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Proposed management and exemption of radioactive waste in nuclear medicine facilities according to the recommendations of the ICRP Publication 103

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Abstract

The ICRP recommendations deal with issues related to radiological protection of man and the environment against the risks and damage caused by ionizing radiation through the dissemination of its publications that are accepted and implemented by national and international entities. This study aims to evaluate the environmental deposition of radionuclides used in nuclear medicine facilities in the City of Rio de Janeiro and a model will be proposed, at the national level, which aims to implement a radiation protection system for the management and exemption of radioactive waste based on ICRP Publication 103.
Keywords: ICRP, dose limits, reference levels and risk levels, management and exemption of radioactive waste, nuclear medicine, radiological protection, environment.

1 Introduction

The International Commission on Radiological Protection (ICRP) is a non-governmental body independent created in 1928 during the International Congress of Radiology [1], with the main objective to protect human health and the environment against the effects of radiation exposures. The ICRP publishes its recommendations involving aspects related to radiological protection and the risks associated with ionizing radiation in the form of reports, called ICRP Publications [1–3]. The ICRP works closely with other agencies to ensure that its recommendations are published, such as the International Commission on Radiation Units and Measurements (ICRU), which is responsible for defining the quantities and units used in radiation protection and the United Nations Scientific Committee on Effects of Atomic Radiation (UNSCEAR), which is responsible for research in the literature on the biological effects of radiation. The International Atomic Energy Agency (IAEA) follows the ICRP recommendations organizing them as standards, so that its recommendations are accepted by the member countries [4].

2 ICRP publications

The ICRP recommendations deal with ionizing radiation, the protection of man and the environment, and serve as a practical character guidance to knowledge of radiobiology and radioprotection [5] to regulatory agencies, management groups and professionals in the field of radiation protection. The ICRP Publication 1 in 1928 contained recommendations that were only adopted in 1958. The ICRP Publications 26 in 1977, 60 in 1991, 91 in 2003, 103 in 2007, 108 in 2008 and 114 in 2011 were important in general regarding radiation protection, in establishing radiological quantities geared to man and the environment, their relationships and methods within a more coherent design possible [5–7].

ICRP Publication 26 quantified the risks of stochastic effects of radiation proposing a dose limitation system along with the principles of justification and optimization. In this publication, there was an anthropocentric vision in which the radiological protection standards recommended by the ICRP were focused only on the human being leaving, in the background, the biota [5].

ICRP Publication 60 defined the concept of practice [4] and proposed changes in its recommendations regarding ICRP Publication 26 based on reviews of radiation exposure risk estimates, expanding its philosophy for radiological protection system keeping the fundamental principles of radiation protection [1, 4]. The ICRP questioned the paradigm of environmental protection because there are controversial statements related the risks to the species that are present in the ecosystem [5].

The ICRP Publication, ICRP 91, presented the development of a unique system of protection of biota giving bases and objectives for radiological protection through ethical principles and scientific evidence, and how this protection could directly or indirectly affect human health, so that national laws were necessarily aggregated to protect the environment from the harmful effects of radiation [5].

ICRP Publication 103 involved a series of approaches to radiological protection that changed important concepts and paradigms in relation to ICRP Publication 60, such as the definitions of the concepts of planned exposure situations, emergency exposure situations and existing exposure situations [7]. The main contribution of this publication was the final breaking of the anthropocentric view that emerged in ICRP Publication 26, because the environmental protection could not be linked to human protection considering the need to develop, with scientific basis, a more specific framework to assess the relationship between exposure and dose and the relationship between dose and effect, and the consequences of the effects caused by radiation in the ecosystem as a whole [1].

ICRP Publication 108 defined the concept of reference animals and plants (RAP), focusing on radiological protection in humans and the environment through selection criteria, description of groups and demonstration of exposure pathways, calculation of conversion factors of activity concentration in absorbed dose rate, the collection and evaluation of information in terms of derived limits on the relationship between dose and effects on RAP, proposing the relationship between dose ranges and any biological damage, added to applications and extrapolations, exposure situations, radiation dosimetry and effects of radiation in RAP [5].

ICRP Publication 114 added the ICRP Publication 108 recommendations, focusing their attention on the behavior of radionuclides in the ecosystem, providing environmental modeling with the transfer parameters for 39 types of radionuclides that were used for the calculation of absorbed dose as a standard for environmental protection [5, 8].

3 Brazilian standards and ICRP recommendations

In Brazil, the Basic Standards on Radiological Protection (BSRP) were approved by the National Nuclear Energy Commission (CNEN, initials in Portuguese and means Comissão Nacional de Energia Nuclear) in 1973, establishing the Basics of Radiological Protection and dose limits following the ICRP recommendations. BSRP were repealed and replaced by the CNEN-NE-3.01 Standard in 1988, entitled "*Basic Guidelines for Radiation Protection*". This standard was based on the recommendations of ICRP Publication 26, which introduced the concept of detriment associated with the probability of occurrence of damage caused by radiation and established the radiological protection principles: justification, optimization and dose limitation [6]. At the beginning of 2005, CNEN approved the CNEN-NN-3.01 Standard, entitled "*Basic Guidelines on Radiological Protection*", along with the regulatory positions, replacing the CNEN-NE-3.01 Standard, being updated by CNEN Resolution 164/2014 [9]. This standard is based on ICRP Publication 60 recommendations. Moreover, the three radiological protection principles were called Requirements [6, 10]. With ICRP Publication 103, however, there are discussions nationwide so that Brazilian standards should be reviewed and appropriate, because Brazil is at a disadvantage in relation to radiological protection worldwide [4], and it is necessary to change the concepts of protection and the weighting values of the particles/radiation and the organs and tissues, in order to update the data related to the damage caused by radiation to humans and the environment [7].

4 Nuclear medicine facilities in Brazil

Nuclear medicine is a medical modality that uses nuclear energy through the use of radioactive substances in the form of non-sealed sources that decay for a given period, for administration of *in vivo* patients or by use of *in vitro* techniques for diagnostic purposes or therapy [11].

The physical structure of a nuclear medical service must have the following dependencies: exclusive waiting room and exclusive toilet for injected patients; handling laboratory and storage of radioactive sources in use; administration of radiopharmaceuticals room; examination room; location for the temporary storage of radioactive waste; adequate room, from the point of view of the radiological protection, physically delimited, located within of the nuclear medicine service, for performing pulmonary ventilation studies; exclusive room for exams with cardiac stress for radiology purposes with radiopharmaceuticals, physically delimited; exclusive room, with individual spaces for radiopharmaceuticals administration and back rest of the injected patient, when using diagnostic equipment by positron emission; and room for therapy with hospitalization, when therapeutic doses of radiopharmaceuticals are administered [12].

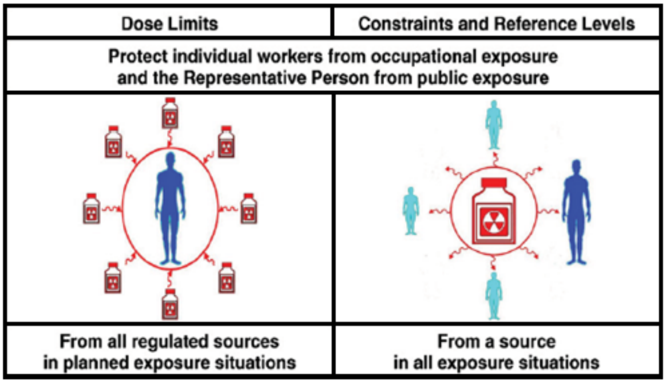
5 Management and exemption of waste on the basis of the ICRP Publication 103

Radioactive waste management is defined as the set of technical and administrative activities involved in the collection, segregation, handling, processing, packaging, identification, transport, storage, control, dispense and deposition [13]. It aims to provide greater protection for human beings and help preserve the environment in order to limit possible radiological impacts for future generations [14].

Radioactive waste generated in nuclear medicine facilities in Brazil are classified as Class 1 by CNEN (very short half-life waste – VSHLW), because this waste contains radionuclides with lower half-lives in the order of 100 days, with activity levels or activity concentrations above their respective exemption levels [15].

The exemption of radioactive waste is given by the removal of regulatory control of radioactive materials or objects associated with an authorized practice [9]. After processing in common medical waste due the radioactive decay, it applies to the disposal of solid radioactive materials in urban waste collection system, or in landfills, and liquid radioactive materials in the sewer system [14].

The dose limit aims to limit the exposure of man, restricting the way of how it is exposed to radiation. This concept is applied in control of all radiation emitting sources only for planned exposure situations. The restriction levels and reference levels are intended to protect the man that operates the source. This concept is applied to all situations where exposures occur (planned exposure



(a) (b)

Figure 1: (a) Implementation of the individual dose limit for all sources in planned exposure situations; (b) Application of the restriction levels and reference levels for individuals' protection for all situations [1].

situations, emergency exposure situations and existing exposure situations) [4]. Figure 1 illustrates the contrast of these two concepts.

6 Methodology

In Brazil, the number of nuclear medicine facilities in operation authorized by CNEN at the time of writing this paper is estimated at 400. In this study, only the nuclear medicine facilities in operation in the City of Rio de Janeiro were considered, whose period of research was carried out in January 2016. The number of different types of radionuclides distributed to these facilities was still estimated at 17. In each radionuclide, the following data were provided: radioisotope's name, activity given in milicurie (mCi) and frequency (weekly, daily, biweekly, monthly). Among the types of radionuclides, technetium-99m (^{99m}Tc) is what stands out for being the most widely used due to its physical properties, such as physical half-life (6 hours) and low effective energy (140 keV). Other radionuclides, such as fluorine-18 (^{18}F), iodine-131 (^{131}I), gallium-67 (^{67}Ga), thallium-201 (^{201}Tl), samarium-153 (^{153}Sm) and iodine-123 (^{123}I), also stand out due to their physical half-lives are relatively low and are used both the diagnosis and treatment of patients. A spreadsheet was used to convert the units for activity and frequency in order to estimate the value of the total activity for all radionuclides for the year 2016, so that the quantity of activity was converted from milicurie (mCi) to becquerel (Bq), a unit of the International System (SI), and the frequency of each radionuclide converted to annual.

During the research, a topographic map of the City of Rio de Janeiro in scale of 1:31,000 was used, on which points of identification of nuclear medicine facilities located by regions and districts were marked. It was possible to check the imminence of the facilities to the banks of rivers, channels, lagoons and seafronts, in order to identify the effluent dispersal pathways containing radionuclides released into the sewer system.

This study is under development, which will be carried out the collection of sewage samples to detect the presence of radionuclides originating from Nuclear Medicine facilities in the City of Rio de Janeiro from the analysis by gamma spectrometry. The samples will be taken for analysis in the Real Time Neutron Radiography Laboratory (LNRTR/PEN/COPPE/UFRJ). The mass of each sample will be measured with use of a precision balance of brand Gehaka, model BG 4000, with a sensitivity of ± 0.01 g. The analysis of the samples will be carried out by a spectrometer of brand Canberra, with coaxial high-purity germanium detector (HPGe), model GC3020 (see Figure 2), coupled to a preamplifier, model 2002 CSL, operated at low noise, and a software Genie-2000. The preamplifier is associated with vertical cryostat, model 7500SL-DRC-4, and a dewar with a capacity of 30 L. The multi-channel system to be used will be a DAS 1000 (Digital Spectrum Analyzer) with 8192 channels and an energy range from 50 keV to 2 MeV, amplifying the pulse Gaussian format with fast rise of 8.8 μs from the preamplifier. The voltage to be used for the creation of the depletion area will be 4500 V. The count time of the samples to be collected will be 8 hours. The geometry to be used for placement of the samples is a polypropylene bottle with low background radiation, with a volumetric capacity of 500 mL. The dimensions of the bottle and the height of the sample will be provided for the software Genie-2000 to calculate the volume of the sample. The calculation of the density of the sample will be the ratio of the mass measured on the balance and the bottle volume calculated by the software.

Figure 2: Spectrometer of brand Canberra, model GC3020.

7 Results and discussions

29 Nuclear Medicine facilities in operation were researched in the City of Rio de Janeiro. The North Zone (marked in yellow) has the largest number of Nuclear Medicine facilities in operation with 9 facilities, followed by Downtown (marked in blue) and the South Zone (marked in green) with 8 facilities each, and the West Zone (marked in red) with 4 facilities. Figure 3 shows the map of the City of Rio de Janeiro containing the points of identification of Nuclear Medicine facilities, where Downtown has the greatest concentration of Nuclear Medicine facilities because of the proximity between them, while the North Zone records the greater spread of Nuclear Medicine facilities.

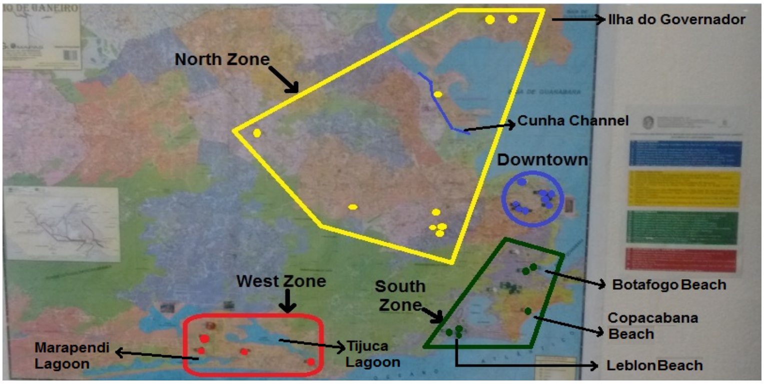


Figure 3: Map of the City of Rio de Janeiro containing the points of identification of nuclear medicine facilities per region: yellow, North Zone; blue, Downtown; green, South Zone; red, West Zone.

The location and the distance between the nuclear medicine facilities and the bank of rivers, channels, lagoons and seafronts were checked on the map. In Downtown, from 8 existing nuclear medicine facilities, 5 are close to the banks in Guanabara Bay. In the North Zone, from 9 existing nuclear medicine facilities, 4 are close to the banks of rivers, 1 is close to Cunha Channel and 2 are close to the seafront on the south of Ilha do Governador. In the South Zone, from 8 existing nuclear medicine facilities, 6 are close to the seafront: 2 at Botafogo Beach, 1 at Copacabana Beach and 3 at Leblon Beach. In the latter, 2 nuclear medicine facilities are close to Jardim de Alah Channel, which connects Leblon Beach to the Rodrigo de Freitas Lagoon. In the West Zone, from 4 existing nuclear medicine facilities, 1 is located within a city natural park and 3 are close to the banks on the lagoons: 1 at Tijuca Lagoon, 1 between Tijuca Lagoon and Marapendi Lagoon and 1 at Marapendi Lagoon.

17 different radionuclides distributed to 29 Nuclear Medicine facilities in the City of Rio de Janeiro were authorized by CNEN and the total number of distributed radionuclides was 185 (see Table 1). The radionuclides that had the

highest distribution were technetium-99m and iodine-131 (present in 24 facilities each), thallium-201 (present in 23 facilities) and gallium-67 (present in 22 facilities). The radionuclides that had the lowest distribution were lutetium-177 (present in 7 facilities), yttrium-90 (present in 5 facilities), chromium-51 (present in 4 facilities), carbon-14 (present in 2 facilities) and tritium-3 and gallium-68 (present in 1 facility each).

Table 1: Types of radionuclides distributed in Nuclear Medicine facilities in the City of Rio de Janeiro. In the right column, the percentage distribution of radionuclides (source: CNEN, link: http://www.cnen.gov.br/instalacoes-autorizadas. Compiled on January 22, 2016).

Radionuclide	Number of radionuclides distributed in nuclear medicine facilities	%
Gallium-67	22	11.9
Iodine-131	24	13.0
Technetium-99m	24	13.0
Thallium-201	23	12.4
Fluorine-18	9	4.9
Samarium-153	16	8.6
Iodine-123	19	10.3
Indium-111	14	7.6
Radium-223	10	5.4
Chromium-51	4	2.2
Iodine-124	2	1.1
Lutetium-177	7	3.8
Yttrium-90	5	2.7
Carbon-14	2	1.1
Tritium-3	1	0.5
Iodine-125	2	1.1
Gallium-68	1	0.5
Total number of radionuclides	185	100.0

Based on the values in the spreadsheet, there were calculated the estimated values of total activities for radionuclides authorized by CNEN for Nuclear Medicine facilities in the City of Rio de Janeiro for the year 2016 (see Table 2). Among the 17 types of radionuclides surveyed in this study, the technetium-99m [total activity = 1.38×10^{14} Bq; average = $(5.74 \pm 3.48) \times 10^{12}$ Bq], fluorine-18 [total activity = 4.18×10^{13} Bq; average = $(5.34 \pm 4.93) \times 10^{13}$ Bq] and lutetium-177 [total activity = 1.76×10^{13} Bq; average = $(2.51 \pm 3.36) \times 10^{12}$ Bq] are the radionuclides who stand out for performing, respectively, SPECT (Single Photon Emission Computerized Tomography) scintigraphy exams, PET (Positron Emission Tomography) exams, and for incorporation of patients with hematological (lymphomas) and solid (lung cancer) tumors submitted to radioimmunotherapy. Iodine-131 [total activity = 1.58×10^{13} Bq; average = $(6.59 \pm 9.42) \times 10^{11}$ Bq] also stands out for its high total activity for use in thyroid incorporation in patients for both scintigraphy exams and for admission to therapeutic room (radioiodine). Carbon-14 [total activity = 1.87×10^{9} Bq; average = $(9.34 \pm 13.00) \times 10^{8}$ Bq] is used to perform breath tests for detection and research of *Helicobacter pylori*, a bacterium responsible for gastric infection.

Table 2: Estimated values of the total activity and the average of radionuclides. Between parentheses is the number of nuclear medicine facilities operating with the radionuclide.

Radionuclide	Total activity (Bq)	Average (Bq)
Gallium-67 (n = 22)	1.08×10^{12}	$(4.92 \pm 4.04) \times 10^{10}$
Iodine-131 (n = 24)	1.58×10^{13}	$(6.59 \pm 9.42) \times 10^{11}$
Technetium-99m (n = 24)	1.38×10^{14}	$(5.74 \pm 3.48) \times 10^{12}$
Thallium-201 (n = 23)	2.16×10^{12}	$(9.41 \pm 10.70) \times 10^{10}$
Fluorine-18 (n = 9)	4.81×10^{13}	$(5.34 \pm 4.93) \times 10^{12}$
Samarium-153 (n = 16)	4.72×10^{12}	$(2.95 \pm 1.65) \times 10^{11}$
Iodine-123 (n = 19)	1.45×10^{12}	$(7.64 \pm 5.21) \times 10^{10}$
Indium-111 (n = 14)	4.98×10^{11}	$(3.55 \pm 3.35) \times 10^{10}$
Radium-223 (n = 10)	1.51×10^{11}	$(1.51 \pm 2.80) \times 10^{10}$
Chromium-51 (n = 4)	2.96×10^{10}	$(7.40 \pm 3.70) \times 10^{9}$
Iodine-124 (n = 2)	1.11×10^{11}	$(5.55 \pm 0.00) \times 10^{10}$
Lutetium-177 (n = 7)	1.76×10^{13}	$(2.51 \pm 3.36) \times 10^{12}$
Yttrium-90 (n = 5)	2.41×10^{12}	$(4.81 \pm 1.65) \times 10^{11}$
Carbon-14 (n = 2)	1.87×10^{9}	$(9.34 \pm 13.00) \times 10^{8}$
Tritium-3 (n = 1)	8.88×10^{7}	8.88×10^{7}
Iodine-125 (n = 2)	1.86×10^{9}	$(9.30 \pm 13.00) \times 10^{8}$
Gallium-68 (n = 1)	1.85×10^{11}	1.85×10^{11}

The management of waste containing radionuclides has not been a very relevant issue in Brazil. However, it is important to note that occupationally exposed individuals (workers) should be aware of the risks of unnecessary exposure or incorporation of unsealed sources used in nuclear medicine facilities. The criteria for segregation, storage and decay of radionuclides present in the waste to permissible levels for exemption in accordance with the CNEN-NN-8.01 Standard is being used as the discard control instrument, since, after the radioactive decay, are treated as hospital waste [15, 16].

The exemption of radioactive waste generated in nuclear medicine facilities is based on the CNEN-NN-3.01 Standard, in line with ICRP Publication 60 recommendations, because the concept of practice is still present and the radiological protection is only focused on occupationally exposed individuals, not taking into account the undue exposure of radionuclides present in the waste that impact on the environment. This is because, even after reaching the limits of exemption, the radionuclides still tend to decay by emitting particles/radiation in the ecosystem according to their activities and half-lives and can go several pathways to get to the individual. The Brazilian standards are outdated in the context of radiation protection and need to be reviewed and must follow the ICRP recommendations that deal with the protection of biota with stricter monitoring of waste arising from nuclear medicine facilities describing the routes of exposure of radionuclides in the ecosystem, the application of concepts Planned Exposure Situations, Emergency Exposure Situations and Existing Exposure Situations, and the relationship of these concepts with dose limits, risk levels and reference levels.

8 Final considerations

The concept of Practice defined by the ICRP Publication 60 is still present in the Nuclear Medicine facilities in Brazil due to accident risks of contamination of occupationally exposed individuals, injected patients and accompanying, by surface contamination and management of radioactive waste arising from the decontamination process and the source fault.

From the point of view of radiological protection, it is necessary that the current Brazilian standards are reviewed and the recommendations of the ICRP Publication 103, so that the concepts of planned exposure situations, emergency exposure situations and existing exposure situations are introduced and incorporated specifically targeting the protection of individuals and the environment from undue exposure of ionizing radiation.

This work is being developed to assess the environmental doses of radionuclides from the nuclear medicine facilities nationwide, through the waste exemption pathways containing radionuclides, in order to propose a model for the implementation of a radioprotection system on the basis of the ICRP Publication 103 recommendations.

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