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Comparison of the response of two scintillator detectors used in an environmental and occupational radiometric survey during the operation of the Argonauta reactor

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ABSTRACT

The Argonauta research reactor at the Institute of Nuclear Engineering - IEN operates, under normal conditions, at powers ranging from 1.7 to 340 W, developing activities of a scientific-technological nature in the areas of neutron radiography, radionuclide production and conduction from experimental practices to graduate courses at CNEN research institutions and other Brazilian institutes of science and technology. During some security operations, the presence of investigators, students and/or operators inside and around the main hall of the Argonauta is required. Therefore, it is important to assess normal occupational exposure conditions when the reactor is in critical condition. This makes it possible to verify in greater detail the equivalent doses of ambient gamma radiation contained by the combustion of the fuel element inside the reactor room and in the surrounding areas, according to the Radiation Protection Plan (RPP) of this installation. In this work, a didactic activity was carried out to familiarize the students of the first period of the Master's Course in Nuclear Engineering, at the Military Institute of Engineering, with the procedures involved in the radiometric survey of the free, controlled and subsequent locations of this nuclear installation. This practice aims to identify the doses to which Occupationally Exposed Workers (OEW) and the general public are admitted, verifying compliance with regulatory requirements regarding the monitoring of environmental and local activities, as well as a comparison between the radiation monitors used.

Keywords: **radiometric survey, reactor, scintillator detector, radiation monitor.**

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1. INTRODUCTION

It is extremely important to carry out a radiometric survey in areas of research energy installations so that there is control through monitoring of radiation levels and verification of the possibility of radioactive contamination in low places [1,2].

The safety and radiological protection procedures at the IEN facilities are promoted by a team of specialists in radioprotection, physical protection, occupational safety and health, in order to guarantee the required requirements for the proper functioning of the nuclear research facilities [2] .

The Argonauta research reactor has concrete blocks on the side, around the reflector; at the top, concrete blocks coated with a steel plate and on the opposite side of the external thermal column, an armor tank containing water [3]. These shields ensure that the dose in areas around the reactor are safe for students, faculty and facility staff.

It is important to remember that the radiological protection routine at the IEN/CNEN facilities is very stringent, and both testing and analysis of collected materials are done by qualified personnel who work at the facilities at Instituto de Engenharia Nuclear [2].

To ensure the safety of everyone in the facilities, measurements of direct radiation are made, both internal and external parts, using a thermoluminescent dosimeter (TL), in addition to smear tests to verify contamination at specific points stipulated by the team of Radioprotection [4].

According to the CNEN standard NN 3.01 [5], it is possible to stipulate the classifications of free, controlled and supervised areas, and through this same standard, it is possible to determine that the normal exposure of occupationally exposed individuals and public individuals must not exceed the tabulated values for annual effective dose of 50.0 mSv and 1.0 mSv respectively.

Understanding the importance of complying with the aforementioned rule, the work was proposed academic paper in article format from the acquisition of data for the disciplines of Detection and Nuclear Instrumentation and Radiological Protection, taught at the Military Institute of Engineering.

2. MATERIALS AND METHODS

The area chosen for carrying out the radiometric survey was the building in which the activities with the Argonauta reactor are carried out. The location is characterized by having an operations control room, a hall in which the reactor is located, work rooms and laboratories. Figure 1 represents a sketch of this nuclear facility, highlighting the controlled, supervised and free areas. The points at which area monitoring was carried out are also explained.

It is important to remember that the students were accompanied by technical professionals, who carried out a standard radiometric survey procedure in the locality, carrying a PNM-200 detector to verify the dose rate from neutrons, and a Geiger-Muller detector (model PSN 7013) for the acquisition of the contribution of gamma radiation.

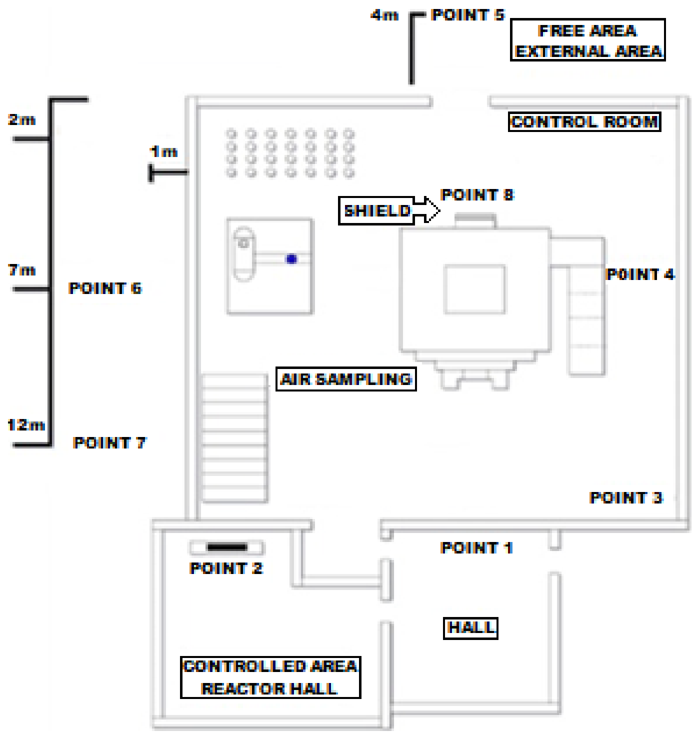
To measure the ambient dose equivalent rate from gamma rays from the nuclear reactions generated by the leaking neutrons during the operation of the Argonauta reactor, two scintillator radiation monitors (detectors) were used, duly calibrated. These detectors are capable of recording the dose rate value in the operational range of 0.01 μSv/h to 100 mSv/h, detecting gamma rays in the energy range of 60.0 keV to 3.0 MeV.

The detectors were positioned at a distance of 1 m from the ground, close to the navel, following the standard distances used by IEN professionals for periodic measurements. This height is justified by the approximate location of where direct exposure occurs on the spine.

A measurement time of approximately 80 seconds in real time was adopted for each measurement. At each measurement point, three measurements were taken for better accuracy.

The measurements obtained were compared in order to evaluate the performance of these equipments, which have different properties with regard to the scintillation crystal, being the radiation monitor 1 composed of a $CeBr_3$ crystal detector, and the radiation monitor 2 composed of a NaI (Tl) crystal detector. In addition, the spectra generated by the scintillator detectors were compared, in order to verify the occurrence of changes in relation to the background radiation (background) of the installation. Finally, the results obtained for the ambient dose equivalent rates obtained with the individual dose limits predicted for normal exposure situations were compared [1].

Figure 1: Sketch of the Argonauta Installation



Source : Prepared by the authors based on the facilities of the Argonauta reactor, 2022.

3. RESULTS AND DISCUSSIONS

According to the results presented in Table 1, it was possible to verify that at the measurement points, considering the Argonauta reactor in the criticality condition, the ambient dose equivalent rate values showed values below the predicted dose limit for the OEW (50.00 mSv in 2000 annual working hours = 25.00 µSv/h). The possible discrepancies in the values found can be explained by the existence of systematic errors, linked to human factors and the difference in the scintillation crystals.

It was found that the highest measured dose rate was at point 5, which is the passageway for loading and unloading the Argonauta reactor. This high dose rate is only possible due to direct irradiation of the reactor through one of the maintenance channels. A safety measure adopted on this exit, indicated as point 8 in figure 1, was the placement of an extra shield. Another security measure is the signaling made by means of security lights that warn when the reactor is in operation, this measure helps to minimize the passage of people in this area during the operation of the Argonauta, thus avoiding unnecessary exposure.

Table 1 : Dose Equivalent Rates and Standard Deviation

POINT	PLACE	DETECTOR 1 $(\mu Sv/h)$	STANDARD DEVIATION	DETECTOR 2 $(\mu Sv/h)$	STANDARD DEVIATION
	Background	0.095	0.005	0.140	0.005
1	Hall	0.314	0.018	0.321	0.002
2	Control Room	0.261	0.010	0.303	0.004
3	Reactor Room (Extreme Right)	0.459	0.018	0.473	0.010
4	Reactor Room (Near the Hydraulic System)	1.048	0.458	2.193	0.325
5	Loading and Unloading Gate	0.470	0.314	2.570	0.201
6	External Area (Hydraulic System)	0.451	0.039	0.534	0.006
7	External Area	0.273	0.004	0.327	0.005

The results related to the spectra, explicit in figures 2 to 5, obtained with the previously described methodology, showed that the scintillator detector 1 presents better resolution of the Gaussian peaks, discriminating in more detail the energies, in the range between 0 and 3 MeV, when compared to the scintillator detector 2.

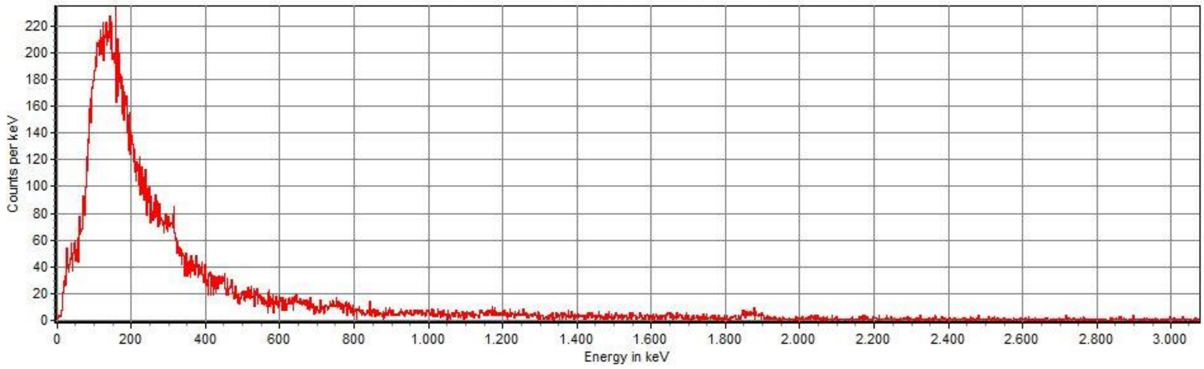
The dead time is the minimum time that can elapse after the arrival of two successive particles and still result in two separate pulses [6]. Observing Table 2, it is possible to verify that the scintillation detector 1 has a longer dead time than the scintillation detector 2, despite having a greater number of counts even at lower energy. This indicates that despite having greater efficiency, the associated electronics cannot process all the pulses, saturating faster than Detector 2.

In addition, it is also possible to notice that in both cases, the values are below the occupational limit foreseen for the OEW, showing the correct classification of the area as being controlled, as foreseen in the RPP of this installation.

Table 2 : Dead Time

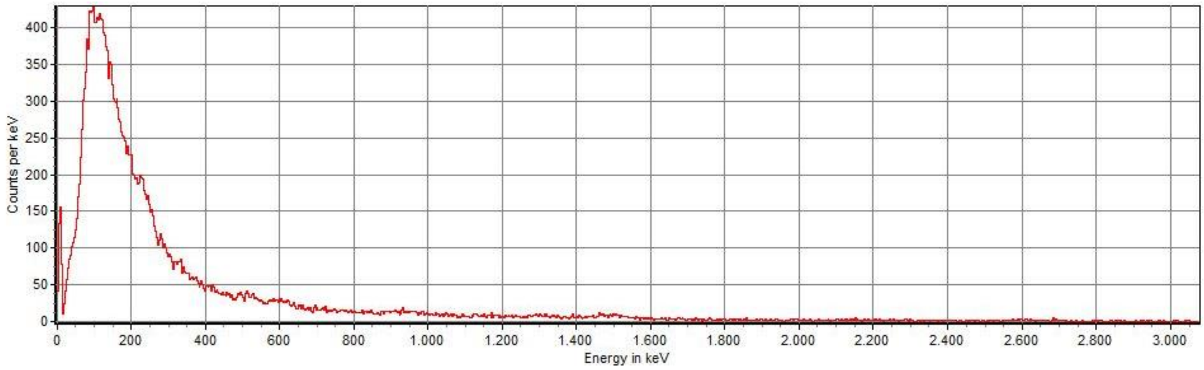
POINT	PLACE	DETECTOR 1 DEAD TIME (s)	DETECTOR 2 DEAD TIME (s)
	Background	1	
1	Hall	2	0
2	Control Room	1	0
3	Reactor Room (Extreme Right)	8	0
4	Reactor Room (Near the Hydraulic System)	8	2
5	Loading and Unloading Gate	13	0
6	External Area (Hydraulic System)	9	0
7	External Area	5	0

Figure 2: Detector 1 at point 1.



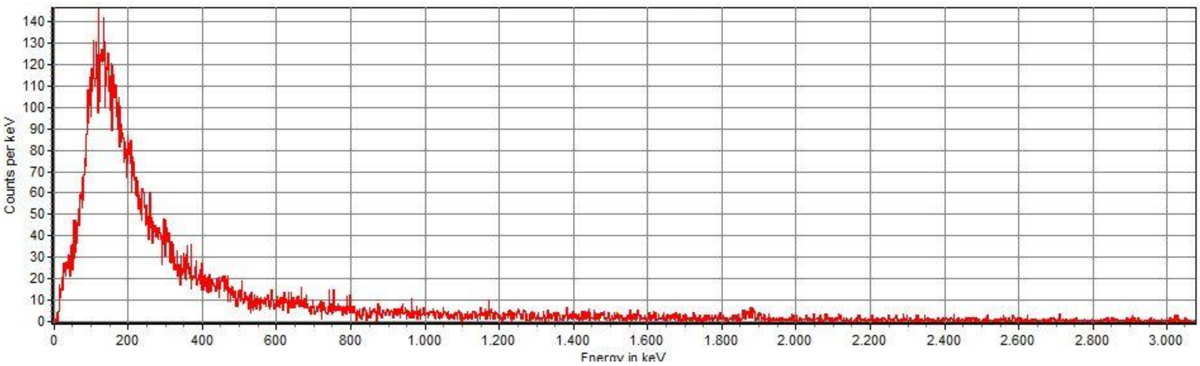
Source: Image generated in the spectrometry program for detector 1.

Figure 3: Detector 2 at point 1.



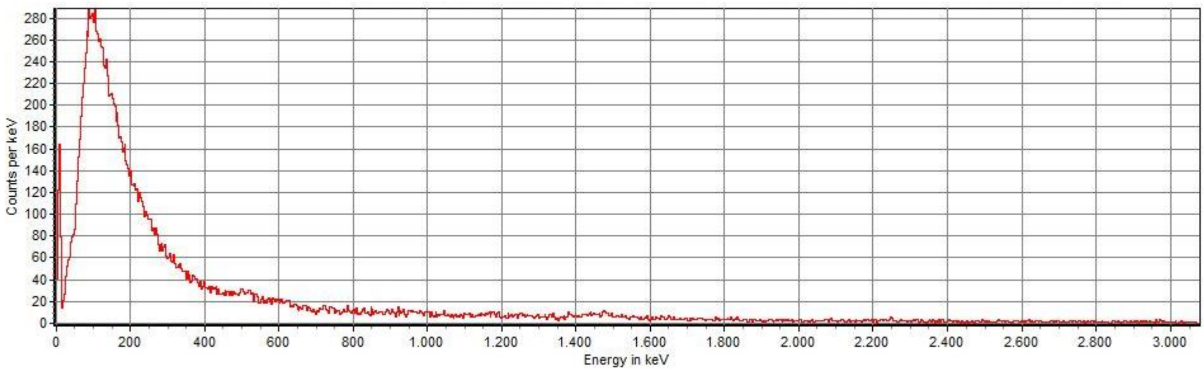
Source: Image generated in the spectrometry program for detector 2

.**Figure 4:** Detector 1 at point 7.



Source: Image generated in the spectrometry program for detector 1.

Figure 5: Detector 2 at point 7.



Source: Image generated in the spectrometry program for detector 2.

4. CONCLUSIONS

This work demonstrated the importance of the methodology used in the evaluation of the radiometric survey of a nuclear installation, with a view to complying with the guidelines indicated by the regulatory authorities, in addition to providing students with practical knowledge, developed in the field that allowed the analysis of the data obtained and comparison between two radiation monitors, one with a $CeBr_3$ crystal detector and one with a NaI (Tl) crystal detector.

Within the proposed comparison, the $CeBr_3$ crystal detector proved to be effective in use in radiometric surveys and in the generation of radiological spectrum.

The results achieved in this study made it possible to verify the correct classification of the areas in the evaluation of the points chosen for carrying out the measurements, as provided for in the IEN RPP.

It is concluded that the work was motivated because it was possible to promote the students' familiarization with the detectors used, in addition to the possibility of monitoring standard radioprotection tests at the IEN/CNEN facilities.

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