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The Cs-137 radiological accident in Goiânia, Brazil: Conditions and results of the airborne radiometric survey

Barretto[a], P. M.C.; da Fonseca[a], E.S.

[a]*Instituto de Radioproteção e Dosimetria (IRD), CEP 22783-127, Rio de Janeiro, RJ, Brazil*

paulobarretto@aol.com

ABSTRACT

This paper describes the details of the aeroradiometric operations, the radiation detection system used and discusses the results. The low-altitude survey was carried out over Goiânia a few days after information of the accident was received by the national competent authority, the Brazilian Nuclear Energy Commission (CNEN). Given the little information at the time of the accident and the urgency to respond to the local and federal authorities, an aerial radiometric survey was proposed to evaluate the extent of the contamination and dispersion of the radioactive powder. The city's entire urban area and nearby dwellings centers, plus the two creeks crossing the city were surveyed in two days. The survey found only one additional contamination point 2.8 x 10^{-4} C/kg/h (1.1 R/h) that had not yet been identified by ground survey crews. Furthermore, no contamination was found along the margins of the Capim Puba Creek and Meia Ponte rivers which could be contaminated due to rainwater common at that time of the year. Detection tests conducted at different altitudes over the main contamination area showed that the Cs-137 gamma radiation could be detected even at altitudes of 350m above the ground. This was much higher than the 40 m - 70 m decided for the overflights. The survey demonstrated that the contamination was restricted to a few locations in the neighborhood of the metal scrap place where the source shield was broken. These locations were under the control of CNEN radiological emergency response personnel. Such a finding was an important indicator to calm down the population and the government authorities. This allowed concentrating attention on the remediation of the known points of high gamma activity.

Keywords: **aeroradiometric, gamma radiation, radiological accident.**

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1. INTRODUCTION

The radiological accident with Cs-137 that occurred in the city of Goiânia in 1987 was described by the International Atomic Energy Agency (IAEA) [1] as one of the world's "worst nuclear disasters" and classified as “Category 5” in the International Nuclear Event Scale (INES). It resulted in four deaths, 249 people directly irradiated, and a large emotional, psychological, and economic impact on the local population [2]. It is unique in two aspects. First, because it took place in the center of a large city, the capital of the State of Goiás, and second, because the source of the radioactivity is a fine and soluble powder, therefore easily dispersed. These two aspects greatly influenced the monitoring and recovery work of the contaminated area. There is abundant information, both historical and scientific, about this accident. Much of it relates to medical aspects and the impact on the environment. However, little is available about the conditions, the limitations, and the results of the aeroradiometric survey that resulted in the definitive discard of the then-dominant perception of general contamination of the city.

As soon as information about the accident reached CNEN, a group of technicians was sent to the city of Goiânia to survey the real situation of the occurrence and identify what type of contamination and dispersion could be expected. The following possibilities were considered:

a)Dispersion by locomotion and social contacts of individuals directly contaminated in the breaking of the capsule containing radioactive material;

b)Dispersion through the sale and transport of contaminated metals and materials existing in the scrapyards involved;

c)Dispersion by local transport by common winds in the region, by rainwater, and infiltration into the soil.

The concern at that time was that considering the seven days that elapsed between the breakage of the capsule with 97 g of Cs-137 salt (13/Sept/1987) and the alert given (19/Sept/1987) associated with the fact that cesium salt is a very thin and soluble powder, the above mechanisms could have spread the radionuclide over a reasonably large area [3]. This indeed happened, as contamination outbreaks began to appear in the Aeroporto and Ferroviários districts. With the intense and constant information about the accident by the media, which was not always correct and sometimes exaggerated (such as comparisons with the Chernobyl accident), quickly, the generalized expectation of the residents of Goiânia was that the entire city was contaminated [2,3]. This included the rivers and drainage, water supply, and agglomeration water supply like the race track, zoo, and schools (Figures 1 and 2). This resulted in a growing panic on the part of the population, leaving their homes for other cities where they were not always welcomed, rejection of local food and clothing, the closing of businesses, and popular demonstrations.

Figure 1: *The large area covered by the radiometric survey and, in the center, the location of the known contamination points at the time of the survey.*

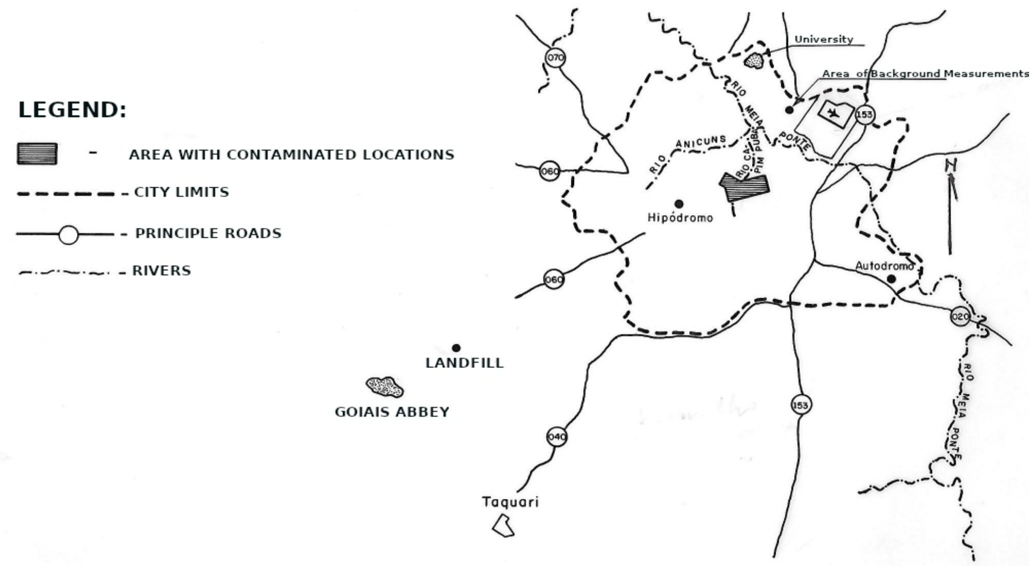
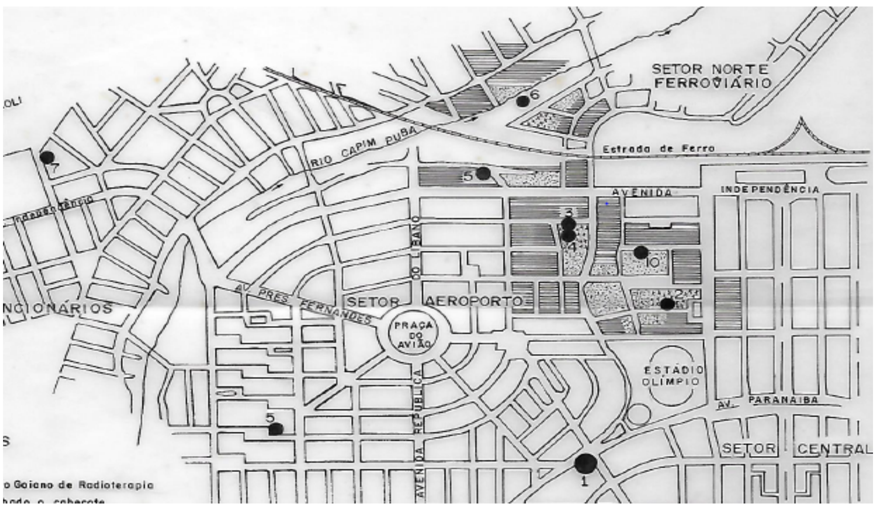


Figure 2: *Main radiation points earlier and under control.*



Thus, it was necessary to make an urgent assessment of the extent and intensity of the contamination. Therefore, it was decided to use the technique of an airborne radiometric survey with the use of a helicopter.

2. MATERIALS AND METHODS

At the time of the accident, neither the CNEN nor the IRD had a radiation detection system dedicated to aeroradiometric surveys or even by surveys by car (an airborne system was improvised later [4]. Additionally, due to the urgency of responding to pressure from the population and the federal government on the level and extent of contamination, it was not possible to hire a company specialized in aerial surveys due to the delay in defining and finalizing a commercial contract. It was, therefore, necessary to improvise with the radiometric equipment and material available at the IRD and which could be quickly transported to Goiânia. The equipment was mounted on a helicopter, model Esquilo, provided by the police of the state of Goiás.

This system consisted of two portable gamma spectrometers, one by model GR-410A and the other by Scintrex model GAD-6, both with gamma energy discriminators adjusted for measurements between 200 to 3000 KeV. As the gamma radiation of Cs-137 is 660 keV, the system was operated with the energy discriminators open. In this way, the entire spectrum above 200 keV was considered. A third spectrometer, also a Scintrex model GAD-6, owned by the Instituto Astronomico e Geofísico (IAG) at the University of São Paulo, was also installed as backup equipment. To record the gamma spectrum, a two-track analog recorder, model Primeline from SOLTEC, was used (Figures 3 to 5). The flight team consisted of a pilot and co-pilot of the federal police of the state and the two authors, employees of CNEN-IRD, as operators of the equipment (Figure 6).

The entire system above, including the recorder, was powered by l.5V batteries to work independently and without interference from the aircraft's electrical system. The detectors were fixed to the floor of the helicopter, away from the aircraft structure to minimize shielding effects. The electronics of the spectrometers (power supply and multichannel analyzer) were placed on the rear seat, and the recorder was placed under and behind the pilot/co-pilot seats. After the installation, tests were carried out to verify their proper operation.

Figure 3: *The portable two-channel analog recorder.*

Figures 4 and 5: *Position of the detectors on the shock-absorbing cushion, the spectrometer console and auxiliary equipment.*

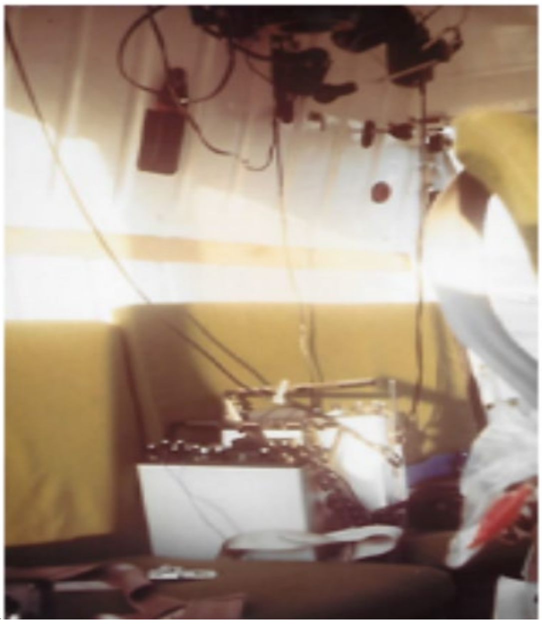
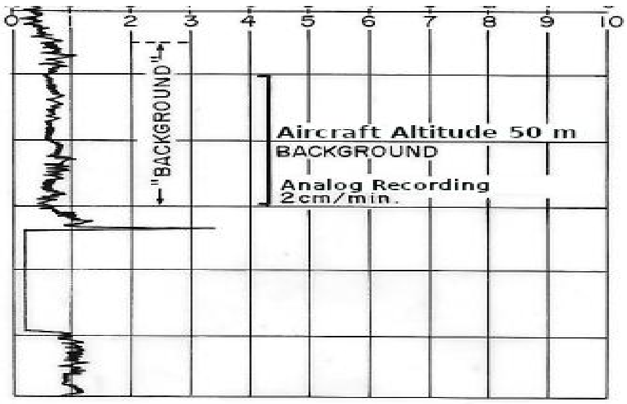


Figure 6: *The helicopter pilots, the mechanic (center), and the CNEN-IRD operators of the radiation equipment (left and right sides).*

2.1. Parameters for radiometric measurements

The first step was the determination of the regional background for and reference for the subsequent radiometric measurements. A strip of vacant land over 6 km long was selected, located to the northeast of the airport, where test flights were carried out at 50 m and 100 m in height. This land strip would then be flown over, with reference, before each production flight (Figure 7).

Figure 7: *Local radiation background at 50 m height.*



Considering (1) the height of the city buildings, (2) the urban flight conditions, and (3) the desired sensitivity (an attenuation by the atmosphere of up to 50% of the intensity on the ground. The following parameters were calculated for the production overflights whenever possible:

- Flight height between 40 m – 70 m;

- Aircraft speed less than 100 km/h.

Seventy meters would be a reasonable height in terms of flight safety, given the average height of buildings in Goiânia (Figure 8). Next, a point with known contamination were flown over to validate these considerations (Figure 9). Helicopter height and speed controls were performed by the aircraft instruments and navigation was visual (the helicopter did not have a radar altimeter).

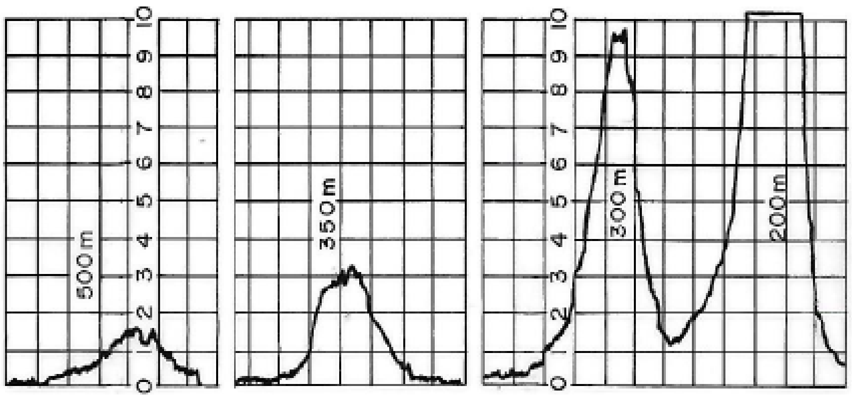
Figure 8: *Relative altitude positioning of the helicopter with the buildings in downtown Goiânia.*

The possible dispersion of cesium by the helicopter-caused wind was considered at the time. Although dispersion could occur this possibility would be minimized by the following factors: (1) the accident happened during the rainy season and indeed heavy rains caused much damage in the city as noted by local news; (2) due to the cesium solubility and the clayey nature of the local soil, most of the cesium was likely trapped in the soil; and (3) by avoiding to fly over the already-known hot spots except in few cases as the flights over the Ferro Velho to check the equipment sensitivity at different heights.

This being the first time that such a detection system was used for this purpose [5,6], the question remained whether the sensitivity of the set would have the desired sensitivity. In this case, the sensitivity would depend on factors such as aircraft speed, detector volume, flight height, and the geometry/position of the source and detector. The answer was to carry out a test with overflights, at various heights, over the metal scrap collecting site known as “Ferro Velho” on Street 15-A, close to the Capim Puba stream. Figure 9 is a graphical reproduction of the recorded radiation in overflights of this site contamination at 200, 300, 350, and 500 m. Under these conditions, the intensity fraction at those heights was respectively 0.03% and 0.01% of the measurements on the ground.

The first step was the determination of the regional background for and reference for the subsequent radiometric measurements. A strip of vacant land over 6 km long was selected, located to the northeast of the airport, where test flights were carried out at 50 m and 100 m in height. This swath would then be flown over, with reference, before each production flight (Figure 7).

Figure 9: *Reproduction of the radiometric records for flights over the "Ferro Velho" at several heights.*



Another issue was to estimate which terrain surface would be covered or "seen" by the detector due to the limitation of flying over a city. The traditional fine-mesh flight mode with equidistant flight lines could not be used. The option was to fly over the streets and avenues as well as along the rivers that cross the city. As much as possible, the distance between the flight lines was maintained at approximately 100 m in the central area of the city (size of the city blocks) and 200 m in the neighborhoods. Under these conditions, the range of undetectable terrain or "seen" by the detector would be, respectively, 20 m and 120 m.

For a flight height of 40 m with a non-collimated detector, the area "seen" by the detector corresponds to a circle of approximately 80 m in diameter at each reading (counting time of 1 second). Considering that the detector moves continuously along the flight line, then the analyzed area would be a strip of 80 m wide in the direction of this flight line. This is valid for the case of an empty terrain surface, that is, devoid of constructions. When there are buildings, as in the case of a city, these constructions act as screens, attenuating or absorbing part of the emitted radiation. This is one of the limitations of the aeroradiometric technique when used in low-altitude flights over cities.

On the other hand, due to the large area "seen" by the non-collimated detectors, the existence of small satellite points, of low activity, close to the main radiation point, could be masked. This does not change the value of the information, as the objective was to identify the contaminated area and not its specific location.

3. RESULTS AND DISCUSSION

Production flights were carried out on October 7th, 8th, and 9th for a total of 110 flight hours. During these three days, the entire urban area of Goiânia, including subdivisions on the outskirts, the Federal University of Goiás (UFG) Campus, the speedway Track (where there was an international motorcycle race on September 27 with a large crowd of people and rumors of contamination), the Government Palace, the Zoo, the Olympic Soccer Stadium, etc. (Figures 1 and 9). Figure 9 shows the respective records of flights over the above city point of public interest. No contamination. In contrast, the flight over the Olympic Soccer Stadium (on the right) which was used in the screening of the population shows a distinct, localized radiometric anomaly.

Figures 10, 11, 12, and 13 are photos of the original recorded radiometric strip chart. They were selected and presented here, rather than their graphical reproduction, as they are rich in details to the expert eye (aircraft speed, approximated size of contaminated area, relative gamma activity comparison with other contaminated spots, and operator's annotations on the chart). This is the first time they are made public. They show the count rates observed by the detectors as recorded in two channels set at different scales.

Figure 10 shows the flight over the metal scrap site at Street 57th. It clearly shows the high activity in this contaminated area as the count rate, in one of the channels (right side), went off the scale. It also shows that there are three hot spots within the contaminated area. It should be noted the confirmation of the anomaly by two over-paths in different directions. Both records were taken with slower helicopter speed (see the one-second reading integration time).

Figure 11 shows the flight over a few subdivisions of Goiania (Vila Novo Mundo, Palmito, Universitário, Vila Osvaldo Rosa, Praça Boa Ventura, and crossing the BR-153) all with normal radiation background except for the very narrow and small size of the newly detected contaminated point at Vila Osvaldo Rosa. Note, in the center of the chart, the confirmation of this anomaly by two additional over-fights. Such immediate confirmation of radiometric anomalies shows the advantage of using a helicopter over fixed-wing aircraft for such kinds of surveys.

Figure 10: *Radiation record over the metal scrap site at 57th Street.*

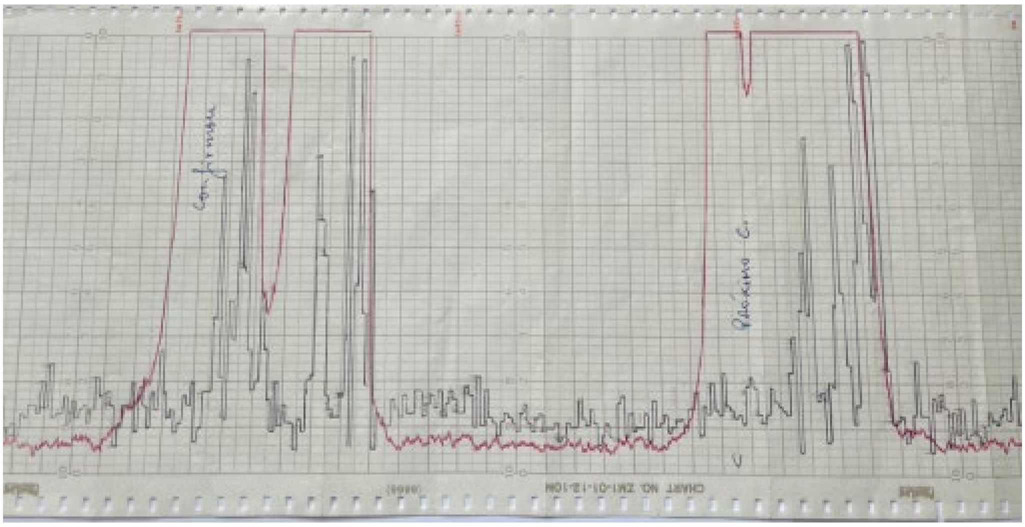


Figure 11: *Vila Osvaldo Rosa anomaly.*

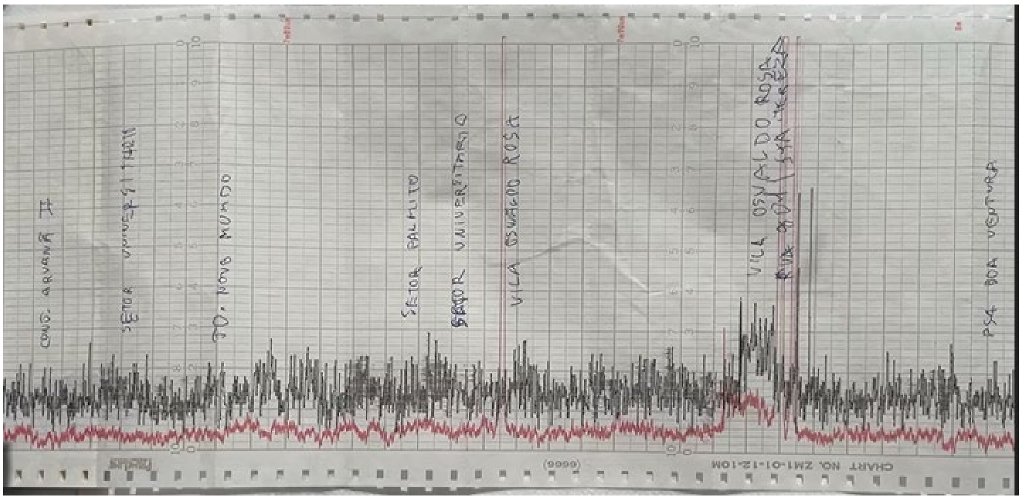
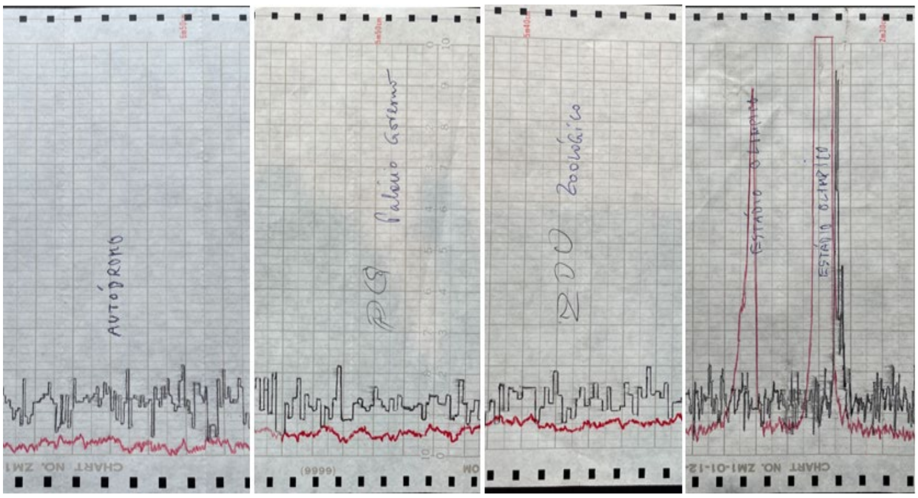


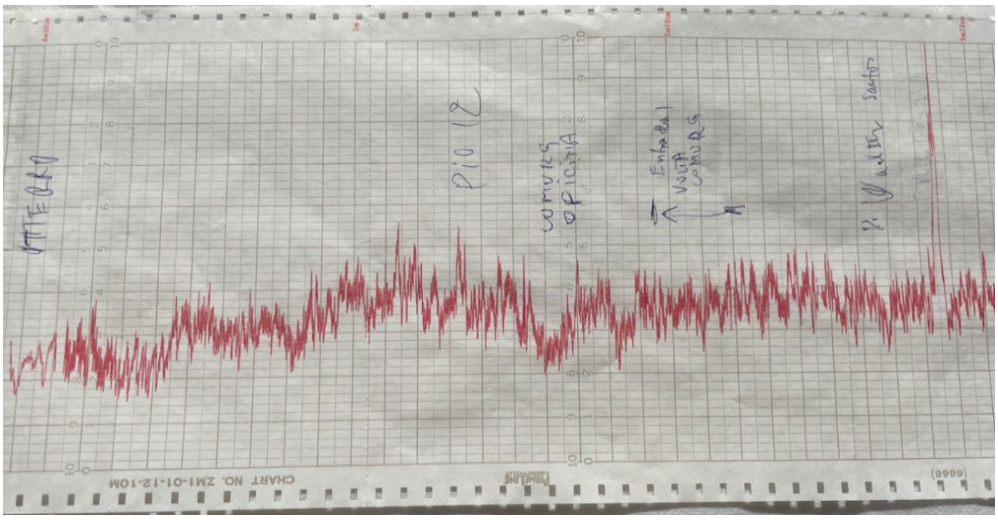
Figure 12 shows the records of flights over the city point of public interest (the speedway, the Governor's Palace, and the Zoo) indicating no contamination. In contrast, the flight over the Olympic Soccer Stadium (on the right) shows a distinct, localized radiometric anomaly. The Olympic Soccer Stadium was used in the screening of the population hence the contamination.

Figure 12: *Radiometric records of Goiânia points of public interest.*



As metal scrap collection points and junkyards are known as places where lost radioactive sources and materials have been found in many countries, the Goiania sanitary landfill (COMURG) was a primary target for investigation. It was also surveyed. However, in this case, only one gamma-ray spectrometer mounted on a field vehicle was used (Figure 13). No radioactive contamination was detected. Also shown in this figure is the background radiation of Pio XII Square and, on the right of the chart, a contaminated point near Walter Santos Square where waste paper collectors used to meet in the evenings.

Figure 13: *Carborne radiometric survey of COMURG landfill and the Walter Santos Square anomaly.*



4. CONCLUSION

The aero radiometric survey of Goiânia fully met expectations, namely, coverage of a large area in a short time. During the two days of flight, approximately 67 million square meters of the urban area of Goiânia were monitored. Only one new focus was found.

1- In this short period, it was possible to confirm that radioactive contamination by Cs-137 was limited to the isolated points already under the control of CNEN. None of the rivers, population centers, or sports centers, was then contaminated. This conclusion, in those early days of the accident, was a dominant factor in reassuring the population and government authorities of the limitation and character of the accident. This made it possible to focus actions on recovering and remediation of the contaminated areas and caring for the persons that were exposed to the radiation.

2- The results indicate that in the case of similar radiological accidents, a sophisticated and heavy airborne detection system is not necessary for rapid identification and delimitation of contamination. This is important information for developing countries where limited resources in radiological monitoring equipment are limited.

3- The results and experience of this survey and the follow-up actions (population screening, caring for exposed personnel, cleaning of contaminated areas, and environment restoration) have direct application in the assessment of the extent and the intensity of the radioactive contamination caused by a "dirty bomb" explosion in a metropolitan area. In such an event, the radioactive material will likely be from a single radionuclide and discreet gamma energy. The explosion would pulverize the source material around the buildings and streets that later would be further disseminated by similar mechanisms observed in Goiânia.

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