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Two-dimensional radiometric map of environmental radiation levels in a nuclear medicine service

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Abstract: Nuclear Medicine in Brazil has shown significant growth, with approximately 2 million procedures performed annually across 436 facilities. Ensuring that radiation exposure remains within safe limits is critical to protect patients and staff, making radiometric surveys an essential part of safety protocols. This study investigated the distribution of radiation in a nuclear medicine service in Florianópolis, Santa Catarina, using biweekly measurements collected between 2021 and 2023. A total of 2,000 samples were gathered at 40 points using a Geiger-Müller detector. The data were analyzed and mapped onto the facility's floor plan using Paint and Excel software to generate a radiometric map. The results identified areas with elevated radiation levels and notable regional differences. The highest exposure rates were found primarily in the radiopharmacy—where radioactive materials are handled, stored, and prepared—and in radiopharmaceutical administration rooms. This radiometric map proved effective in guiding radiological protection measures and highlights the importance of continuous radiation monitoring in clinical nuclear medicine environments.

Keywords: Nuclear Medicine, radiation protection, radiometric survey, radiometric map.

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Mapa Radiométrico bidimensional do nível de radiação ambiental em um serviço de medicina nuclear

Resumo/Resumen/Résumé: A Medicina Nuclear no Brasil tem apresentado crescimento significativo, com cerca de 2 milhões de procedimentos realizados anualmente em 436 unidades. Garantir que a exposição à radiação permaneça dentro dos limites seguros é fundamental para proteger pacientes e profissionais, tornando os levantamentos radiométricos uma ferramenta essencial para a segurança. Este estudo investigou a distribuição da radiação em um serviço de medicina nuclear em Florianópolis, Santa Catarina, por meio de medições quinzenais realizadas entre 2021 e 2023. Foram coletadas 2.000 amostras em 40 pontos utilizando um detector Geiger-Müller. Os dados foram analisados e mapeados na planta baixa da instalação, usando os softwares Paint e Excel, para gerar um mapa radiométrico. Os resultados permitiram identificar áreas com níveis elevados de radiação e diferenças regionais significativas. As maiores taxas de exposição foram encontradas principalmente na radiofarmácia — onde os materiais radioativos são manuseados, armazenados e preparados — e nas salas de administração de radiofármacos. O mapa radiométrico mostrou-se eficaz para orientar medidas de proteção radiológica e destaca a importância do monitoramento contínuo da radiação em ambientes clínicos de medicina nuclear.

Palavras-chave: Medicina Nuclear, proteção radiológica, levantamento radiométrico, mapa radiométrico.

1. INTRODUCTION

In Brazil, there are 436 Nuclear Medicine Services (NMS), performing approximately 2 million procedures annually. Since 2018, the number of procedures has increased by 5% per year, reflecting a positive trend in the expansion of nuclear medicine (NM) in the country. This growth indicates a significant increase in service availability, procedure demand, and the resulting radiation exposure [1].

The use of radioactive sources in medicine, particularly in Nuclear Medicine, plays a crucial role in diagnostic imaging procedures, as it enables the visualization of organ physiology [2, 3]. However, the use of unsealed radioactive materials without proper justification and optimization—as regulated by the National Nuclear Energy Commission (CNEN)—can result in elevated radiation exposure levels. Such exposure may cause various health effects, depending on its intensity, type, and duration, and can affect both the general public and occupationally exposed individuals (OEIs) [1, 4].

The CNEN is a Brazilian federal agency that plays a fundamental role in regulating and overseeing nuclear activities in the country [3]. It is responsible for establishing national regulations and ordinances, including CNEN NN 3.05, which defines safety guidelines and radiological protection principles in nuclear medicine. The three core principles of radiation protection, justification, optimization, and dose limitation, are essential to ensuring the safety of both patients and occupationally exposed individuals (OEIs). Moreover, each facility must implement a radiation protection plan that includes the sector's floor plan, equipment layout, radiometric surveys, and staff training. [5].

In this context, implementing effective monitoring and control strategies is essential to mitigate the risks and effects of radiation. These actions require exploring various approaches to track and visualize complex data, particularly radiation exposure levels within nuclear medicine services (NMS) [6]. Biweekly radiometric surveys, conducted using a Geiger-Müller detector, can generate such data, forming a database that provides information on exposure levels across different areas of the NMS [7].

Considering the points discussed above, it is evident that nuclear medicine is a practice that requires continuous monitoring and oversight to ensure compliance with CNEN regulations and the implementation of radiological protection measures, as outlined in various protocols, one of which is the radiometric survey. Therefore, the objective of this study was to create a two-dimensional map of the floor plan of a Nuclear Medicine Service (NMS), using a database provided by the facility. The radiometric map aims to assess exposure and contamination risks associated with each sector of the service, to facilitate the understanding and visualization of areas with higher levels of ionizing radiation exposure for both patients and professionals.

2. MATERIALS AND METHODS

This study adopted a retrospective and descriptive documentary approach, combining quantitative and qualitative methodological principles for data analysis. This type of research explores existing and emerging records to characterize a population or phenomenon [8-10]. The study did not involve the collection of sensitive data or experiments involving humans or animals, strictly adhering to established ethical principles, ensuring data integrity, and complying with all applicable legal requirements.

The following sequential steps were outlined for the execution of the research: access to the database, a site visit for data contextualization, statistical analysis, and development of the radiometric map.

The study was conducted in a Nuclear Medicine Service (NMS) located in the Greater Florianópolis area, Santa Catarina, which granted the researcher access to the service sectors, floor plans, and radiometric survey databases.

After obtaining access to the radiometric survey data, a site visit to the NMS was performed to familiarize the researcher with the facility layout, allowing the linkage of the collected data to the actual conditions of the facility, thereby clarifying and enhancing the data interpretation process. Information was gathered regarding how and when the radiometric survey was conducted, as well as the location of each measurement point or room on the floor plan.

Forty points within the NMS were analyzed during the period from October 2021 to October 2023, with exposure rate measurements taken biweekly using a digital Geiger-Müller detector, model RadEye G20-10 (Thermo Fisher Scientific), featuring a sensitivity range between 0.01 and 2.00 mSv/h and an energy range from 17 keV to 3 MeV, and properly calibrated.

Among the 40 measurement points collected, there were: two therapeutic rooms (four beds), two ergometry rooms, two rooms for injected patients, four resting rooms, six patient restrooms, two dressing rooms for injected patients, two radiopharmaceutical administration rooms, four examination rooms, and one waste disposal room.

With the data identified, an Excel spreadsheet was created to develop the radiometric map and perform statistical analysis. Each point was marked with its coordinates, numbering, and corresponding room identification. Subsequently, statistical analyses were conducted for each reference point, calculating the median and standard deviation. These parameters enabled projections of radiation exposure rates and the visualization of areas with higher exposure risks on the two-dimensional radiometric map, represented by warmer tones (red), and regions with lower exposure depicted using cooler tones (blue and green).

For improved data organization, each room or measurement point in the sector was assigned a numerical identifier. The floor plan and its corresponding identifications are shown in Figures 1 and 2.

Figure 1: Numerical identification of the lower rooms

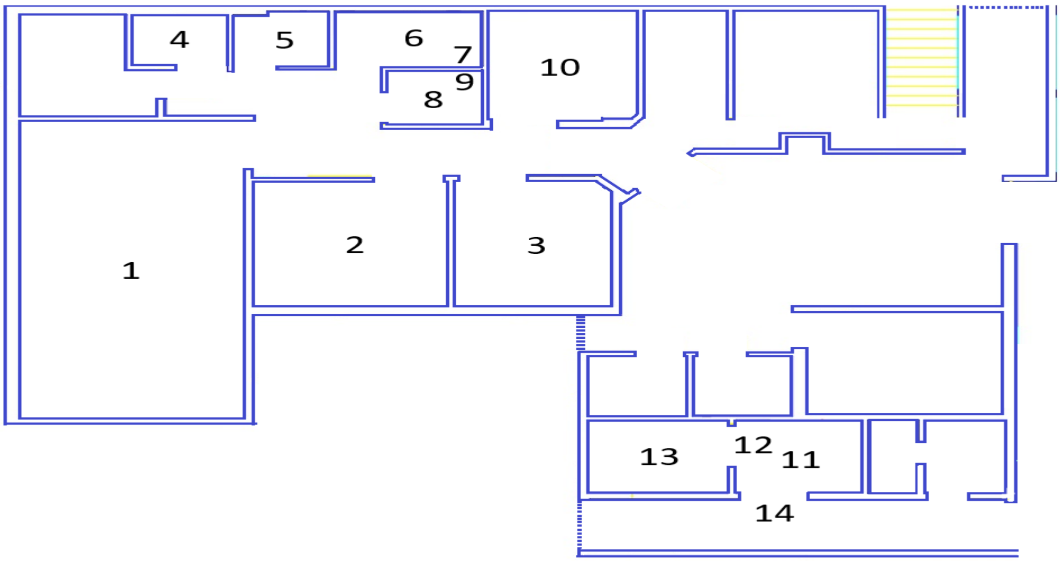
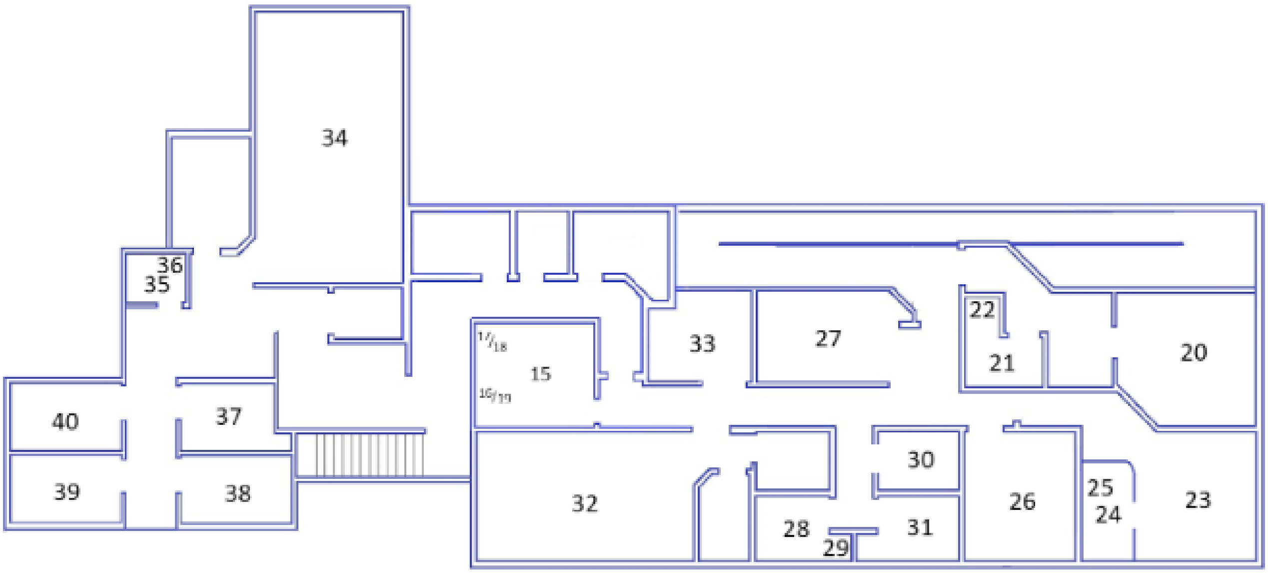


Figure 2: Numerical identification of the upper rooms



Tables 1 and 2 below list the room names in sequential order, organized by floor level. The first section of each table presents the rooms located on the ground floor (lower level), while the second and third sections correspond to rooms situated on the first floor (upper level).

Table 1: Identification of the lower rooms with their respective numbers.

Point	Lower Rooms	Point	Lowers Rooms
1	Examination room - Gamma-camera Symbia T2	8	Injected patient restroom – middle
2	Injected patient room	9	Injected patient restroom – toilet
3	Ergometry room	10	Radiopharmaceutical administration and inhalation room
4	Injected patient changing rooms	11	Radioactive waste storage -center - ante-room
5	Injected patient changing rooms	12	Radioactive waste storage -in front of the door (internal)
6	Injected patient restroom middle	13	Radioactive waste storage -middle storage
7	Injected patient restroom toilet	14	Radioactive waste storage -in front of the door (external)

Table 2: Identification of the upper rooms with their respective numbers.

Point	Upper Rooms	Point	Upper Rooms
15	Handling laboratory-middle	27	Injected patient room
16	Handling laboratory - handling chamber	28	Injected patient room- middle
17	Handling laboratory - generator -at the level of the crystalline lens	29	Injected patient restroom – toilet
18	Handling laboratory - generator - chest height	30	Injected patient changing room
19	Storage - in front of the door	31	Radiopharmaceutical administration room
20	Therapeutic room - bed 1 and 2 - middle	32	Examination room - Gamma-Camera ADAC

Point	Upper Rooms	Point	Upper Rooms
21	Therapeutic room - bed 1 and 2 - restroom - center	33	Examination room - Gamma-Camera Cardio MD
22	Therapeutic room - bed 1 and 2 - restroom - toilet	34	Examination room PET/CT
23	Therapeutic room - bed 3 and 4 – middle	35	Restrooms for injected patients PET/CT – middle
24	Therapeutic room - bed 3 and 4 - restroom-middle	36	Restrooms for injected patients PET/CT – toilet
25	Therapeutic room - bed 3 and 4 - restroom- toilet	37	Resting room PET/CT - room 1
26	Ergometry room	38	Resting room PET/CT - room 2
		39	Resting room PET/CT - room 3
		40	Resting room PET/CT - room 4

3. RESULTS

Between 2021 and 2023, data collection was conducted over a total of 50 days for each of the identified points, resulting in 2,000 samples for statistical analysis, ensuring a robust representation of the results. With the 40 collection points accurately identified and a substantial sample size, data analysis was performed using Excel software.

The first analysis performed was the calculation of the median, followed by the standard deviation for each floor of the service, as presented in Table 3. These statistical measures provided valuable insights into data variability and enabled an accurate estimation of the exposure distribution at each location on the floor plan, guiding the development of the radiometric map.

The mean was not used because it does not accurately represent the study's reality, given the presence of highly variable values that could disproportionately influence the results. Therefore, the decision was made to use the median. Values may vary depending on the day of the week due to the receipt or absence of radioactive material on that day, as well as potential radioactive contamination.

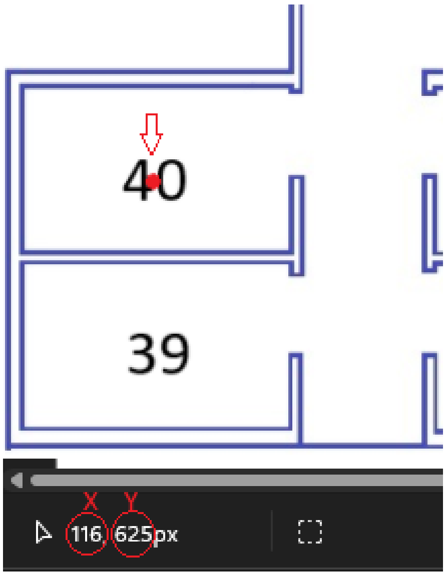
Table 3: Statistical analysis of dosimetric data in the Nuclear Medicine Service, presenting the median and standard deviation of radiation exposure measurements in different areas of the facility.

Point	Lower Rooms	Median	Standard Deviation
1	Examination room - gamma-camera Symbia T2	0.23	0.5
2	Injected patient room - lower rooms	0.26	0.08
3	Ergometry room	0.30	0.15
4	Injected patient - changing rooms	0.20	0.10
5	Injected patient - changing rooms	0.20	0.06
6	Injected patient restroom rooms - middle	0.26	0.08
7	Injected patient restroom - middle- toilet	0.26	0.11
8	Injected patient restroom - middle	0.23	0.05
9	Injected patient restroom- toilet	0.26	0.06
10	Radiopharmaceutical administration and inhalation room	2.80	1.57
11	Radioactive waste storage - center - ante- room	0.31	0.85
12	Radioactive waste storage -in front of the door (internal)	0.30	4.91
13	Radioactive waste storage -middle storage	0.26	8.24
14	Radioactive waste storage -in front of the door (external)	0.26	1.53
15	Handling laboratory - middle	3.48	33.36
16	Handling laboratory - handling chamber	3.12	9.60
17	Handling laboratory -generator - the level of the crystalline lens	8.63	26.89
18	Handling laboratory -generator - chest height	24.10	48.31
19	Storage - in front of the door	2.52	6.45

Point	Lower Rooms	Median	Standard Deviation
20	Therapeutic room - bed 1 and 2 - middle	0.27	38.62
21	Therapeutic room - bed 1 and 2 - restroom – center	0.27	0.17
22	Therapeutic room - bed 1 and 2 - restroom - Toilet	0.27	0.16
23	Therapeutic room - bed 3 and 4 - middle	0.81	1.16
24	Therapeutic room - bed 3 and 4 - restroom- middle	0.44	0.24
25	Therapeutic room - bed 3 and 4 - restroom- toilet	0.34	0.37
26	Ergometry room	0.60	1
27	Injected patient room	0.31	0.11
28	Injected patient room- middle	0.25	0.06
29	Injected patient restroom - toilet	0.23	0.07
30	Injected patient changing room	0.22	0.07
31	Radiopharmaceutical administration room	0.26	0.18
32	Examination room - Gamma Camera ADAC	0.27	0.06
33	Examination room - Gamma- Camera Cardio MD	0.30	0.07
34	Examination room PET/CT	0.22	0.09
35	Restrooms for injected patients PET/CT – middle	0.20	0.13
36	Restrooms for injected patients PET/CT – toilet	0.21	0.06
37	Resting room PET/CT - room 1	0.63	25.48
38	Resting room PET/CT - room 2	0.27	0.10
39	Resting room PET/CT - room 3	0.35	0.20
40	Resting room PET/CT - room 4	0.28	0.17

Following the statistical analysis, image processing of the floor plan was performed using Paint software. During this process, each point of interest on the floor plan was identified by determining the X and Y pixel coordinates corresponding to these points. For instance, point 40 was assigned coordinates of X: 116 and Y: 625, as shown in Figure 3. These coordinates were recorded for all 40 points of interest. Subsequently, the data were input into an Excel spreadsheet to facilitate the map's creation.

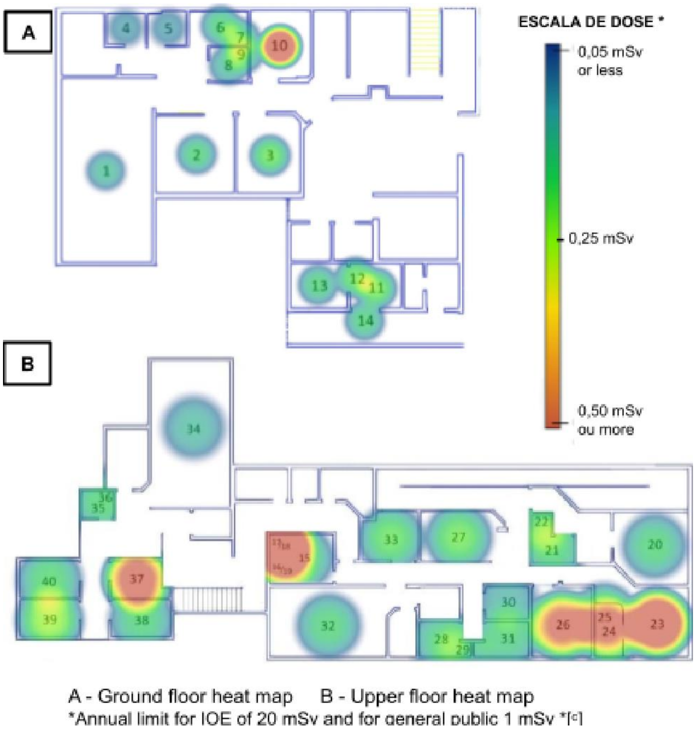
Figure 3: Example of identification of the coordinates and X and Y axes of point 40.



To generate the map, the floor plan was adapted to enhance clarity, retaining only the walls and numerical identifications, as shown in Figure 1. The adapted floor plan was first imported into Excel and then used within the 3D Map tool, located under the 'Insert' tab, to create the map.

When configuring the tool, the medians were used since they better represent the values of each point/room to create the radiometric map, allowing for an accurate visualization of areas with different radiation intensities. Once the radiometric map was completed, it was overlaid onto the floor plan, as illustrated in Figure 4.

Figure 4: Two-dimensional radiometric map



4. DISCUSSIONS

Evaluation of Table 3 reveals significant variation in radiation exposure rates, as demonstrated by the median and standard deviation analyses. Similarly, Figure 4 illustrates the differences in exposure rates at each point within the NMS, displaying varying shades according to their intensity. Notably, the highest exposure rates were observed in the radiopharmaceutical administration room (lower floor, point 10) and the radiopharmaceutical manipulation laboratory (points 15, 16, 17, 18, and 19). Other areas with elevated exposure rates included therapeutic rooms 3 and 4 (point 23), the ergometry room (upper floor, point 26), and room 1 of the PET/CT rest area (point 37).

The map highlights a significant difference between points 10 and 31, corresponding to the two administration rooms in the facility, showing exposure rates of 2.68 and 0.26 μSv/h, respectively. Although both rooms serve a similar volume of patients, Room 10 exhibited a higher exposure rate. Discussions with the facility's physicist suggested that this difference may be due to pulmonary inhalation procedures conducted in room 10, which can lead to airborne contamination and consequently increase exposure levels. To mitigate this risk, the installation of an exhaust fan would be recommended [11].

Analysis of the map reveals that the area with the highest exposure rate was the radiopharmacy, encompassing points 15, 16, 17, 18, and 19. This area is responsible for receiving, storing, preparing, and distributing radioactive materials for clinical use, resulting in higher exposure rates compared to other facility areas, along with occasional contamination peaks. Furthermore, the standard deviation of the measurements is notably high, indicating significant variations over the 15-day intervals. Similar findings have been reported in studies such as those by Pinheiro [12], which also highlight the radiopharmacy as the area with the highest exposure rates and considerable variability.

Another significant difference in exposure rates was observed between rooms 3 and 26, both designated for ergometry. The median exposure rate in Room 3 is 0.32 mSv, while in Room 26 it reaches 0.6 mSv, which is twice the exposure. This discrepancy is explained by the fact that Room 26 is used for the stress phase of myocardial perfusion scintigraphy, which involves the administration of radiopharmaceuticals while the patient undergoes physical or pharmacological stress [13]. In contrast, Room 3 is used for other examinations that do not require radiopharmaceuticals, or only in specific cases such as pulmonary inhalation or occasional stress tests, typically when the administration room (point 10) is occupied or when the use of Room 26 (upper ergometry) is not feasible, resulting in lower exposure levels.

Finally, the facility includes four PET/CT rest rooms, as shown in Figure 4; however, point 37 exhibits a significantly higher exposure rate than the others, presenting double the exposure compared to the remaining rooms. This is believed to occur because room 37, being the first in the allocation order, is almost always occupied, while the other rooms are filled based on demand. Villa [7] notes in his research that these elevated exposure rates are expected due to the presence of injected patients in these areas. A similar pattern is observed when comparing the therapeutic rooms, where point 23, representing therapeutic rooms 3 and 4, shows a higher exposure rate than point 20 (rooms 1 and 2). Although there are hypotheses regarding these discrepancies, it is not possible to definitively determine the underlying causes of the differences between the therapeutic rooms and the PET/CT rest rooms.

It should be noted that during the radiometric survey, two situations may arise: one in which specific measurements cannot be performed due to the initiation of procedures that may influence the results, primarily in the radiopharmacy; and another in which measurements are taken after the service has begun, including room usage and procedure execution. The two-dimensional radiometric map helped clarify the operational dynamics of the nuclear medicine service, allowing observation of the flow of injected patients, administrations, and overall service activity.

The map visually represents areas with higher exposures for both patients and occupationally exposed individuals (OEIs), serving as a valuable tool for radiological protection in Nuclear Medicine. It aligns with the optimization principle by enabling improved management of these areas. As demonstrated by Villa [7] and Pinheiro [12] in their respective studies, the primary outcome was the spatial distribution map of exposure rates or dose projections, highlighting locations where occupancy should be minimized.

As demonstrated throughout this manuscript, the present work presents the two-dimensional radiometric map of exposure rates as a radiological protection tool, as it can be incorporated into the Radiological Protection Plan to indicate regions with higher exposures. This map can be displayed within the clinic's premises to assist IOEs and patients, through the visual resource, in identifying areas with higher exposure within the facility, so that they can minimize their time spent in those areas.

4. CONCLUSIONS

This study successfully mapped radiation levels in a nuclear medicine service using radiometric data, identifying areas of higher exposure. Although all measured doses remained within regulatory limits, the methodology proved effective in highlighting critical zones, such as the manipulation laboratory and radiopharmaceutical administration room. Continued monitoring and deeper analysis are recommended to enhance radiological protection and ensure long-term safety for professionals, patients, and the environment.

CONFLICT OF INTEREST

All authors declare that they have no conflicts of interest.

REFERENCES

[1] Ministério da Saúde. Instituto Nacional do Câncer - INCA. 2022. Available at: https://www.gov.br/inca/pt-br/assuntos/causas-e-prevencao-do-cancer/exposicao-no-trabalho-e-no-ambiente/radiacoes/radiacoes-ionizantes. Accessed on: 26 nov. 2023

[2] CAMOZZATO, T.S.C. et al. **Medicina Nuclear na prática**. Florianópolis: IFSC 2020. 237p. Available at: https://ifsc.edu.br/do cuments/30701/523474/Medicina+Nuclea+na+Pr%C3%A1tica/affd6204-e5f3-4e10-9040-7025ea465+44. Accessed on: 26 nov 2023.

[3] CNEN. Comissão Nacional de Energia Nuclear: sobre a CNEN. Sobre a CNEN, 2021. Available at: Https://www.gov.br/cnen/pt-br/acesso-a-informacao/institucional/sobre-a-cnen. Accessed on: 19 ago. 2023.

[4] CNEN. Comissão Nacional de Energia Nuclear: CNEN NN 3.05: requisitos de segurança e proteção radiológica para serviços de medicina nuclear. 159. ed. [S.L.], 2013. 26 p. Available at: http://appasp.cnen.gov.br/seguranca/normas/pdf/Nrm305.pdf. Accessed on:: 24 ago. 2023.

[5] MACHADO, M. A. D. et al. Revisão: radioproteção aplicada à medicina nuclear. **Revista Brasileira de Física Médica**, [S.L.], v. 4, n. 3, p. 47-52, abr. 2011. Available at: https://www.rbfm.org.br/rbfm/article/view/97/v4n3p47. Accessed on: 08 ago. 2023.

[6] DIAS, V. F. Heatmap: aplicação colaborativa baseada em mapas de **calor** para partilha da cidade. 2020. 87 f. **Dissertação (Mestrado)** - Curso de Novos Media e Práticas Web, Universidade Nova de Lisboa, Lisboa, 2020. Available at: https://run.unl.pt/handle/10362/111912. Accessed on: 08 ago. 2023

[7] VILLA, S. A. Guia para levantamento radiométrico em serviços de medicina nuclear. 2021. 38 f. **Trabalho de conclusão de curso** (Graduação) - Curso de Bacharel em Física, Universidade Federal do Rio Grande do Sul, Porto Alegre. Available at: https://www.lume.ufrgs.br/bitstream/handle/10183/235359/001137152.pdf?sequence=1&isAllowed=y. Accessed on: 22 set. 2023.

[8] MARQUES, R. J.; COSTA SOBRINHO, W. F. R. D. Detecção das ocorrências de focos de queimadas e produção de mapas de calor em Timon, MA. **Revista Geonorte**, [S.L.], v. 11, n. 37, p. 210-228, 15 jul. 2020. Available at: https://periodicos.ufam.edu.br/index.php/revista-geonorte/article/view/6621/5627. Accessed on: 17 out. 2023. DOI: http://dx.doi.org/10.21170/geonorte.2020.v.11.n.37.210.228.

[9] PEDROSO, J. S.; SILVA, K. S.; SANTOS, L. P. **Pesquisa descritiva e pesquisa prescritiv**a. IX Jicex, v. 9, n. 9, 2018.

[10] HOCHMAN, B. et al. Desenhos de pesquisa. **Acta Cirúrgica Brasileira**, [S.L.], v. 20, n. 2, p. 2-9, 2005. Available at: https://www.scielo.br/j/acb/a/bHwp75Q7GYmj5CRdqsXtqbj#ModalTutors. Accessed on: 17 out. 2023. DOI: http://dx.doi.org/10.1590/s0102-86502005000800002

[11] ALVES, M. et al. Exposição dos técnicos de medicina nuclear durante testes de ventilação pulmonar. **Saúde & Tecnologia**, [S.L.], p. 29-36, 1 ago. 2022. Available at: https://journals.ipl.pt/stecnologia/article/view/544. Accessed on: 24 jun. 2024. DOI: http://dx.doi.org/10.25758/SET.2141.

[12] PINHEIRO, R. M. Mapeamento do nível radiométrico e construção de mapa espacial em serviço de medicina nuclear. 2013. 22 f. **Monografia** (Especialização) - Curso de Física Médica, Instituto de Biociências da Universidade Estadual Paulista "Júlio de Mesquita Filho", Botucatu, 2013. Available at: https://repositorio.unesp.br/server/api/core/bitstreams/b7e02a5c-4ac0-4966-a1b9-902b25cb065f/content. Accessed on: 18 ago. 2023.

[13] AMORIM, B. J.; MESQUITA, C. T. Diretriz para cintilografia de perfusão miocárdica de repouso e estresse: guideline for rest and stress myocardial perfusion scintigraphy. International Journal of Cardiovascular Sciences, Campinas, p. 243-247, mar. 2016. Available at: http://sociedades.cardiol.br/socerj/ijcs/english/sumario/29/pdf/v29n3a14.pdf. Accessed on: 29 maio 2024.

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