Invited Paper

ASPECTS OF THE INITIAL AND RECOVERY PHASES OF THE RADIOLOGICAL ACCIDENT IN GOIÂNIA, BRAZIL

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Abstract

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In September 1987, the removal of the rotating assembly of the shielding head of a teletherapy unit and the dismantling of the capsule containing 50.9 TBq (1375 Ci) of ^{137}Cs resulted in a widespread contamination of central Goiânia, a Brazilian city of one million inhabitants. Notwithstanding the recommendations contained in publications concerning emergency response planning and preparedness, this radiological accident showed that several adverse vectors not mentioned in the literature were a reality. Thus, not only social, political, economic and technical problems had to be faced but also psychological aspects had to be dealt with. Of these, discrimination against the victims was the most important. The paper draws attention to several aspects of the actions that were necessary to minimize the exposure of the population to external radiation and discusses the initial procedures undertaken by the National Nuclear Energy Commission (CNEN) in Goiânia.

1. ACKNOWLEDGEMENT OF THE STATE OF EMERGENCY

The National Nuclear Energy Commission (CNEN) learned about the radiological accident in Goiânia from a telephone call to the Department of Nuclear Installations (DIN) made by physicist W.F. at 3.00 p.m. on 1987-9-29 at the request of the Secretary of Health of the State of Goiás. The DIN was informed that several persons were at the Hospital for Tropical Diseases or were camped down in tents at the Olympic Stadium and presented symptoms characteristic of radiation syndrome.

The description of the facts and the collection of data regarding the radioactive installations in Goiânia suggested that the occurrence had resulted from the loss of the sealing protection of radioactive material coming from some radiotherapy equipment. After consulting its records, the DIN telephoned the Goiânia Institute for

A: IGR clinic
B: Source first exposed
C: Junkyard I
D: Junkyard II
E: Junkyard III
F: Vigilância Sanitária
G: Physicist W.F.'s house
H: Olympic stadium
J: General Hospital
K, L: Other contamination points
M: Initial CNEN command post
N: Present CNEN office

FIG. 1. Principal sites of contamination.

Radiotherapy (IGR) and was informed by one of its owners, a radiotherapy physician and the physicist in charge of radiation protection, that the occurrence was related, possibly, to a source of ^{137}Cs from its Institute.

The CNEN arranged for its Institutes and Headquarters to provide immediate assistance, and at 6.00 p.m. that day, the director of DIN and technicians of the Institute for Nuclear and Energy Research (IPEN) left for Goiânia to make an initial assessment of the situation. They arrived in Goiânia at half past midnight on 1987-9-30.

Together with the directors of IGR, they went to 1587 Paranaiba Street, where the source was presumed to be. The site was found to be in a state of semi-destruction, unguarded, and with its electric power turned off. After illumination had been improvised, it was found that the ^{137}Cs source was not there and the exposure rates were about the same as from natural radiation. More detailed investigation of the site was carried out later, in daylight.

Next, the group, accompanied by members of the Civil Defence, went to the sites presumably contaminated, where the situation was found to be serious.

At dawn of the same day, contact was made with the Executive Director I of CNEN and the Director of the Institute of Radiation Protection and Dosimetry (IRD), who dispatched teams to Goiânia immediately with the following duties:

— radiological protection
— environmental control
— radioactive waste management and
— medical aid.

The preliminary evaluation indicated that some individuals might require specialized treatment. Therefore, the Marcilio Dias Naval Hospital was placed on the alert.

At daybreak of 30 September, the principal foci (Fig. 1) were isolated. They were:

— Rua 57 (57th street), house No. 58
Downtown District (Setor Central)
— Rua 17-A, block No. 70, lot 26-B
Airport District (Setor Aeroporto)
— Rua 6, block Q, lot 18
North Railroad District (Setor Norte Ferroviário)
— Rua P-19, block 92, lot 4
Civil Service Workers District (Setor dos Funcionários)
— Rua-16-A, No. 792
Public Hygiene Control Unit (Vigilância Sanitária)
— Rua 63, house No. 179
Downtown District
— Rua 26-A, block 2, lot 30
Airport District.

Because of the high exposure rates in the neighbourhood of the Public Hygiene Control building — occasioned by the ^{137}Cs source contained in the metal part that had been brought there previously — it was determined that the part should be shielded with maximum urgency.

The values measured on this occasion were higher than 10 Sv/h near the surface and about 0.4 Sv/h one metre from the source. On 1987-10-1, in conjunction

with the Departments of Health and of Transport of the State of Goiás, steps were taken to shield the source of ^{137}Cs with concrete.

The priorities established for the tasks to be undertaken beginning on the afternoon of 30 September were:

— medical care for the contaminated persons
— washing and changing of the clothing of the individuals contaminated
— provision of food
— monitoring of people
— informing the public.

A technical meeting of the task group in Goiânia was held on the evening of September 30, when it was decided that these teams should join forces to make it possible to provide:

— a reconstruction of the accident as accurately as possible;
— identification of all the foci of contamination;
— monitoring of the people at the Olympic Stadium;
— radiometric surveys;
— environmental monitoring in a joint effort with the Environmental Department of Goiás (SGMAGO);
— care for the victims at the General Hospital of Goiânia (HGG), the transfer of six patients to the Naval Hospital, and the inspection of the screening of persons presumably irradiated and/or contaminated;
— accurate information to the public by means of the Health Organization of the State of Goiás (OSEGO);
— aeroradiometric tracing of the city of Goiânia.

The severity of the clinical picture of the patients, the alarming information about the contamination of the water, and the number of areas affected made for a great confluence of the population at the Olympic Stadium.

2. SCREENING AND CARE OF PEOPLE

The persons who had handled the source or part of it and consequently presented a higher level of irradiation had been evaluated clinically and, with the diagnosis being uncertain, had been admitted to the Hospital for Tropical Diseases (HDT) and to the Santa Maria Hospital. The Olympic Stadium was chosen by OSEGO to shelter the persons vacated from their homes in light tents. In the main foci, the people were evacuated for clinical and radiometric treatments and according to the seriousness of the findings they were sent to the HGG, the State Foundation for the Well-being of Minors (FEBEM), or to the House of the Good Shepherd (Albergue Bom Samaritano).

The persons who lived in places adjacent to the identified foci of contamination or who had had some type of contact with the victims were instructed to go to the Olympic Stadium, where they would be monitored. The levels of contamination that they presented were considerably lower than those of the preceding group.

In addition to these people, 112 000 members of Goiânia's population reported to the Olympic Stadium to be monitored even though their direct relation to the incident had not been established.

The reason for their coming to the stadium was apparently that they happened to be in the city at that time.

The purpose of the monitoring was:

— to identify any contamination
— to apply preliminary decontamination measures as well as to evaluate the efficiency of the procedure
— to refer cases of persisting contamination to a team of specialists for medical follow-up.

In this phase of first aid, contamination was found in 249 persons. Among these, 120 presented contamination of clothing and shoes only; 129 presented external and/or internal contamination and were, therefore, placed under direct medical supervision.

Within the first few post-accident days, 50 other persons were referred to the medical team for clinical and laboratory evaluation.

Among these were some from the Public Hygiene Control Unit, the Military Police, the Fire Department, or from among the close relatives of the victims. Of a total of 100 persons, 21 required hospitalization for intensive medical treatment for their haematological condition and radiodermatitis. Ten of these patients were in a serious condition; four of these died and one underwent amputation of the forearm.

The initial screening undertaken by the State government and the procedure adopted by the CNEN eliminated the possibility of contamination and exposure of persons while they waited to be monitored.

Simultaneously with the technical work being done, professionals from the field of social services gave explanations and support to the public to assuage the anxiety of the population, even though contamination had been found to be restricted to one group of individuals, confirming the initial working hypothesis of the task force.

3. THE SEARCH TO ISOLATE THE CONTAMINATION

After the first day of activity in Goiânia, the technical teams established that the dissemination of ^{137}Cs could be attributed principally to the following factors:

— social contacts maintained by persons directly contaminated through the inappropriate handling of radioactive material

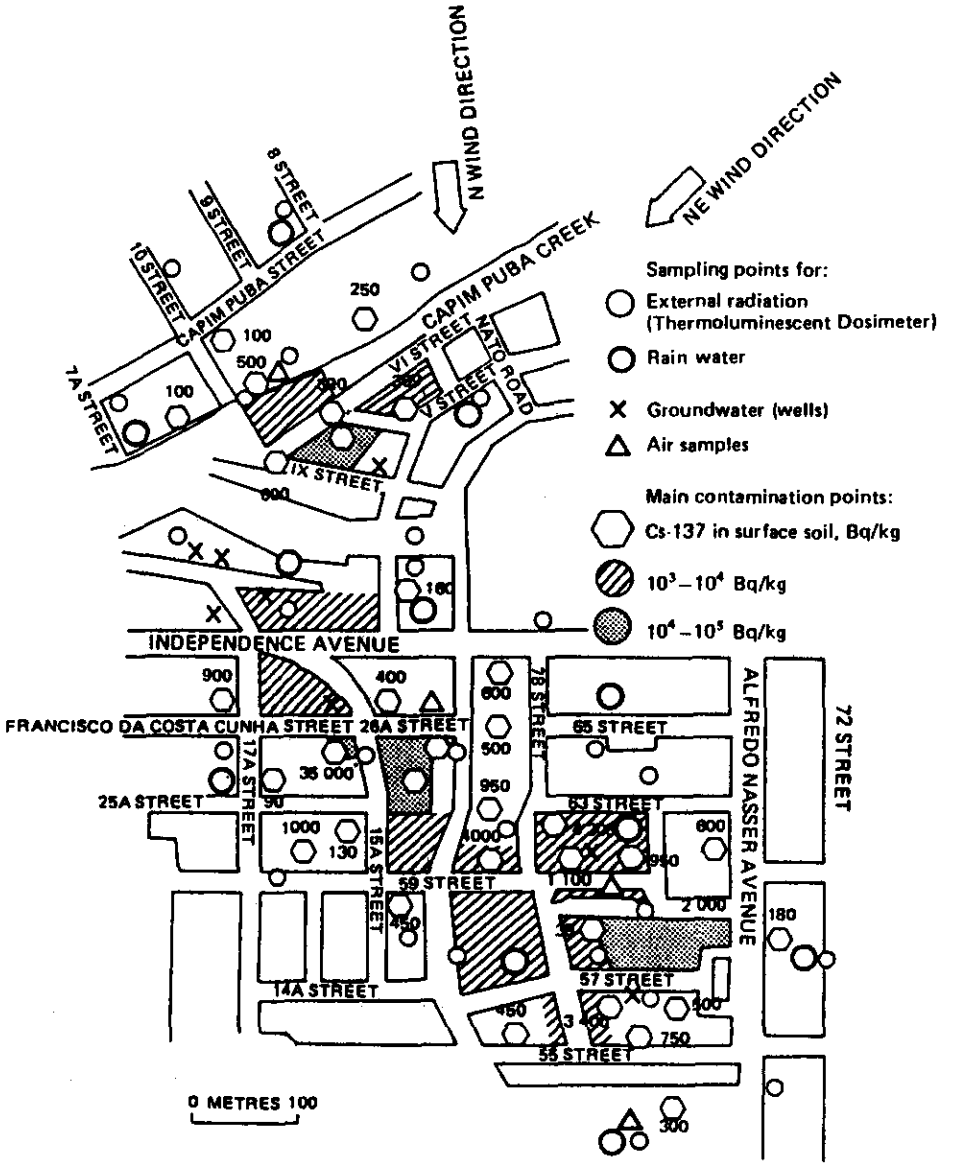

FIG. 2. Principal sites of contamination and sampling points.

— commercial use of contaminated material that came from the junkyards involved
— distribution of fragments of the radioactive source
— dispersion by wind and rain
— The interval of time between splitting open the capsule containing ^{137}Cs on 1987-9-13 and the wider dissemination of the material.

Smaller foci and less contaminated persons were identified in distant regions. This led the CNEN to add aeroradiometric surveying to the inland search that was being conducted.

3.1. Land search

The identification of the contaminated material proceeded according to the following scheme:

— systematic tracking of exposure rates higher than those of natural background radiation;
— on-site verification of information furnished by contaminated persons, their family, friends, and the population.

Seven main foci of contamination were immediately identified and the respective areas isolated. The radiological survey in one of the foci is shown in Fig. 2.

Two weeks later, in October 1987, other sites, some of them located outside the region of Goiânia, had been identified, presenting, however, only a slight amount of radioactive contamination. These sites all underwent initial decontamination, and the resulting radioactive waste was treated and removed to the Olympic Stadium temporarily.

3.2. Air search

On 7–8 October, tracing of the urban area of Goiânia, including complexes at its outskirts, the campus of the Federal University of Goiás (UFGO) and the Autodromo (auto race track), resulted in the finding of only one new focus of contamination in addition to those already known. The Meia Ponte River was examined from north, near the university campus, to south, the auto race track, without any trace of contamination above background being detected.

This survey, performed in two days, ascertained that the ^{137}Cs contamination was concentrated chiefly in the foci isolated and already under control, confirming the initial task team's hypotheses as to the extent of the mishap.

3.3. Other investigations

In addition, points of residual contamination were identified in 42 residences, which may be divided into two groups for the sake of simplicity:

— 20 residences that neighboured on the principal foci and had to be vacated temporarily;
— 22 residences that were distant from these foci.

In the first group, exposure of the persons concerned occurred during the period 13–29 September, at which time they were removed from their residences.

In the second group, in the residences of relatives, friends, of other persons connected with the contaminated homes, the average exposure rate was from 0.1 mR/h to not more than 1 mR/h at any site.

The transit of contaminated persons or part of the source resulted in the contamination of public places at residual levels. A programme for the decontamination of these places was immediately activated.

The lapse of time between the occurrence of the accident and its becoming known, with the persons externally contaminated being identified, indicated the necessity for immediately controlling the money in circulation in Goiânia.

A systematic check-up of the money and local bank agencies was made. Among the 10 240 000 bils monitored, only 68 (0.00066%) were found to be contaminated by ^{137}Cs.

As other bills in contact with those contaminated presented no signs of contamination, with no signs of transference being found when smear tests were performed, it became evident that the contamination was not readily transferred by the simple handling of these bills. Furthermore, the external exposure that might supervene from their being carried or handled would be, for the most part, insignificant (3 μSv/h). The contaminated bills were of course withdrawn from circulation.

4. ENVIRONMENTAL EVALUATION

4.1. The behaviour of caesium

On coming into contact with water courses, caesium chloride in its soluble form is rapidly and strongly retained by the sediment lying at the bottom and by particles in suspension, which then become its chief means of transport. In its airborne dispersion, caesium is deposited on the surface of the soil and plants and can be absorbed by the latter through their roots, leaves and other exposed parts.

Owing to the characteristics of the accident and the affected sites in Goiânia, the chief potential means by which the population in the neighbourhood of the foci

could be exposed to radiation were inhalation, ingestion (fruit and vegetables) and external irradiation.

To evaluate the need for operational measures such as the removal of soil, a ban on the consumption of certain foods or the pruning of trees, ^{137}Cs concentration limits more restrictive than those recommended internationally for radiological emergency situations were used. The methodology for estimating the doses coming from different potential pathways was immediately established.

The intervention level established was aimed at keeping the annual dose from exceeding 300 mrem (3 mSv).

By the beginning of October, samples had been collected from the environment and sent to the IRD for analysis, while other steps were taken to establish a laboratory where measuring could be done in Goiânia.

Contact was made with the State Waterworks Department of Goiás to obtain the hydrological information necessary for characterizing the region.

With the participation of SEMAGO, it was possible to plan the steps necessary for making a preliminary assessment of the environment, including the rain water, sewer, and potable water systems; groundwater; foods; and evaluation of the environmental dose levels.

4.2. Potable water supply system

Samples were taken from the waters of the João Leite River at the point where the city's water supply is drawn off, situated on the bank opposite the Meia Ponte River, and from different points in the drinking water supply system, as well as from the water and mud of the filter bed of the filtration plant. The radiometric results indicated that the potable water of the city of Goiânia was not contaminated by ^{137}Cs. The detection limit was 1.5 Bq/L.

4.3. Sewage and rainwater systems

By studying the hydrographic network of the region affected, it was found that its contamination by ^{137}Cs could occur first through the emptying of the sewage and rain water into the Capim Puba Creek, later affecting sections of the Botafogo Creek, the Anicuns Stream, and the Meia Ponte River.

Consequently, with the co-operation of technicians of the State Technology and Basic Sanitation Company of São Paulo (CETESB) careful tracing was carried out of the rainwater galleries and sewer system, consistently downstream from the areas whose surfaces had been found to be contaminated.

It was concluded that the concentrations of ^{137}Cs measured with a sodium iodide detector in the sewer and rain water were due particularly to the waters coming from 57th, 63rd, and 26-A Streets. However, from the point of view of radiological safety, the values found did not present any risk to the population.

4.4. Analysis of sediments

The results obtained from the samples collected from the sediment of the bed of the Meia Ponte River indicated ^{137}Cs concentration values of 100 to 800 Bq/kg in the sections downstream from the mouth of the Anicuns Stream. This observation was confirmed by the tracing done with a sodium iodide probe by the staff of the Nuclear Development and Technology Centre/Brazilian Nuclear Enterprises Inc. (CDTN/NUCLEBRAS).

The results obtained after this period showed a rapid decrease in the concentration in the sediment, indicating that the exposures due to ^{137}Cs were within the typical limits of variation of natural exposure.

4.5. Study of the groundwater

As the opening of the source and its initial handling took place in non-cemented areas, rainfall in the region favoured the penetration of ^{137}Cs into the soil despite its argillaceous composition.

In view of this, measurements were made of the:

— concentration of ^{137}Cs in soils at different depths (soil profiling)
— concentration of ^{137}Cs in the water of wells near the foci of contamination.

Preparation of the soil profile was first entrusted to the School of Agriculture of the Federal University of Goiás (UFGO) and later IPEN. The results obtained from the samples indicated that the major part of the ^{137}Cs, until 30 October, was concentrated in the top 20 centimetres, this pattern being similar in all the areas studied.

4.6. Measurement of the environmental dose rate

To furnish data regarding the environmental dose rate to furnish data regarding the environmental exposure characteristics for the city of Goiânia, various measuring stations equipped with thermoluminescent dosimeters (TLDs) were installed in these places:

— OSEGO
— SEMAGO headquarters
— Zoological Garden
— Jardim das Palmeiras Cemetery
— Water reservoir of SEMAGO.

To evaluate the rate of exposure in the areas close to the foci of contamination, TLD stations were installed within a radius of 180 metres from each focus and in nearby residences. Analyses were planned to be made every three months.

4.7. Rain and aerosols

Eleven stations for the collecting of the complete deposition of rainwater and dust were installed in the Airport District. Caesium-137 was not detected in any of the samples collected.

4.8. Food products

Samples of the food products sold in the markets near the areas isolated as well as in the region that produced them, were collected. The presence of ^{137}Cs was not detected in any of them.

In the areas close to the sites most affected, 216 samples of vegetables, and also fruit and greens cultivated in home gardens from within a radius of 180 metres, were analysed. The results showed that the farther the plants were from the foci of contamination the less ^{137}Cs activity there was.

Based on the limits derived for ^{137}Cs in vegetables and fruits, as a precaution it was recommended that the fruit and greens be removed and that some trees that could present additional risk to the population be pruned. All the vegetables and greens were gathered then, and trees were isolated. A few trees whose levels of radioactivity could be of concern to the population were removed. Only in a few cases did these levels exceed the values allowed by the national and international regulations. Finally, a long term environmental follow-up programme was established in conjunction with SEMAGO.

5. IDENTIFICATION AND CLASSIFICATION OF WASTE RESULTING FROM THE ACCIDENT

The waste generated during the process of decontaminating persons and sites was classified according to the categories established in the experimental norm: 'Management of Radioactive Waste in Radioactive Installations' approved by CNEN resolution 19/85 of 11/27/85 — Official Government Report D.O.U. 12/17/85:

(a) *Non-radioactive solids*
Those that presented specific activity below 74 kBq/kg of material.

(b) *Solids with low level radiation*
Those that presented an exposure rate less than or equal to 2 mSv/h on the surface of the package.

(c) *Solids with medium level radiation*
Those that presented exposure rates from 2 mSv/h up to 20 mSv/h on the surface of the package.
Liquid waste was solidified with cement and classified as solid waste, obeying the criteria described above.

5.1. Packaging of waste

The packaging containers used were industrial carbon steel drums (barrel part, bottom, and lid of 18 gauge, of 40 litres, 100 litres, and 200 litres capacity) and metal chests. The 40 litre and 100 litre drums were normally encapsulated in 200 litre drums or in metal cases.

6. TRANSPORTATION OF THE WASTE

The transportation of the radioactive waste was effected according to the Presidential Decrees No. 2063 of 1983-10-6 and No. 88821 of 1983-10-6, adopted by the CNEN and dealing with highway transportation of dangerous freight and products; the CNEN Resolution 5/81 of 1981-7-27, which adopts the International Atomic Energy Agency regulations concerning the safe transportation of radioactive material; and, wherever pertinent, CNEN Norm 06/77, 'The Physical Protection of Operational Units in the Nuclear Area' of 1981-7-17.

Once closed, these packages were inspected so as to determine any residual contamination of their exterior and marked accordingly after monitoring to determine surface exposure rates and those at one metre distance. Later, they were dispatched in trucks, transported under 'completely loaded' conditions, that is, the vehicles were exclusively for this use. The drivers and their helpers were duly instructed as to the obligatory procedures both in normal and emergency situations.

To prevent an accident or to be able to act in the event of one, the following measures were taken:

- the vehicles proceeded in convoys accompanied by a police escort
- radiation protection technicians accompanied the vehicles on their route with instruments and auxiliary material
- a system of communication by radio was maintained to keep the central station informed about the various stages en route
- the speed of the vehicles was restricted to 20 km/h in cities and 40 km/h on highways.

The measures stipulated for possible emergency situations during transportation were later put into practice when a vehicle loaded with four cases containing radioactive waste toppled over. The radiological protection team accompanying the transportation operations immediately isolated the spot with the aid of the escort and, with the assistance of a rescue team, restored normal conditions for the transportation to proceed.

After unloading at the repository, the trucks were completely monitored to determine whether they could be released into immediate circulation or not. If there was contamination, the vehicle was decontaminated until the level permitted for conventional transportation was attained.

7. TEMPORARY REPOSITORY

The waste generated during the initial process of decontamination made it imperative to determine a site for storage outside the area affected in order that the local levels of radiation not be increased by the accumulation of packages stored in the isolated areas.

The matter was discussed with the State government, which indicated two alternative areas, on the understanding that this storage would be of a temporary nature. Considerable time was taken to reach a feasible solution, and this affected the effectiveness of the clean-up operation.

The area selected is of about 2 hectares (almost 5 acres) located 20 km from the centre of Goiânia and 2.5 km from the city of Abadia de Goiás.

The technical group co-ordinated by CNEN, working jointly with the Department of Transport of Goiás, prepared an engineering project for the construction of nine concrete platforms, 60 × 18 × 0.2 m where the packages would be placed. During construction, aspects that guaranteed the quality of drainage, physical safety, illumination, sanitary installations, and access for vehicles were taken into consideration. To ensure the safety of the workers and preservation of the environment, occupational and environmental radiological protection programmes were implemented. To achieve this, samples of the soil, vegetation, sediment, surface water, rain water and aerosols were collected. In addition, five TLD stations were installed along the fence that delimited the areas, and a well was sunk to collect underground water as part of the routine programme of monitoring the environment.

8. INVENTORY OF THE SOURCE

An inventory of the source was carried out (Heilbron, 1988), the starting point being fundamentally the contents of the chests of waste collected in the city of Goiânia, since the dispersion of radioactive material was restricted to few sites and the material was handled by a group of persons who had been identified. The best estimate for the source recovery was 1200 Ci or 44 TBq.

The results of the extensive environmental monitoring formed the primary basis for the assurance that there was no significant residual hazard.

9. TASK TEAMS AND TECHNICAL AID

The CNEN was able to co-ordinate the work of several members of their professional staff, in the areas of radiological protection, waste, decontamination and environmental monitoring and for providing co-ordination and maintenance. In addition, professionals from FURNAS, NUCLEBRAS, the Centro de Desenvolvimento

da Tecnologia Nuclear (CDTN), NUCLEÍ, the Ministry of the Navy, and EsIEX (Special Army Division) were added to the working team.

Teams at the headquarters and institutes of the CNEN provided continuous support to the activities in Goiânia by effecting:

- analyses of the faeces and urine of the patients hospitalized in Rio de Janeiro and Goiânia;
- cytogenetic dosimetry of the persons who suffered major exposure and contamination;
- evaluation of internal contamination, utilizing whole body counters (for both technicians and patients);
- calculations of the dose of internal contaminations in the patients, using data obtained from the analyses of excreta;
- analyses of environmental samples;
- radiation protection at the Marcilio Dias Hospital;
- the preparation of radioactive standards;
- calibration of equipment and maintenance;
- preparation of material for decontamination;
- management of the waste from the hospital;
- manufacture of special equipment;
- control and storage of the waste;
- evaluation of the doses to technicians, using various types of personal dosimeters.

Detailed technical publications in each field have been published in proceedings of national and international meetings.

In addition to these professionals, hundreds of individuals from the State of Goiás, hired firms, universities, the Civil Defence of the State of Rio de Janeiro, and local volunteers collaborated directly in various supporting activities, transportation, and civil engineering.

10. QUALITY CONTROL OF EQUIPMENT AND RECOMMENDATIONS FOR USE

The equipment employed in the emergency actions in Goiânia was submitted on site to quality control tests and checked for proper functioning and maintenance.

The quality control programme established during the second week of work included various measuring procedures, depending on the type of equipment and its purpose.

Owing to the multiplicity of types of equipment, the many different manufacturers, and the turnover of users, recommendations included such considerations as: distance, energy and directional dependency, types of radiation that might be detected, response time, calibration factors, and conditions for equipment use.

11. COMMUNICATIONS WITH THE PUBLIC

The accident in Goiânia had a great psychological impact on the Brazilian population owing to its association with the accident at the Chernobyl nuclear power station in the USSR in 1986. Many people feared contamination, irradiation and damage to health; worse still, they feared incurable and fatal diseases.

Some of the inhabitants of Goiânia were discriminated against, even by their relatives. Sales of cattle, cereals and other agricultural products, the main economic product of Goiás State, fell by a quarter in the period after the accident.

In order to allay these fears, the working team was encouraged to explain to people what they were doing and why, and, for example, to accept offers of drinking water and food from people's houses. They thus gained people's confidence and raised the credibility of official statements. Team workers made frequent appearances on television. A considerable effort was made by the co-ordinators to use the media to answer all questions and to treat the problem in an open and friendly manner. Their approach was to draw analogies, using simple language, with common applications of radiation, such as for medical X rays, and to recount as much as was known of the situation at the time.

However, the co-ordinators found it difficult to explain some aspects of radiological protection to the press. Talks were given for journalists, explaining in basic terms the applications and the biological effects of radiation. A pamphlet was produced jointly with the Health State Authority entitled "What You Should Know About Radioactivity and Radiation", and 250 000 copies were distributed. A telephone service operated 24 hours a day to answer inquiries and receive information about other possibly contaminated people or sites.

Several talks were given to different sections of the population and to community groups in order to restore confidence so that public life could proceed normally.

There were two distinct phases in the reaction of the communications media (the press, radio and television). The first was characterized by sensationalism, misinformation and criticism of the authorities.

In the second phase there was a much more mature coverage of events, seeking to inform the public and describing more clearly what was happening and what actions were being taken by CNEN and the Federal and State Governments. Later, CNEN decided to install a professional scheme of communication, taking away this extra burden from the local co-ordinators.

To encourage a more responsible presentation of events, CNEN personnel went to great lengths to clarify matters for the communication media, demonstrating and explaining their work.

News reporters could accompany CNEN technicians engaged in decontamination work and attending to casualties.

12. NATIONAL AND INTERNATIONAL CO-OPERATION

During the initial phase of handling the accident in Goiânia several experts were requested or sent through international agencies or through the existing bilateral agreement.

The Brazilian authorities informed the IAEA of the accident soon after its discovery, and requested assistance under the terms of the International Convention on Assistance in the Case of a Nuclear Accident or Radiological Emergency. The assistance given included the provision of experts and equipment.

In addition, several members of the Brazilian scientific community were present at the accident site, providing assistance and expertise.

13. LESSONS LEARNED

(1) The physical and chemical properties of a radioactive source are important factors in an accident. The records of sealed sources should contain that information. It is suggested that physical and chemical properties of sources should be taken into account in the licensing for manufacture of such a source.

(2) An adequate system of social and psychological support should be provided following a radiological accident. The psychological support should be provided to those individuals directly and indirectly affected and the personnel working in response to the emergency. A psychologist should be available for counselling, joining the group responsible for making quick decisions and planning action to be taken, and evaluating the possible stress to the casualties.

(3) The effectiveness of international assistance following a radiological accident depends on the substructure of the country concerned and on the professional profile of the expert and his will to get involved in the actual work instead of producing paperwork of questionable value. Emergency training courses should be held in developing countries as well as in developed countries where facilities are available and work well. In general, these programmes deal with emergencies responded to by strong organizations under a priori known conditions. In many countries circumstances are very different, equipment is diverse, the climate is adverse and matters are administered differently.

(4) Instrumentation should be capable of being adjusted to withstand field conditions so that it can be used in high humidities, high temperatures and unstable environmental conditions. Personnel using instruments should be trained to be able to obtain a clear indication of dose rate response for a wide range of doses; and to know the most suitable equipment in different conditions and its calibration factors.

(5) The provision of a temporary waste storage site near the area affected by a radiological accident is considered indispensable. A delay, usually a political one, in the decision on where to construct a site could permit greater dispersion of radioactive material in the environment.

(6) In general, a programme of inspection of radiological equipment and facilities is very important. However, it is only effective if coupled with some kind of enforcement system, such as assigning civil or professional liability in licensing sources.

14. FINAL REMARKS

The rule that radiation sources must be secure and under control must be given expression by competent national authorities in an appropriate regulatory system supported by appropriate rules and regulatory inspections, which was indeed the case in Brazil.

However, such a system cannot diminish the responsibility of the person designated as liable for a radioactive source. The regulatory system cannot and must not detract from managerial responsibilities; in particular, it cannot substitute for the licensee's responsibility for safety.

If, in spite of all precautions, an accident does occur and a radiological hazard is foreseen, there should be a well understood chain of information and command. In particular, in order to respond to a serious accident, a country would probably need to engage many of its qualified personnel, possibly from many widely separated establishments, and make use of much of the equipment available to it. An emergency plan should anticipate the need for integration, and this command structure should have been set up in advance.

In this regard it is important not only that responsibilities are assigned, but also that the necessary authority to obviate bureaucracy is conferred. For instance, the accident in Goiânia was remote from the centres of radiological expertise. The logistics of mobilizing personnel and arranging for material were a major difficulty (air transport was found to be essential). A clear chain of command will facilitate the provision of means necessary during emergencies, including means for enabling immediate mobilization. It follows that preparedness to respond to radiological emergencies should extend not only to nuclear accidents but to the entire range of possible radiological accidents.

In the accident in Goiânia, a number of practical problems were encountered in carrying out surveying and decontamination. However, two observations are worthy of note here:

(a) emergency equipment must be capable of operating in adverse ambient conditions;

(b) there will almost certainly be a need to engage workers without previous experience of radiological work, and even professional staff may not have had relevant operational experience.

Provision for training should therefore be made within emergency plants.

The dissemination of information to the media, the public and, indeed, the response force is particularly important.

The accident in Goiânia was one of the most serious radiological accidents to have occurred to date. It resulted in the injury by radiation of many people, of whom four died, and the radioactive contamination of parts of the city. Radiological accidents are rare events; but this should give no grounds for complacency. No radiological accident is acceptable, and the public must feel confident that the competent authorities and individuals are doing all in their power to prevent them. Part of this process is to learn the lessons of the accident in Goiânia.

Annex I

THE SHIELDING OF THE REMNANT SOURCE CAPSULE

The rotating metal assembly holding the remains of the ^{137}Cs source capsule was enveloped by a cloth bag and placed on a chair, as shown in Fig. 3, which in turn, was taken to the corner of the Health Department courtyard.

The dose rates measured at the surface of the bag were greater than 10 Gy/h and equal to 0.4 Gy/h at a distance of 1 metre, indicating a radioactive content of about 4.5 TBq (120 Ci), which represented less than 10% of the original source (i.e. 1375 Ci in Sep. 1987).

The radiation levels in the nearest sidewalk reached values of up to 30 mSv/h and the neighbourhood was quite apprehensive, not only because of the external radiation field but especially because of the possibility of the spread of contamination through rain and the falling of the source from the chair.

It was thus decided that immediate measures were to be taken to shield the whole set (chair + source) not only to reduce the exposure rates and therefore to minimize the number of evacuated houses but also recognizing the depressive state of the local inhabitants.

The best solution thought of at the time was to place a concrete sewer pipe over the chair, with the help of a truck, generally used for civil engineering purposes, equipped with a crane. Some difficulties had to be overcome during this operation, for instance:

- the chair was behind a 2 metre wall and very close to it (less than 20 cm away)
- the pipe oscillated when lifted
- the pipe had to be moved downwards slowly to prevent the chair from turning over.

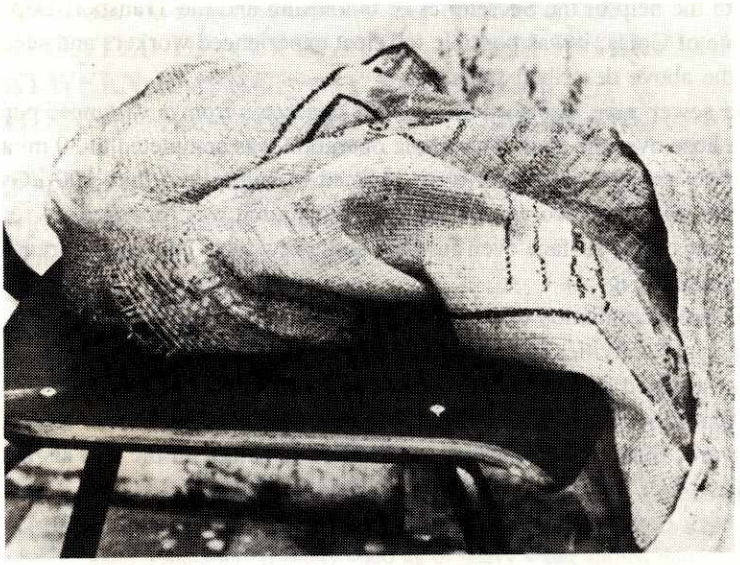

FIG. 3. The chair after removal from the office. The dose rate at the surface of the cloth bag was 10 Gy/h, and at a distance of one metre 0.4 Gy/h.

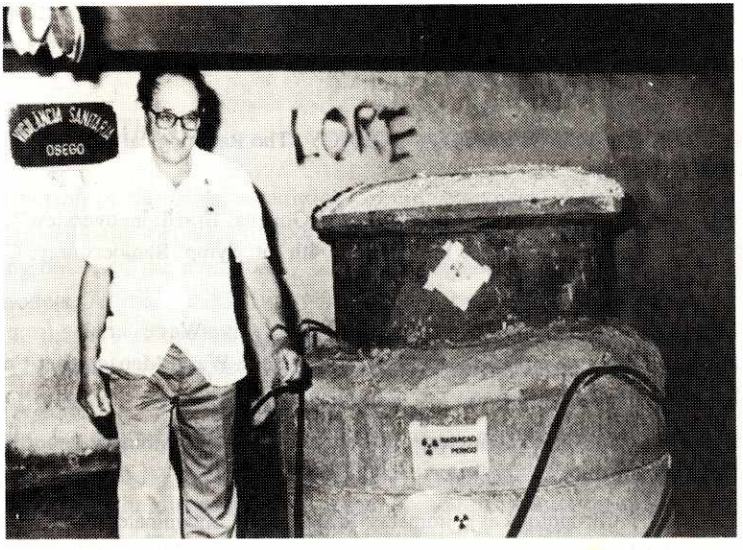

FIG. 4. The shielded source and chair. The operation was completed in 30 minutes.

With the help of the Secretaries of the Health and the Transport Departments of the State of Goiás, it was possible to select experienced workers and successfully conduct the above described steps.

The sewer pipe was then filled with concrete, from a distance, pumping it through a hose over the wall. The whole operation was completed in 30 minutes and the radiation levels in the street were reduced to values less than 100 μGy/h.

In the following two weeks, the shielded source was repacked, to reduce the exposure rates at its surface even further, and a few days later it was transferred to the storage site (Fig. 4).

The decontamination of the courtyard and office was carried out over 15 days and the normal activities of the Health Department were resumed.

An estimated dose of 1.3 Gy was calculated for the technician who received the bag, placed it on his desk and left it there for some time, before removing it to the courtyard. Since the ^{137}Cs remanent source remained in the bag his intake was negligible.

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