reconnaissance vehicle (RV), used in area monitoring actions based on the occurrence of a radiological event. Two scintillating detectors, NaI and $LaBr_3$, were used to carry out field measurements of surveying for different distances from a simulated detector position in the vehicle, in order to compare the energy spectra obtained in each measurement system. The Brazilian Army Technological Center (*Centro Tecnológico do Exército - CTEx)* region was chosen to carry out the measurements. The meteorological information was annotated to verify the conditions into which the experimental apparatus would be submitted. The results suggest that both the NaI and $LaBr_3$ scintillating detector could be used in radiological emergency response RV, offering satisfactory responses in the gamma radiation detection. However, the NaI detector was chosen considering the wide network of technical assistance and its low operational cost. The relevance of this investigation shows the importance of planning responses in emergency situations and the influence of efficient instrumentation in the measurement processes.

Keywords: **Detectors, Scintillators, Vehicle, CBRN, Defense.**

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1. INTRODUCTION

The study presents a theoretical-experimental analysis of a system for detecting and recognizing ionizing radiation in an operational vehicle of the Brazilian Army, aiming to meet the needs of its Chemical, Biological, Radiological and Nuclear Defense System (*Sistema de Defesa Química, Biológica, Radiológica e Nuclear do Exército - SisDQBRNEx*).

By hypothesis, and within this context, an experimental study becomes relevant, seeking to evaluate the levels of exposure to ionizing radiation, if an accident and/or radiological incident occurred, with potential danger for human health and for the environment [1, 2]. This analysis would allow to verify in more detail the adequate selection of the site for the execution of nuclear activities and practices, improving the logistics to be used by the radiological emergency response team in the area of Chemical, Biological, Radiological and Nuclear (CBRN) defense.

The objective of the research aims to develop a theoretical and methodological studies on the mentioned theme, and to analyze the data obtained to define the detection system that could be used in the reconnaissance vehicle (RV), when radiological events occur. Finally, field measurements were performed, simulating the detector position in the RV.

2. MATERIALS AND METHODS

2.1. Description of the reconnaissance vehicle

The vehicle for the detection and reconnaissance of ionizing radiation was based on a commercially available 4x4 vehicle. It has a metal body that can be used to transport crew and/ or cargo on various terrains, whether flat or bumpy. Thus, the vehicle stands out for its robustness, safety and versatility of application.

Aiming at the greater efficiency of operation of the RV for the detection of ionizing radiation, the following requirements should be observed:

- The scintillator detector will be installed externally to the vehicle, below the front headlight, as illustrated in Figure 1.

- A display should be installed for the transmission of the data collected by the scintillator detector, to a control center, internal to the vehicle.
- The CsI(Tl) scintillator detector will be installed internally to the cabin, closer to the driver, for individual monitoring purposes.
- A compartment must be installed inside the cabin for the accommodation of contaminated material, collected for analysis.
- The cabin will not have traditional windows, to preserve the environment as free of particulate matter as possible.
- To provide internal cooling of the cab, a split-type air conditioner with hood will be installed.
- The cabin must have an electrical distribution frame connected to an outlet that can be connected to an external battery bank (DC voltage) or to the electrical grid (AC voltage).
- The cabin must have a small reserved and isolated environment, where it will be possible to change clothes contaminated in external areas.

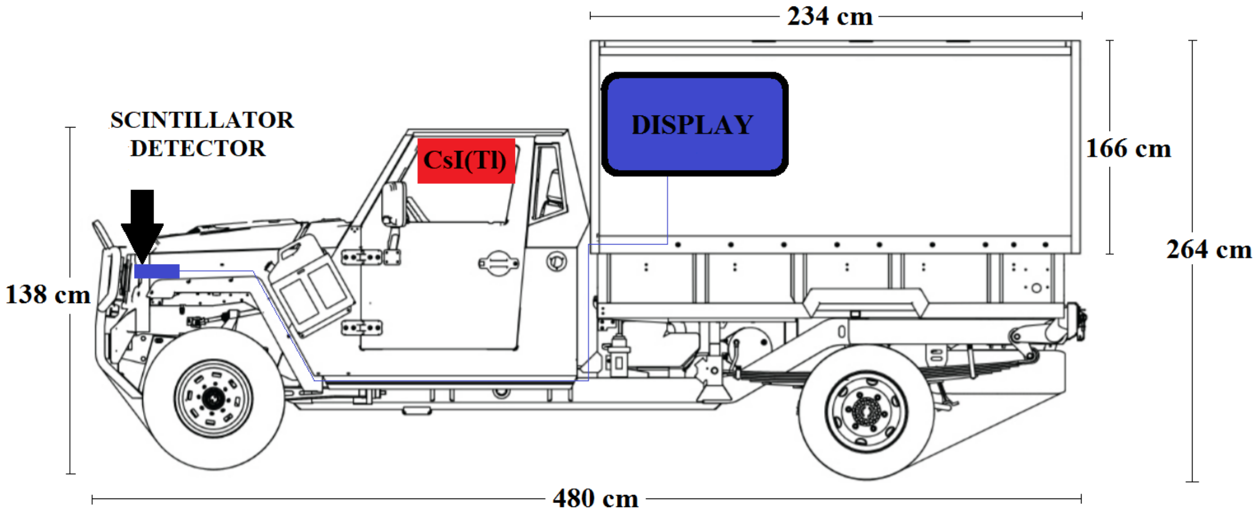

Figure 1: *Side view of the CBRN defense reconnaissance vehicle (RV).*
Source: Authors.

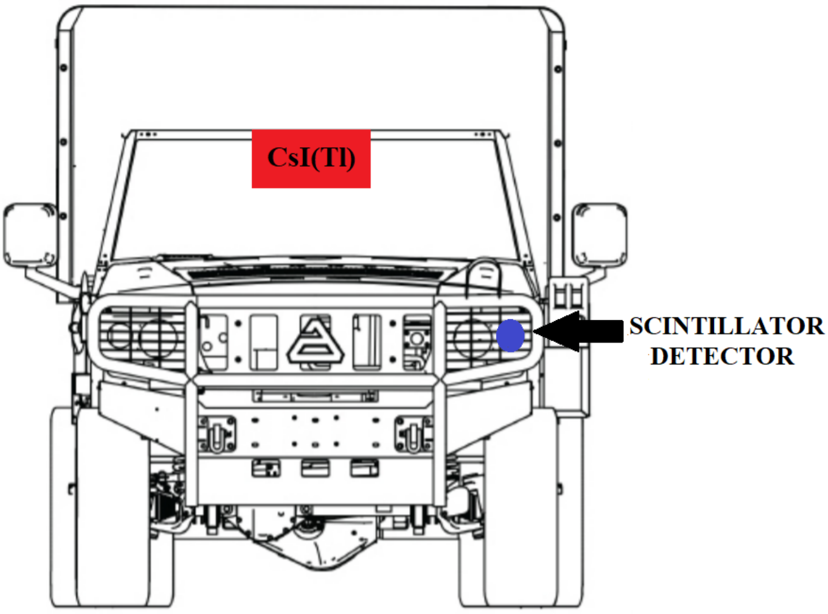

Figure 2: *Front view of the CBRN defense reconnaissance vehicle (RV).*
Source: Authors.

2.2. Detectors

For the application of the proposal of this work, was considered the use of scintillating detectors, due to the higher detection efficiency and greater mechanical and thermal robustness [3,4], in addition to the fact that the RV acts mainly in the detection of γ radiation.

In this sense, to perform the experimental analyses, the NaI and $LaBr_3$ scintillator detectors were used, both with 5 μs dead time, which is the minimum time in which the detector will analyze two distinct pulses as separated events [5,6], in order to identify the radiation spectrum at the site, and a CsI(Tl) scintillator monitor, for the survey of the dose received by the operators [7,8].

In this context, the SpiR-ID, RIIDEye and RadEye PRD-ER4 scintillator detectors were chosen. For the design of the RV will be provided a data relay unit connected to the scintillator identifier, which will allow the visualization of the data measured by the detector to both operators and their superiors in some remote operation command center. The scintillator identifier will be attached to the bumper holder, as showed in Figures 1 and 2, in order to facilitate the reading of the site scan and the retransmission of data.

2.2.1 Scintillator Detector SpiR-ID

The SpiR-ID scintillator detector is a NaI(TI) detector, which can operate in the temperature range of -20°C to 50°C and with relative humidity until 100%. It has resistance to vibration, shock and falls; in addition to conforming to the MIL461D EMI, presenting IP65 for dust and water inlet. It has a rechargeable Li ion built-in battery and charger, making the detector rechargeable with a battery life of up to 10 hours, with battery compartment in case of immediate power requirement.

The SpiR-ID has dimensions of 320 x 145 x 175 mm (width x height x length) with 4.9 kg. It acts on a variant energy margin of 25 keV to 3 MeV when it comes to gamma radiation, with measurement range from 0.01 μSv/h to 10 mSv/h. It also has MCA 1024 digital channels for communication and data transfer, and the acquisition of continuous spectra and stabilization are performed without need for calibration in the field. In addition, it calculates the actual dose rate by weighting the spectra created based on a dead time of 5 μs [9].

2.2.2 Scintillator Detector RIIDEye

The RIIDEye scintillator detector is a $LaBr_3$ detector, which can operate in the temperature range from -20°C to 50°C and with relative humidity until 100%. It has resistance to vibration, shock and falls; in addition to conforming to the MIL461D EMI, presenting IP65 for dust and water inlet. It has a rechargeable Li ion built-in battery and charger, making the detector rechargeable with a battery bank autonomy of up to 8 hours and a compartment for 8 AA alkaline batteries in case of immediate power of up to 12 h.

RiIDEye has dimensions of 135 x 285 x 215 mm (width x height x length) with 2.9 kg. It acts on a variant energy margin of 25 keV to 3 MeV when it comes to gamma radiation, with a measurement time of 40 ns to 2.1 μs. It also has MCA 1024 digital channels for communication and data transfer, and the acquisition of continuous spectra and stabilization are performed without the need for calibration in the field. Similarly, it calculates the actual dose rate by weighting the spectra created based on a dead time of 5 μs [10].

It is observed that the operating conditions are extensive, evidencing the good resilience and lightness of the equipment, perfectly meeting the national and operational climatic characteristics. Table 1 presents the main information of this detector.

Table 1: Intrinsic efficiency of RIIDEye.
Source: Handheld Radio-Isotope Identification Device Mode RIIDEye X-G, -H, -GN, -Hn

Source	Energy (keV)	Intrinsic Efficiency
^{57}Co	122	63.95
^{133}Ba	356	39,65
^{137}Cs	662	26,5
^{60}Co	1173	14,35
^{60}Co	1332	13,10

2.2.3 Scintillator Detector RadEye PRD-ER4

For the safety of the operators of the vehicle, the RadEye PRD-ER4 of Thermo Scientific was used. It is a scintillator detector type CsI (Tl), whose dead time is 300 ms.

The device is powered by two AAA alkaline batteries, in addition to a battery lasting up to 170 h. Its main advantage lies in its power autonomy, which gives the operator a smaller limitation of its movement in the field. Accompanied by its mass, which is approximately 195 g, which is an advantage with regard to the portability of the instrument, this instrument has communication outputs via USB for infrared (IR) and settings and can be activated via Bluetooth. Its measuring range for low doses is from 10 nSv/h to 250 μSv/h, and for high doses it is 250 μSv/h at 10 Sv/h [11].

2.3. Scenario description for detector measurements

To perform the measurements with the scintillators, NaI and $LaBr_3$, installed in the RV described in item 2.1, and later comparison between the responses obtained, it was considered a hypothetical scenario of radiological accident where this vehicle will perform area monitoring [12, 13, 14], as well as the reconnaissance and delimitation of suspicious areas. For this, the measurements were conducted within the The Brazilian Army Technological Center (*Centro Tecnológico do Exército - CTEx*) facilities, in a safe, isolated area (to minimize radiation scattering) and in the open field, aiming at the radioprotection of the technical team.

In this sense, the measurements were performed with the detector scintillator simulating its installation position on the front of the vehicle, with the instrument positioned below the front headlight and at a height of 85 cm from the ground. With regard to the detector CsI(Tl), its installation is projected in the internal cabin of the RV, next to the driver's seat. However, due to mechanical problems of the vehicle, it was not possible to use it in the measurement process. Thus, during the measurements, the detector scintillator was positioned at 85 cm high from the ground, so that it reproduced it position in the RV. It is advisable to address the limitations of this simulation in the future since the metal structure of the RV would provide a greater degree of radiation scattering.

Regarding meteorological conditions, the experiment was conducted on a cloudy day with a maximum recorded temperature of 28°C at the CTEx facilities located in Guaratiba - Rio de Janeiro - RJ. The Detector scintillator NaI was positioned at 5 m, 10 m, 15 m and 20 m away from a sealed source of Cesium-137, with activity of 136.5 mCi and manufactured on 01/25/89, obtaining the energy spectrum of this radioisotope, in each of the selected distances.

The experiment with the Detector of $LaBr_3$ was carried out on a cloudy day with a maximum recorded temperature of 23°C in the CTEx. This detector was positioned in the same experimental condition used for the NaI scintillator and with the same radioactive source. The energy spectrum was also acquired for each of the pre-established distances.

3. RESULTS AND DISCUSSION

3.1. Scintillator Detector SpiR-ID

Measurements were performed using a scintillator detector based on NaI at distances of 5 m, 10 m, 15 m and 20 m, all with a time of 60 seconds, whose spectra are found in Figure 3 with identifications A, B, C and D, respectively.

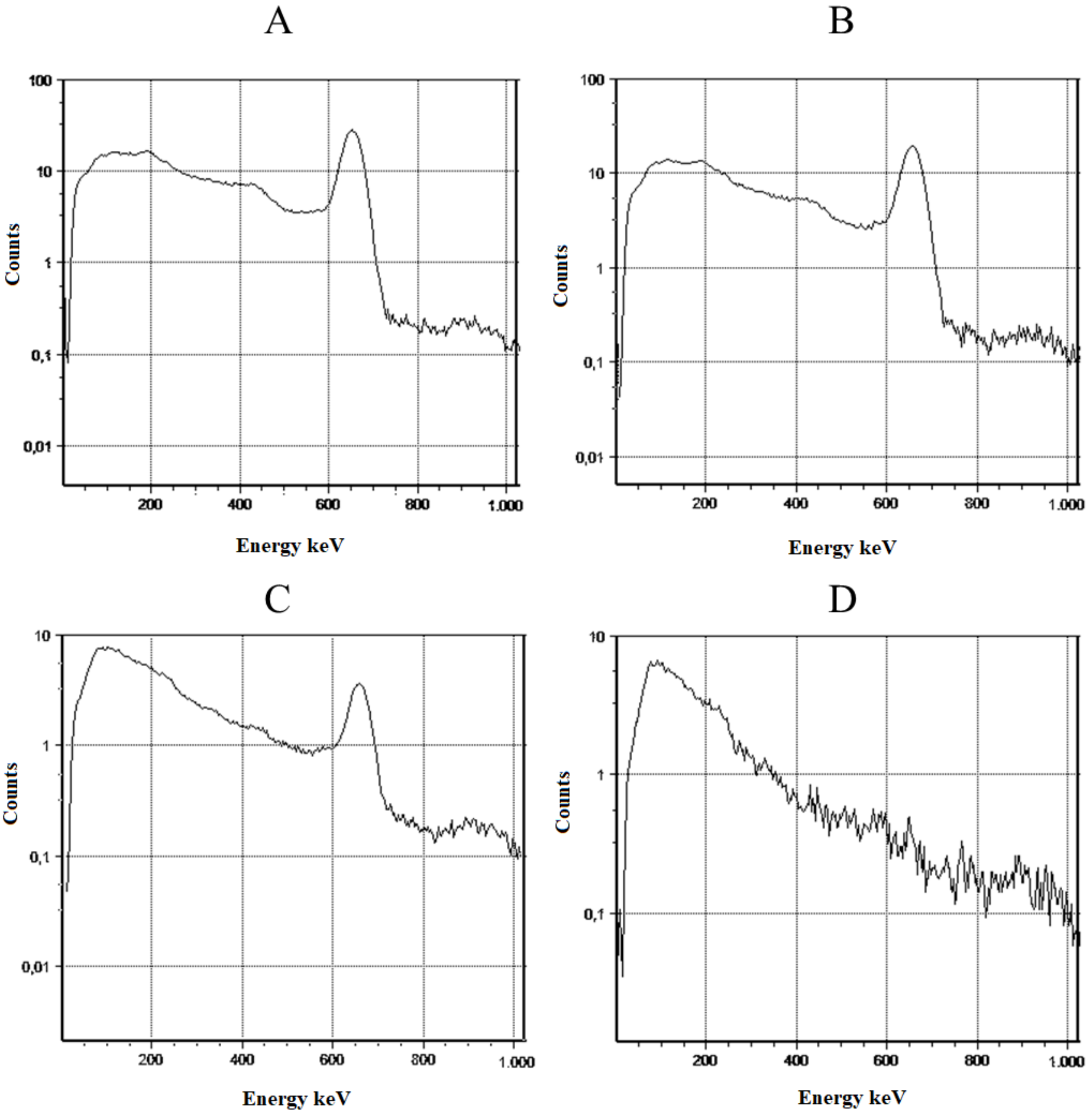

Figure 3: *NaI scintillator spectra at (A) 5 m; (B) 10 m; (C) 15 m; (D) 20 m.*

Source: Authors.

On the spectra presented in Figure 3, the results show a loss of resolution with the increase in distance. The relationship between measurement distances and counting efficiencies is highlighted from the results of Figure 3. It is evident that the loss of energy resolution for Cesium-137 is remarkable in the spectrum referring to 20 m. In the spectra referring to distances of 5 m and 10 m, it was noticed, for energies below 200 keV, the occurrence of high counts compared to the spectra obtained for 15 m and 20 m. This fact can be justified by a greater scattering of gamma radiation at these distances, as expected. It was also possible to verify, at distances 5 m and 10 m, an enlargement of the photo peaks. This characteristic indicates the occurrence of detector saturation at these distances.

In addition, it was noticed, up to the distance of 15 m between the detector and the source, the photo peak of Cesium-137, whose corresponds to an energy of 662 keV in the spectra analyzed. However, at a distance of 20 m from the source, the detector did not present the photopeak characteristic of this radionuclide. The other photo peaks found refer to radionuclides from the uranium, thorium and potassium decay series; being therefore associated with background radiation.

Additionally, it was verified that the spectrum referring to the distance of 20 m, presented in Figure 3 (D), showed a low resolution in the detection. In this context, the results demonstrate a greater influence of background radiation on the obtained spectrum, which is tied to a decrease in the detection of photons from the source used, indicating even greater proximity to the detection threshold for 662 keV energy photons. In the spectra obtained, in the final third to the right of the same, it was verified the influence of the electronic noise of the instrumentation used in the measurements obtained.

3.2. Scintillator Detector RIIDEye

Measurements were performed using a scintillator detector based on $LaBr_3$ at distances of 5 m, 10 m, 15 m and 20 m, all with a time of 60 seconds, whose spectra are in Figure 4 with identifications A, B, C and D, respectively.

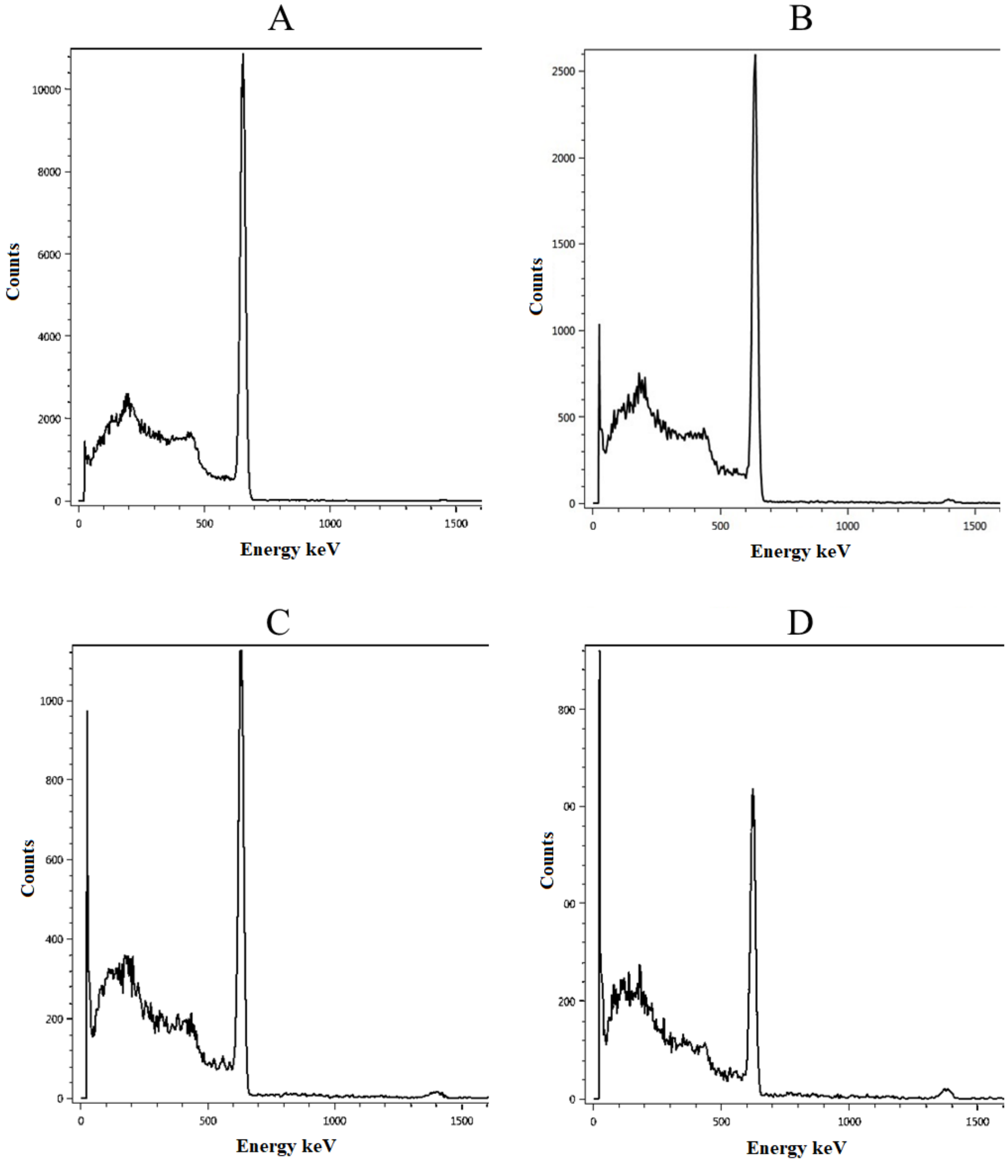

Figure 4: *Spectra of the Scintillator $LaBr_3$* to *(A) 5 m; (B) 10 m; (C) 15 m; (D) 20 m.*
Source: Authors.

Based on Figure 4, the results allow verifying the occurrence of high counts in the spectra referring to distances of 5 m and 10 m, compared to the spectra obtained at distances of 15 m and 20 m, for energies below 200 keV. This fact can be justified due to the increased scattering of gamma radiation at these distances, as expected. Unlike the spectra obtained by NaI, there was no widening of the photo peaks using the $LaBr_3$ detector; therefore, there is no evidence of detector saturation at these distances.

In addition, it is also possible to verify the occurrence of the photo peak of Cesium-137 at all distances where the measurement occurred. The other photo peaks found refer to radionuclides from the Uranium, Thorium and Potassium decay series; being therefore associated with background radiation .

Additionally, it was noticed that the spectrum referring to the distance of 20 m, presented in Figure 4 (D), showed a resolution similar to those obtained in the other distances, which is attributed to the good statistics of counting in the analyzed time. Finally, there was a greater influence of the background radiation on the spectrum obtained at a distance of 20 m, which can be justified by the decrease in the detection of photons from the source used, indicating greater proximity to the detection threshold for photons with energy of 662 keV. In the four spectra obtained, in the final third the right of them, it was not possible to influence the electronic noise of the instrumentation used to obtain the measurements.

4. CONCLUSION

The objective of the research was achieved through a theoretical and experimental studies of the radiological detection system to be installed in a 4x4 vehicle of the Brazilian Army used in radiological emergency response actions.

The main results of this research showed that, in the spectra of Figure 3, items: A, B and C, recorded by the scintillator NaI, it was possible to identify the radiation spectrum emitted by the source of Cesium-137, being the value of 15 m the longest distance in which the equipment was able to identify the radionuclide. In the spectra recorded by the scintillator $LaBr_3$, it was noted the identification of the radiation spectrum emitted by the source of Cesium-137, for all distances used in this work.

Another relevant finding is that there is an increase in the counting rate in the low energy region in the spectrum obtained in NaI, whereas in the $LaBr_3$ detector there was no increase in the same magnitude. This is attributed to the difference in detection efficiency between the detectors analyzed in this energy range [15], considering that the existing scattering conditions were the same for both equipment. Regarding the performance in the field, the detectors presented, under the same atmospheric conditions, responses in agreement as provided in their respective manuals.

According to the literature [16,17], the NaI detector has higher counting efficiency and lower energy resolution, compared to $LaBr_3$, in the case of active volumes of the same geometry and dimensions. For the choice of the best detector to be used, one should consider the wide network of technical assistance of NaI detectors and their low operational cost. However, in this work it was experimentally demonstrated that, for the desired objective, both detectors and detectors could be used in RV, offering satisfactory answers in the gamma radiation detection.

Continuing in the qualification of the detection system to be used, focus of this work, the same measurements will be performed, under the same experimental conditions, but with higher temperatures, around 40°C. In the continuation of this study, we intend to evaluate the operational aspects due to mechanical shock, trepidation and the influence of electromagnetic field in the vicinity of detection equipment.

Thus, the research shows that, for studies involving nuclear instrumentation, with the well-defined characterization of the ionizing radiation source, the methodology applied to measurement systems in area monitoring vehicles allows verifying the compliance with the standards regarding the planning of responses in emergency situations and the influence of an effective instrumentation in the measurement processes [18]**.**

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REFERENCES

[1] TAUHATA, L.; SALATI, I.P.A.; DI PRINZIO, R.; DI PRINZIO, A.R.; **Radioproteção e Dosimetria: Fundamentos**. 10ª revisão. Abril/2014 - Rio de Janeiro - IRD/CNEN. 344p Available at: <http://www.ird.gov.br/index.php/material-didatico/send/36-apostilas/105-radioprotecao-e-dosimetria-fundamentos-final-i>. Last access in: 05 April 2021.

[2] DELLAMANO, J.C.; MARUMO, J.T.; SANCHES, M.P.; VICENTE, R.; BELLINTANI, S. **Noções Básicas de Proteção Radiológica**. São Paulo, S.P.: DDRH/DSN/IPEN, 2002

[3] KNOLL, GLENN F; **Radiation Detection and Measurement**. 3rd ed.. New York, NY. 2000.

[4] CERRITO, Lucio. **Radiation and Detectors: Introduction to the physics of radiation and detection devices.** 1. ed. London, UK: Springer InternationalPublishing, 2017. 217 p.

[5] MURRAY, l. RAYMOND. **Nuclear Energy**. Butterworth Heineman, 5° edição, 1975. Cap.10.

[6] TSOULFANIDIS, Nicholas et al.**Measurment and Detection of Radiation**. 2. ed. Washigton, DC: Taylor e Francis, 1995. 636 p.

[7] BAPTISTA, Alfredo. **Equipamentos detectores de radiação e sua utilização. Curso de proteção e segurança radiológica em Radiografia Industrial**, Lisboa, p. 1-44, 23 ago. 2020.

[8] XAVIER, A; Moro, J.T; Heilbron, P.F.L; **Princípios Básicos de Segurança e Proteção Radiológica**. 3a ed. Revisada. 2006 – Porto Alegre – UFRGS

[9] MIRION TECHNOLOGIES. **SpiR-ID Nai - Handheld Detection and Identification**. USA 2014,

[10] THERMO SCIENTIFIC. **RIIDEye - Handheld Radiation Isotope Identifier**. USA, 2012.

[11] THERMO SCIENTIFIC. **RadEye PRD/PRD-ER Personal Radiation Detector**. USA, 2008.

[12] CANBERRA INDUSTRIES. **Model 802: Scintillation Detectors**. USA: Canberra Industries, 2003. 9 p.

[13] CANBERRA INDUSTRIES. **Model 2005: Scintillation Preamplifier**. USA: Canberra Industries, 2003. 21 p.

[14] CANBERRA INDUSTRIES. **Model 2007: PM Tube Base.** USA: Canberra Industries, 2006. 14 p.

[15] PHOTON IS OUR BUSINESS. **Photomultiplier Tubes: Basics and Applications**. 3. ed. [S. l.]: Hamamatsu Photonics K. K, 2007. 323 p

[16] LIMA, C. A., 2006, Avaliação **da Performance de Detectores Iodeto de Sódio NaI(Tl) em Centrais Nucleares – Dissertação de Mestrado**, COPPE/UFRJ, RJ.

[17] MILBRATH, B. D.; CHOATE, B. J.; FAST, J. E.; HENSLEY, W. K.; KOUZES, R. T.; SCHWEPPE, J. E. **Comparison of $LaBr_3$:Ce and NaI(Tl) Scintillators for Radio-Isotope** Identification Devices. U. S. Department of Homeland Security - U.S. Customs and Border Protection and Domestic Nuclear Detection Office under U.S. Department of Energy Contract DE-AC05-76RL01830, 2006.

[18] Comissão Nacional de Energia Nuclear. **CNEN-NE 5.01 - Transporte de Materiais Radioativos**. 1988.