



The Posgraduate Program in Radiation Protection and Dosimetry of the Institute of Radiation Protection and Dosimetry: 20 years of history and achievements

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Abstract. The Institute of Radiation Protection and Dosimetry (IRD) is a research and teaching institution, linked to the National Nuclear Energy Commission (CNEN), an autarchy linked to the Ministry of Science, Technology and Innovation (MCTI). It works in collaboration with universities, government agencies and industries to promote the safe use of ionizing radiation and nuclear technology. Among its various activities, the strong tradition in the training of human resources can be highlighted, such as through its *Stricto Sensu* Postgraduate Program in Radiation Protection and Dosimetry (PPG/IRD), in the master's modalities (since 2001) and doctorate (Ph.D., since 2011) academics. The PPG/IRD consists of 4 Concentration Areas, namely: Biophysics of Radiations, Medical Physics, Metrology and Radioecology. The PPG/IRD requires a minimum of 27 and 38 credits (for the master's and doctorate, respectively), in the disciplines of the general, specific and elective nuclei, with theoretical and practical classes, including some in the distance format. The PPG/IRD has already had a total of 248 works defended (206 dissertations and 42 theses). So, this paper aims to present a panoramic view of these 20 years of the PPG/IRD, leaving its memory as a record and discussing new perspectives for the training of human resources in the area of radiation protection. In this sense, it can be said that the PPG/IRD is considered a national reference and as a perspective it is expected to expand the scope of action, especially in the Metrology part, considering that it is a national reference center.

1. Introduction

The Institute of Radiation Protection and Dosimetry (IRD) is a research, development and teaching institution, linked to the Research and Development Directorate (DPD) of the National Nuclear Energy Commission (CNEN), an autarchy linked to the Ministry of Science, Technology and Innovation (MCTI). It works in collaboration with universities, government agencies and industries to promote the safe use of ionizing radiation and nuclear technology [1]. Its research, development, provision of specialized technological services and teaching have enabled the benefits of using ionizing radiation to safely reach an increasing number of Brazilians [1].

Among its various activities, we can highlight the strong tradition in the training of human resources, such as through its *Stricto Sensu* Postgraduate Program in Radiation Protection and Dosimetry (PPG/IRD), in the academic master's and doctoral (Ph.D.) modalities [2]. The PPG/IRD was created in



2001, at the master's level, offering a doctorate from 2011 onwards. The PPG/IRD consists of 4 (four) Areas of Concentration, namely: Biophysics of Radiations, Medical Physics, Metrology and Radioecology. As it is a federal educational institution, the PPG/IRD is free, being the only academic course in South America in Radiation Protection and Dosimetry [2].

As it is a program evaluated¹ by the Interdisciplinary Area of the Coordination of Higher Education Personnel (CAPES), with grade 4, it includes in its scope, for example, the fundamentals of phenomena that produce radiation, chemical methods of analysis, mathematical simulation and/or computation of processes and phenomena, radiation biophysics, nuclear medicine, issues of regulatory and socio-environmental problems involved, metrology of ionizing radiation and the basic operating principles of detection instruments [2].

In this sense, students end up engaged in projects that develop the scientific method of work, consolidating their interest in scientific and technological research, putting their skills and qualifications to the test to work in the scientific area. Many dissertation and thesis projects are carried out in the IRD's own laboratories and a significant number, in collaboration with other organizations, such as: universities, hospitals and industries [2].

The IRD has an extensive structure of laboratories that range from the measurement of radiometric and dosimetric quantities, involving high-resolution instruments for the analysis of radiochemical samples, to experimental methods for determining genetic damage. As a highlight, the National Laboratory of Ionizing Radiation Metrology (LNMRI) is among the IRD facilities [2]. In this way, this work aims to make an evaluation of the program's activities, showing the results in all these years of operation, so that, from this analysis, to assist in the elaboration of new possibilities of action for the future.

2. Materials and Methods

This paper aims to present a panoramic view of these 20 years of the PPG/IRD to preserve the knowledge gained during this period and discussing new perspectives for the formation of human resources in the area of radiation protection. It will then show the structure of the course, present-ing its purpose, listing the subjects offered and the profile of the teachers.

This is a qualitative and quantitative research [3], with a view to evaluating the information disseminated and activities carried out by the PPG/IRD (qualitative analysis), as well as surveying and demonstrating its academic production (quantitative analysis), focusing on applied studies through Scientific Knowledge Management (SKM) [4-6]. The survey of the works defended during the studied period was done from the Sucupira Plat-form and from the Theses and Dissertations Bank (BTD) of CAPES [6].

3. Results and Discussion

3.1. General Organization

The PPG/IRD aims to train qualified human resources, at Master and Doctoral level, in the various areas of activity in the field of Radiation Protection and Dosimetry, aiming at [2]:

- I. Train human resources to work in the areas of teaching, research and technological development in the nuclear sector and related areas;
- II. To stimulate interdisciplinary research and technological development in Radiation Protection and Dosimetry in the areas of concentration of Biophysics of Radiations, Medical Physics, Metrology and Radioecology; and

¹ According to Capes, there are 9 areas of knowledge: Exact and Earth Sciences; Biological Sciences; Engineering; Health Sciences; Agricultural Sciences; Social and Applied Sciences; Human Sciences; Linguistics, Letters and Arts; and Multidisciplinary. In addition, there are a total of 49 Assessment Areas.



III. Disseminate the concepts and values of radiation protection aiming at the development of Brazil and society.

The PPG/IRD is based on the premises of the IRD itself and the selection of candidates takes place through a specific public notice. The number of students to be admitted to the PPG/IRD, respecting CAPES rules, will be determined by the Postgraduate Collegiate (“CPG”), based on the specific development, technological advancement of the areas of concentration and the availability of human and materials resources of PPG/IRD. In this sense, the PPG is structured as follows:

- The PPG/IRD is made up of the Collegiate, the Coordination, the Graduate Department (“SPG”) and the Faculty and Students;
- The Graduate Collegiate (“CPG”) is formed by the faculty;
- The Coordination is formed by the Coordinator and Vice-Coordinator, who are elected by the Collegiate, with a term of office of 2 (two) consecutive years and responsible for conducting the activities of the PPG/IRD, with the attributions contained in this Internal Regulation.
- The SPG is the administrative support body responsible for the administrative functions and academic control of the PPG/IRD;
- The teaching staff will be made up of permanent teachers, collaborators and visitors; and
- The student body will be formed by the students regularly enrolled, among which must be chosen by their peers, annually, a representative of the students with the Collegiate, chosen by simple election of the most voted among the candidates. The elected representative will participate in the CPG meetings at the invitation of the Coordination, when appropriate.

3.2. Faculty

The PPG/IRD professors must, necessarily, have the title of Doctor recognized in Brazil. The effective faculty of the PPG/IRD is composed of three sets of professionals, namely:

I. Permanent faculty - composed of active, inactive servants or researchers who have a formal relationship with the PPG/IRD, whose performance is of a perennial nature. The category of permanent professors is made up of professors who, in assessments carried out in the last 4 (four) years, meet the following requirements:

- a. development of teaching activities, participation in research projects and guidance of PhD and Master's students of the PPG/IRD;
- b. functional-administrative bond with the IRD or, exceptionally, the placement in one of the following special conditions:
 - i. a) as a professor or retired public servant: who have signed a term of commitment to participate as a professor at the PPG/IRD;
 - ii. b) have been assigned, by formal agreement, to act as a professor at the PPG/IRD;
 - iii. c) at the discretion of the Collegiate, when the permanent professor who does not develop teaching activity due to the non-programming of the discipline under his responsibility or to his absence to carry out a post-doctoral internship, senior internship or relevant activity in Education, Science and Technology. It is also necessary that they hold a Doctor's degree for at least 2 (two) years and that they work as a permanent professor, at most, in up to 3 (three) PPG's;

II. Collaborating faculty - composed of active, inactive employees or researchers who have a formal relationship with the PPG/IRD, whose work with the PPG/IRD is of a temporary nature and who also comply with all the conditions described in the current CAPES Ordinance. The category of collaborating professors is made up of the other members of the faculty of the PPG/IRD, who have held a PhD degree for at least 1 (one) year, who do not meet all the requirements to be classified as permanent professors or as visitors, but meet at least 2 (two) of the following requirements: systematically participate in the development of research projects; develop teaching activities; supervise or co-supervise PPG/IRD Doctoral or Master's students; and

III. Visiting faculty - composed of a group of associated researchers, for technical support to academic and scientific activities. These, however, do not make up the effective faculty of the PPG/IRD.

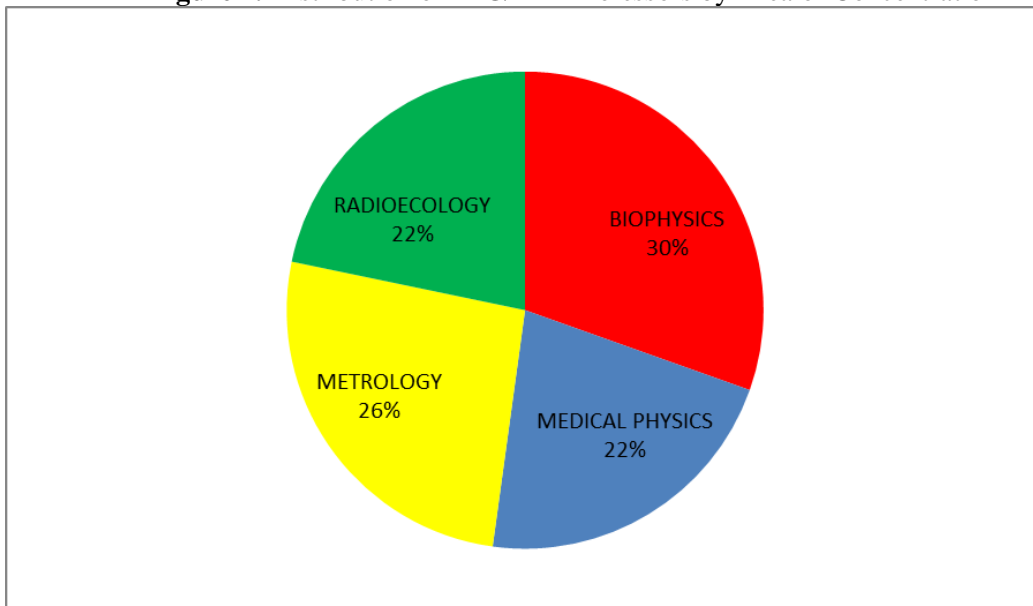
The category of visiting professors is made up of professors or researchers who have a functional-administrative link with other institutions, Brazilian or not, who are released, by formal agreement, from the activities corresponding to such bond, to collaborate, for a continuous period of time and on a full-time basis, in a research project and/or teaching activities in the Program, allowing them to act as advisors and in extension activities. The ratio of guidance/advisor is subject to a maximum limit of 8 (eight) students per advisor. Regarding the Student Body, the PPG-IRD currently has 14 doctoral and 9 master's scholarship holders, while with regard to the Faculty, the PPG-IRD has a total of 23 professors (Table 1 and Figure 1).

Table 1. Faculty of PPG/IRD

FACULTY/ CONCENTRATION AREA			
BIOPHYSICS	MEDICAL PHYSICS	METROLOGY	RADIOECOLOGY
7 Professors .6 men .1 woman	5 Professors .3 men .2 women	6 Professors .6 men	5 Professors .1 man .4 women

Source: [2]

Figure 1. Distribution of PPG/IRD Professors by Area of Concentration



Source: [2]

3.3. Areas of Concentration and Research Lines

The training of masters and doctors in protection methods and teaching methods involves an area of theoretical and practical knowledge of interest. Students are engaged in projects that develop the scientific method of work, consolidating their interest in scientific and technological research and engaged in their skills and qualifications to work in the scientific area. In this way, the PPG/IRD is divided into the following Areas of Concentration, namely:

1) Biophysics of Ionizing Radiations - studies developed on the interaction of radiation with biological systems. Such studies are radiums and lines of research related to human radium and chldis



in the body external dosimetry of photons and trons. The projects developed here are essentially multidisciplinary, with concepts of biology, physics and chemistry;

2) Medical Physics - contributes to the effectiveness of radiodiagnostic procedures, seeking to ensure the radiological protection of occupationally exposed patients and professionals, as well as assisting in the development and improvement of imaging techniques (for ex-ample, mammography, computed tomography, PET, SPECT, etc.). It also contributes to the development of therapeutic techniques (e.g. implantation of radioactive seeds, IMRT, radi-osurgery, antiparticle therapy, etc.). Mathematical simulations are also carried out, with the development and adaptation of computer programs for theoretical dose calculations and detector simulation. in planning treatments and monitoring treatment procedures and equipment, in order to ensure that the dose prescribed by the radiotherapist is delivered, as accurately as possible, to the target volume and that healthy tissues are preserved as much as possible;

3) Metrology - it is important to have accepted and accurate measurements agreed and com-petent across the country. In this concept, it is in line with the need for a more realistic concept of greater precision, reliability and speed of measurements. Environmental chang-es and major decisions are calculated as environmental changes, and major decisions are calculated as environmental and major changes. Metrology is a factor of quality, competi-tiveness for the country and especially for the citizens; and

4) Radioecology - aims to train qualified human resources to contribute to the solution of en-vironmental problems related to the nuclear sector and related areas. In this way, the focus is on knowledge transfer and the assimilation of methodologies to broaden the understand-ing of the physical, chemical and biological processes that modulate environmental radio-activity. Aspects such as the assessment of environmental impacts of activities related to the nuclear sector and related are also addressed, as well as the sustainability of technologies and remediation actions used for environmental recovery.

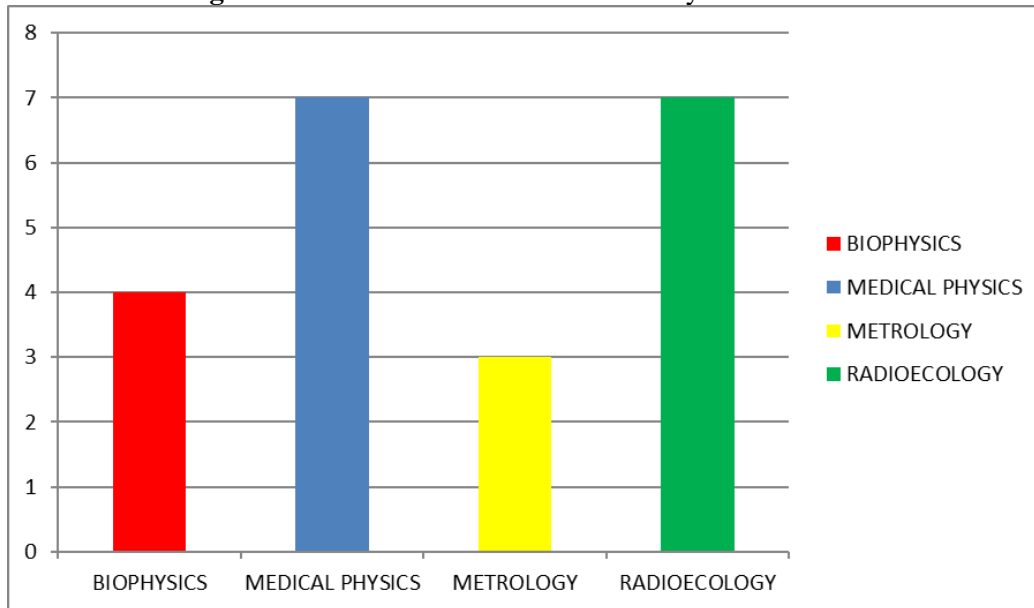
Regarding the Research Lines, they are divided according to Table 2.

Table 2. PPG/IRD Research Lines

RESEARCH LINES			
BIOPHYSICS	MEDICAL PHYSICS	METROLOGY	RADIOECOLOGY
Evaluation of Occupational Radiation Protection in the Industrial Area	Radiological Risk Assessment in Medical Physics	Metrology in Neutrons	Application of Isotopic and Nuclear Techniques
Development and Optimization of Dosimetric Systems	Development in Medical Biophysics	Metrology in Radionuclides	Environmental Radiological Impact Assessment
Dosimetry in Mathematical Simulators of the Human Body	Development in Medical Physics	Metrology in X-rays, Gamma, Electrons and Charged Particles	Environmental Modeling
Occupational Internal Dosimetry	Dosimetry in Medical Physics		Radioecology of Aquatic Ecosystems
	Research in Medical Physics		Radioecology of Terrestrial Ecosystems
	Radiological Protection in Medical Physics		Environmental Radiation Protection
	Image Quality and Dose in Fluoroscopy and Digital Systems	Transfer and Reactivity of Pollutants	

Source: [2]

Figure 2. Distribution of Research Lines by Area of Concentration



Source: [2]

3.4. Didactic Regime and Subjects

The PPG-IRD requires the completion of a minimum of 27 (twenty-seven) credits in subjects for the master's course (19 credits from the general core and 3 credits from the specific core) and 38 (thirty-eight) credits in disciplines for the doctoral course (13 credits from the general core and 3 credits from the specific core). The other credits are chosen by the student, with the consent of their advisor.

The didactic regime of the PPG/IRD is quarterly. The first quarter begins with the inaugural class and in the second quarter, there will be the Graduate Week. In the second quarter, at least 3 (three) credits from the Specific Core subjects of each PPG/IRD concentration area must be offered. All disciplines of the General Core must be offered annually between the first and fourth quarter. The disciplines can be offered in Classroom, Virtual and Classroom/Virtual formats. Enrollment in the disciplines of each quarter must be carried out by the student, within the period established by the SPG, with the approval of their supervisor. Listening students may be accepted, at the sole discretion of the course professor, who must notify the SPG of the name of the accepted listeners.

The number of vacancies in the disciplines will be the responsibility of the professor of each discipline offered, considering that: for the disciplines of the General Core, there are no limits on vacancies; the disciplines of the Specific Core will be taught to at least one student, with no criteria for a limiting number of vacancies; The Elective Core subjects will be taught to a minimum of 2 (two) students, with continuity for only 1 (one) student at the discretion of the professor. The verification of the performance and attendance of the students in the subjects of the PPG/IRD is carried out at the discretion of the teacher and according to the characteristics of each subject, and different forms of evaluation can be used, such as tests, seminars, exercises, reports, works, projects among others.

The verification and use of the performance of each discipline of the PPG/IRD will be expressed by the marks from 0 (zero) to 10 (ten). A student who has a minimum attendance of 75% (seventy-five percent) per discipline or allowance due to the teacher's justification and obtains a grade greater than or equal to 7.0 (seven point zero); The student who obtains a grade lower than 7.0 (seven point zero) will fail the PPG/IRD subject, without credit. In order to obtain the Master of Science degree, the PPG/IRD requires the following requirements from the student:



- I. Have a minimum attendance of 75% (seventy-five percent) per subject or allowance for justification of the teacher and obtain approval in the same, under the regimental terms;
- II. Be enrolled in the PPG-IRD Master's program for: a minimum of 12 (twelve) months and a maximum of 36 (thirty-six) months;
- III. Complete the credits as established in Article 63 of this bylaw;
- IV. Pass the English Language Proficiency Exam, specific to the Master's degree;
- V. Have participated in the Graduate Week in your second year of enrollment;
- SAW. Submit and have a Master's dissertation approved.
- VII. Have a draft in Portuguese of an article to be published in an indexed journal. This draft should be Appendix I of the body of the dissertation to be presented.

To obtain the degree of Doctor of Science, the PPG-IRD requires the following requirements from the student:

- I. Have a minimum attendance of 75% (seventy-five percent) per subject or allowance for justification of the teacher and obtain approval in the same, under the regimental terms;
- II. Be enrolled in the PPG/IRD Doctorate for: at least 24 (twenty-four) months and at most 60 (sixty) months;
- III. Complete the credits as established in Article 63 of the Internal Regulations;
- IV. To be approved in the English Language Proficiency Exam, specific for the Doctorate;
- V. Have participated in the Graduate Week in their second and fourth year of enrollment;
- VI. Have at least one scientific article approved for publication in a scientific journal indexed in the SciELO, Web of Science, SCOPUS, PubMed and ISI databases. The patent filing at the INPI will also be considered as a scientific production or a patent deposited at the INPI, both referring to the thesis topic, and the article, or its proof of approval, or the proof of the deposited patent must be inserted as Appendix I the body of the thesis to be presented;
- VII. Pass the Area Seminar;
- VIII. Pass the Qualifying Exam;
- IX. Present, defend and have approved a doctoral thesis.

The issuance of the diploma will only be carried out through the SPG, after all the requirements described in this Internal Regulation have been fulfilled, and will be signed by the Director of the IRD, the Coordinator of the PPG/IRD and the Graduate.

3.5. Curricular Structure

The curricular structure of the PPG/IRD is constituted by the following subjects and academic activities: I. Subjects of the General Core; II. Specific Core Disciplines; III. Elective Core Subjects; IV. Graduate Week; V. Area Seminar (specific for Doctorate); VI. Qualifying Exam (specific for Doctorate); VII. Preparation and Public Defense of the Thesis/Dissertation. Each discipline of the PPG/IRD will have a value expressed in credits, each credit corresponding to a minimum of 15 (fifteen) class hours. The presentation in the postgraduate week and the report of the presentations in your area of concentration are worth 1 (one) credit in the General Nucleus. The subjects are distributed according to Table 3 and Figure 3.

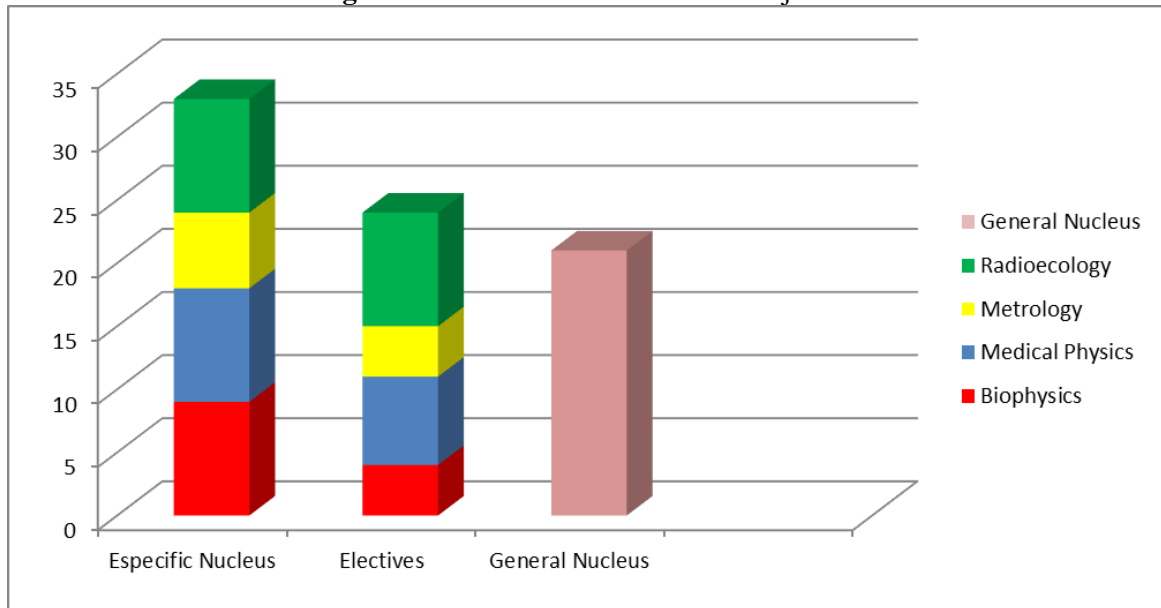
Table 3. PPG/IRD Disciplines

GENERAL NUCLEUS		
SUBJECT	CREDITS	FREQUENCY
Preparation of Scientific Documents	2	2nd Semester
Statistic	3	1st Semester
Radiation Physics	4	1st Semester
Fundamentals of Radiobiology	3	4th Semester

Nuclear Instrumentation	4	1st Semester
Principles of Radiation Protection and Dosimetry	4	2nd Semester
Follow-up Seminar	1	2nd Semester
SPECIFIC NUCLEUS		
BIOPHYSICS		
External Dosimetry	3	3rd Quarter
Occupational Internal Dosimetry	3	4th Quarter
Occupational Radiological Protection	3	2nd Quarter
MEDICAL PHYSICS		
Medical Physics in Nuclear Medicine	3	2nd Quarter
Medical Physics in Radiodiagnostics	3	3rd Quarter
Medical Physics in Radiotherapy	3	3rd Quarter
METROLOGY		
Metrology of Ionizing Radiations	3	3rd Quarter
Metrology in Radionuclides	3	2nd Quarter
RADIOECOLOGY		
Radioecology of Aquatic Ecosystems	3	2nd Quarter
Radioecology in Terrestrial Environment	3	2nd Quarter
Radioecology in Biosphere Modeling	3	2nd Quarter
ELETIVES		
BIOPHYSICS		
Fundamentals of Databases Applied to Radiation Protection	1	3rd Quarter
Special Topics in Radiation Biophysics	3	
MEDICAL PHYSICS		
Dosimetry in Radiotherapy	2	
Monte Carlo Method Applied in Dosimetry	2	
Special Topics in Medical Physics	3	
METROLOGY		
Uncertainty Assessment	1	1st Quarter
Special Topics in Metrology	3	
RADIOECOLOGY		
Radioactive Waste Management in Radiative and Nuclear Installations	2	3rd Quarter
Introduction to Hydrogeology and Hydrogeochemistry	3	2nd Quarter
Environmental Monitoring Using Geotechnologies	1	3rd Quarter
Special Topics in Radioecology	3	

Source: [2]

Figure 3. Distribution of PPG/IRD Subjects



Source: [2].

3.6. Student Body and Academic Production

Regarding the Student Body, the PPG-IRD currently has 29 doctoral and 35 master's scholarship holders, the majority of which are scholarship holders (Table 4).

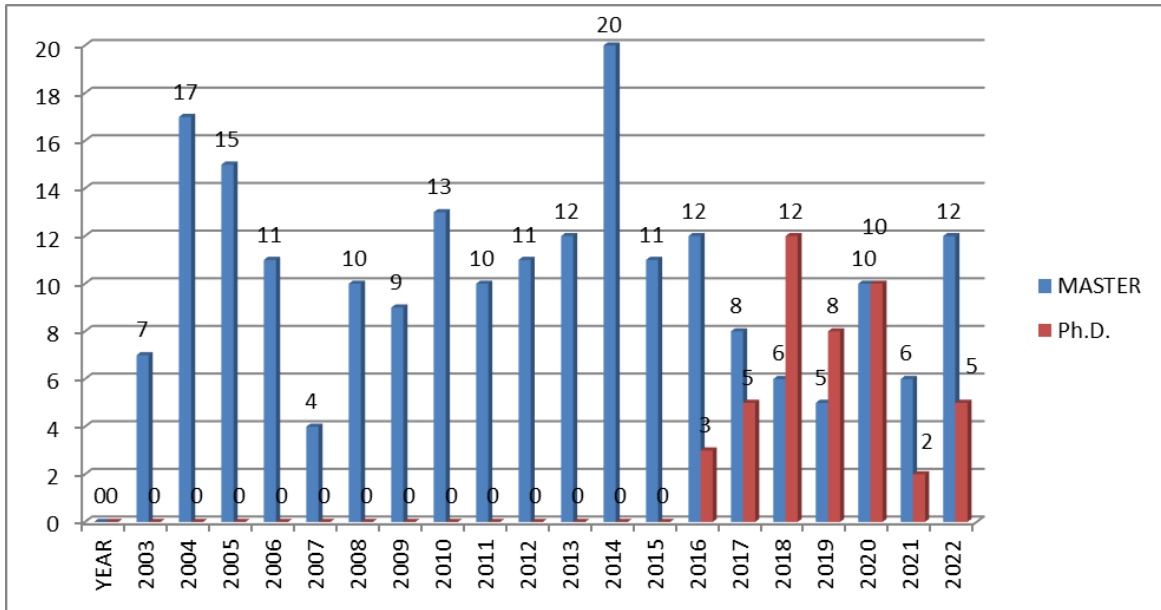
Table 4. PPG/IRD Disciplines

	PPG/IRD	
	MASTER	Ph.D.
ACTIVES	35	29
USED CAPES SCHOLARSHIPS	8	11
USED CNEN-IRD SCHOLARSHIPS	5	2

Source: [2].

The PPG/IRD had its first dissertation defended in 2003, having, by the year 2021, a total of 248 works (in this case, 206 dissertations - D and 42 theses - T) (Figure 4 and Table 5).

Figure 4. Temporal distribution of PPG/IRD defenses



Source: [2; 6].

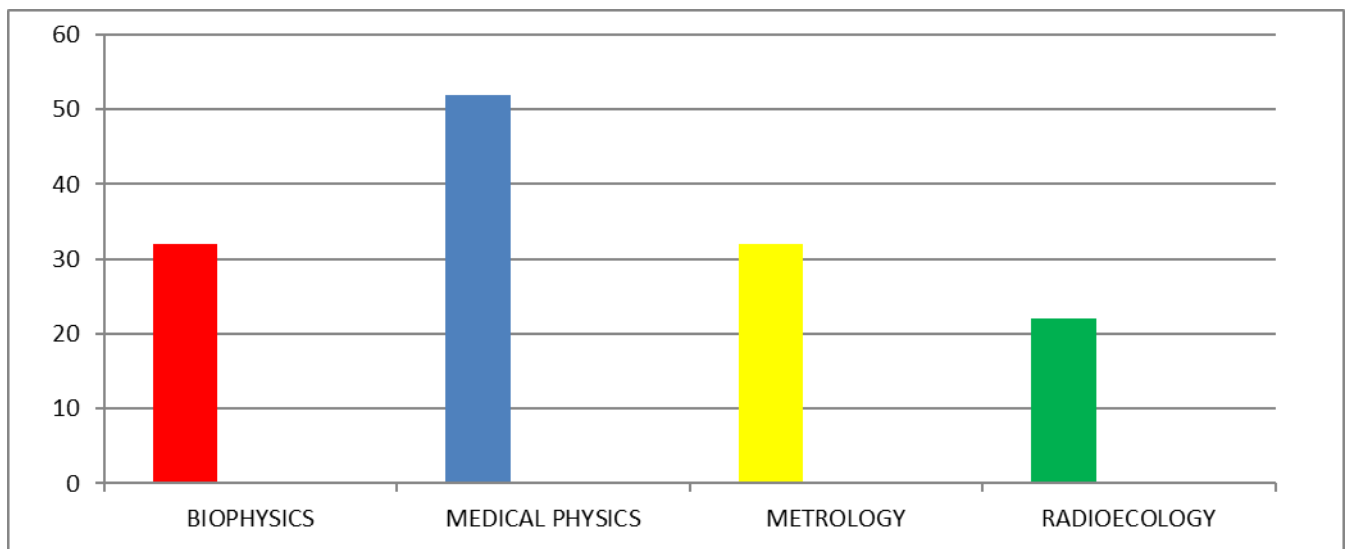
Table 5. Total PPG/IRD T and D

YEAR	D	T
2003	7	-
2004	17	-
2005	15	-
2006	11	-
2007	4	-
2008	10	-
2009	9	-
2010	13	-
2011	10	-
2012	11	-
2013	12	-
2014	20	-
2015	11	-
2016	12	3
2017	8	5
2018	6	12
2019	5	8
2020	10	10
2021	6	2
2022	12	5
Total	209	45

Source: [2; 6].

Thus, the program presents an average of 12.5 works defended per year, with its peak in 2014 and 2020 (with a total of 20 works). The PPG/IRD is assessed by the Capes Multidisciplinary Knowledge Area and Interdisciplinary Assessment Area. The distribution of works according to the Concentration Area is as follows: Medical Physics (52), Radiation Biophysics (32), Metrology (32) and Radioecology² (22) (Figure 5).

Figure 5. Distribution of T and D by Area of Concentration



Source: [2; 6].

4. Conclusion

The objective of this work paper was to demonstrate the activities and results obtained in these 20 years of the PPG/IRD in Radiation Protection and Dosimetry. In this sense, it can be said that the PPG/IRD is consolidated in its 4 Areas of Concentration, which makes it a national reference in radiation protection and dosimetry.

As a perspective, it is expected to expand the scope of action, especially in the area of Metrology, considering that it is a national reference center, as well as enabling the participation of foreign students (from Latin America and from Portuguese-speaking countries around the world) to participate in the PPG/IRD.

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² Another 105 works appear in Capes' BTB. However, as they were defended before 2013 (prior to the implementation of the Sucupira Platform), and therefore are not classified by Area of Concentration.



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