Trends in Occupational Exposure at Different Practices in a Nuclear Facility

Janete C G G Carneiro, Matias P Sanches, Demerval L Rodrigues, Paula P N Silva, Brigitte R S Pecequilo

Instituto de Pesquisas Energéticas e Nucleares (IPEN/CNEN-SP)
Av. Professor Lineu Prestes 2242
05508-000 São Paulo, SP-Brazil
+55-11-3133-9674 (Phone and Fax)
janetegc@ipen.br

ABSTRACT

The Nuclear and Energy Research Institute State of São Paulo, Brazil, IPEN is recognized as a national leader institution in research and development in the areas of radiopharmaceuticals, industrial applications of radiation, basic nuclear research, nuclear reactor operation and nuclear applications, and others sources. IPEN has a rigorous program of radiological control and nuclear safety for the activities related to nuclear and radiological aspects. This program comprises personal and environmental monitoring and radiological emergency assistance. The goal of the occupational safety and health programs is to foster a safe work environment, and also a protection of the public who may be impacted by the workplace environment. For this purpose, the aim of this study was to provide information about the level of occupational exposure arising in different practices in the institution. The trends are analyzed and presented, over 10 years period from 2001 to 2010. The data analysis was based on the records of the radioprotection service and analysis of trends of annual effective dose, numbers of monitored workers and percentage of measurably exposed workers. Most of the dose comes from external exposures and the greatest contribution to the occupational exposure comes from radiopharmaceutical and cyclotron facility. The average annual effective dose for workers involved in these practices was 3.3 $mSv.y^{-1}$ over time. In addition, the direct environmental gamma radiation levels near the nuclear and radioactive IPEN facilities, assessed with thermoluminescent dosimeters during the last ten years, presented a mean value of 1.5 $mSv.y^{-1}$. In summary, the monitoring practice is such that more workers are individually monitored than is strictly necessary to meet regulatory requirements, with the consequence that only a fraction of 4% those monitored received measurable doses.

Key words: Occupational exposures, effective dose, external radiation, individual monitoring.

1. INTRODUCTION

The Nuclear and Energy Research Institute, IPEN is located in São Paulo city-Brazil, with the main purpose of doing research and development in the fields of nuclear energy and its applications. The Institute is recognized as a national leader institution in research and development in the areas of radiopharmaceuticals, industrial applications of radiation (two Isochronal Cyclotrons), basic nuclear research, nuclear reactor operation (Swimming Pool Nuclear Reactor) and nuclear applications, materials science and technology, laser technology and applications.

The radiation risks to people and the environment that may arise from the use of radiation and radioactive material must be assessed and controlled through the application of standards of safety.

In order to improve radiation protection, it is necessary to have knowledge of the occupational radiation dose levels in all radiation facilities. In this context, the IPEN has a rigorous program of radiological control and nuclear safety for the activities related to nuclear and radiological aspects. This program comprises personal and environmental monitoring and radiological emergency assistance according to national and international radiological protection standards [1,2,3].

The aim of this study was to provide information about the level of occupational exposure arising in different practices carried out at IPEN during the years 2001 to 2010.

Besides that, for the same period, the present study compares the contribution of background radiation of the IPEN measured by an environmental program around the facilities with the annual effective dose. The major nuclear and radioactive facilities at IPEN, which have contributed to the background, are the IEA-R1 Swimming Pool Nuclear Research Reactor, two isochronal Cyclotrons, and a Radiopharmacy Center. [4].

Occupational radiation exposures resulting of these practices can occur and have become a focus of attention of radiation protection team to protect of workers in controlled practices by a routine monitoring program. In previous assessment the external radiation exposure was more important than internal radiation exposure according to routine monitoring, but workers may be exposed to internal radiation. However, internal exposures have not been included in reported statistics, although the data from internal doses were evaluated by direct measurements (body counter).

Over the years the average doses to monitored workers and the number distribution ratios are, however, sensitive to the decisions and practices concerning which workers are involved in a particular workforce task.

2. METHODOLOGY

A summary of the IPEN´s facilities and the dose evaluation related to different practices as well as background radiation of the surrounding IPEN facilities over ten-year-periods, are given in this study.

The present study focuses mainly the three IPEN´s facilities that has been produced the radioisotopes including the Radiopharmaceutical facility, Cyclotron Accelerators operation and Research Reactor operations.

The data analysis was derived from examinations of the administrative records of institution IPEN and individual dose records of the radioprotection service; analysis of trends of annual effective dose (dose range), numbers of monitored workers and percentage of measurably exposed workers were evaluated.

In most circumstances, doses due to external irradiation can be readily assessed by the routine individual monitoring of workers. In this case all workers involved with radiation sources use a passive dosimeter, type Thermoluminescent Dosimeter, TLD. The dosimeter generally is worn on the surface of the body for a month period, and at the end of this period it is read and the doses recorded. All doses that exceed reporting levels specified in the national standard and any doses questioned by the customer are always investigated [1].

At IPEN, a regular environmental monitoring program is established since 1988. The external gamma radiation is determined also with TLD. Currently, holds 15 monitoring stations using TLDs - five of them at points of maximum predicted ground-level concentration, and the ten remaining ones in locations with no direct influence from the Institute facilities. The background radiation of the surrounding IPEN facilities was determined considering the annual mean value of those 10 locations [4].

2.1 Radiopharmaceutical facility

Radioisotopes are produced for a great variety of industrial and medical purposes. The production of Radiopharmaceutical is divided in three different areas: Radioisotopes (Tc-99m generator and primary radioisotopes); Labeled compounds for diagnosis and for therapy; and Lyophilized Kits for Labeling with Tc-99m. Among the radioisotopes produced during 2001-2010, the Tc-99m generator activity production had a significant contribution, about 87% of total activity handling, and the remainder corresponding for others primary radioisotopes and labeled compounds.

The main source of occupational exposure in radioisotope production and distribution is external irradiation; internal exposure may be significant in some cases, and arrangements are then made for individual monitoring [5, 6].

For the period studied 100% of the workforce was monitored by TLD and direct measurements in the whole body.

2.2 Cyclotron Accelerator

The Cyclotron Accelerator Facility, located at IPEN, is used basically for nuclear physics research and for medical purposes, i.e. therapy and radiopharmaceutical purposes. This facility is responsible for the operation of the cyclotron and carry out the irradiation for obtaining the cyclotron produced radioisotopes. There are two cyclotrons accelerators: The Cyclone-30 that can accelerate protons to energies between 15 and 30 MeV and it is now used for the production of Iodine 123 and Fluorine-18; the Cyclone-18 which accelerates protons to 18 MeV is used to produce Fluorine-18.

Most exposures from accelerators result from induced radioactivity and occur mainly during the repair, maintenance, and modification of equipment. They come from gamma radiation from activation of solid surrounded materials by penetrating radiation. The potential for internal exposure in the normal operation of accelerators is slight, and doses via this route are negligible in comparison with those from external irradiation [5,7].

For the period studied 100% of the workforce was monitored for external irradiation by TLD and direct measurements in the whole body.

2.3 Research Reactor operations Center

The IPEN-CNEN/SP´s research reactor MTR-IEA-R1 is the facility responsible to produce the radioisotopes for use mainly in medicine. The IEA-R1 is a research reactor pool type, moderated and cooled with low temperature light water. This reactor is already quite old (more 50 years) and it is practically the only one producer of radioisotope in the country.

The IEA-R1 has been operated most of time at 4.5MW power level in 64 hours regime per week to attend the production capacity of radioisotopes, sample irradiation, new experiments and research in different fields, such as medicine, industry and agriculture.

External gamma radiation is the main source of occupational exposure at IEA-R1. There is a small contribution comes from internal exposure and the contribution of neutrons to the overall level of external exposure is insignificant.

Most of exposures occur during schedule plant shutdowns, when planned maintenance and safety modifications and also activation products, and to a lesser extent fission have been source of external exposure. Routinely the highest level of exposure occurs during removal of the irradiated material of the pool.

A routine monitoring for reactors workers has been carried out by TLD system and some type of direct-reading dosimeter, such as “Dosicard” or a digital electronic dosimeter and by direct measurements (whole body).

For the period studied 100% of the workforce was monitored for external irradiation by TLD and direct measurements in the whole body.

3. RESULTS AND DISCUSSION

The number of exposed workers has consistently increased over the 10 y of the study. In 2010, there were 990 workers compared with 720 in 1996, an increase of 73%.

Data on occupational radiation exposures, in this study, were evaluated for three broad practices at IPEN: Radiopharmaceutical facility, Cyclotrons operation and Nuclear Research Reactor (IEA-R1). The considerations, analyzed in terms of trends over time during 2001-2010, were limited for these practices.

The average exposure levels of workers involved in "others sources of radiation" at IPEN, are in general low dose (or zero), below the recording level (0.2 $mSv.month^{-1}$) and were not included in this study [1].

The Table 1 present the total number of workers monitored at IPEN, i. e., workers potentially exposed in some occupation where radiation exposure may be involved.

The distribution of effective dose has following six different doses ranges (mSv) used to control the individual, such as: 0-5; >5-10; >10-15;>15-20; >20-50;>50 mSv. This ranged was used until 2004, according to national regulatory (the annual limit on effective dose of 50 $mSv.y^{-1}$ [CNEN –NE-3.01-1988 [8]. In 2005, was adopted the new legislation to dose limits changing to 20 $mSv.y^{-1}$, average over five-years period [1-3].

However, the international recording level recommended by ICRP-60 is 5 $mSv.y^{-1}$ and doses values below this limit may be considered zero, i.e., there is no health risk. In this context, the Table 1 followed the criteria of ICRP [2].

The individual dose records analyzed in terms of trends over time, 2001-2010 were based on two approaches: Trends in total numbers of monitored workers/year and number of workers aggregated in each dose range as presented in Table 1.

Table 1. The occupational exposures of IPEN workforce arising from all sources of radiation: number of monitored workers by dose range over 10-y period.

Dose Range ($mSv.y^{-1}$)	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	Total
0 – 5	689	684	697	679	713	780	805	868	926	964	7805
>5-10	18	17	26	15	23	22	22	20	23	21	207
> 10-15	5	5	6	16	12	14	7	6	9	2	82
>15 – 20	5	0	2	2	2	0	5	8	1	3	28
>20 –50	3	0	1	1	1	0	2	0	1	0	09
> 50	0	0	0	0	0	0	0	0	0	0	00
Total of monitored workers	720	706	732	713	751	816	841	902	960	990	8131

According to the Table 1, a total of 8131 individual records were evaluated, approximately 96% of workers received doses below de recording level (0-5 mSv) and the value recorded may be zero. The remainder (4%) was considered exposed workers receiving a measurable dose and subject to the evaluation. Therefore, seems reasonable to conclude that the ratio between the total number of exposed workers and the number of exposed workers receiving measurable doses is relatively low at IPEN facilities.

3.1 Occupational Exposure - Doses associated with specific practices

More detailed analysis has been carried out on data for the years 2001 to 2010, where the dose per exposed worker receiving a measurable radiation dose tends to decrease according to the following installations: Radiopharmaceutical Facility, Cyclotron Accelerator Facility and Research Nuclear Reactor Facility. Data on occupational exposure for these installations are summarized in Table 2 (a,b,c) respectively. In this table the dose ranged adopted is in accordance with national regulatory, where the recording level is 2.4 $mSv.y^{-1}$[1].

Table 2. Trends in total numbers of monitored workers/year and number of workers aggregated in each dose range

2(a) Radiopharmaceutical workforce

Dose Range ($mSv.y^{-1}$)	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	Total
0 – 2.4	100	118	100	73	81	88	102	133	127	159	1081
>2.4 – 5	22	22	46	12	12	26	29	24	39	30	262
>5 – 10	20	17	21	13	16	16	18	16	16	16	169
>10 – 15	06	03	04	11	09	12	05	04	08	02	64
>15 – 20	00	00	00	02	02	00	03	07	00	02	16
> 20	01	00	00	00	00	00	01	00	01	00	03
Total of monitored workers	149	160	171	111	120	142	158	184	191	209	1595

Data on the distribution shows that 68% of a total of 1595 individual records of workers, over the years, received dose zero, (health zero risk), bellow the recording level (RL) in concordance with national standard and in comparing with the ICRP about 84% of them received dose zero; 1.3% of monitored workers received doses higher than 15.0 mSv, which required investigation. The workers involved mainly in the packing-task group, and also due fault in operational procedure contributed with this dose range.

The radioisotope production there is a trend of an increasing number of workers and a decrease in the average collective effective dose and the average effective dose has remained constant during the years [9].

2(b) Cyclotron Facility workforce

Dose Range ($mSv.y^{-1}$)	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	Total
0 – 2.4	8	13	9	5	6	11	4	8	6	10	80
>2.4 – 5	2	3	6	6	4	4	5	5	10	4	49
>5 – 10	0	0	2	2	6	5	4	4	6	5	34
>10 – 15	0	2	2	5	3	2	2	2	1	0	19
>15 – 20	2	0	1	0	0	0	2	1	1	1	08
> 20	0	0	0	0	1	0	1	0	0	0	02
Total of monitored workers	12	18	20	18	20	22	18	20	24	20	192

A total of 192 individual records were evaluated over the years, and the distribution in dose range showed that 42% and 67% of them received dose of recording level according to national and international standards respectively. The number of workers with dose higher than 15 mSv was 5.2% of them, which was attributed mainly to maintenance in targets system [1,2].

2(c). Research Nuclear Reactor, IPEN- IEA-R1 workforce

Dose Range ($mSv.y^{-1}$)	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	Total
0 – 2.4	-	136	139	157	160	186	153	116	166	189	1402
>2.4 – 5	-	0	0	0	0	0	0	62	7	0	69
>5 – 10	-	0	0	0	0	0	0	0	0	0	0
>10 – 15	-	0	0	0	0	0	0	0	0	0	0
>15 – 20	-	0	0	0	0	0	0	0	0	0	0
> 20	-	0	0	1	0	0	0	0	0	0	1
Total of monitored workers	-	136	139	158	160	186	153	178	173	189	1472

*In 2001, no data information

The total individual records of monitored workers at IEA-R1 was 1472, being the fraction of them which received doses of recording level was 95.24% and 99,93% according to national and international standards, respectively. This high percentage of low dose reflects better protection standards at the radiation level of workplace and also the handling irradiated materials, which was considered low. The number of workers with dose higher than 15 mSv was less than 0.1% of them.

The Figure 1 illustrates the dose distribution (average percentage) for the IEA-R1 group according to task carried out.

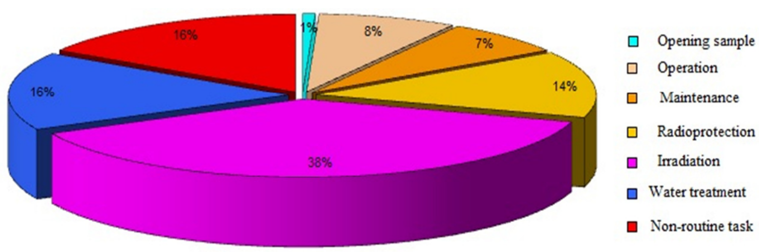

Figure 1. Dose distribution according to different task carried out.

Most of exposures arising from the task-related monitoring (38%) were during removal of the irradiated material of the pool.

The trends in annual effective collective dose for the workers involved in the research reactor IEA R1 over last 5-years is presented in Figure 2.

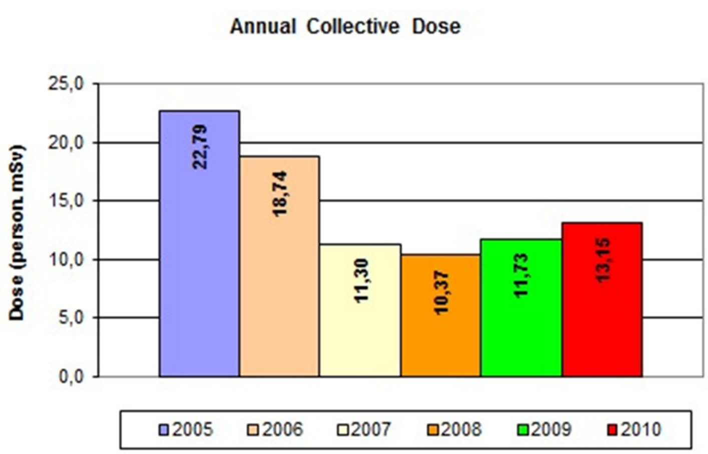

Figure 2. Trends in collective effective dose over five-year periods, for research reactor workers.

The annual collective dose has fallen over the years; there is a considerable variation between the first year and the last year, a reduction by a factor of 1.7. However, the collective dose associated with the research reactor workers has remained relatively constant since 2007 to 2010.

Analysis of dose records shows that in the 10-y period (2001-2010), there were 326 events (records) in which workers received individual annual doses higher than 5 mSv. This represents 4% of all annual doses over the same time period. Doses higher than 5 mSv were mainly arising from the Radiopharmaceutical and Cyclotron facilities.

Over the years, there were 9 events (dose records) above the annual dose limit of 20 mSv.

3.2 Environmental monitoring program of IPEN

The average annual effective dose during the 2001-2010 was about 1.0 $mSv.y^{-1}$ of the same order of values obtained by others investigators [9,10].

The highest values were obtained, in 2010, for the points of maximum predicted concentration (2.25 $mSv.y^{-1}$ and 1.14 $mSv.y^{-1}$ over the bunker site) are consequence of handling radioactive waste and the normal operation of the cyclotron, respectively. In these monitoring stations there is no circulation of people [4].

4. CONCLUSIONS

In general, monitoring practice is such that more workers are individually monitored than is strictly necessary to meet regulatory requirements, with the consequence that only a fraction of those monitored receive measurable doses.

The recording and reporting practices are governed by regulations and can be different for various practices of workers depending on their anticipated levels of exposure.

Individual radiation exposures during execution of some specific tasks are found be quite high. The evolution of doses due to maintenance and operation at cyclotron, radioisotope production and reactor with elevated levels of exposure can be the consequence of many factors. However, the trend of doses observed over the period studied showed that the majority of monitored workers received low doses in compliance with regulatory requirements.

The data indicate that improvements should be continuously reinforced, as reduction in the number of tasks performed by worker, the updating of ALARA program and training of workers has contributed to dose remained satisfactory and are compliance with the national and international standards.

The results presented in this paper were obtained from the individual monitoring of external radiation of 8131 individual records, performed by using TLDs in the 10-years period. Only 4% of the monitored workers exceeded 5 mSv. The results show that no worker exceeded a total effective dose of 50 mSv per year.

In conclusion, the statistical analysis was carried out in order to better understand the occupational radiation doses at different practices in a nuclear facility. In the future, there is a plan to carry out an epidemiological study in order to evaluate health radiation effects of the workers based on radiation dose data.

REFERENCES

1. COMISSÃO NACIONAL DE ENERGIA NUCLEAR. Diretrizes Básicas de Proteção Radiológica, CNEN-NN-3.01, CNEN, Rio de Janeiro (2005).
2. INTERNATIONAL COMMISSION ON RADIOLOGICAL PRTECTION. 1990 Recommendations of the International Commission on Radiological Protection, ICRP Publication 60. Pergamon Press. Oxford, (1991).
3. INTERNATIONAL ATOMIC ENERGY AGENCY. International basic safety standards for protection against ionizing radiation and for the safety of radiation sources. Vienna, 1996. (IAEA-SS-115).
4. RELATÓRIO DE AVALIAÇÃO DO PROGRAMA DE MONITORAÇÃO RADIOLÓGICA AMBIENTAL DO CMR, IPEN (**2010**).
5. United Nations. United Nations Scientific Committee on the Effects of Atomic Radiation, UNSCEAR 2000 Report to the General Assembly, with scientific annexes. (New York: United nations) (2000).
6. RADIO 2011 **Occupational exposure to ionizing radiation associated with the production of radioisotopes.** Janete CGG Carneiro; Matias P Sanches, Demerval L. Rodrigues and Gian Maria A A Sordi.
7. 2011 International Nuclear Atlantic Conference, INAC 2011. **Neutron and gamma radiation levels analysis for 18 MeV cyclotron operation at IPEN-CNEN-SP**. Paula P N Silva, Ivani M. Fernandes; Amanda J da Silva, Demerval L. Rodrigues and Christovan R. Romero Filho.
8. COMISSÃO NACIONAL DE ENERGIA NUCLEAR. **Diretrizes Básicas de Proteção Radiológica**, CNEN-NE-3.01, CNEN, Rio de Janeiro (1988).
9. CARNEIRO, Janete C.G.; BETTI, Flavio; SANCHES, Matias P.; SORDI, Gian-Maria A. A.; PECEQUILO, Brigitte R. S. **Assessment of the environmental outdoor gamma radiation levels in Sao Paulo city**. Int. J. Low Radiation, v. 7, n. 5 -p. 359-365 (2010).
10. 2011 International Nuclear Atlantic Conference, INAC 2011. **Three years of seasonal dose assessment from outdoors gamma exposure in Sao Paulo city, Brazil.** Janete C.G.; BETTI, Flavio; SANCHES, Matias P.; PECEQUILO, Brigitte R. S.(2011).