2011 International Nuclear Atlantic Conference - INAC 2011
Belo Horizonte, MG, Brazil, October 24 to 28, 2011
ASSOCIAÇÃO BRASILEIRA DE ENERGIA NUCLEAR – ABEN

ACCIDENTS IN INDUSTRIAL RADIOGRAPHY IN BRAZIL FROM 2005 TO 2010

Cristiane de Queiroz Oliveira[1,2], Josilto Oliveira de Aquino [1,2], and Ricardo Tadeu Lopes [1]

[1] Universidade Federal do Rio de Janeiro (COPPE/UFRJ – RJ)
Programa de Engenharia Nuclear – PEN
Centro de Tecnologia, Bloco G, sala 101, Ilha do Fundão
21945-970 Rio de Janeiro, RJ
ricardo@lin.ufrj.br
[2] Comissão Nacional de Energia Nuclear – CNEN/Sede
Rua Gal Severiano, 90 - Botafogo
22290-901 Rio de Janeiro,RJ
cristiane@cnen.gov.br
josilto@cnen.gov.br

ABSTRACT

Analysis of accidents occurring in industrial radiography in Brazil from 2005 until 2010 led to the study of the main characteristics of the events, their risks and dangers. This study outlines the main doubts on the subject, through a simplified analysis of the contents of high dose reports sent to CNEN by the companies that provide services for industrial radiography and from examining the growing number of radioactive sources for industrial radiography in Brazil, over this period. We classified the recorded events, as incidents, accidents, negligence, sabotage, and others, and studied their main consequences. We concluded that from 76 accidents that occurred during that period - 25 were real accidents, 13 minor accidents and 22 were inadvertent incidents. We found that the rate of growth in the number of sources is much greater than the rate of growth of accidents, with a ratio of 7.57 between them. The continuation of this study over some years, will allow the construction of a pyramid of accidents like the one developed by the Insurance Company of North America, specifically for industrial radiography to forecast the number of incidents and accidents that lead to serious or fatal injury.

1. INTRODUCTION

In Brazil, the concern with accidents in the workplace arose during the thirties, with the industrial revolution, but not many good results were obtained and during the 70's Brazil was pointed as Champion of accidents in the workplace.

According to HEMÉRITAS [1], Occupational Safety should be concerned with prevention of worker's physical integrity, but also should be considered as a factor of production, to be understood as accident prevention in industry. Accidents, whether they cause or not lesions to the worker, negatively affect production through loss of time and other possible consequences such as material losses or even reduction of efficiency of the injured worker when he returns to work or his colleagues due to the impact of the accident.

According to SOTO [2], the figures related to accidents in the workplace represent an obstacle to the socio-economic development plan of any country, these figures increasing in the form of spending on medical care, and rehabilitation of disabled workers, compensations and pensions to the victims or their families, financial losses due to stoppage of production, damage to equipment and material losses.

Thus, during the last few decades, experts devoted to the study of potential accident prevention.

On June 08, 1978, the Labor Minister of Brazil, Arnaldo Prieto, approves Ordinance 3.214, which creates twenty-eight Regulatory Standards (RN) concerning Occupational Health and Safety, which provide the detailed application of the articles included in Law 6.514 [3], of September 22, 1977.

The objective of one of the Regulatory Standards is to clarify the implementation of the stipulations contained in the articles (from 154 to 201) of Chapter V, Title II, of Law 6.514, without necessarily sticking to existing technical issues, although mentioning them when necessary, to guide those seeking to meet legal directives.

The risk may be understood as one or more conditions of a variable with potential to cause damage such as personal injury, damage to equipment and facilities, damage to the environment, loss of material being worked or reduction of the production capacity. Risk existence implies the possibility of adverse effects.

In Occupational Safety Engineering [4], the major occupational hazards are classified into 5 groups according to their nature and the standardization of the corresponding colors. In this way, we have physical hazards, chemical hazards, biological hazards, hazards associated with non-application of ergonomic principles and those of accidents.

Physical hazards correspond to the green color in the map of hazards and include: noise, vibrations, ionizing radiations, non-ionizing radiations, cold, heat, abnormal pressure, humidity.

The regulatory standard RN-15 [5], of occupational safety, deals with unhealthy operations and activities and annex 5 refers to the physical risk of ionizing radiations, saying that CNEN is responsible for the control of activities with radiation sources, according to Standard CNEN-NE-3.01 (1988) [6] or the one that replaces it. In that case Standard CNEN-NN-3.01(2005) [7] is in effect, and it defines accident as "*any unintended event, including operating errors and equipment failures, actual or potential consequences of which are relevant from the viewpoint of radiological protection".*

The main objective of this study is the prevention and control of accidents in industrial radiography practice, especially in the practice of gammagraphy. Accident prevention and control is performed through the knowledge and practice of radiological protection requirements provided in Standard-CNEN-NN.6.04 [8] for industrial radiography. However, a classification of accidents according to their potential does not exist. In Standards CNEN-NN.3.01 and 6.04 the accident potential ranges from disabling to near-miss.

A survey of the growth of the number of authorized sources operating in Brazil from 2005 to 2010, indicated a significant increase, and we can consider that by increasing the amount of risk in the workplace, because of the amount of sources in operation, we can also expect an increase in the number of accidents.

It is understood as accident when the worker occupationally exposed to radiation- OEI (occupationally exposed individual) - receives a dose higher than expected for a day and greater than 0.0793 mSv, considering the annual limit of 20 mSv, in 12 months with 21 working days. The limit for dose investigation is 1.2 mSv and CNEN asks to submit a report of dose investigation for accidents with doses above 4 mSv according to Annex C of Standard CNEN-NN.6.04.

It is necessary to seek an understanding and an interpretation of what means near-accident which can be defined as *"when the event does not result in real consequences, although potentially relevant from the point of view of radiological protection"*.

We understand as incident when the OEI does not receive any dose fraction.

The most common accidents in industrial radiography are: 1) lost source followed by its recovery; 2) relax of radiological protection requirements leading to negligence; 3) proximity of the irradiator during maintenance; 4) limited working space and lack of proper marking; 5) noisy environment preventing the OEI to hear the beep when the source is not completely retracted in the irradiator shielding and lack of equipment with the vibration function; 6) entry inside the X-ray room with the equipment turned on; 7) perform maintenance of the X-ray equipment turned on. In all those cases, the OEI receives dose.

The most common cases of incidents are: 1) when the OEI forgets or loses his dosimeter near the source during a certain time, generating a dose that should not be computed on the OEI's dose history, because it is a dose that was not absorbed by him; 2) when an OEI hiddenly catches his dosimeter or the dosimeter of a colleague and places it close to the source to be withdrawn from work or to undermine a colleague, respectively. In this case, we say that dosimeter sabotage occurred and the OEI does not receive the dose.

The regulatory standards on occupational safety arose in Brazil in June 8, 1978 no Brasil, while the first norm *CNEN-NE-3.01: "Basic Guidelines for Radiation Protection"*, came a decade later, in July, 1988. Therefore, a better interface between occupational safety and radiation protection was sought taking advantage of some occupational safety concepts already well established. The analysis of the accidents in industrial radiography from the point of view of occupational safety engineering will contribute to the introduction of these accidents in the occupational safety statistics of companies that provide industrial radiography services or operate X-ray equipment.

In occupational safety engineering, according to Bird apud OLIVEIRA [9 e 10], occupational safety is obtained by fighting any kind of accident and the reduction of loses releases new safety resources.

As ANSELL and WHARTON [11] state, risk is an inevitable feature of human existence. Neither the man nor the organizations and society to which he belongs can survive for a long period without the existence of dangerous tasks.

In 1969, the Insurance Company of North America (ICNA), following Bird's studies, analyzed and published a summary of statistical data collected in 297 companies employing about 1,750,000 individuals, where 1,753,498 occurrence reports were obtained. This sample, considerably larger, allowed making a list, more accurate than Bird's in relation to accident proportion, besides including a new fact – the near-miss.

As can be seen in Fig. 1, the proportions obtained by ICNA demonstrate that for every accident involving major injury, 10 accidents with minor injury, 30 property damage accidents and 600 without injury or visible damage – the near-accidents- occur.

It is worth emphasizing the importance of including accidents without injury or visible damage, because, being near-accidents they reveal huge accident potentials, i.e. situations with high potential hazard although personal or non-personal loss has not occurred yet.

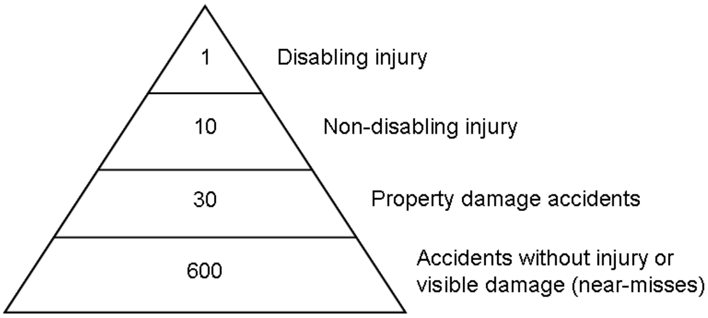

Figure 1: Pyramid of industrial accidents [12].

Occupational Safety Engineering has significant data, once it controls the 5 risk groups. The base of the industrial accident pyramid is composed by accidents without visible injury or damage that can be understood as incidents, since there was no injury to the worker.

This paper suggests an initial classification of accidents in industrial radiography as function of their risk potential. As the dose, which is (causes) a non visible injury, any near-accident in which the worker was not exposed to the dose, will be considered as incident.

The block of property damage accidents concentrates accidents that caused damages to the equipment, parts or working environment. In industrial radiography we can consider cases of source loss, irradiator drop, irradiator maintenance, failures in the couplings, handle, guide tube, forgetting to use a radiation detector, shielding or collimator, use of inadequate equipment for the workplace, such as a beep that does not vibrate in noisy environment, confined space for area marking, underestimated marking, relaxation of radiological protection practices, locking failure of the X-ray room during operation and others that have contributed with a dose for the worker.

The block of non-disabling accidents includes injuries that can lead to the withdrawal of the worker during a short period of time, such as a cut of a limb tissue or bone displacement or fracture among others. In the case of radiation, we can consider cases with real consequences for the worker in which he received a dose sufficient to cause the minimum cytogenetic alteration that is detected on the blood mapping exam, that can lead the worker to a stochastic effect, such as cancer development, during his life period.

Finally, at the top of the pyramid, are the most severe accidents that leave the worker unable to return to the work he performed, or even causes his death. An example of disability is the case of a mason that falls from a scaffold and loses one leg, or both. He will not be able to work as a mason, but he can still pursue a profession as physically handicapped, using only his hands, such as telephone operator or typist. In the case of radiation, we can consider cases in which the harm exceeds cytogenetic alterations, leading or not to cancer development in the future, and those where immediate deterministic effects occurred such as burns, that lead to the loss of a limb like a finger, a leg or an arm, or to the accelerated development of a cancer leading to death within a short interval of time.

Data on radiation protection in industrial radiography are restricted to physical risk of radiation. It is important to enhance that this paper is about the control of accidents with dose accumulation to the worker and all the other types of accidents causing injuries to the worker or property damage, but do not accumulate dose will be treated as near misses or incidents, since the hazard we seek to control is radiation. Also the cases of sabotage of personal dosimeters, or forgetfulness or loss of the dosimeter close to the source should be withdrawn from the history of worker dose, because the doses absorbed by the personal dosimeter were not absorbed by the worker, who will not be withdrawn from work, avoiding, in this way, a conflict of information and lack of consistency in the history of worker's doses.

2. MATERIALS AND METHOD

All records of accidents in industrial radiography, of all the companies that provide such service, which were included on their licensing and monitoring processes performed by the Brazilian regulatory agency, which is the CNEN, from 2005 to 2010 were analyzed. Important information was extracted and compiled in order to facilitate a thorough and accurate analysis on the most frequent and more relevant features of those accidents.

The characteristics of the accidents in industrial radiography were listed as follows: date of the accident, day of the week, shifts, type of installation, whether open or closed type of radiation source, doses received by the OEIs, whether or not cytogenetic alteration was caused, the actions taken by the RPS to prevent accident recurrence, the action taken by the company in relation to the OEI after the accident and finally, the real causes of the accident.

Finally the rate of growth of the number of sources over those years was assessed and compared with the rate of growth of number of accidents and a relation was established.

3. RESULTS

3.1. Date of accident

The accidents were classified by company, grouped into years and every year, the date of the accident was recorded as well as the characteristics of the accidents. In this way, the results of all the companies were compiled in a single spreadsheet, divided into years, keeping the characteristics of the accidents of all the companies for each year, as follows:

3.2. Days of the week

The frequency of the accidents occurred from 2005 to 2010 were added, as shown in Fig. 2, and the trend line was drawn.

It is possible to observe that the frequency of accidents begins high on Mondays and declines almost linearly during the week. This behavior may be attributed to the fact that the OEI mended a week of work in the next, being physically and psychologically exhausted to restart a new workweek, without a weekend break to rest with the family. But the reverse case is also possible, for having spent the weekend resting; they are not alert at work on Mondays. In this case, they become aware of their responsibilities in the course of the week.

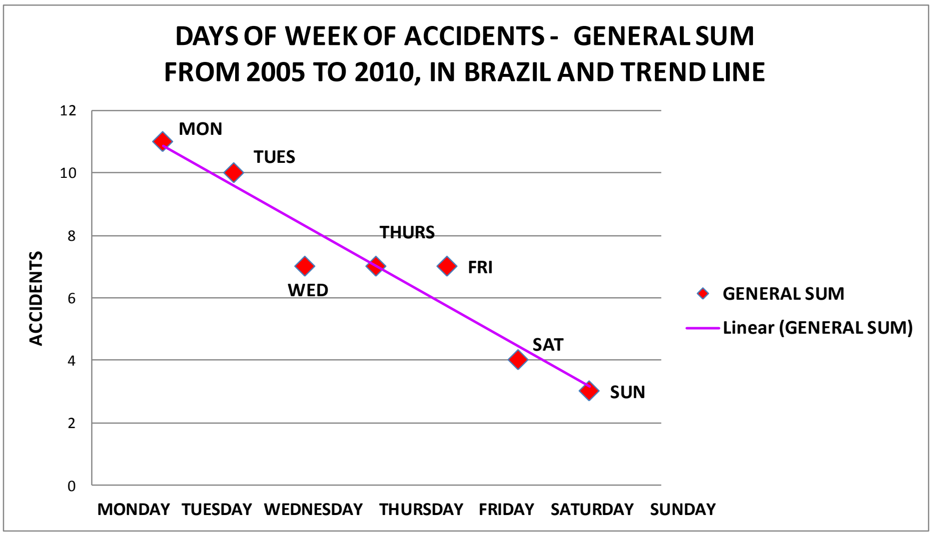

Figure 2: Frequency of accidents per day of the week, from 2005-2010.

3.3. Shifts

Fig. 3 presents the frequency of accident occurrence per shifts: morning (06:01h – 12:00h), afternoon (12:01h – 18:00h), night (18:01h - 24:00h) and graveyard shift (00:01h – 06:00h).

Adding the results of all the years and drawing the trend line, we observe that the frequency of accidents increased during the day, with higher number at night to decrease again at dawn. This behavior can be explained because most industrial radiography service providers are asked to perform their work on the companies that contract them, during the night, to protect the employees from radiation, once they will be absent and also to facilitate demarking of the area, without impairing the company production. Thus most services are performed at night. During the day, services are mostly executed at the company bunker. In this way, we concluded that most services are performed at the contracting companies and accidents were more frequent during the night shift.

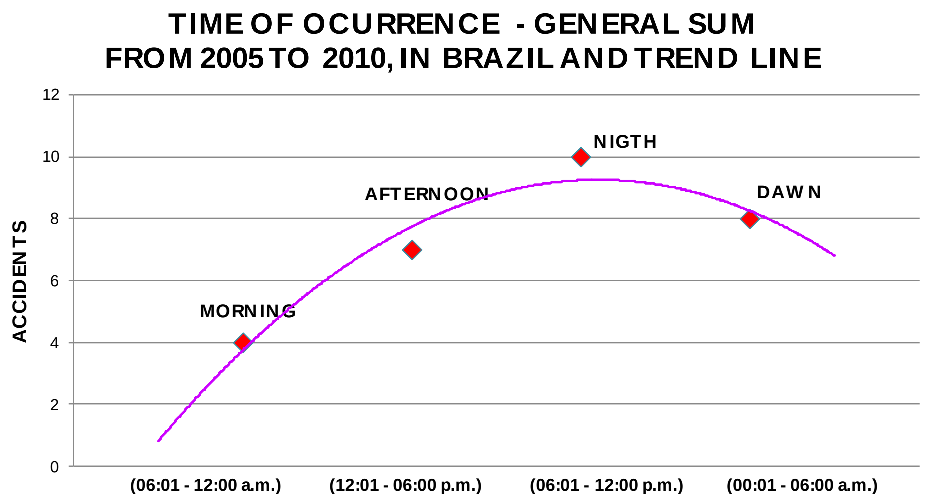

Figure 3: Frequency of accidents per shift, from 2005-2010.

3.4. Type of Installation

There are three main types of installations for industrial radiography. Closed installation is called bunker and comprises a physical structure to protect OEIs and individuals from the public at a certain distance. There are two types of open installation: one within the company and another in specific urban or rural areas, where radiographs are taken in the middle of the sidewalks, streets, close to shops, bus stops, public phones, houses, farms, animals or schools for example. In both cases, lead screens to shield part of the scattered radiation, a collimator to narrow the scattered radiation beam and area demarcation are used.

Fig. 4 shows that in 2008 and 2009 there was an increase of accidents in open installations of contracting companies, with less frequency in bunkers of service providers and still less in open installations in urban areas.

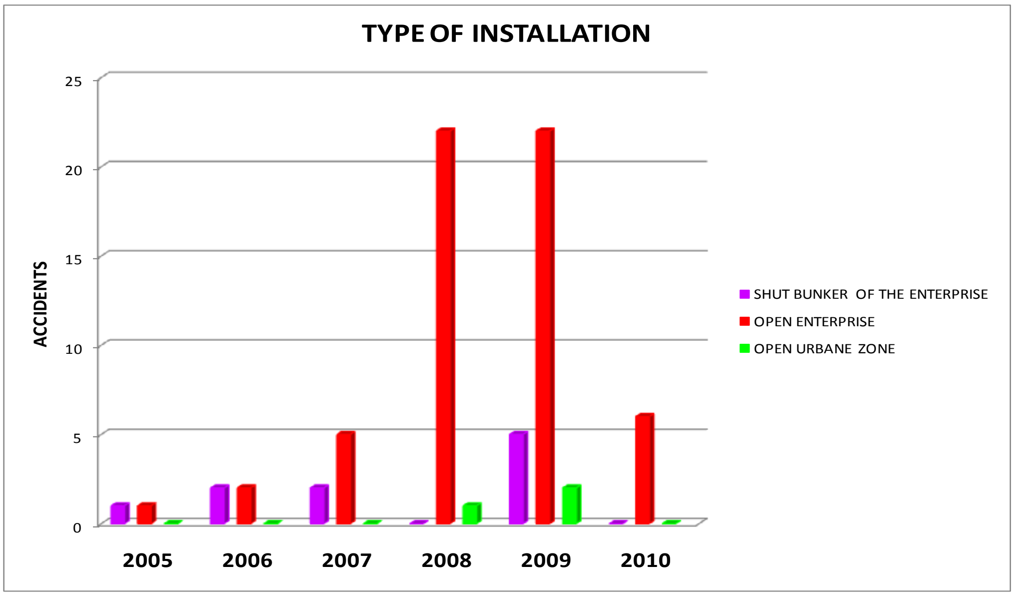

Figure 4: Frequency of accidents in open installations in contracting companies and urban zones and service provider bunkers during the years of 2005, 2006, 2007, 2008, 2009 and 2010.

It is possible that the high frequency of accidents in open installations at the contracting companies is explained by the absence of supervision, and consequent relaxation of good radiological protection practices, signaling the necessity of audits to control the quality of services and radiological protection.

3.5 Types of Radiation Sources

The types of radiation sources used in industrial radiography are radioactive sources and X-ray equipment. The radioactive sources most frequently used in Brazil are Ir-192, Se-75 and Co-60, where de type of source it is chosen in accordance with to the thickness of the pieces to be inspected and their activities were classified in this study as < 20 Ci to < 100 Ci, in 20 Ci intervals and > 100 Ci. The accidents were added over the years 2005 to 2010 and Fig. 5 shows that they occurred with higher frequency when Ir-192 was used with average activity

> 40 Ci and < 60 Ci. This is explained because about 80% gammagraphy are performed with Ir-192 in Brazil.

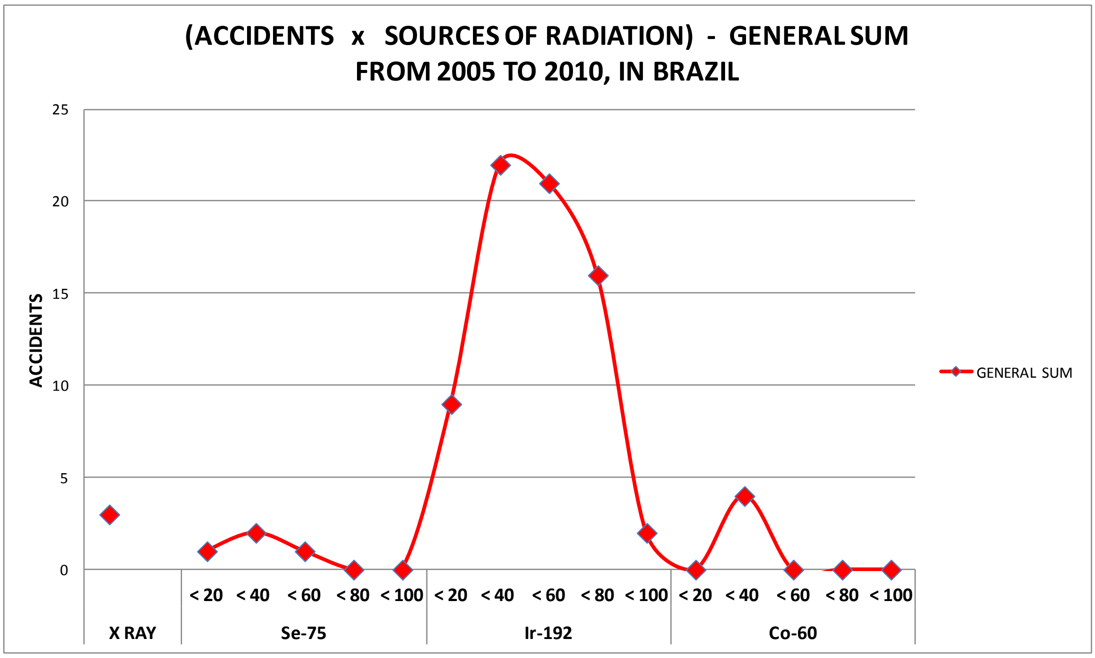

Figure 5: Frequency of accidents with radiation sources: X-ray, Se-75, Ir-192 and Co-60, from 2005 to 2010.

3.6. Dose Received by the OEI

Most of the doses received by the OEI, did not surpass the 5-year average annual limit which is 20 mSv. In some cases this limit was surpassed reaching a dose value of 30 mSv, but without causing harm to the worker. An accident occurred with around 80 mSv, and another with around 100 mSv and still another above 100 mSv, but those three accidents were really incidents because the worker did not receive the dose and the cytogenetic examinations presented no alterations. The reason of the accidents was the loss or forgetfulness of the dosimeter near the source during a certain time. In Fig. 6, the doses received by the OEIs are classified from < 5 mSv to < 100 mSv, in 5 mSv intervals, and >100 mSv.

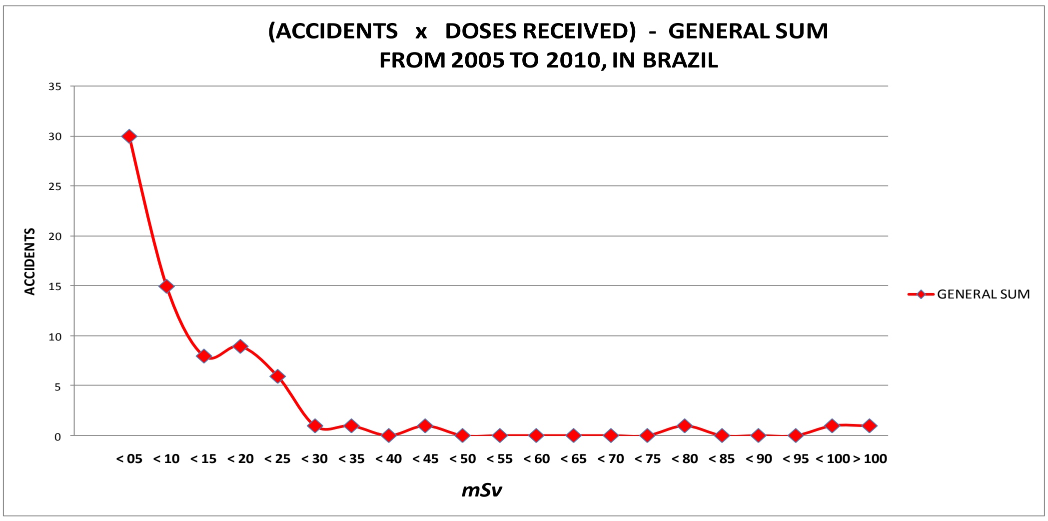

Figure 6: Most frequent doses in accidents from 2005 to 2010.

3.7. Cytogenetic Alterations

There is not a direct and objective relationship between deterministic effects and low doses, it is only possible to say that they are stochastic effects and that we can only expect a cytogenetic alteration observed in blood mapping. When these doses exceed the value of 100 mSv and are received in a single time, during an industrial radiography accident, a cytogenetic alteration may be expected, but there are no studies determining the dose threshold above 100 mSv, from which cytogenetic alterations are observed in industrial radiography practice.

It is necessary to follow-up severe cases where the doses exceed 100 mSv and that are real accidents, when the employee receives the dose.

Fig. 7 presents the results and shows that there was not a single case with cytogenetic alteration, which might be expected for accidents with doses above 80 mSv, when they were real.

3.8. Measures taken to prevent other accidents

Companies usually adopt three types of measures: talking, refreshing and practical test.

Talking is most usually employed when an incident and not an accident occurred. In this case the OEI may have forgotten his personal dosimeter near the source, sometimes attached to the coat which was left inside the bunker or then thrown on top of the metallic box used to transport the irradiator.

Refreshing occurs when an accident actually occurred and the OEIs did not demonstrate sufficient qualification to perform the rescue or bring the situation back to normality, when they were not submitted to high doses or when there was relaxation of good radiation protection practices. This refresher training is more effective when it is accompanied by a practical test, where an accident is simulated with a low activity source, called cold source, and the OEIs undergo practical training, performing the rescue as quickly and efficiently as possible, so they are trained to receive the lowest possible dose in the case of a real accident.

Fig. 7 shows that the measure applied more often during all those years was the refreshing training. Talking was less used although it is known that most of the recorded accidents were actually, incidents. This reinforces the conservative attitude adopted by professionals in radiation protection in Brazil, giving up hours worked that would be converted into money for the company changing them into class hours. An issue that deserves more attention is the extent to which refresher training will be effective as the only measure to prevent accidents, over the years and with the increase of radiation sources in operation in Brazil.

3.9. Measure taken with the OEI

After an accident, the worker is temporarily removed from work with the radiation source, his personal dosimeter is sent for reading and the worker is sent to a complete blood count-CBC to verify if there was a decrease in the number of plaques caused by the dose he received. When there is a decrease in the number of plaques of de blood, and the dosimeter confirms a dose received, the worker is sent to perform a blood cytogenetic mapping.

The company does not punish the worker if the CBC shows no alteration.

After a real accident, the worker is temporarily removed from work with radiation sources, complementary examinations are conducted, and if they prove cytogenetic alterations and the dosimeter shows high dose, the worker is removed from work with radiation sources until his annual accumulated dose decreases.

The company also applies the punitive measure of dismissal if the employee neglects his employment contract and is legally authorized to make the resignation.

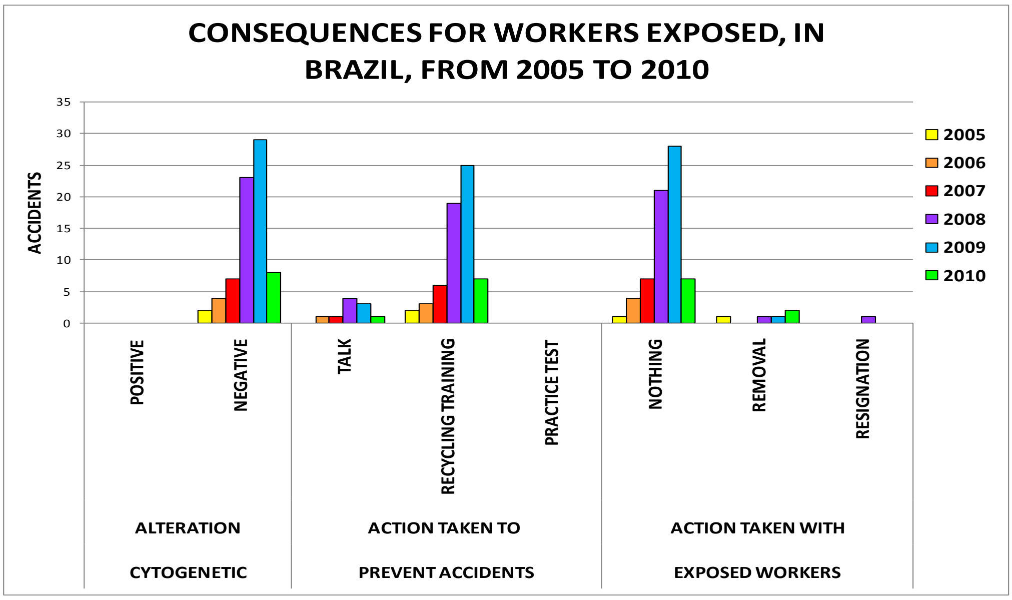

Figure 7: Consequences for the workers after the events from 2005 – 2010.

Fig. 7 shows that a punitive measure was not applied in most cases of accidents, once the doses absorbed by the workers in most of the accidents that occurred during that period were small and did not cause cytogenetic alterations. Workers were removed from their work with radiation sources for a longer period than expected for exams, when the dose absorbed exceeded the annual limit of 20 mSv. But these cases were so few, that the low frequency of removal is explained.

3.10. Causes of the Events

The knowledge of the real causes of the events confirmed by the estimates of doses received in personal dosimeters, laboratory examinations and additional, allowed to suggest an accident classification as function of the degree of risk. Seventy-six events occurred from 2005 to 2010.

The analysis of those events showed that 38 were real accidents, with 25 due to source loss and procedure for its recovery, 9 accidents were caused by negligence of the workers, with relaxation of the good radiological protection practices provided in Standard-CNEN-NN.6.04, 1 accident occurred because of negligence during irradiator maintenance, 1 accident because the area was not demarked as necessary for workers protection because of confined space and 2 accidents occurred because the source was not completely retracted into the irradiator shielding and the workers did not hear the individual monitor with audible alarm (bip) because of the excess of noise in the middle of the boilers. In these events the workers received the highest doses of this survey. They may be classified as property damage accidents, because in those cases, the dosimeter is sent for reading in advance, the irradiator suffers maintenance, the irradiator operation is interrupted and the work suspended, an investigation report must be provided and sent to CNEN, among others.

Unfortunately, 25 accidents with very low doses (below 5 mSv) occurred but the radiation protection supervisors did not find the causes of the events. These cases include those that occurred with X-ray equipment and the workers must have received those doses. They may be classified as property damage accidents, once the real cause of the accident is unknown, the operation of the irradiator is interrupted and the work suspended, the dose surveillance report must be provided and sent to CNEN, among others.

Of the 22 remaining events from 76, 18 were due to forgetfulness or loss of the dosimeter close to the source, 2 to sabotage of the personal dosimeter, 1 to loss or theft of the irradiator inside the factory, 1 to the murder of a worker who deviated from the original route approved by the company and was shot inside the car where the irradiator and the radioactive source were. The car, with the irradiator and the source, remained parked at the police station for a few hours. The workers did not receive any dose during those events. They can be classified as near misses or incidents.

3.11. Growth of the number of radiation sources and accidents in Brazil from 2005 to 2010

Fig. 8 presents the growth of the number of radiation sources used in industrial radiography and authorized by CNEN, from 2005 to 2010, divided in two groups, X-ray and radioactive Ir-192, Se-75 and Co-60.

The number of X-ray equipments remains constant over the years and there were very few cases of accidents with this type of equipment. Although the X-ray equipment cannot be discarded from this study, it is clearly noticeable that most accidents occur with radioactive sources and that they add a much greater risk to the practice of industrial radiography. Due to its low risk, the amount of X-ray equipments was not considered in the final analysis of results (Fig. 9).

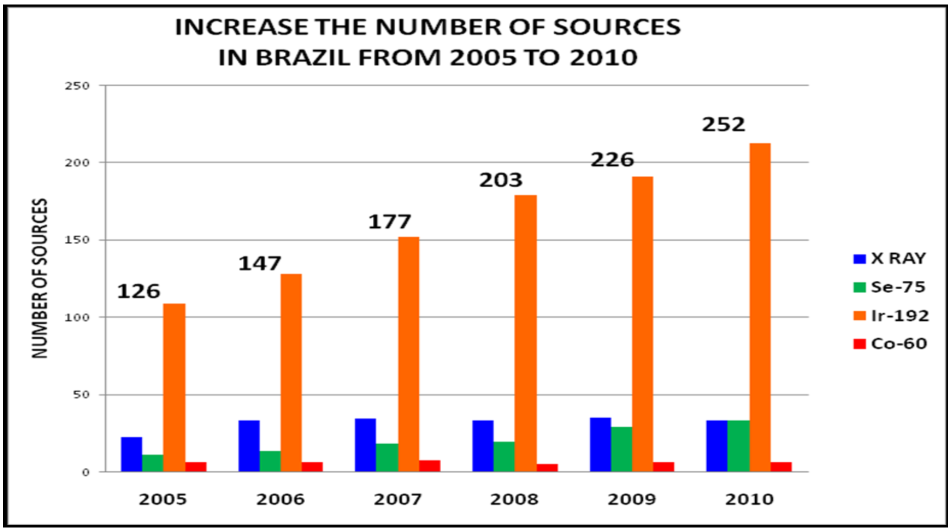

Figure 8: Increase of the number of authorized sources in Brazil from 2005 to 2010.

It is also possible to observe, that there was a small growth of the number Se-75 sources, over this period and that the number of Co-60 sources remained constant while the number of Ir-192 sources grew markedly and linearly from 2005 to 2010. The sum of Ir-192, Se-75 and Co-60 sources in every year shows that the total number of sources in 2005 was 126 and in 2010 this number doubled to 252 sources.

The conclusion of this study is presented in Fig. 9, which shows the total number of radioactive sources and the trend line, described by equation 1:

$$F = 25.51t + 99.2 \quad (1)$$

where: F – number of sources,
t – time in years.

The total number of real accidents and incidents is presented in Fig. 9, for each year and the trend line is described by the equation 2:

$$A = 3.371t + 0.2 \quad (2)$$

where: A – number of accidents,
t – time in years.

This led us to conclude that the ratio between the rate of growth of the number of sources and the rate of growth of accidents was equivalent to a factor of 7.57, from 2005 to 2010. This indicates there was an increase of one accident or incident for every 7 or 8 new authorized sources.

Fig. 9 also shows that there was a significant increase in the number of accidents in 2008 and 2009, with 23 and 31 accidents, respectively, and a sharp decrease in 2010, when only 9 accidents were recorded. This indicated that the accident preventive measures adopted by the industrial radiography service suppliers were efficient.

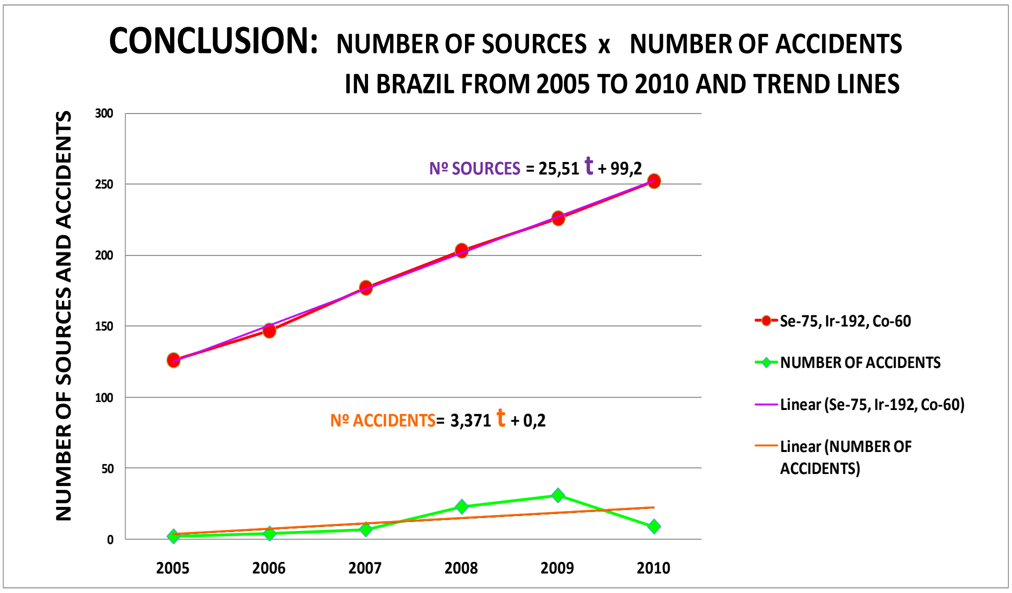

Figure 9: Growth in the number of sources from 2005 to 2010.

The calculated ratio is fundamental for controlling the accidents in industrial radiography, during the next years, because a decrease of this ratio will indicate that the number of accidents is increasing in relation to the number of sources and may be used as parameter to indicate that new radiation protection measures must be provided in the practice of industrial radiography to avoid that Brazil is included in the history of accidents in industrial radiography as is the case of Peru (1999), Bolivia (2003), Chile (2005), Equator (2009), Venezuela and Argentina (2010), but unfortunately there are no references.

4. CONCLUSIONS

This study suggest an initial classification of accidents in industrial radiography as a function of their risk potential and that further studies should be undertaken in other industrial or medical areas that use radiation sources.

The frequency of accidents was high on Mondays and Tuesdays decreasing almost linearly towards the end of the week, Saturday and Sunday. This behavior may be attributed to the fact that the OEIs were exhausted because of continuous work or that they began the workweek with lack of attention and only became conscious of their responsibilities over the week.

Accidents were more frequent during the night shift (18:01h – 24:00h) and in open installations, of contracting companies, because the greatest flow of work of the industrial radiography service providers is on such companies and usually the service is performed at night, when their employees are not around. The high frequency of accidents in those open installations indicates the need for audit of the industrial radiography service providers, during the night shift.

Most of the accidents occurred with Ir-192 source, with average activity > 40 Ci and < 60 Ci. This is because about 80% gammagraphy in Brazil are performed with Ir-192.

Most of the doses received in Brazil were below the annual limit of 20 mSv, with few cases reaching 30 mSv, but without worker injuries. Since most of the accidents were with low doses for the workers, cases with cytogenetic alterations were not observed.

The accident preventive measure most frequently applied over all those years was refreshment training, despite the high number of incidents.

In most of the cases of accidents, a punitive action was not taken, because most accidents were with doses below 30 mSv, and they did not result in cytogenetic alteration.

There were 76 events, with 38 real accidents, the workers received the highest doses of this survey and they may be classified as property damage accidents because the work was interrupted.

Unfortunately, 25 accidents with very low doses (below 5 mSv) occurred but the radiation protection supervisors did not find the causes of the events. In those cases it is considered that the workers received the doses and the accidents are classified as property damage accidents because work was interrupted.

The workers did not receive any dose in the 22 remaining events from76 which can be classified as near misses or incidents.

From 2005 to 2010, there was a slight growth in the number of Se-75 sources, the number of Co-60sources remained constant while the number of Ir-192 sources rose sharply and linearly. The sum of all the sources each year showed that the number of sources doubled in 2010.

We concluded that the ratio between the rate of growth of the number of sources and the rate of growth of accidents is equivalent to a factor of 7.57, from 2005 to 2010. A decrease in this ratio indicates that the number of accidents increases in relation to the number of sources and can be used as a parameter to indicate that new radiation protection measures must be provided in the practice of industrial radiography to prevent serious accidents in Brazil.

REFERENCES

1. HEMÉRITAS, Ademar Batista. *Organização e Normas*. São Paulo, Brasil, p.89-104, 1981.
2. SOTO, José Manoel Gama. "O problema dos acidentes do trabalho e a política prevencionista no Brasil". *Revista Brasileira de Saúde Ocupacional*, São Paulo, Brasil, v.6, n.21, p. 23-28, 1978.
3. LEI 6.514, *Ministério do Trabalho*, Brasil , D.O.U. , 1977.
4. PIZA, Fábio de Toledo, *Informações Básicas Sobre Saúde e Segurança no Trabalho*. São Paulo, Brasil, 1997.
5. ANEXO 5, *Radiações Ionizantes*. NR 15, Atividades e Operações Insalubres, Ministério do Trabalho. Portaria nº 3.214, Brasil, D.O.U., 1978.
6. CNEN-NE.3.01. *Diretrizes Básicas de Radioproteção*. Brasil, D.O.U. , 1988.
7. CNEN-NN.3.01. *Diretrizes Básicas de Radioproteção*. Brasil, D.O.U., 2005.
8. CNEN-NN.6.04. *Funcionamento de Serviço de Radiografia Industrial.* Brasil, D.O.U., 1989.
9. BIRD JR., Frank. *Management Guide to Loss Control*. Institut Press, Georgia, p. 243, 1974.
10. OLIVEIRA, Wilson Barbosa. Programas de Segurança Baseados na Prevenção e Controle de Perdas. *Curso de Segurança, Saúde e Meio Ambiente* – Petrofértil, Brasil, 1991.
11. ANSELL, Jake, WHARTON, Frank. Risk: *Analysis Assessment and Management*. John Wiley & Sons Ltda - England, p. 220, 1992.
12. DE CICCO, Francesco, FANTAZZINI, Mario Luiz. *Introdução à Engenharia de Segurança de Sistemas*. 3 ed. Fundacentro - São Paulo, Brasil, p. 113, 1993.