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Analysis of the external doses received by workers involved in the mitigation of the Goiania radiological accident

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ABSTRACT

In 1987, after identification that a stolen head of a ^{137}Cs radiotherapy irradiator was violated, it started, in Goiania, the screening of the involved persons, the decontamination and the collection of the radioactive waste. The contaminated areas were isolated and the professionals who worked within these areas received individual film monitors and TLD rings, provided by the *Instituto de Radioproteção e Dosimetria* of the *Comissão Nacional de Energia Nuclear* (IRD/CNEN), to evaluate their external dose. The aim of this paper is to present a statistical analysis of the external occupational doses received by this intervention staff. The used data were extracted from the Goiania accident database, maintained by IRD/CNEN. 1091 workers were monitored, some for only a few days and others for almost one year. All the total external occupational doses, received during these works, including the management of the radioactive waste, were lower than the individual annual dose limit of 50 mSv for practices. Only one dose exceeded the value of 20 mSv. Their estimated mean effective doses were about 1.0 mSv, which is the annual dose limit for public exposure. About 80% of the doses were lower than this value. The measured extremity doses were even lower than the measured whole body doses values.

Keywords: Goiania radiological accident, external occupational dose, intervention work, dose limits.

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1. INTRODUCTION

As it is well known, in 1987, it happened, in the city of Goiania, Brazil, one of the world's worst radiological accident. On September 13, a shielded radioactive caesium-137 source (50.9 TBq, at the time) was removed from its protective case in a teletherapy unit from an abandoned clinic. In the attempt, the source capsule was ruptured. The scavengers, who stole this capsule, broke its iridium window, allowing high gamma radiation and a beautiful blue light to escape from the source inside it. Thus, the capsule appears to contain very valuable material, so it was broken into pieces. Some of those pieces were sold to a junkyard, and others were used for decorative and magical purposes. Fragments of the source the size of rice grains were distributed to several families. The radioactive source was in the form of caesium chloride salt (93 grams), which is highly soluble and readily dispersible. The ^{137}Cs was encased in a shielding container made of lead and steel. The International Atomic Energy Agency (IAEA) describes this container – 51 millimetres in diameter and 48 mm long – as an "international standard capsule". The dose rate at one meter from the source was 4.56 grays per hour. Contamination of the environment ensued, with one result being the external irradiation and internal contamination of several persons, before recognition of the radiological accident [1,2].

Many individuals incurred external and internal exposure. In total, some 112 000 persons were monitored, of whom 249 were contaminated either internally or externally. For external irradiation, cytogenetic analysis was very helpful in distinguishing the severely exposed persons from those less. More than 110 blood samples from persons affected by the accident were analysed by cytogenetic methods. The dose estimates varied from zero up to 7 Gy [3]. Twenty individuals needed medical care. Ten of them had extensive decontamination and radiation-damage treatment and four have died within one month [1].

A local physicist was the first to assess, by monitoring, the scale of the accident and took actions on his own initiative to evacuate two areas. At the same time the authorities were informed, upon which the speed and the scale of the response were impressive. The IAEA states that it had been recovered about 44 TBq of ^{137}Cs during the clean-up operation, which represents 87% of the total contamination. This means that 7 TBq remained in the environment; it must have decayed to about 3.5 TBq in 2016.

The actions taken to clean up the contamination can be divided into two phases. The first phase corresponds to the urgent actions needed to bring all potential sources of contamination under control. The second phase, which can be regarded as the remedial phase aiming to restore normal living conditions, lasted until March 1988. In the first phase, action levels were set:

- For control of access - 10 μSv/h;
- For evacuation and prohibited access -2.5 μSv/h;
- For houses - 10 μSv/h;
- For unoccupied areas - 150 μS/h; and
- For workers participating in the accident management – normal occupational dose limits and corresponding dose rates per day, week and month.

In total, 85 houses were found to have significant contamination, and 200 individuals were evacuated from 41 of them. After two weeks, 30 houses were free for reoccupation. It should be emphasized that these levels, which correspond roughly to one tenth of the lowest values of the intervention levels recommended by the International Commission on Radiological Protection and the IAEA (non-action levels), were extremely restrictive, owing to political and social pressures.

The remedial phase, consisting mainly of actions undertaken for recovery, faced various difficulties in surveying the urban area and the river basin. Instead of being washed out as expected, radioactive materials were deposited on roofs, and this was the major contributor to dose rates in houses. Levels of contamination in drinking water were very low. The groundwater was also found to be free of contamination, except for a few wells near the main foci of contamination with concentrations of caesium just above the detection level. The main countermeasures undertaken during this remedial phase were the decontamination. For decontamination at the main foci, heavy machinery was necessary to remove large amounts of soil and for the demolishing of seven houses. The investigation levels selected for considering the various actions corresponded to a dose of 5 mSv in the first year and a long term projected dose of 1 mSv per year in subsequent years. Of 159 houses monitored, 42 required decontamination. The action levels for these remedial actions were selected also under strong political and public pressures. The levels were set substantially lower than would have resulted from an optimization process. In most cases, they could be regarded as more applicable to normal situations than to an accident recovery phase. After the Christmas holidays in December 1987 the areas of lower dose rate surrounding the main foci were decontaminated. There was no need for heavy machinery, and optimization procedures were developed and adopted. This stage lasted until March 1988. The large quantities of radioactive wastes generated were kept in a temporary waste storage site 20 km from Goiania. The total volume of waste stored was 3500 m^3. The economic burden of such levels, especially in the latter phase, is far from insignificant. Only in 1997, the temporary deposit became definite, with several modifications as new cases for the radiological waste and a grounding of them, creating a garden park on top.

Hundred of workers were needed for these decontamination tasks. They were allocated in many places and they had different expertise and experience. Of these workers, only 262 had previously worked in or had received some training in radiological protection work. Personal dosimetry for all these workers was made by the Instituto de Radioproteção e Dosimetria of the Comissão Nacional de Energia Nuclear (IRD/CNEN) at Rio de Janeiro city. This paper presents a statistical analysis of the external occupational effective doses received by the staff called to perform all the tasks during the emergency response after the radiological Goiania accident from September 1987 to the end of 1988. In 1988, the tasks were performed in the temporary waste deposit.

2. MATERIALS AND METHODS

IRD/CNEN operated, from 1972 to 2016, a routine individual monitoring service for photon whole body dosimetry using the film technique and, up to now, a photon extremity monitoring service with TLD rings [4]. Since the 80s, the film dosemeter was a plastic badge with four different metal filters and a 3 cm x 4 cm Agfa personal monitoring film detector composed of two photographic emulsions with different sensitivities. This individual film dosemeter is shown in Figure 1. The IRD/CNEN film individual monitoring service was one of the Brazilian authorized service providers in 1987. The operational quantity evaluated by all authorized photon whole body individual monitoring services was the photon dose equivalent, H_x. Their measurements are traceable to the national air kerma standard.

The IRD/CNEN extremity individual monitoring service uses a TLD ring individual dosemeter with one LiF:Mg, Ti TLD chip (TLD100) inside a disposable plastic homemade adjustable finger ring as shown in Figure 2. The measured operational quantity is the personal equivalent dose at 0.07 mm depth, $H_P(0,07)$, which is also traceable to the national air kerma standard. Up to now, there is no regulation for extremity individual monitoring service in Brazil.

Figure 1: *IRD/CNEN film dosemeter.*

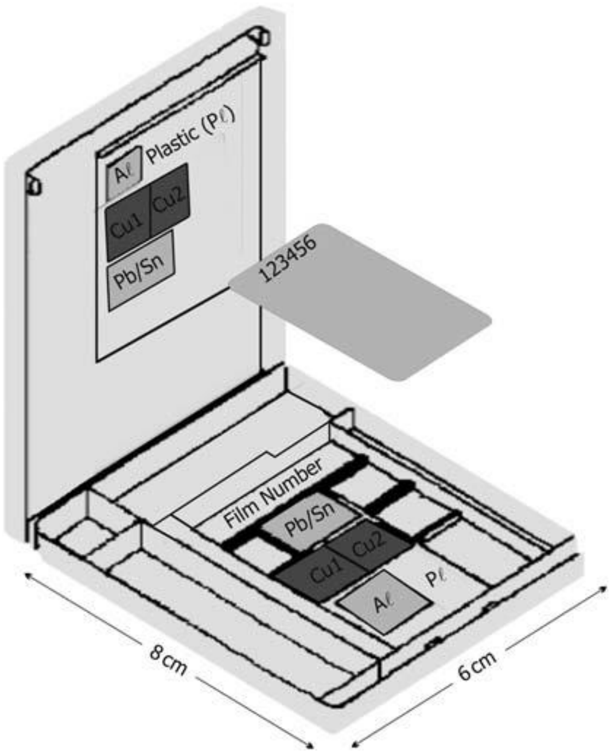


Figure 2: *IRD/CNEN TLD ring dosemeter.*

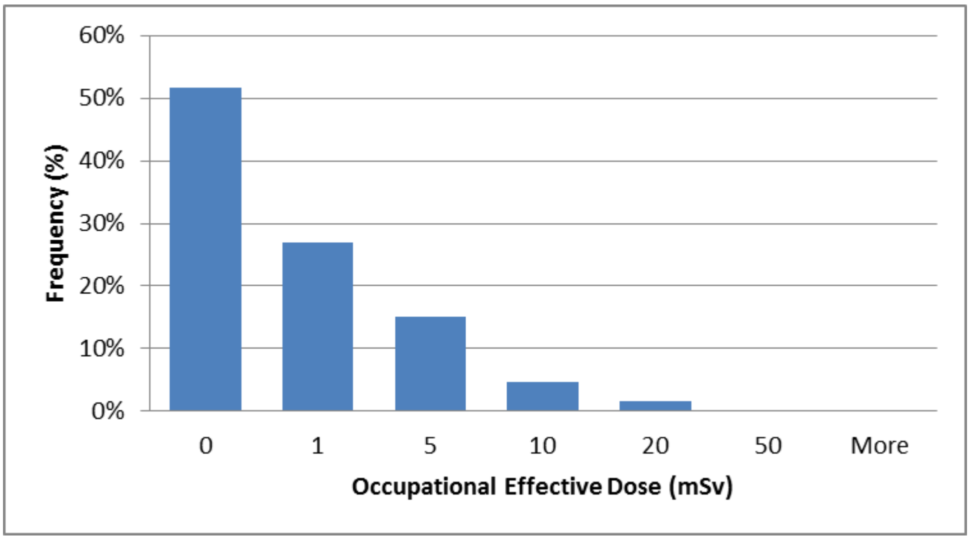
After the identification of the Goiania radiological accident, IRD/CNEN was in charge of monitoring all workers called to participate in the intervention activities, with film whole body and TLD extremity dosemeters. They were changed after one month of use or at the end of a specific work. For another different task, new dosemeters were assigned. The measured doses were stored in a separate database at IRD/CNEN. All data used in this work were extracted from it. There is no information about the function of the workers, or their previous experience, in that database. The external doses were copied to an Excel file and analysed using the dynamic worksheet tool. Whole body and extremity doses were analysed. In this work, when one member of the intervention staff used the same type of dosemeter for several periods and different activities, their measured doses, for each type of dosemeter (film thorax or TLD ring), are summed. The Goiania accident occupational dose database contains doses from September 1987 to the end of 1988. From April 1988 onwards, 14 people used the dosemeters only at the temporary repository of radioactive waste.

3. RESULTS AND DISCUSSION

A total of 1091 interventional workers were monitored after the Goiania accident. Their tasks were related to actions to mitigate the consequences of the radioactive dispersion of the ^{137}Cs source released from a teletherapy unit. The total external occupational effective doses received by all these workers were estimated by the use of photon whole body film dosemeters. All of their dose values were lower than the individual annual dose limit of 50 mSv for radioactive practices. Only one dose value exceeded the mean annual individual effective dose value limit of 20 mSv, and this dose was received for one specific worker. He worked during the entire year of 1988 at the temporary repository of radioactive waste. The frequency of distribution of the effective dose values received by these workers is presented in Figure 3. About 50% of the monitored workers received whole body doses lower than the monthly record level of 0.2 mSv and about 80%, doses lower than 1.0 mSv, which is the annual effective dose limit for public exposure. Their mean estimated effective doses were about 1.0 mSv.

Only 154 interventional workers used, additionally to the whole body dosemeter, dosimetric rings to estimate their extremity dose equivalent. The measured extremity doses were even lower than the effective doses. 67% of them were lower than the record level of 0.2 mSv and about 3% of them higher than 2.0 mSv, being the highest value of 9.1 mSv, which was lower than the whole body measured value for the same work. Only about 6% of the extremity dose where higher than the whole body doses, but none of them by a factor higher than 3.

Figure 3: *Histogram of the measured external doses received by the Goiania accident mitigation workers.*



Although the internal dose has not been the subject of evaluation of this study, it was verified that only one of the 20 workers, who received the highest estimated effective doses, was also monitored for internal contamination. Moreover, for all of them, their internal dose was lower than the minimum detectable value.

4. CONCLUSIONS

Intervention works after the Goiania accident did not result in any external occupational dose above the legal annual occupational dose limit. The available data do not allow any further evaluation of the optimization and/or effectiveness of radiological protection planning during the intervention activities after the Goiania accident.

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