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RESULTS OF THE STUDY OF VARIABLES RELATED TO TASKS OF WORKERS OF A RADIOACTIVE FACILITY

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ABSTRACT

This paper presents the results of the evaluation study of the association degree between physical risk agent, ionizing radiation, and tasks performed by the occupationally exposed individuals (OEI), in the production of radioisotopes and radiopharmaceuticals of a radioactive facility. Initially, has been performed a qualitative assessment of the workplace, workgroups and the processes as well. Starting from the inventoried subjective information, interviews and observations were identified seven homogeneous exposure groups, assuming they receive the same exposure to a range of specific agents. The data were analyzed by means of descriptive statistics with quantitative and qualitative approaches of the variables. In the analysis was used nonparametric tests (Equality of two proportions, Chi-square and Yates correction), descriptive measures of location (mean, median and quartiles) and dispersion (standard deviation and coefficient of variation). A significance level of 5% ($p < 0.05$) was adopted. The results have shown five risk factors (variables) related to the tasks performance. After the characterization distribution of the relative frequencies, all variables showed a significant degree of association ($p < 0.001$) to the exposure to ionizing radiation. Descriptive analysis of effective doses received by OEIs (n=102) resulted in the average of 4.06 mSv obtained in 2013 and 3.41 mSv in 2014. The collective doses corresponding to the same year were 414.41 mSv.person and 347.61 mSv.person. The doses values found during the analyzed period are in accordance to the limits established by the current national standards.

Keywords: ionizing radiation, physical risk agent and risk factors.

1. INTRODUCTION

The variables to consider in the occupational risks classification are the exposure of the worker in its workplace, working conditions and task performed. The group of occupational risks includes the risk agents physical, chemical, biological, ergonomic and accident. Once identified risk agents in the workplace, the probability of this agent to cause some adverse effects to the worker’s health occurs in function of their nature, concentration or intensity and exposure time [1, 2].

The work process of the occupationally exposed individuals, OEIs, in the production of radioisotopes and radiopharmaceuticals includes singularities that do not exists in the process of others categories. Can be cite as a relevant example for this study: the exposure to risk agent of physical nature, ionizing radiation [1].

The aim objective of this study was to perform an evaluation of the association degree between the main occupational risk agent, ionizing radiation, existing in the workplace of the OEIs of a radioactive facility and their performed tasks.

Mendes (2007) and Silva (2012) describe a systematic to the identification and assessment exposure to the occupational risks, with focus on health quality improvement of the workers. According to the literature, there are no reports about assessments to occupational risks associated with the application of test statistics related to the tasks of workers in a radioisotope and radiopharmaceuticals production.

However other studies were performed on public hospital network through interviews and observations or application of questionnaire [3, 4]. Puga et al., reported about practical example of basic characterization, involving qualitative assessment and prioritization of the occupational risks [5].

In summary, it can be concluded that the occupational risk is omnipresent in any workplace, however it differ how can be noted or valued.

2. METODOLOGY

This paper is a descriptive and exploratory character study, with quantitative and qualitative approaches of the risk factors (variables) related to the tasks of the OEIs. Performed at a radioactive facility of the *Instituto de Pesquisas Energéticas e Nucleares*, IPEN / CNEN-SP, the Central Radiopharmacy (CR). The data collection and analyses occurred in the period of April 2013 to June 2014.

The choice for a quantitative and qualitative approaches was done because the need of integrate numerical data to the subjective questions in an attempt to complement the data.

The CR population is composed by 204 workers divided in: 102 federal public employees (50%), 57 outsourced (27.94%) and 45 students / trainees (22.06%). However, only the public employees, representing 50% of the CR population, constituted the studied sample.

The development of the study comprised a detailed evaluation process, covering a basic characterization of the workplace, workgroups and the identification of the probable occupational risks to which the worker is subject in workplace due the execution of their tasks [6].

The collection data started applying a questionnaire about the work process, as materials and substances they used, environmental conditions in the OEIs' workplace, use of personal and collective protective equipment and the identification of the possible occupational risk agents. Besides, the collection data was complemented by interviews, observations and analysis of occupational doses records, available in the facility.

The respondent of the questionnaire (autofill) was the manager of each workgroup of the facility.

The data was analyzed using statistical programs: SPSS V17, Minitab 16 and Office Excel 2010. Initially, was performed descriptive statistics aiming the frequency and distribution of a determined event, such as the study of qualitative and quantitative variables [7, 8].

The statistics tests applied were nonparametric tests (Equality of two proportions, Chi-square and Yates correction), descriptive measures of location (mean, median and quartiles) and dispersion (standard deviation and coefficient of variation). A significance level of 5% ($p < 0.05$) was adopted [9-12].

In an attempt to test the formulated hypotheses, a statistic called p-value was attributed to the study. Thus, the significance level (how much it admits to miss in the statistical conclusions, so the statistical error that is permissible to commit in the analyses) defined to the analyses realized was 0.05 (5%), consequently, all confidence intervals made along the study were built with 95% of statistical confidence [12].

3. RESUTS AND DISCUSSIONS

3.1. Qualitative assessment of physical risk, ionizing radiation

Through of subjective information collected after application of the questionnaire was possible to perform the qualitative assessment by basic characterization of the workplace, workgroups and tasks performed [13, 14].

The workers of the CR were grouped according to the tasks: radiopharmaceuticals production, quality control, quality assurance, research and development, infrastructure and support and radioprotection. The radiopharmaceuticals production encompasses primary radioisotopes, labeled compounds and lyophilized reagents, totaling eight tasks.

After analysis of the tasks OEIs and the workplace, was identified the presence of physical risk, ionizing radiation, in all tasks.

Because it is a radioactive facility, the possibility of exposure to ionizing radiation is inevitable due to the influence of the radiation fields arising from radionuclides produced and marketed by the CR. Besides, most of the workers have access to radiopharmaceuticals production areas, except the group of workers who perform the quality control tests.

Groups of workers who present the same profile of exposure to a specific range of occupational risk agents are called homogeneous exposure groups (HEG). To determination of the HEG, was done a survey according to a systematic assessment of the subjective information collected [14].

As already mentioned, the facility has eight tasks. However, the tasks primary radioisotopes production and labeled compounds production present exposures to the same occupational risks, with a similar frequency, performing their tasks in the same workplace and making use of the same materials. Therefore, was considered seven HEGs: production, reagents, quality control, quality assurance, research, infrastructure and radioprotection.

3.2. Statistical analysis – risk factors quantitative and qualitative assessment (variables)

The statistical analysis performed with the purpose to ascertain which risk factors (qualitative variables) relating to the tasks of OEIs are associated to their exposure to physical risk agent, ionizing radiation.

Through analysis of the relative frequencies distribution (percentages) of the occupational risks identified, according to their nature (physical, chemical, biological, ergonomic and accident), was carried the grouping of the workers in three risk groups (Risk groups 1, 2 and 3). These groups of workers are exposed to risks with similar nature, HEGs.

The Table 1 shows the analysis of frequencies performed by the nonparametric statistical test Equality of two proportions.

Table 1: Relative frequency distribution of the variable occupational risk among risk groups

Group	Occupational risk	Number of workers (N)	Frequency (%)	p-value
Risk 1	Physical, ergonomic and accident	29	28.4	0.020
Risk 2	Physical, chemical and ergonomic	45	44.1	Ref.
Risk 3	Physical, chemical, biological, ergonomic and accident	28	27.5	0.013

Note: p-value considered significant statistically due the significance level adopted ($p < 0,05$).
Ref. (reference) considered the response prevalent level, or that shows the highest frequency and consequently the highest percentage. Used only when the variable in study presents three or more response levels.

According to Table 1, the risk group 2, compound by HEGs production, reagents and radioprotection, showed the highest percentage (44.1%). The risk group 1, compound by workers pertaining to HEGs quality assurance and infrastructure, shows a percentage similar to risk group 3, consisting by HEGs of the quality control and research.

3.2.1. Distribution of the relative frequencies of the risk factors (variables)

Through of the questionnaire applied could be analyzed five risk factors (variables) related to the OEIs tasks performance, such as:

- Working journey;
- Frequency and duration of tasks;

- Handling of radioactive material;
- Generation of waste (radioactive waste);
- Training needs (recycling).

The nonparametric test Equality of two proportions was applied to character the relative frequencies distribution (percentage) of the qualitative variables cited above. The Table 2 shows the relative frequencies analysis of the variables in study.

Table 2: Relative frequencies distribution of the risk factors (variables)

Risk factors (variables)		N	%	p-value
Working Journey	30 hours	25	24.5%	< 0.001
	30 hours/turn	8	7.8%	< 0.001
	36 hours	57	55.9%	Ref.
	40 hours	9	8.8%	< 0.001
	48 hours	3	2.9%	< 0.001
Frequency and duration	Daily / 8 hours	4	3.9%	< 0.001
	Daily / mean of 4h	23	22.5%	< 0.001
	Daily / mean of 6h	62	60.8%	Ref.
	Daily / less than 6h	8	7.8%	< 0.001
	Not established	5	4.9%	< 0.001
Handling of radioactive material	18F, 153Sm, 111In, 123I, 177Lu, 90Y, 68 Ga, 51 Cr e 32P	8	7.8%	< 0.001
	99mTc / 99Mo, 201Tl e 67Ga	27	26.5%	0.535
	99mTc / 99Mo, 201Tl, 153Sm, 111In, 131I, 123I, 177Lu, 90Y, 67Ga, 68Ga, 51Cr e 18F	23	22.5%	0.204
	99mTc / 99Mo, 201Tl, 153Sm, 111In, 131I, 123I, 177Lu, 90Y, 67Ga, 68Ga, 51Cr, 18F, 32P, 130Te e 125I	7	6.9%	< 0.001
	99mTc / 99Mo, 201Tl, 153Sm, 111In, 131I, 123I, 177Lu, 90Y, 67Ga, 68Ga, 51Cr, 18F, 32P, 166Ho, 188Re e 64 Cu	5	4.9%	< 0.001
	Does not apply	32	31.39%	Ref
Generation of waste	Solid waste – common trash	23	22.5%	0.031
	Liquid waste – own network of waste disposal Liquid and solid discarded in tanks and storage for decay	37	36.3%	Ref.
	Trash segregated	5	4.9%	< 0.001
	Does not generate waste	8	7.8%	< 0.001
	Does not apply	29	28.4%	0.231
Training needs	Every two years	4	3.9%	< 0.001
	Annual	42	41.2%	Ref.
	Rarely	33	32.4%	0.191
	Semiannual	23	22.5%	0.004

Can be verified that there are various significant statistically results, except in the distribution of handling of radioactive material, generation of waste and training needs (Table 2), where it is observed p-values above 0.05 ($p < 0.05$). In that case, there are two ways of interpreting these values:

1. According to the significance level adopted (statistical error), so with $p = 0.535$; $p = 0.204$; $p = 0.231$ e $p = 0.191$ we admitted an error respectively of ± 53%; ± 20%; ± 23% and ± 19% when accept exactly the obtained values. However, the analysis distribution of the qualitative variables is just the first step of all statistical process carried, thus was accepted the error established by p-value.

2. One $p = 0.204$; $p = 0.231$ e $p = 0.191$ is located in an “instability limit”, it means, relatively close to the acceptance limit; soon, we can say that exist a trend towards significance.

3.2.2. Statistical analysis of the association degree among the risk factors (variables)

The obtainment of the association degree between physical risk, ionizing radiation, and the risk factors (variables) characterized above was carried through of the application of nonparametric test Chi-square and Yates correction.

Is noteworthy that the Yates correction only was used when the number of observations (answers) on each table information is less than or equal 5, and the frequency expected is also less than or equal the 5%.

To confers if there was association between physical risk, ionizing radiation, and the risk factors, the absolute values and its percentages were observed, comparing the distribution of total column with the remaining columns (intermediate). The probable statistical associations are observed when exists some value (per line) that differs of the value in the total column.

The Table. 3 shows the results of the association degree among physical risk agent, ionizing radiation, and risk factors (variables).

It is verified that the physical risk, ionizing radiation, has statistical association to the five factors analyzed ($p < 0.001$), although of some factors does not show relative percentages (absence of values or 0%) or shows percentages below 60% according the analysis of values arranged in the columns of Table 3.

So, all the factors have significantly influences to occurring of ionizing radiation exposure, with an association degree prevailing of 82%.

Table 3: Association degree of the physical risk agent and risk factors (variables)

Risk factors (variables)		Risk 1		Risk 2		Risk 3		Total		p-value
		N	%	N	%	N	%	N	%	
Working journey	30 hours	25	86%	0	0%	0	0%	25	25%	< 0.001
	30 hours /turn	0	0%	8	18%	0	0%	8	8%	
	36 hours	0	0%	37	82%	20	71%	57	56%	
	40 hours	4	14%	0	0%	5	18%	9	9%	
	48 hours	0	0%	0	0%	3	11%	3	3%	
Frequency and duration	Daily / 8 hours	4	14%	0	0%	0	0%	4	4%	< 0.001
	Daily / mean of 4h	0	0%	0	0%	23	82%	23	23%	
	Daily / mean of 6h	25	86%	37	82%	0	0%	62	61%	
	Daily / less than 6h	0	0%	8	18%	0	0%	8	8%	
	No established	0	0%	0	0%	5	18%	5	5%	
Handling of radioactive material	18F, 153Sm, 111In, 123I, 177Lu, 90Y, 68 Ga, 51 Cr e 32P	-	-	8	19%	0	0%	8	11%	< 0.001
	99mTc / 99Mo, 201Tl e 67Ga	-	-	27	63%	0	0%	27	39%	
	99mTc / 99Mo, 201Tl, 153Sm, 111In, 131I, 123I, 177Lu, 90Y, 67Ga, 68Ga, 51Cr e 18F	-	-	0	0%	22	81%	22	31%	
	99mTc / 99Mo, 201Tl, 153Sm, 111In, 131I, 123I, 177Lu, 90Y, 67Ga, 68Ga, 51Cr, 18F, 32P, 130Te e 125I	-	-	8	19%	0	0%	8	11%	
	99mTc / 99Mo, 201Tl, 153Sm, 111In, 131I, 123I, 177Lu, 90Y, 67Ga, 68Ga, 51Cr, 18F, 32P, 166Ho, 188Re e 64 Cu	-	-	0	0%	5	19%	5	7%	
Generation of waste	Solid waste – common trash Liquid waste – own network of waste disposal	0	0%	0	0%	23	82%	23	23%	< 0.001
	Liquid and solid discarded in tanks and storage for decay	0	0%	37	82%	0	0%	37	36%	
	Trash segregated	0	0%	0	0%	5	18%	5	5%	
	Does not generate waste	0	0%	8	18%	0	0%	8	8%	
Training needs	Every two years	4	14%	0	0%	0	0%	4	4%	< 0.001
	Annual	0	0%	37	82%	5	18%	42	41%	
	Rarely	25	86%	8	18%	0	0%	33	32%	
	Semiannual	0	0%	0	0%	23	82%	23	23%	

Note: The statistical associations are contrasted in yellow. Was considered only the percentages above 60%. The answers “does not apply” and the answers level with prevalence below three cases were not considered for the association analysis.

3.3. Descriptive statistical analysis of effective doses

The Table 4 shows complete descriptive analysis for the effective dose received by OEIs in the years 2013 and 2014. The descriptive measures used in this analysis were location and dispersion measures.

Table 4: Complete descriptive analysis to the effective doses

Descriptive analysis	**2013**	**2014**
Mean dose (mSv/year)	4.06	3.41
Median (mSv/year)	2.47	2.41
Standard deviation	3.37	2.25
Coefficient of variation (CV)	83%	66%
1º Quartiles (Q1)	2.40	2.20
3º Quartiles (Q3)	4.59	3.62
Minimum (mSv)	1.18	0.40
Maximum (mSv)	21.12	11.88
Number of workers	102	102
Confidence interval (CI)	0.66	0.44
Collective dose (mSv.person/year)	414.41	347.61
Number of workers above of mean dose	28	27
Number of workers below of registry value (2,4 mSv/year)	49	51

In the complete descriptive analysis for the effective dose (Table 4) it is verified that the mean effective dose, in 2013, was 4.06 ± 0.66 mSv. In 2014 the mean effective dose was 3.41 ± 0.44 mSv. It is observed a decrease of 16% annual effective dose of the workers in 2014 compared to 2013.

According to the Fig. 1, was established a CI of 95% for the mean effective dose in which the value acquired would vary among 3.41 mSv (minimum value) to 4.72 mSv (maximum value) for 2013 and 2.97 mSv (minimum value) to 3.85 mSv (maximum value) in 2014.

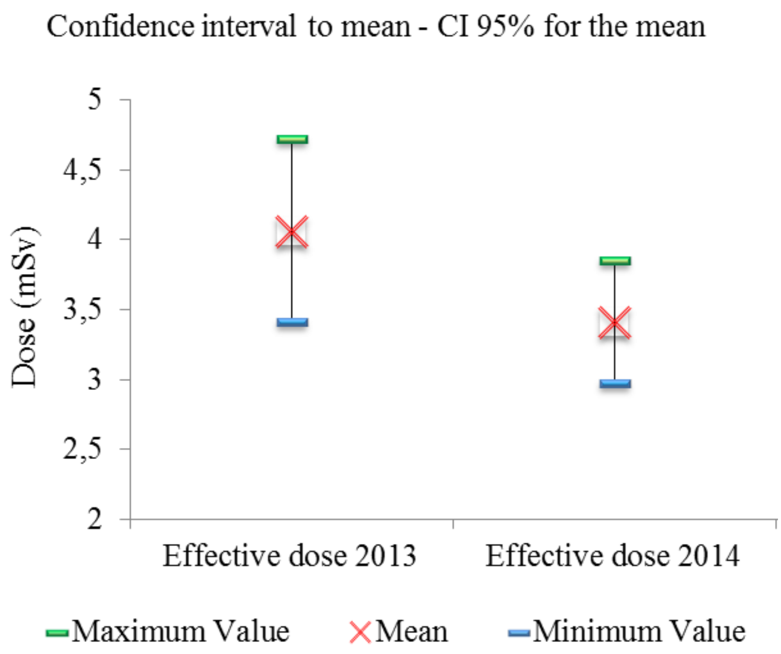

Figure 1: Confidence interval to mean effective dose, referring to the years 2013 and 2014.

Even in the Table 4, it is also observed an approximate reduction of 16% in the collective dose for the year 2014 compared to 2013. The collective dose was 414.41 mSv.person in 2013 and 347.61 mSv.person in 2014.

The variability (standard deviation) is large compared to the mean and the coefficient of variation referring to the year 2013 and 2014 equates respectively 83% and 66%, more than 50%. It demonstrates the data heterogeneity.

This heterogeneity may be related to the number of workers that compound the sample. With numbers below 10 individuals, the probability of obtaining a coefficient of variation bigger than 83% would be too vast, in this case, was chosen to analyze the doses entirety and not according to the established HEGs in the study.

3.4. Individual control of the workers - ionizing radiation

For individual control of external radiation the workers use thermoluminescent dosimeters (TL), ported on the chest. In case of internal contamination, the evaluation is done by full body measures. The results of the individual effective doses are obtained through the summation of the external and internal dosimetry.

The Fig. 2 and 3 shows the effective doses distribution (mSv), in dose intervals, received by workers of each HEGs, in the years 2013 and 2014. The data analysis of the individual monitoring was obtained through the consultation of historical dose.

In the year 2013, of the total 102 workers in the analyzed sample, only one worker of HEG production exceeded the limit of 20 mSv / year. Of the 35 workers at the same group, 13 received doses higher than 2.4 mSv / year, that is, above of the register level, according to established in national standard [15].

Already in the year 2014, doses over of limit established in standard (20 mSv / year) were not found. The HEG production received the highest doses, in which 17 workers received doses above of the register level (2.4 mSv / year), a higher index than the 2013.

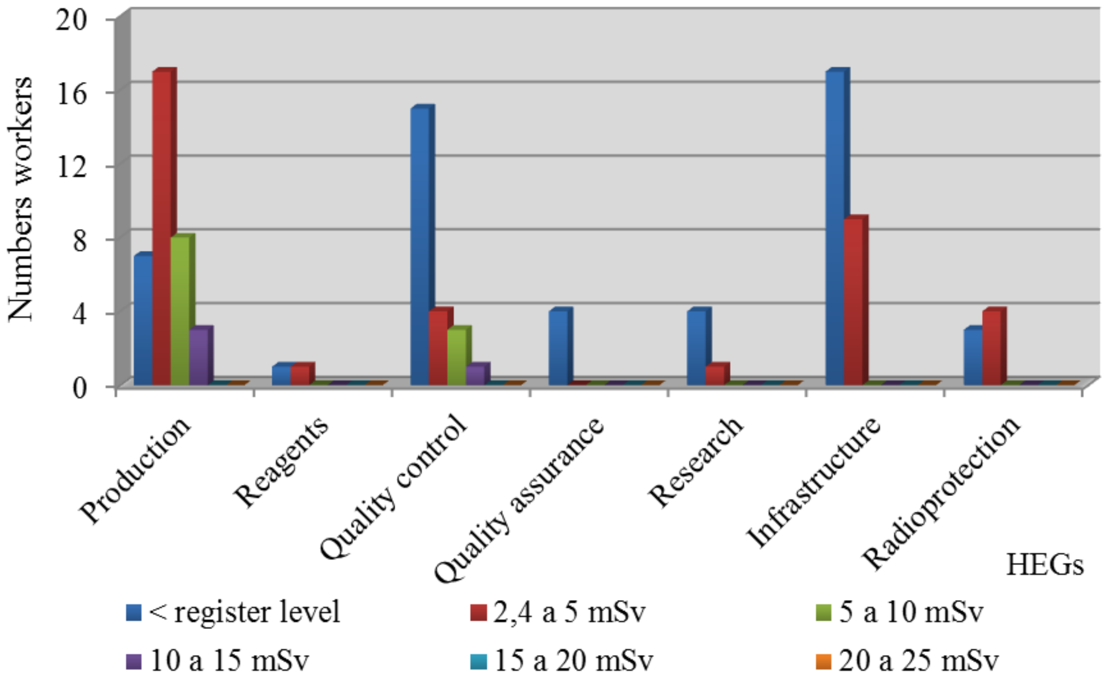

Figure 2: Effective doses distributions of the workers in each HEGs, organized in dose intervals in 2013.

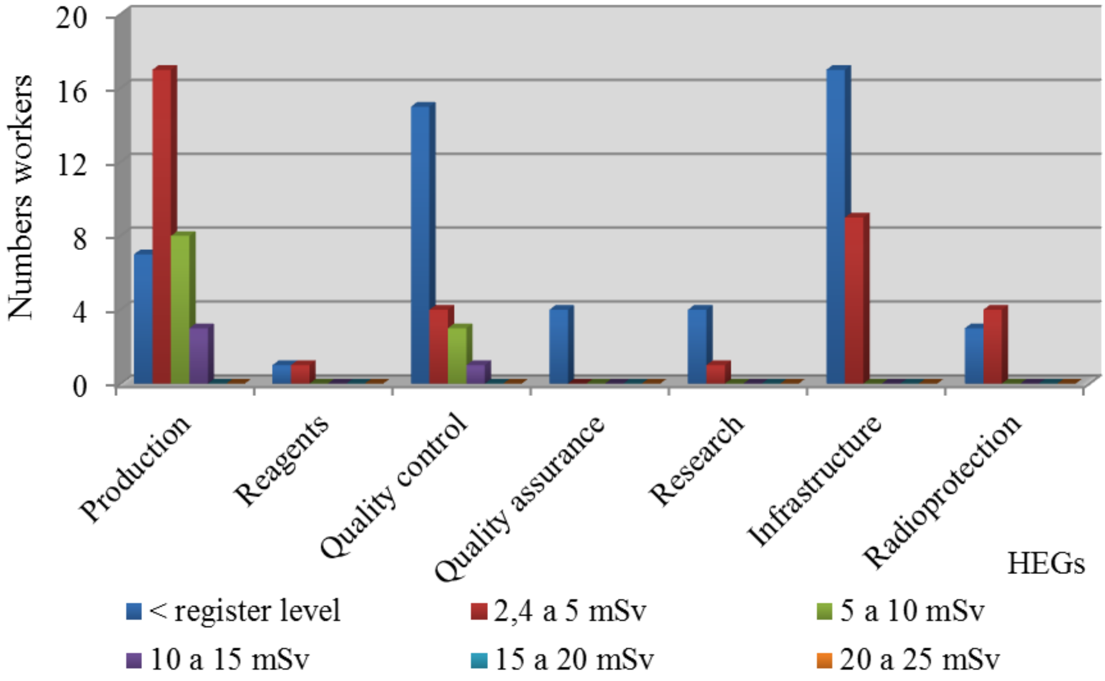

Figure 3: Effective doses distributions of the workers in each HEGs, organized in dose intervals in 2014.

4. CONCLUSIONS

The qualitative evaluation (basic characterization) permitted to know the workplace (the way it is organized), the workgroups and work processes (sample of workers that develop their tasks in there) carried on the radioactive facility in study.

From the inventoried subjective information, interviews and observations, were identified the potential exposure risk agents of each task perform, prevailing the exposure to ionizing radiation and the determination of the seven HEGs, assuming that the workers are exposed to a specific range of occupational risk agents.

After the relative frequencies distribution, the five risk factors (variables) showed a significant degree of association ($p < 0.001$) with exposure to ionizing radiation.

The doses values found during the analyzed period are in accordance to the limits established by the current national standards.

A team of radiological protection has played their actions effectively and routinely, applying the monitoring techniques in preventive and confirmatory characters. A reduction of 16% in the annual effective dose and collective dose could be observed in 2014 comparing to 2013. However, in 2013, a worker of the HEGs production exceeded the limit of 20 mSv / year established in national standard.

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