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## ● Overview of the Accident

### MEDICAL AND RELATED ASPECTS OF THE GOIÂNIA ACCIDENT: AN OVERVIEW

A. R. Oliveira

Indústrias Nucleares do Brasil S.A., Av. Pres. Wilson 231/11, Rio de Janeiro, CEP 20030, Brazil

and

J. G. Hunt

Instituto de Radioproteção e Dosimetria/CNEN, Av. das Americas Km 11,5, Rio de Janeiro, CEP 22602, Brazil

and

N. J. L. Valverde

Furnas Centrais Elétricas, Rua Real Grandeza 219, Rio de Janeiro, CEP 22283, Brazil

and

C. E. Brandão-Mello

Instituto de Radioproteção e Dosimetria/CNEN, Av. das Americas Km 11,5, Rio de Janeiro, CEP 22602, Brazil

and

R. Farina

Instituto de Radioproteção e Dosimetria/CNEN, Av. das Americas Km 11,5, Rio de Janeiro, CEP 22602, Brazil

**Abstract**—On 13 September 1987, a radiation accident occurred in the city of Goiânia in Central Brazil. Approximately 250 people were exposed to a  $^{137}\text{Cs}$  source from an abandoned radiotherapy unit. At least 14 patients showed some degree of bone marrow depression, and eight developed the classical signs and symptoms of acute radiation syndrome (ARS). Twenty-eight people presented local radiation injuries ranging from first to third degree, and 104 individuals showed evidence of internal contamination. This paper describes the circumstances of the event, the first-aid measures taken, the criteria adopted for triage of the exposed population, and the radiation protection procedures used during the clinical management of the irradiated individuals.

#### DESCRIPTION OF THE ACCIDENT

ON SUNDAY, 13 September 1987 (day 0) in the city of Goiânia, state of Goiás, Brazil, a source assembly containing a 50.9-TBq ( $^{137}\text{Cs}$ ) source was removed from a radiotherapy unit by two scavengers and left behind in an abandoned clinic. The assembly, weighing about 100 kg, was removed from its shield, loaded onto a wheelbarrow, and taken to the home of one of the men. Neither of them had any idea of its significance. A preliminary attempt was made to dismantle the assembly with the use of a maul and punch. The men managed to break the shutter of the collimator orifice, exposing and rupturing the source in such a manner that fragments of it were spread over the adjacent areas. Small bits of the source were also withdrawn with the aid of a screwdriver. This operation took place on a plot of land shared by several

families living in a housing development. The attempted dismantling, which lasted 2–3 h, could not be completed because of the strong resistance of the device (IAEA 1988).

About 3 h after the attempt to break open the apparatus, both men developed nausea followed by vomiting; one of them had diarrhea. The gastrointestinal disturbances persisted for 4–5 d (Valverde et al. 1990).

On 14 September (day 1), the assembly was apparently offered to a junkman, according to one of the scavengers. According to the junkman's version, however, it came into his hands on 18 September (day 5), around 4:00 p.m., and was placed in a dump in his backyard. At 9:00 p.m., when he went back to the dump, he noticed that the object he had purchased earlier emitted some sort of luminescence, which intrigued him sufficiently to cause him to bring it into his house. It remained in the living-room until 21 September (day 8), accessible to family,

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friends, and curious neighbors. Later, it was taken back to the dump, broken into pieces, and distributed among various individuals, mostly relatives and friends.

The assembly was left at the junkyard until 28 September (day 15), while the ruptured capsule was sent to a second junkyard, where others tried to break it open with a power saw.

The wife of the junkman noticed that an increasing number of people were showing such gastrointestinal symptoms as loss of appetite, nausea, vomiting and diarrhea, and suspected that some relationship might exist between the luminescent material and the health disturbances. She then persuaded her husband into agreeing to hand over the source capsule to the Sanitary Surveillance Division (SSD).

She took this task upon herself, and on the afternoon of 28 September (day 15), accompanied by an employee of her husband's, she carried the source capsule, by bus, to the SSD. There, several individuals were exposed to the radiation emitted by the  $^{137}\text{Cs}$  source, and at least five received significant radiation doses (from 0.2 to 1.3 Gy). No one ever suspected what the material involved actually was. A fire brigade was called because it was thought that the capsule might contain "toxic gas," and the area was cordoned off as a precaution.

One of the technicians from SSD and one of the physicians from the Toxicology Information Center of the State Health Department suspected that the material in question was radioactive. They called in a nuclear physicist at 8:30 a.m. on 29 September (day 16) to perform preliminary measurements of dose rates in the immediate vicinity of the source. During the first assessment with a scintillometer, the physicist noted that the monitor went off scale. The physicist then ordered the evacuation of the building, and access to the area was controlled.

The physicist returned with a Geiger-Müller (GM) monitor with a wider range and made a preliminary survey of the radiation levels in the area. Help was requested from the State Secretary of Health and Civil Defense organization. A few military policemen and firemen responsible for the security of the area during the previous night were exposed to radiation as they approached the source too closely.

On the same day, the National Nuclear Energy Commission (CNEN) was notified of the situation and the Director of the Nuclear Installations Department was sent to Goiânia. This official monitored the source with a teletector, which consists of a Geiger-Müller camera mounted on the end of a 4-m telescopic rod. Dose rates higher than  $10\text{ Gy h}^{-1}$  on the surface of the source and about  $0.4\text{ Gy h}^{-1}$  at a 10-cm distance were found (Rosenthal et al., this issue). Being advised of the large number of exposed persons, he had CNEN informed of the seriousness of the incident and requested medical specialists and radiation protection personnel to handle the emergency.

The accident history and source characteristics explained the manifestations presented by the patients, i.e., local radiation injuries, coexistence of internal and exter-

nal contamination, and the clinical signs and symptoms of acute radiation syndrome. Such manifestations were presented in each patient to a greater or lesser degree (Valverde et al. 1990).

The radiotherapy apparatus of the Goiânia Institute of Radiotherapy (GIR), from which the source had been removed, was a Cesaphan F3000 model purchased in 1971 from the Italian firm Generay (no longer in business). The Cs pellet, with a 3-cm diameter and measuring 3 cm high, consisted of  $^{137}\text{CsCl}$  with a mass of 91.9 g. The high water solubility of CsCl contributed to the wide dissemination of the radioactive material (IAEA 1988).

According to a report presented by CNEN (Rosenthal et al., this issue), eight major contaminated sites were confirmed. Such extensive dissemination was caused mainly by social contacts with contaminated individuals and by the sale and transfer of contaminated material from the two junkyards. A dose rate of  $1.1\text{ Gy h}^{-1}$  was measured at the spot where the two scavengers broke into the source on 13 September. At the home of a severely contaminated patient who eventually died, a dose rate of  $0.5\text{ Gy h}^{-1}$  was measured under her bed (Valverde et al. 1990).

Detailed descriptions of environmental contamination, critical contamination points and corresponding dose rates, aeroradiometric surveys, and decontamination operations performed in the city of Goiânia can be found in other papers (Alves 1990; IAEA 1988; Rosenthal et al., this issue).

#### PRELIMINARY TRIAGE OF THE RADIATION-EXPOSED POPULATION

The initial assessment was carried out at the Olympic Stadium, a soccer stadium used by the local authorities as a triage center. The individuals who handled the source, or part of it, showed the highest level of contamination and irradiation. Those people living in houses adjacent to contaminated sites, or who had some type of contact with the victims, also had to report to the Olympic Stadium for monitoring (Tauhata and Binns 1989).

In addition, approximately 113,000 individuals (a significant segment of Goiânia's population of 1.2 million), were eventually monitored. The large number of people was elicited by the dissemination of alarming public information about water contamination and the risk to pregnant women. Radiological monitoring and triage had the following objectives:

- to identify the presence of contamination;
- to apply preliminary decontamination measures and evaluate the effectiveness of such procedures; and
- to direct the patients to the Goiânia General Hospital (GGH) for medical control by a team of specialists, should any contamination persist.

In that first evaluation phase, a total of 249 individuals were identified as contaminated. Among them, 120 presented only clothing and shoe contamination; 129 showed external or internal contamination, and of these,

50 were subjected to direct medical surveillance on 30 September (day 17). A significant number were employees of SSD, members of the Military Police and Fire Department, and close relatives of the victims. Of the total individuals given more comprehensive examination, at least 20 required specialized in-patient treatment because of their clinical and hematological abnormalities as well as their local radiation injuries.

### THE PLAN FOR LEVELS OF PATIENT CARE

#### *Levels of patient care*

Various types and degrees of injuries that may occur in a radiation accident call for a system of levels of patient care ranging from simple medical attention to the more sophisticated hospital structures. In the Goiânia accident, such a system was established with the following levels defined (Fig. 1):

- Primary care level: The dispensary of the Institute for Protection of Minors (IPM);
- Secondary care level: Goiânia General Hospital; and
- Tertiary care level: Naval Hospital, Rio de Janeiro.

At the primary level were to be patients presenting external contamination and slight internal contamination, warranting decontamination measures impossible to implement elsewhere. It was recognized that included among the patients at IPM would be those who had their homes

and properties interdicted, which added a medico-social character to this level.

Attended at the secondary level were to be those patients with first- and second-degree local radiation injuries, or those who had received doses capable of causing a slight-to-moderate impairment (1 to 2 Gy) of the hematopoietic system but who would not require special isolation measures or replacement therapy (platelet transfusions, for example). Patients with moderate-to-severe internal contamination were also maintained here, where they could benefit from  $^{137}\text{Cs}$  removal procedures.

The tertiary level was to deal with those patients with severe impairment of the hematopoietic system, as well as those presenting third-degree local radiation injuries.

Some of the objective indicators to be used in discharging patients from the Goiânia General Hospital to IPM or to their homes were:

- absence of symptoms;
- recovery of the hematopoietic system;
- good evolution of local radiation injuries; and
- elimination of external contamination.

#### *Transfer of patients*

Transfer of the patients was a difficult task, primarily because not only patients but medical and radiation protection teams, ambulance drivers, and aircraft crews were required to wear special clothing (aprons, caps, masks, gloves, and overshoes) not only to protect patients from microbial contaminants in the environment, but also to prevent possible radionuclide contamination of the aircraft, ambulances, and personnel by patients themselves. Second, such transfer operations obviously make patients and their relatives and friends highly uneasy and apprehensive, causing operational disturbances in the hospitals involved. In addition, such transfers cause apprehension among the other patients concerning the possible hazard to their own health.

Third, transfers necessitate a massive mobilization of human and material resources—military aircrafts with crews, equipped ambulances at both airports, medical and radiation protection teams, and emergency medicines—all of which impose a tremendous logistic burden. Finally, one must deal with the interest of the media in covering all phases of such operations, including disturbing efforts to interview technical team members and even the patients.

### IMPLEMENTATION OF THE PATIENT CARE PLAN

The specialized medical team arrived in Goiânia 10 h after the severity of the accident was recognized on 29 September (day 16). Preliminary measures initiated among those housed at the Olympic Stadium consisted of clinical and laboratory evaluations as well as radioactivity monitoring. This was followed, when indicated, by external decontamination baths with warm water and neutral soap. If radiation injury was suspected, the deci-

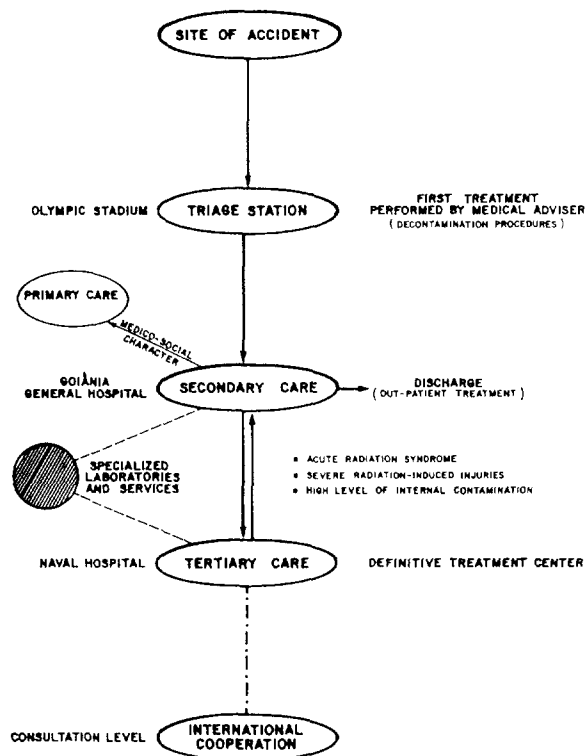


Fig. 1. Flow chart representing the different medical care levels.

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sion as to where patients should be hospitalized was based on criteria adopted on the first day by the medical team:

- level of impairment of the hematological system: decrease in lymphocyte and neutrophil counts;
- severity of local radiation injuries: rapidity of development and intensity of local signs of skin injuries; skin erythema, blister development, bullous epithelitis, ulcer and tissue necrosis; and
- intensity of internal or external contamination, based either on accident history or surface radiation monitoring.

Eleven patients who had originally been sent to other local hospitals with initial diagnoses of contact dermatitis, pemphigus, and food intoxication were seen at GGH. Before attending them, the team members put on caps, masks, aprons, gloves and special slippers, and personnel radiation dosimeters.

In assessing the severity of the patients' conditions, the following indications were considered:

- each patient's history of involvement with the  $^{137}\text{Cs}$  material;
- clinical data gathered from the medical history;
- laboratory evaluation by means of blood counts; and
- body surface monitoring to determine whether external or internal contamination was present.

It was, however, understood from the beginning that dose estimation, a very important parameter for medical prognosis, would be a major problem. Unlike an occupational mishap, where radiation monitoring is usually available, this accident affected members of the public who were without personnel dosimeters. The protracted nature of the doses received, as indicated by patients' histories, imposed further difficulties in the interpretation of clinical and laboratory parameters, such as the time pattern of prodromal symptoms and the frequency of chromosome aberrations in peripheral blood lymphocytes, which could help establish the magnitude of the radiation exposure and, thus, determine the corresponding prognosis.

However, we were soon able to recognize the individuals who had received strongly inhomogeneous and protracted whole-body exposure, internal and external contamination and, in some of the cases, significant localized exposure. Immediate determination of the body burden of internally contaminated individuals was not possible because of the lack of appropriate facilities. On the basis of the available prognostic data, we selected the six most seriously injured of the 12 patients in the Goiânia Hospital for removal on 30 September (day 17) to the Marçílio Dias Naval Hospital in Rio de Janeiro, the reference center recommended by CNEN for treating serious radiation accident victims. It was believed that the transfer of more patients might compromise the intensive, high-quality, multidisciplinary assistance these six patients needed. The removal of this group to Rio de Janeiro made

it possible to concentrate on treating those patients remaining in Goiânia. It also enabled the receipt of other victims.

From the day it was broken (13 September) to the day it was surrendered to the SSD (28 September), the source was handled by many people. Emergency teams had the laborious task of identifying such people during the first days of team operation. In part, this explains the fact that some patients were not hospitalized immediately, but some days later when they were discovered by local authorities. Another 30 individuals living close to the principal areas of contamination, or who were identified as relatives of the victims, were lodged in a primary care unit under medical supervision, mainly for decontamination purposes.

## CLINICAL AND LABORATORY EVALUATION

During the critical period, a significant number of clinical, laboratory, and radiometric evaluations, some routine and others specialized, were performed on patients hospitalized at the Goiânia General Hospital and the Naval Hospital. These included hematological analyses of the peripheral blood and bone marrow; biochemical evaluations involving at least two dozen parameters representative of human metabolism; evaluations of the immunologic status; serial microbiological analyses of patients with immunosuppression or local radiation injuries; cytogenetic analyses for biological dosimetry; electroencephalographic and electrocardiographic examinations; computer tomography; scintiscans; ophthalmological examinations; sperm counts; magnetic resonance imaging studies (MRI); pathological examinations; radiochemical analyses of feces and urine; and whole-body counts (Lipzstein et al., this issue; Brandão-Mello et al. 1989; Oliveira et al. 1990; Ramalho et al. 1988; Ramalho and Nascimento, this issue).

The patients lodged at the primary care unit, as well as those treated on an out-patient basis, underwent more limited examinations based on appropriateness, as determined on a case-by-case basis.

## THERAPEUTIC MEASURES

The therapeutic procedures used during the critical period may be summarized as follows:

- those intended to overcome the critical phase of the acute radiation syndrome (ARS) represented by bone marrow aplasia or hypoplasia;
- those designed to deal with local radiation injuries;
- those intended to accelerate  $^{137}\text{Cs}$  removal from the body; and
- general supportive psychotherapeutic measures.

### *Acute radiation syndrome*

These procedures may be divided into general and specific measures. The former were aimed at preventing infection as well as maintaining the patients' basal conditions. They consisted of reverse isolation, rest, a diet

free from raw foods, vitamin therapy, parenteral nutrition (in some cases), replacement of liquids and electrolytes, and prevention and treatment of infection through broad-spectrum antibiotic coverage, including antifungal and antiviral agents (Brandão-Mello et al., this issue).

Replacement measures were intended to offset the reduction of blood cell elements by means of transfusions of packed red cells, platelets and such other blood fractions as plasma and human albumin. Recombinant human granulocyte-macrophage colony-stimulating factor (GM-CSF) was used on eight patients who presented moderate-to-severe bone marrow failure (Butturini et al. 1988; Brandão-Mello et al., this issue).<sup>\*</sup> For these patients, bone marrow transplantation was not indicated because of the protracted and uneven distribution of the radiation exposure, as well as the coexistence of severe internal contamination and extensive local radiation injuries (Baranov et al. 1989).

#### *Local radiation injuries*

These procedures consisted of daily washing of the injuries with antiseptic and analgesic solutions, use of ointments and creams designed to revitalize the areas affected and stimulate local microcirculation, use of medicinal preparations intended to reduce the inflammatory process and accelerate healing, use of systemic vasodilators, and surgical intervention. Local therapy produced no clear benefit in accelerating the recovery of the lesions [Oliveira et al., this issue (a)].

#### *To accelerate $^{137}\text{Cs}$ excretion*

On 2 October, treatment with Prussian Blue (ferric ferrocyanide) began, sometimes associated with an oral diuretic, in doses recommended by the scientific literature (NCRP 1980) until the full  $10\text{-g d}^{-1}$  dose was reached. As the possibility of  $^{137}\text{Cs}$  removal through perspiration was confirmed, latex gloves were used for those patients with a high level of contamination on their hands; in addition, ergometric exercises and a sauna were employed to stimulate sweating (Farina et al., this issue).

The effectiveness of this treatment was evaluated by daily radiochemical analyses of feces and urine, and by means of serial evaluations of patients through whole-body counting measurements (Lipzstein et al., this issue).

#### *Supportive and psychotherapeutic measures*

These procedures were intended to manage diseases identified during the hospital treatment period, such as arterial hypertension, heart failure and arrhythmia, and urinary infections. Special emphasis was given to supportive psychotherapy, not only to minimize psychological aftereffects from prolonged confinement and the in-

juries sustained as a result of the accident itself, but also to assure effective psychiatric treatment for some previously psychopathic patients.<sup>†</sup>

### **RADIATION PROTECTION**

During the triage, transportation, and hospital care of the patients, radiation protection procedures were adopted to assure that doses received by the emergency workers were maintained as low as reasonably achievable, to ensure rapid decontamination of the patients, and to avoid the spread of contamination to uncontrolled areas. During the transportation of the patients, the airplane and ambulance seats, stretchers, and floors were covered with plastic sheeting, and the personnel involved in the transport used protective clothing and gloves. Respiratory protection was not required.

At the hospital, the ward was divided into controlled, supervised, and free areas (Fig. 2). The patients were restricted to the controlled area. The patients showed a maximum dose-equivalent rate of  $1\text{ mSv h}^{-1}$  at the thorax, and up to  $5\text{ mSv h}^{-1}$  of  $\gamma$  radiation at the hands and feet. Over the 4-mo period in which the patients were hospitalized, all medical, paramedical, and radiation protection staff that entered the controlled area were monitored for external radiation using film, TLD, and pen-type dosimeters. The highest dose integrated over this period was 3 mSv (Biagio et al. 1989). The majority of the workers received doses under 0.2 mSv. Whole-body counting was also administered for all hospital workers whose results showed negligible internal  $^{137}\text{Cs}$  body burdens.

During the medical treatment of the patients, their level of internal contamination was evaluated by whole-body measuring techniques [Oliveira et al., this issue (b)] and by measuring the dose rate for each patient at 26 points of the body surface, and at a point 1 m in front of the abdominal region, every other day (Hunt and Oliveira 1990). These dose rates were measured by various technicians using a number of different portable Geiger-Müller detectors, which complicated the work of data analysis and, in certain cases, resulted in the loss of information.

It was found that the most representative point for measurement of dose rate using portable Geiger-Müller monitors in relation to the internal  $^{137}\text{Cs}$  body burden was the axilla, possibly due to:

- the axilla being a good reference point, which permits a constant geometry of measurement;
- reduced interference from surface contamination, as this area is not usually contaminated externally;
- the axilla showing the highest dose rates due to internal contamination with  $^{137}\text{Cs}$ .

It is possible to recommend this point for dose-rate measurements due to internal contamination for other whole-body critical organ radionuclides.

<sup>\*</sup> Oliveira, A. R.; de Souza, P. C.; Tabak, D.; Brandão-Mello, C. E.; Valverde, N. J. L. Use of a hematopoietic growth factor (rHv GM-CSF) for treating irradiated persons: The Goiânia experience. Paper presented at the European School of Haematology course on acute and late effects of irradiation on the hematopoietic system. Paris, 28–29 June 1989.

<sup>†</sup> Carvalho, A. R. The psychological impact of the Goiânia radiological accident. Paper presented at the International Symposium on Recovery Operation in the Event of a Nuclear Accident or Radiological Emergency. Vienna, Austria, November 1989.

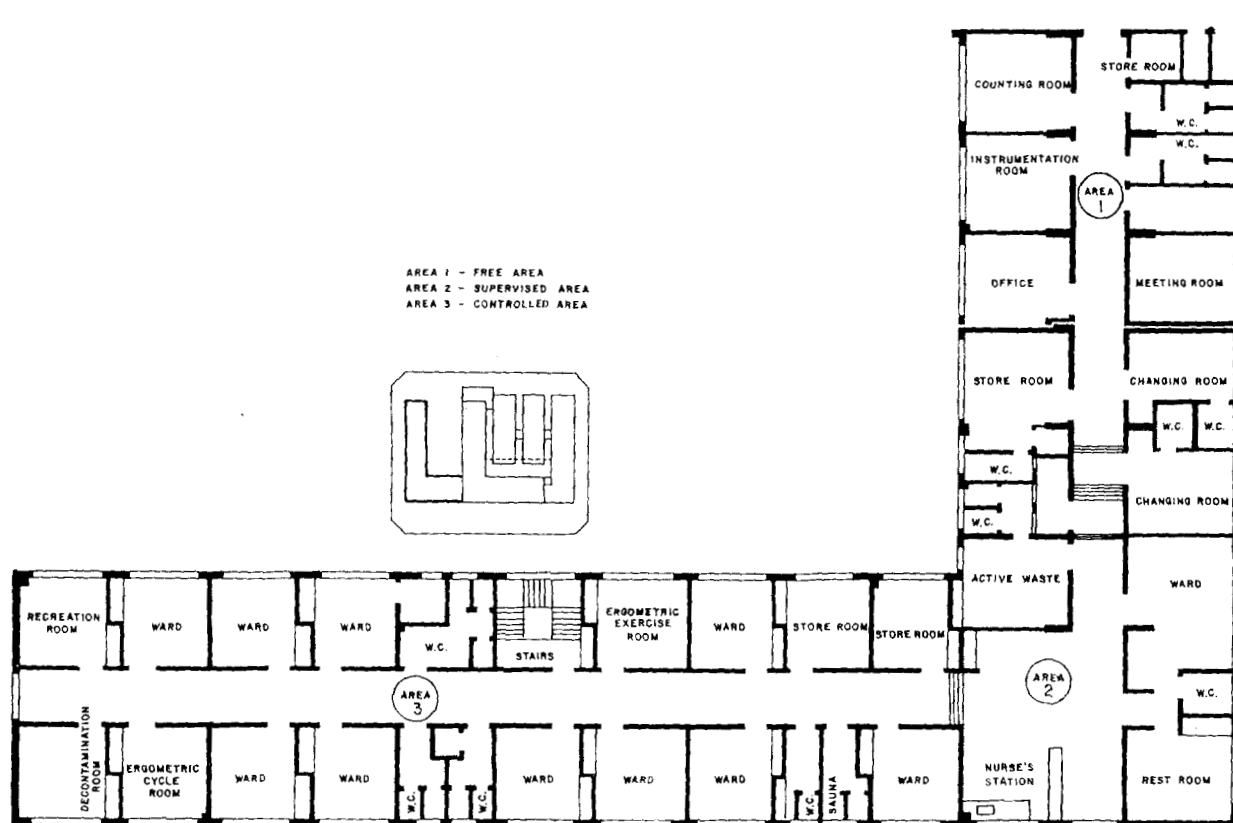


Fig. 2. Radiation accident treatment ward at Goiânia General Hospital.

Maximum removable surface contamination levels of  $60 \text{ Bq cm}^{-2}$  in the controlled area were reduced to background levels at the free area. The supervised area was reserved for the medical and paramedical staff. The free area, with a projected dose rate of less than  $1 \text{ mSv y}^{-1}$ , was open for the relatives of the patients and non-monitored staff. At a control point at the exit of the supervised area, each professional was monitored with a large-area surface-contamination monitor. The gloves and overshoes were discarded as active waste. Contaminated clothing or equipment was decontaminated or also discarded as active waste.

During the critical phase, visits were limited. Distance was maintained between the visitor and patient not only to protect the patient against the infection, but also to ensure that the visitor would not receive unnecessary radiation doses (NCRP 1970, 1976). Children and pregnant women were advised not to enter the ward. Regular visits to patients began after the sixth week postexposure, as the patients were already showing overt signs of hematological system recovery. Consideration was given to the potential benefit of these visits to the well-being and emotional comfort of the patients, who by this time were beginning to show the elation-and-depression symptoms associated with prolonged confinement.

### EXTERNAL DECONTAMINATION

Skin contamination surveys were made for all patients to permit external decontamination measures. All patients showed external contamination on the hands and feet. Due to the blue light emitted by the  $^{137}\text{CsCl}$ , two patients intentionally placed the powder on their skin: one on the chest and the other on the neck. The hands of these and other patients also entered into direct contact with the radionuclide.

The contamination survey began with  $\gamma$  dose-rate measurements made by portable Geiger-Müller monitors to identify any high contamination areas. The main difficulties in monitoring for surface contamination was the interference caused by the  $\gamma$ -radiation field coming from the internal contamination.

Where the  $^{137}\text{Cs}$  had been placed directly on the body surface, the resulting high dose rate caused local radiation injuries, which indicated the area of contamination. Beta radiation levels at the site of radiation burns were measured by placing  $\beta$  dosimeters directly over the points of interest. Each dosimeter contained four 0.20-mm thick  $\text{CaSO}_4:\text{Dy}$  polytetrafluorethylene (PTFE) pellets sealed in a black plastic film that was  $16.5 \text{ mg cm}^{-2}$  thick. Two of the pellets were shielded with PTFE filters that were

315 mg cm<sup>-2</sup> thick (Campos and Rosa 1988). Maximum  $\beta$  radiation dose rates of 38 and 23 mGy h<sup>-1</sup> were measured.

Classic decontamination techniques were used during the first 2 d of patient hospitalization. Repeated baths in warm water with neutral soap substantially reduced the levels of skin contamination (NCRP 1980). Dilute acetic acid was used for turning the Cs more soluble.

In the case of soles and palms with higher levels of contamination (up to 5 mSv h<sup>-1</sup> of  $\gamma$  radiation), titanium dioxide mixed with hydrated lanolin to form a paste was applied. The paste was then gently rubbed over the contaminated area, and the Cs was removed by abrasion. For patients with severe sole contamination (some individuals habitually walked barefoot and had developed a plantar hyperkeratosis), additional mechanical methods for decontamination were employed, such as callus abraders, rigid bristle nylon brushes, and pumice stone.

After all of the above-mentioned methods were ex-

hausted, use was made of an ion exchange resin, carboxymethyl cellulose, associated with Prussian Blue. The decontaminant was placed inside surgical gloves and plastic overshoes. As well as promoting sweating, the gloves and shoes permitted the close contact between the chemicals and the skin surface. A decontamination efficiency of 50% was measured after a 30-min application of this treatment to the feet of one patient. No adverse side effects were noted, and this method can be recommended in the case of future hand and feet decontamination requirements.

We hope the information provided in this paper will be helpful in the preparation of emergency plans. The reader is referred to the Appendix for additional sources of information on radiation accidents.

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## APPENDIX

Please refer to the following for additional sources of information on radiation accidents:

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