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The 1987 radiation accident in Goiânia: Medical and Organizational Experiences

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December 1989
Radiation Medicine Division
Núcleos - Instituto Nuclebrás de Seguridade Social

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SUMMARY

On 13 September 1987, two scavengers inadvertently removed a teletherapy device containing a 50.9 TBq (1375 Ci) cesium source, from a clinic in Goiânia, central part of Brazil. They took the apparatus home and tried to dismantle it. They managed to rupture the capsule exposing the source in such a manner that fragments of cesium and its powder spread out on the ground and were eventually disseminated over an area of 2000 m² in the center of the city.

Approximately 250 people were directly affected by the radiation, receiving slight to very severe external, partial or whole body irradiation, and presenting internal and external contamination. The authors describe the circumstances of the event, the first aid measures taken on the site, and the medical structure organized to triage and treat the casualties. Aspects relating to hospital contamination control, the environment, and radioprotection and decontamination procedures are also discussed.

Since the Goiânia patients showed only signs and symptoms compatible with the hematopoietic type of the acute radiation syndrome, comments will be made regarding treatment of bone marrow failure with conventional therapy (platelet transfusions, control of infectious complications, etc). The experience gained with the use of a hemopoietic growth factor (GM-CSF) to stimulate bone marrow recovery will be described.

PREFACE

Accidents involving the use of cesium 137 in industry, medicine or research are rare. A recent review identified only four cases of significant exposure to cesium. In two of these cases, the nuclide was used for purposes of suicide, with the consequent death of the persons involved. The third case was a worker who inadvertently put a ^{137}Cs cesium source in his right and left trouser pockets, successively. The severe lesions thus provoked on both thighs with radionecrosis of the femoral arteries, made it necessary to amputate both members. In the fourth case, a child was deliberately and criminally exposed to an industrial source by his own father, resulting in severe radiolesions on various parts of the body. This case, which occurred in the USA, had considerable repercussion in the press and was the subject of two publications in the scientific literature.

Naturally, the Goiânia accident developed under circumstances entirely different from the instances just cited, as it involved a large number of people afflicted by cesium powder or by small fragments which had been removed from the container of a source used for medical purposes. Many days passed before the local and national authorities were able to discover the origin of the problem which had permitted exposure of 250 people to radioactive material.

This accident, considered one of the most serious to date, has taught us innumerable lessons and we are certain that they will remain engraved in the memories of all who worked at controlling the various situations which had derived from the event, especially the medical professionals responsible for treatment of the radiation victims.

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I - The accident

On 13 September, 1987, a 50.9 TBq (1375 Ci) ¹³⁷Cs medical source was removed from its housing in a teletherapy machine. The device had been left in an abandoned clinic - the Instituto Goiano de Radioterapia - in Goiânia, capital of the State of Goiás, in central Brazil. The apparatus, weighing about 100 Kg consisted of the rotating assembly from the shielding head of a radiotherapy unit. Two scavengers, neither of whom had any idea of its significance, removed the rotating assembly from its base and took it home in a wheelbarrow, where they attempted to break open the outer protective shield with the use of a maul and punch. They managed to break open the shutter of the collimator orifice, exposing the source in such a manner that fragments spread out over the adjacent areas. Small fragments of it were withdrawn with the aid of a screwdriver. This operation took place near a mango tree and a dividing wall on a plot of land shared by several families in a house development. The attempted dismantling lasted 2-3 hours, but owing to the strong resistance of the protective shielding, it was not fully carried out.

About 3 hours after the attempt to break open the apparatus, both men developed nausea, followed by vomiting, and in the case of one of them, diarrhea. These gastrointestinal complaints persisted for 4-5 days.

On 18 September, around 4:00 p.m., the source assembly was sold to a scrap metal dealer, and left in a dump in his yard (Junkyard I). At 9:00 p.m. the junk dealer noticed that the object he had purchased earlier was emitting a blue glow in the dark. He brought it into his house as a curiosity, and it remained in the living-room until 20 September, accessible to family, friends and neighbours. Later, it was taken back to the dump and broken into pieces. Brilliant fragments of the source, the size of rice grains, were distributed among various individuals, mostly relatives and friends. The shield was left at Junkyard I and the remainder of the source assembly was sent to another junkyard (Junkyard III), where others would try to open it completely with a power saw.

By 28 September, the wife of the scrap metal dealer, noticing that an increasing number of persons were complaining of gastrointestinal symptoms (loss of appetite, nausea, vomiting and diarrhea), suspected that some relationship might exist between the object and these health problems. She convinced her husband to hand over the object kept in Junkyard III to the Sanitary Surveillance Division (SSD). Accompanied by an em-

Junkyard II exists but is irrelevant to this report



Figure 1 - Part of the cesium source handed over to the Sanitary Surveillance Division by the junkman's wife. Primarily, the source was placed on a chair and removed to a courtyard. The dose rates measured on the source surface were higher than 10 Gy/h and about 0,4 Gy/h, one meter from the source. As one can see, the source remnants, together with the chair, were buried in concrete utilizing two sections of sewer pipes. As a result of this operation, the dose rates in the vicinity of the source were significantly reduced

ployee of her husband's she took what remained of the source to the SSD and dumped it on a doctor's desk, saying " This is killing my family". The doctor suspected that the material might contain toxic gas, and was sufficiently worried to have it removed to a courtyard, where it was set on a chair and left for a day. The fire brigade was called as a precaution and the area was cordoned off. The suspicions of two men, one a technician from the Sanitary Division and the other a physician from the Toxicology Information Center of the State Health Department, eventually led them to call in a nuclear physicist at 8:30 a.m., on 29 September, to perform preliminary measurements of dose rates in the vicinity of the source. When the physicist noticed that the monitor of the cintilometer he was using had reached full scale, a second assessment was performed with a high range detector, which indicated high levels of radiation. He immediately evacuated the building, and the cordoned-off area was expanded. Military policemen and firemen were instructed to prevent anyone from entering the premises of the Sanitary Division. At the same time he contacted the State Secretary for Health and the Civil Defense, to ask for help.

On the same day, the National Nuclear Energy Commission (NNEC), notified of the problem, dispatched the Director of the Nuclear Installations Department to Goiânia, with two technicians from IPEN, a NNEC subsidiary headquartered in the city of São Paulo. The NNEC team went, on their arrival, to SSD where the first measurement with a teletector telescopic monitor showed a dose rate of 0,4 Gy/h one meter from the source remnants, indicating radioactivity of about 4,5 TBq (120 Ci), or less than 10% of the original source (Figure 1).

The nuclear physicist who discovered the nature of the source, showed the principal contamination sites (Figure 2) to the NNEC team and acting on their advice, the local authorities evacuated all residents in areas where the dose rates exceeded 2,5 uSv/h. After the evacuations, which took place on the evening of 29 Sep-

tember, the nuclear physicist and team went to the Olympic Stadium (Figure 3), where contaminated residents had been accommodated in tents.

II - The Radiotherapy Unit and the Cesium Source (Figure 4)

The radiotherapy apparatus from which the cesium source had been taken was a Cesaphan F. 3000 model, purchased in 1971 from the Italian firm Generay Spa. The sealed source capsule was set in a source wheel made of lead and stainless steel, which formed the rotating shutter system. To produce a radiation beam, the shutter was rotated electrically until the source and the collimator coincided. The unit was so conceived that the rotating assembly (rotating shutter, electric driver and shielding plug) could be removed from its shielding in the radiation head with the use of special tools.

The radioactive source was formed basically of cesium chloride powder, a highly dispersable compound, compacted in a double-sealed stainless steel capsule. Table I gives the general characteristics presented by the source as it was in September, 1987.

TABLE I

137 Cesium Source

Gamma rays:	0,66 MeV (84%)
Beta rays:	0,51 MeV (95%)
	1,17 MeV (5%)
Half-life:	30 years
Residual activity:	50,9 TBq (1375 Ci)
Dose rate at 1 meter:	4,56 Gy/h (456 rads/h)
Radioactive material form:	compacted powder
volume:	$3 \times 10^{-5} \text{ m}^3$ (30 cm ³)
mass:	$91,2 \times 10^{-3} \text{ Kg}$ (91,2 g)

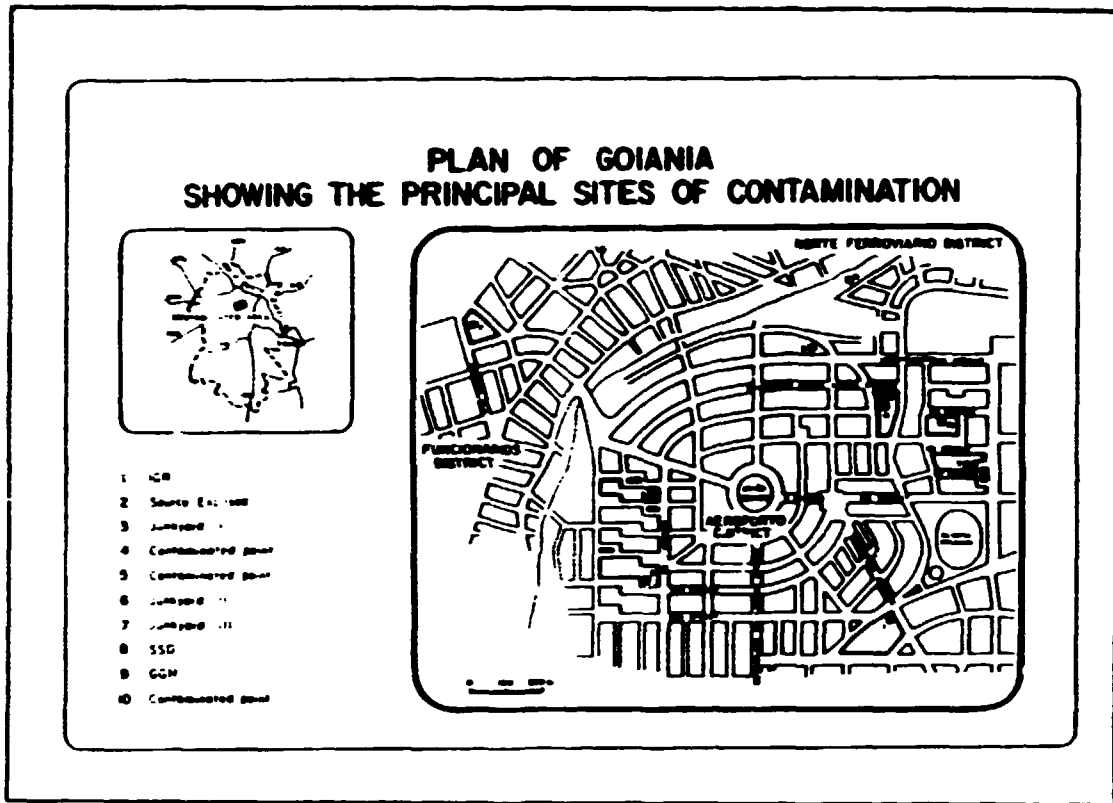
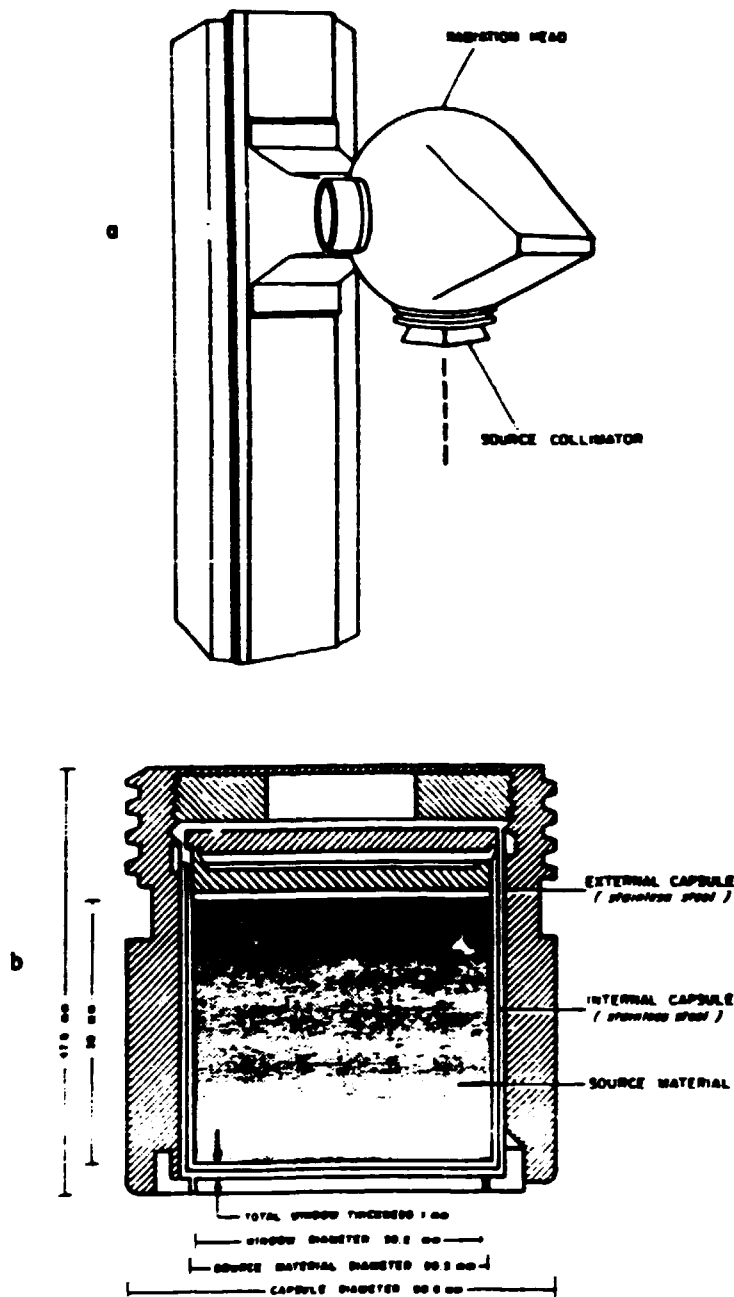


Figure 2 - Plan of Goiania showing the main contamination sites and the Goiania General Hospital



Figure 3 - Partial view of the Olympic Stadium showing tents where the patients were housed. The medical triage and initial decontamination procedures for the most affected patients were performed here

Figure 4 - Schematic view of a ^{137}Cs teletherapy source similar to that removed from the radiotherapy clinic 'a). Cross section of an international standard capsule (b). The capsule containing the radioactive material was ruptured and most of the cesium powder was spread over an area of 2.000 m^2 in the center of Goiânia (IAEA Report).



III - The Victims

During the period from 13-28 September, a significant number of people were directly affected by dissemination of the radioactive material. Most of them had some relationship with the scrap metal dealer or with the individuals who had originally tried to break open the source container. Soon after the nature of the accident was recognized, the emergency teams identified 249 contaminated and irradiated persons. Among them, 120 presented only clothing and shoe contamination, and 129 showed external or internal contamination. The tri-

age, performed by the emergency medical teams indicated 49 individuals as requiring some type of medical treatment, and at least twenty were admitted to the Goiânia General Hospital, where the first specialized procedures were performed. Afterwards, 14 of the twenty were transferred to Marcilio Dias Naval Hospital, designated as the Brazilian center for treatment of radiation accident victims. Twenty-nine patients remained under medical surveillance at a primary care unit set up in the Institute for Protection of Minors (FEBEM), mainly for decontamination purposes. In addition to these people previously mentioned, 112.800 individuals were moni-

tored at the Olympic Stadium. Radiological monitoring had the following objectives:

- a) to identify the presence of contamination;
- b) to apply preliminary decontamination measures and evaluate the effectiveness of such procedures, and
- c) to direct the patient, when necessary, to the Goiânia General Hospital for medical evaluation and, if indicated, for treatment.

The significant number of people monitored at the Olympic Stadium can be explained by the alarm caused by lurid new stories concerning water contamination, the risk to pregnant women from cesium contamination, etc.

Table II shows the number of people involved in the accident and how they were affected.

TABLE II

PERTINENT STATISTICS CONCERNING THE GOIÂNIA ACCIDENT

Individuals surveyed	112.800
Persons contaminated	249
Clothing and shoes only	120
Internal and external contamination	129
Local radiation injuries	28
Hospitalization (GGH and Naval Hospitals)	20
Bone marrow failure	14
Acute radiation syndrome	8
Fatalities	4

IV - Medical Intervention

1) First-aid measures taken at place

The more serious cases had already been hospitalized by 28 September, owing to their gastrointestinal complaints and localized injuries. They had been admitted to two regional hospitals (Santa Maria and Tropical Diseases) where they had been misdiagnosed as presenting contact dermatitis, food intoxication and

pemphigus. They had been treated symptomatically, as the medical and paramedical personnel at the hospitals had no idea of the true reason for their clinical manifestations.

The specialized medical team from Rio de Janeiro arrived at Goiânia 10 hours after the severity of the accident was determined. They began preliminary measures at the Olympic Stadium. Clinical and laboratorial evaluations (blood counts), were performed, as well as external decontamination, when necessary, with warm water and neutral soap. The medical team, accompanied by radiation protection technicians, then went on to the GGH, where a ward had been evacuated to hold the 11 patients who had originally been admitted to the Santa Maria and Tropical Diseases Hospitals. The ward was promptly adapted for their reception and a control point was set up to avoid disseminating the contamination. The ward was divided into controlled, supervised and free areas (Figure 5).

To assess the severity of each patient's condition, the following procedures were observed:

a) Clinical histories and histories based on the involvement of each patient with the radioactive source were analysed and recorded.

b) Hematological counts (red, white and platelet cells) were performed;

c) Body surfaces were monitored to determine possible presence of external or internal radiation.

It was quite clear, however, that the accident exposure suffered by most of these victims was of a strongly heterogeneous and fractionated character. These patients had received significant whole-body and localized irradiations and presented internal and external contamination. It was therefore obvious since the very beginning that dose estimation, a very important parameter for prognosis, would be a major problem.

The fractionated nature of the doses received, as indicated by the patients' histories, imposed equally adverse conditions for analysis of clinical and laboratory parameters. Immediate determination of the body burden of internally contaminated individuals was not

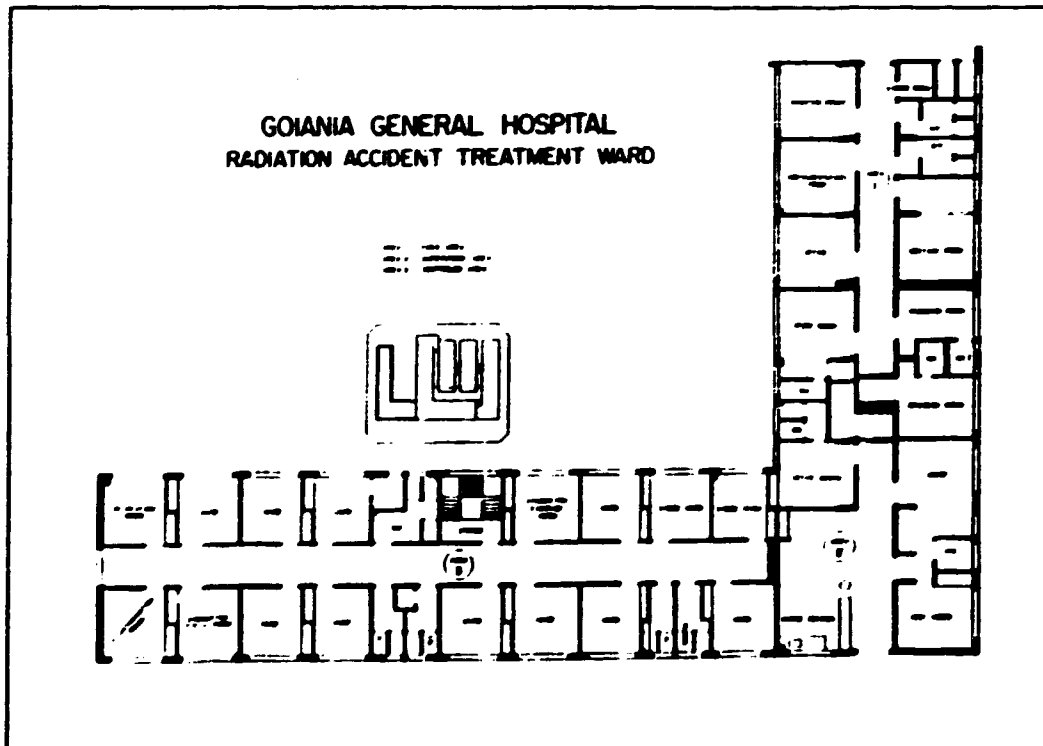


Figure 5 - Diagram of the GGH ward, after its adaptation to receive the irradiated patients. Note the supervised, controlled and free areas, and the location of the main service installations.

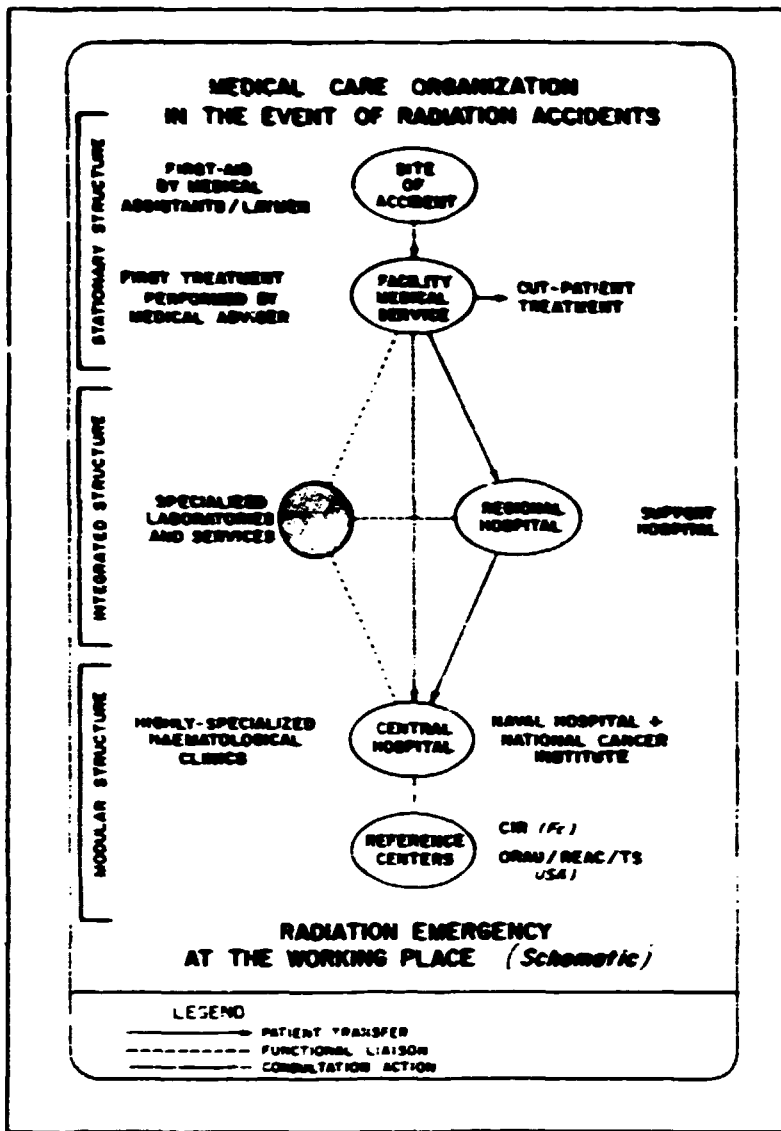


Figure 6 - Organization of medical care for a Brazilian nuclear plant in the event of a radiation accident.

possible at that time because of the lack of appropriate facilities (whole-body counters). However, the intake was estimated by 2 October, through analyses of biological excreta.

2) Triage of victims

Which patients should be transferred to the Reference Center in Rio de Janeiro was a difficult decision for the medical team. Taking into consideration the problems in preparing the Radiation Emergency Center at the Naval Hospital almost from one day to another, it was decided to remove only those who appeared most seriously injured. The criteria adopted for this selection were:

- a) degree of compromise to the hematopoietic compartment, based on peripheral lymphocytes and neutrophils counts.
- b) severity of local radiation injuries: intensity and precocity of local skin injury indications, i.e., erythema, blisters and bullae formation and appearance of ulcer and tissue necrosis;
- c) intensity of internal and external contamination, based on accident history, surface radiation monitoring and, later on, in vitro bioassays.

History and preliminary evaluations of the first individuals transferred to Rio de Janeiro are summarized in the Annex I.

3) Levels of Medical Intervention

It is common knowledge that in the event of a nuclear or radiological accident, a system of patient care levels should be activated. In the Goiânia accident, such a system was established, but only after the existing structure, designed to cope with accidents in nuclear facilities, particularly those involving the nuclear fuel cycle (Figure 6), had undergone various modifications. Three levels of patient care were defined, according to the extent of the patients' injuries and contamination.

1st Level: Primary medical assistance at FEBEM for patients with low levels of internal contamination who presented external contamination warranting decontamination measures impossible to perform elsewhere. It should be noted that most patients accommodated at FEBEM had had their houses and properties interdicted, which conferred a socio-medical character on this first level.

2nd Level: Secondary medical assistance at the Goiânia General Hospital for those patients with first and

second degree radiation burns, or those who had received doses high enough to cause a slight-to-moderate impairment of the hematopoietic system, but who would not require special isolation measures or replacement therapy (platelet transfusion, for example). Patients with moderate-to-severe internal contamination were kept at that level, where they could benefit from cesium removal procedures.

3rd Level: Tertiary medical assistance at the Marcilio Dias Naval Hospital (Rio de Janeiro), for patients with severe-to-very-severe internal contamination, as well as those showing bone marrow failure and third degree radiation burns.

V - Relevant medical organization and Infrastructure

The Goiânia accident compelled the Brazilian authorities to use all human and material resources available to cope with that radiation emergency. The lessons learned as well as the experience acquired by Brazilian specialists in managing that event led us to review concepts and plans prepared previously which contemplated accidents at nuclear facilities with greater or lesser involvement of the public. Some Brazilians institutions engaged in the field of radiation emergency medical assistance participated in the caring of victims soon after the discovery of the accident.

a) Institute of Radiation Protection and Dosimetry (IRD)

It participated actively and extensively in all activities relating to medical care of the victims. During the early phase, a member of the Emergency Monitoring and Evaluation Group of IRD, performed the initial triage of the victims, carried out external decontamination measures, and took samples of hematological and excreta. Thenceforth, he remained at Goiânia General Hospital, acting as practitioner and as one of the coordinators of the irradiated-patients ward.

Other objectives related to the major objectives of IRD were also carried out within the hospital scope: dosimetric control of the emergency medical and paramedical teams (film-badge personal dosimeters and TLD), cytogenetic dosimetry, excreta analyses (bioassays), analyses in-vivo with whole-body counters (NaI (Ti) and phoswich), radiation control in the hospital environment, external decontamination of patient, removal of residual contamination, waste management, environmental control, and other relevant activities.

Specialists from two other institutes belonging to National Nuclear Energy Commission (NNEC), Nuclear Engineering Institute (IEN), and Institute for Nuclear and Energy Research (IPEN), worked jointly with IRD.

b) Marcilio Dias Naval Hospital (MDNH)

MDNH is a large hospital, with approximately 650 beds, offering services capable of meeting the demands of most clinical and surgical specialties. It possesses sophisticated diagnostic equipment needed for the care of irradiated patients: CT-scanner, gamma-cameras, a whole-body counter, solid and liquid detectors, and other radiodiagnostic equipments.

MDNH is the Brazilian hospital designed to treat victims of severe radiation accidents. It set up a treatment center for irradiated patients capable of receiving 8

patients simultaneously in specially designed rooms normally used for cancer treatment by brachytherapeutic techniques. Adjacent to that center there is a burned-patients ward that can be readily converted into an irradiated-patients station. Medical care of the victims is the responsibility of the nuclear medicine department, which can call for support of several specialists available at the hospital.

During the Goiânia accident, MDNH acted as a tertiary care center pursuant to Figure 7, and handled 14 irradiated patients. Of these, 8 developed the acute radiation syndrome, requiring replacement therapy (platelet transfusion, for example) and a broad antibiotic coverage (see section Medical Management and Treatment). These patients were given intensive medical care by hospital staff, under the supervision of Brazilian and foreign specialists.

The patients with severe radiation injuries were evaluated by the nuclear medicine department, as well as those with internal contamination. The whole-body counter belonging to the service could not be used due to high levels of contamination in the patients.

Initial external decontamination procedures were performed at the nuclear medicine department using a specially prepared area.

Necropsies of fatal cases were performed by specialists from the University of Campinas (São Paulo), assisted by experts from Rio de Janeiro Legal Medicine Institute and from the Naval Hospital, using a necropsy room lined with plastic material.

c) Núcleos - Nuclebrás Social Security Institute

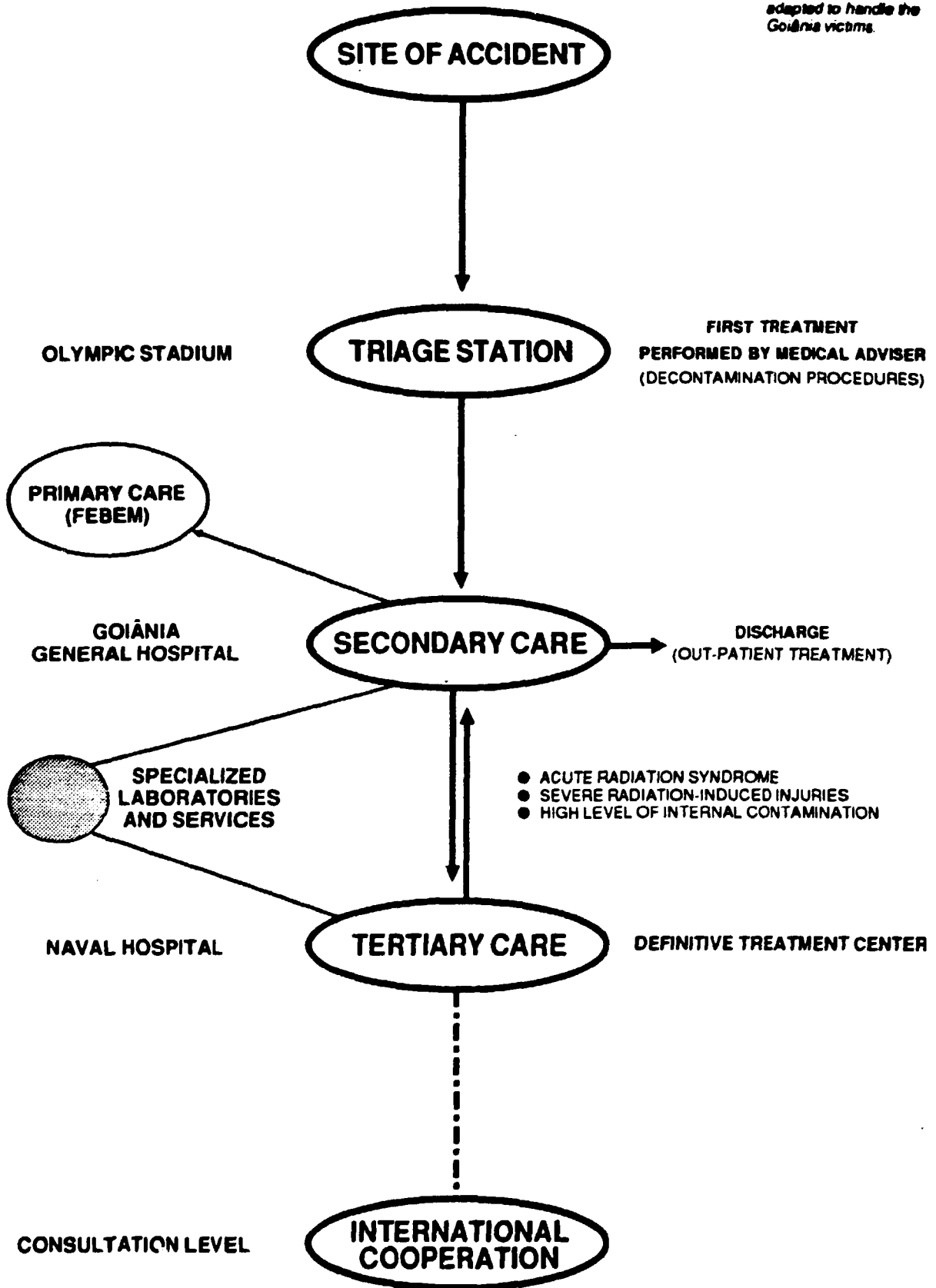
On requests by NNEC, Núcleos sent to Goiânia, on September 30 an occupational health and radiation medicine consultant, where he acted as one of the coordinators of the management and treatment of the Goiânia victims. Núcleos's participation consisted in assigning 7 additional physicians to the place of the accident, where they worked from October 5 to December 17, 1987. Núcleos has developed a personnel training policy for the medical and paramedical area, and even created a radiation medicine division, a group charged with preparing and supervising programmes for medical control of workers exposed to ionizing radiation at different steps of the nuclear fuel cycle. The division keeps a current register of nuclear and radiological accidents.

d) Furnas Power Plants

Responsible for the operation of the first Brazilian Nuclear Power Plant (Angra dos Reis NPP-1) in Rio de Janeiro, Furnas took part in the medical care of cesium victims through an occupational medicine specialist, who participated in the initial phase of triage of victims and in their transfer from the Goiânia General Hospital to MDNH, joining the external decontamination efforts and the medical treatment of victims during the hospitalization in the latter hospital. Three other physicians from that organization participated in the medical care activities in Rio de Janeiro and Goiânia.

The Angra dos Reis nuclear power plant has a medical center for treatment of irradiated patients in Mambucaba the site where a medium-sized hospital will be built. The nuclear emergency medical center is qualified to perform a full evaluation of patients through clinical, laboratory and radiographic examinations. At the center, initial external decontamination measures can be carried out as well as evaluation of internal contamination

Figure 7 - Organization of medical care, as adapted to handle the Goiânia victims.



through whole-body counters installed locally. The center also has an operation room and a ward with four beds.

In the case of radiation emergency, medical and paramedical teams, including personnel trained in ionizing radiation hygiene, will be called out.

e) National Cancer Institute

Considered to be one of the principal cancer treatment centers in Brazil, this 250 bed hospital operates in the area of clinical and surgical oncology. It is one of the reference centers for bone marrow transplantation in Brazil.

The bone marrow transplantation center (CEMO) has been performing transplants since 1984 and about a hundred procedures have been performed to date. The center possesses 5 isolated wards (hepa filters) and 2 laminar-flow units. In addition it has a complete clinical laboratory and immunogenetic service.

During the Goiânia accident, the coordinator of the center acted as a consultant to the medical staff of MDNH, in the area of hematology. The National Cancer Institute will also be designated as a tertiary care center for irradiated patients, complementing the scope of MDNH in those cases when bone marrow transplantations or alternative therapies are required.

f) Clinical Hospital - Campinas University (UNICAMP, São Paulo)

UNICAMP participated in the activities associated with the Goiânia accident through forensic pathologists who not only performed evaluation of irradiated patients from the forensic viewpoint, but also carried out post-mortem studies of fatal victims, assisted by anatomopathologists from the Rio de Janeiro Legal Medicine Institute and the Naval Hospital. In the hematological area, one specialist from UNICAMP performed evaluations of the bone marrow function of patients hospitalized in Goiânia. The patients with severe burns have been subjected to repair surgery at the Plastic Surgery Department of that University.

g) Technical Cooperation - National and International

A large number of professionals and institutions participated directly or indirectly in the medical assistance to the victims of the accident during its critical phase. On a dispensary and hospital level, such assistance was given by physicians from Núcleos, NNEC, Naval Ministry and Furnas Power Plants, in addition to support provided by health officials from the National Medical Assistance Institute of the social security service and from the Health Secretariat of the State of Goiás.



Figure 8 - Significant hair loss observed in a patient who received an estimated whole-body dose of 5.5 Gy.

**TABLE III - DOSE ESTIMATION, SYMPTOMS AND INFECTIOUS COMPLICATIONS
IN THE EIGHT MOST AFFECTED VICTIMS**

PATIENTS	DOSE RANGE	ARS SYMPTOMS		ONSET AFTER EXPOSURE	HEMATOLOGICAL NADIR(count/day)		INFECTIOUS COMPLICATIONS	ANTIMICROBIAL THERAPY
		PRODROME	CRITICAL PHASE		GRANULOCYTES (per mm ³)	PLATELETS (per mm ³)		
LNF	4 - 6	Nausea Vomiting (7 episodes) Erythema (day 2)	Fever Adinamia Stomatitis Tongue Ulcer Sepsis Shock Torpor	3 Hs	0 (25)	22x10 ³ (20)	Sepsis (Klebsiella sp.) Candidiasis (oral)	KGC Piperacilin Vancomycin Amphotericin B
IBS	3 - 4	Anorexia Nausea Vomiting Erythema (fingers) Bulimia	Fever Torpor Sepsis Shock	?	150 (30)	16,2x10 ³ (28)	Sepsis (Klebsiella sp.) Candidiasis (perineal)	KGC Vancomycin Piperacilin TMP + SMZ Micostatin Gammaglobulin
AAS	4 - 6	Anorexia Nausea Burning pain (hand) Erythema, edema (day 7) Epiation (day 12)	Fever Stomatitis Sepsis Shock	?	0 (28)	11x10 ³ (25)	Sepsis (Klebsiella sp.)	Cefobid Amikacin Piperacilin Acyclovir Gammaglobulin
MGF	4 - 6	Anorexia Nausea Vomiting (3 episodes) Alopecia (day 14)	Fever Stomatitis Sepsis Acute renal failure	?	0 (25)	27,7x10 ³ (19)	Sepsis (Klebsiella sp.) Candidiasis (oral and vaginal)	Gentamicin Carbenicillin Piperacilin Vancomycin Amphotericin B Acyclovir
RSA	4 - 6	Fatigue Anorexia Nausea Vomiting (3-5 episodes) Epiation (day 10) Erythema (day 7)	Fever Conjunctival hyper Stomatitis Ulcerations of tongue Agressivity Disorientation	2 - 3Hs	0 (25)	33x10 ³ (22)	Candidiasis (oral) Right forearm (amputation)	KGC Amikacin TMP + SMZ Amphotericin B Acyclovir
WMP	3 - 4	Transient erythema Headache Anorexia Nausea Vomiting (3-4 episodes) Watery diarrhea Epiation (day 13)	Fever Chills Sepsis Shock Left heart failure	3 - 4Hs	400 (34)	10,7x10 ³ (37)	Sepsis (P. Aeruginosa)	Cefhalon Vancomycin Ketoconazole Acyclovir
DAF	4 - 6	Fatigue Anorexia Nausea Vomiting Erythema (day 10) Epiation (day 15)	Fever Prostration	?	0 (18)	20x10 ³ (17)	Candidiasis	KGC TMP + SMZ Micostatin Ketoconazole Amphotericin B Acyclovir
MGA	4 - 6	Fatigue Anorexia Nausea Vomiting (4-5 episodes) Epiation (day 13)	Fever Anorexia Nausea Vomiting Adinamia	2 - 3Hs	0 (30)	21x10 ³ (25)	Candidiasis (oral and vaginal)	Cefobid Imipenem Cefoperazone Piperacilin Acyclovir

In accordance with the provisions of the Convention on Assistance in the Case of a Nuclear Accident or Radiological Emergency, Brazil requested technical assistance in the medical, radiation protection and radioactive waste management areas from the following countries and international organizations: Argentina, France, Federal Republic of Germany, Hungary, Israel, Japan, Netherlands, USSR, United Kingdom, USA, IAEA, WHO, CEC.

VI - Clinical observations

1) Observations relating to the acute radiation syndrome

At least 14 of the twenty hospitalized patients showed various degrees of bone marrow failure, analysed through aspirates or biopsies of the marrow, or from daily peripheral blood counts (see Annex II, Tables 1 to 14). Leucopenia was characterized wherever counts were below 3000 cells per millimeter cubic, neutropenia where counts were below 500 cells per mm³ and severe neutropenia where counts were less than 100 per mm³. Thrombocytopenia was diagnosed for those patients with platelet counts lower than 60×10^3 per mm³. The most seriously affected patients had been in poor general health when admitted to the GGH. Eight developed classical manifestations of the prodromal phase of acute radiation syndrome, i.e., anorexia, nausea, vomiting, fluid diarrhea, cephalgia and fever, with onset of the symptoms varying from 2 to 4 hours after exposure (Table III). Local signs of radiation exposure such as conjunctival hyperemia and transient erythema were also observed. It must be emphasized that when the accident was finally classified as radiological, almost two weeks had elapsed since the first attempt to dismantle the cesium source, and the patients were therefore admitted to the GGH with the critical phase already beginning. Owing to their direct contact with the source, all of them showed some degree of injury to skin or mucosa: epilation (Figure 8), hair loss in pubic and axillary regions and lateral aspects of the face, radiodermatitis of extremities and mucosa ulcers.

The critical phase was characterized basically by infectious complications and hemorrhagic phenomena. Infections were documented in the cases of eight patients who developed bone-marrow depression (Table III), and were a principal factor in the deaths of four of them. The resistant strains of *Klebsiella* sp., isolated in the patients who died, were probably acquired before the institution of antimicrobial therapy, and were responsible for the development of sepsis and secondary, irreversible shock, or renal failure.

Opportunistic infections caused by fungal specimens, developed in 6 patients, affecting oral, esophageal, vaginal and perineal mucosae. Neither herpes virus nor cytomegalovirus infections were identified, although a preventive antiviral therapy had been instituted to prevent activation of herpes simplex virus.

Hemorrhagic phenomena were recognized in 4 out of the 8 patients most seriously ill, and were an associated cause of death in two cases. Hematemesis, melena and epistaxis were the major bleeding manifestations. The autopsies performed showed multiple hemorrhagic areas throughout the entire skeletal musculature and the various organs (heart structures,

lungs, stomach, bowels). In the 4-5 week period following initial exposure, four patients died from ARS complications. The others attained almost full recovery of the hematopoietic system.

2) Clinical features associated with local radiation lesions

Local symptoms appeared a few hours after contact between the source and the skin surface. Pain, sensation of local heat, burning and pruritus, as well as changes in sensitivity were the most frequent complaints. Some patients reported the simultaneous appearance of transient erythema in the affected regions. After a period of latency ranging from a few days to two weeks, a second wave of localized disturbances ensued, characterizing the so called critical phase, which was represented by stronger pain and edema, always preceded by secondary erythema, resembling a classical thermal burn. Soon after, blisters (Figure 9) or bullae developed, coinciding in general with the swollen region (Figure 10). This phase of bullous epithelitis lasted approximately two weeks. In some cases the bullae were so tense and painful that drainage was required to relieve the symptomatology and allow movement of the extremity, a procedure followed by resection of the necrotized tissue. This surgical intervention disclosed a raw and extremely painful dermal surface, with a swollen aspect and sparse reepithelization islands (Figure 11). This phase was followed by a fairly slow regeneration process, characterized by tissue granulation beginning at the outer edges of the injury and progressing toward the middle, a process requiring months to complete. The scar tissue was as a rule thin, translucent and very sensitive to tactile stimulus.

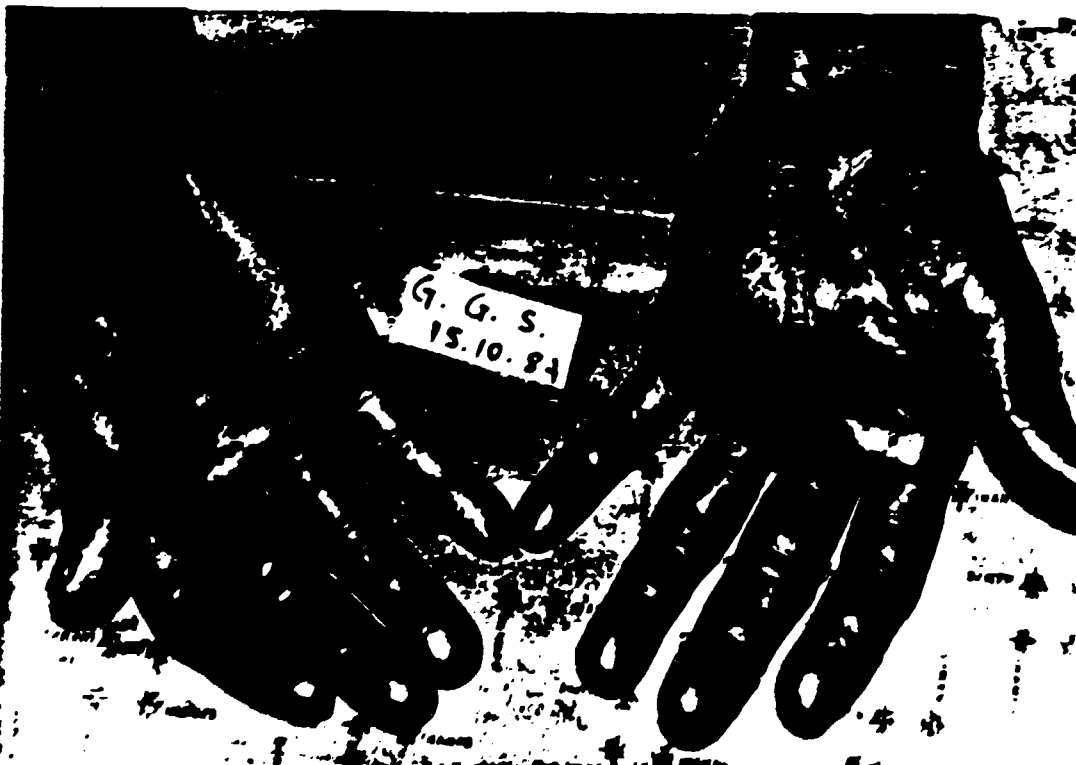
The final aspect of the injury was esthetically poor, owing mainly to its retractile character. Some patients received such intense local irradiation that recovery was never achieved. In such cases, the dermis was covered with a relatively thin layer of fibrin, lightly fixed to the underlying dermis (Figure 12). This necrotic aspect of the injury was observed in at least four patients. Seven patients developed more severe local radiation-induced injuries, resulting in areas of superficial necrosis caused by attenuated (shielded) gamma rays plus beta emissions of cesium, and in deeper necrotic injuries of a darker hue, both requiring surgical intervention. In these cases, a clear-cut reduction in the evolutionary phase was noticed.

VII - Medical management and treatment: Clinical and laboratory evaluation

Medical care was provided on a round-the-clock basis. The eight patients were subjected to a daily assessment of hematological parameters and to a serum chemical profile (electrolytes, glucose and BUN) twice a week, or every other day if necessary. Additional procedures were performed where there occurred associations of such conditions as internal and external cesium contamination with local radiation burns and underlying pathological states. In these cases chest X-rays, electrocardiogram, electroencephalogram, stool examinations and vascular and bone scintiscans were called for.



*Figure 9 - 1 week after exposure
Blisters of different sizes and small
ulcer on the upper part of left arm of a
patient who handled the cesium
powder.*



*Figure 10 - 20 days
after exposure.
Local
radiation-induced
injuries (bullous
epithelitis) on both
hands of a patient
who handled the
source container.*



*Figure 11 - 30 days after exposure
Debridement of the
blisters. The
hypothenar region
shows a superficial
ulcer, characterized
by the swollen,
reddish surface of
the dermis. Some
reepithelization loci
can be seen.*



*Figure 12 - 45 days after exposure.
Severe radiation
burn on the left
hand. Almost all
palmar surface was
affected and raw
dermal surface was
covered by a
fibrinous exudate*

All patients were given individual or two-bed rooms with reverse isolation. Comprehensive radiation protection techniques were adopted to protect the medical and paramedical teams, and the masks, caps, gloves, over-shoes and surgical overalls used by all attending personnel served also to protect the patients themselves from infection.

For gut selective decontamination, use was made of trimethoprim and sulfamethoxazole, later changed to norfloxacin. Ketoconazole was used for treating fungal infections and acyclovir to prevent herpes virus activation. Patients with granulocytopenia and temperature above 38.5o were given systemic antibiotic therapy. Initially two or three associated antibiotics were administered: Carbenicillin (75 mg/kg body weight, every 4 hours); Gentamicin (80 mg/kg, every 8 hours); and cephalotin (30 mg/kg, every 4 hours) in accordance to clinical and bacteriological data. Antibiotics were shifted to cefoperazone and piperacillin (40 mg/kg body weight, every 4 hours). Imipenem (1,5 to 3.0 g/day) as well as vancomycin, were administered too, on the same rationale.

Oral moniliasis was prevented by use of nistatin, and for cases unresponsive to this drug, amphotericin B was given. Two patients received parenteral nutrition through a central access line. All food was cooked and raw vegetables were avoided.

Patients were given total blood transfusions or red packed cells in order to maintain the level of hemoglobin within safe limits (above 10 g/dl). Platelet transfusions were performed to keep these elements at a level above 20.000 per mm³ or whenever bleeding occurred in a patient with a platelet count of less than 60.000 per mm³ (Table IV). Blood products were obtained from healthy volunteer donors unrelated to the victims, and were previously irradiated in a linear accelerator to 25 Gy (2500 rads). To accelerate the process for obtaining platelets, a Fenwall 2922 separator was employed.

VIII - Treatment of Irradiated patients with a hemopoietic growth factor (GM-CSF)

The first major clinical experiment in the use of the GM-CSF for treatment of irradiated individuals with bone marrow aplasia or hypoplasia, was performed on 8 patients with bone marrow failure, resulting from the Goiânia accident. Of the 14 patients referred to the Marcião Dias Naval Hospital, only 8 were eligible to receive GM-CSF. The drug was administered initially to the two most severely injured patients, whose lives were at a risk, and only later to the remaining six. The eight patients (three females and five males), ages ranging from 6 to 57 years, were exposed to 137 Cs during a period of 24 to 41 days prior to the start of therapy. Their ages, dose estimates, hematological counts and the severity of their hematopoietic syndromes are indicated in the Table V. The absolute leukocyte counts at the start of GM-CSF use ranged from 50/mm³ to 2100/mm³. Neutrophils ranged from 0 to 750/mm³, platelet counts from 18.000/mm³ to 295.000/mm³ and hemoglobin between 6.0 g/dl to 13.3 g/dl.

GM-CSF doses were 500 ug (25 x 10⁶ units) per square meter of body surface area per day, maintained until the level of granulocytes reached 2000/mm³ and remained close to that value during three days. The drug was then reduced to 250 ug (12,5 x 10⁶), later to 125 ug

(6,0 x 10⁶), and finally discontinued. The drug was administered through continuous IV infusion, either via a central access line with the use of an infusion pump, or through a peripheral vein. The infusion period was six days for four of the patients, 10 days for two of them and 14 and 16 days respectively for the remaining two. In addition to routine hematological evaluation, bone marrow aspirates and biopsies were obtained from the iliac crest, before and after use of GM-CSF.

Following administration of GM-CSF, a rapid and acute rise in the number of peripheral blood cells was observed. Actually, in less than two days a significant increase in granulocytes counts could already be seen. Within a 24 hour period, one patient showed a granulocyte variation from near zero to 500/mm³; with 5000/mm³ on the second day after the start of infusion and 21.000/mm³ on the fourth day. These values remained high for one week (Curve 1). Another patient received GM-CSF during 14 days and the number of granulocytes varied from 70/mm³ to 18.000/mm³, when the drug was suspended. Even though he presented a septic condition followed by shock during the period of GM-CSF administration, this patient recovered satisfactorily (Curve 2). Two patients, who showed a lower degree of bone marrow depression, also recovered after GM-CSF infusion. The drug was administered during a short period through a peripheral vein (Curves 3 and 4). Four patients who received GM-CSF between the 20th and 25th day after exposure, died between the 6th and 10th of drug administration, owing to uncontrolled infectious complications and hemorrhagic processes. In one particular case (a six year old girl who had undergone severe external exposure, associated with a very high internal burden), there was no hematological response to GM-CSF (Curve 5). Hemorrhagic diathesis, involving lungs and kidneys, associated with sepsis caused by *Klebsiella* sp., formed an irreversible picture for this patient.

One young patient presented a clear response to the proliferating effect of the factor, confirmed by peripheral counting. On day 0, no granulocytes were detectable in peripheral blood; on day 5 the count was 2000/mm³ and on the day of the patient's death, 6000/mm³ (Curve 6). This patient died from septic shock, due to colonization by *Klebsiella* sp.

Despite an aplasia time of 20 days, a 36 year old woman showed a rise (800/mm³), in the number of granulocytes on the day of her death, six days after the start of GM-CSF administration (Curve 7). This patient recovered from acute renal failure, but septic shock followed. Autopsy showed disseminated hemorrhagic diathesis predominating in the lungs and heart, as well as encephalic edema.

Out of the 8 patients analysed, four presented a clear myeloproliferative bone marrow response after GM-CSF administration. Although one patient died from sepsis, he evidenced signs of bone marrow recovery and could have survived had the infectious problems been controlled. Finally, the other 3 patients who died (two females and one young male), showed irreversible compromise of the bone marrow. One might speculate that the absence, or scarcity, of effectors (progenitors cells of the hematopoietic system), upon which the GM-CSF could act, was one of the reasons why the bone marrow of these patients was unresponsive to the drug.

In those patients who clearly responded to GM-CSF, one could notice a concomitant increase of bands

TABLE IV - REPLACEMENT TRANSFUSIONS OF BLOOD COMPONENTS

Patient	Bleeding	Red Packed Cells	Platelet Transfusions	GM-CSF	Outcome
RSA	—	2u (day 29) 1u (day 32) 1u (day 37)	5u (day 24) 8u (day 28) 6u (day 30) 6u (day 32)	No	Recovery
DAF	—	2u (day 23) 1u (day 29)	8u (day 20) 7u (day 23) 8u (day 27) 7u (day 29)	No	Recovery
MGA	Petechiae Rectal bleeding Conjunctival hemorrhage Hematemesis	1u (day 26)	6u (day 20) 6u (day 21) 6u (day 22) 8u (day 25) 6u (day 26)	Yes	Recovery
AAS	Conjunctival hemorrhage Melena	2u (day 31) 1u (day 36)	1u (day 32) 1u (day 33) 1u (day 35) 8u (day 36)	Yes	Died
MGF	Skin and palatal petechiae Orbital hematoma Rectal bleeding	1u (day 18) 1u (day 22) 1u (day 23) 2u (day 27)	5u (day 19) 6u (day 24) 6u (day 25)	Yes	Died
LNF	Epistaxis Melena Hematemesis Rectal bleeding	1u (day 19) 1u (day 22) 1u (day 23) 1u (day 28)	2u (day 18) 3u (day 19) 3u (day 20) 2u (day 21) 2u (day 22) 2u (day 24) 2u (day 26) 2u (day 28)	Yes	Died

and eosinophils and, to a lesser extent, monocytes and lymphocytes. Confirming trials previously performed, drug suspension coincided with an almost immediate reduction in the number of circulating blood cells, sometimes within average values, but also quite below them. No relation was established between GM-CSF administration and the behaviour of hemoglobin.

Use of GM-CSF was based on the assumption that residual stem cells existed and that a factor capable of stimulating their proliferation and differentiation might play an important role in recomposing the natural defense mechanisms of the irradiated patients. As described earlier, the granulocyte-macrophage colony-stimulating factor had been used with encouraging results on patients with leukemia, sarcoma, myelodysplastic syndrome and the acquired immunodeficiency syndrome. It was therefore imagined that similar results might be obtained in irradiated patients showing significant bone marrow failure. If we compare the hematological curves presented by the victims before and after use of the factor with those presented by patients who recovered spontaneously without using such a factor the effect of GM-CSF is apparent. Although in the present case GM-CSF administration began when bone marrow recovery process was to spontaneously start, it seems clear to us that some patients with a severe depression, which had lasted for a number of weeks, responded promptly to GM-CSF, with a remarkable increase in pe-

ripheral blood cells. Was it a mere coincidence? This does not seem the case. The pattern of recovery usually observed in patients going through the recovery process in the hematological type of the ARS is of a progressive character, causing the angle between the upward and the horizontal curves to be less pronounced than in the case of patients who received the GM-CSF (For comparison, see Curves 1 and 8, which show the patterns presented by a patient who was given the factor and another who did not receive it).

Almost three years have elapsed since the accident, and it is time for a critical, objective, and unbiased review of the therapeutical efficiency of some drugs used for the first time in treating radiation victims. Regarding GM-CSF, the essential question is not whether or not it saved some of the victims. This could only be scientifically established if a rigorous, methodical study had been conducted, and in all honesty, we do not believe this to be feasible in a accident situation where the major concern is to save human lives. We consider the use of GM-CSF in our patients was valid, if only because it enabled us to observe its possible effects in proliferating and differentiating progenitor cells of the hematopoietic system as demonstrated in previous experimental studies. We do not hesitate to indicate GM-CSF in future radiation accident cases, particularly because of its low toxicity during administration and also because it has not, so far, altered the capacity of the

TABLE V — EFFECTS OF GM-CSF ADMINISTRATION ON WBC OF ACCIDENTALLY EXPOSED PERSONS

Estimated dose (Gy)		Deg. of BMD	GM-CSF		Leucocytes		Neutrophils		Eosinophils		Lymphocytes		Monocytes		Outcome
Cytogenetics.	Clinical & Hematolog.		Day of adm. after expo.	Initial Dose (ug/m ² /d)	Pre-GM-CSF	Peak	Pre-GM-CSF	Peak	Pre-GM-CSF	Peak	Pre-GM-CSF	Peak	Pre-GM-CSF	Peak	Died
6.0 (5.1-7.3)	4-6	III	24	500	100	*	54	*	0	*	18	*	0	*	Died
5.7 (4.0-6.7)	4-6	III	30	500	50	650	0	*	0	*	0	*	0	12	Died
5.3 (4.4-6.5)	4-6	III	24	500	650	26,200	250	23,000	36	0	243	1,834	0	1,310	Died
4.5 (4.0-5.7)	3-4	II	24	500	550	*	260	*	100	*	220	*	0	10	Died
4.3 (3.4-5.5)	4-6	III	31	500	600	23,100	0	18,711	0	3,220	210	1,848	0	2,541	Survived
2.7 (2.0-3.6)	3-4	II	32	500	550	21,900	350	14,890	30	380	150	1,314	15	219	Survived
2.9 (2.0-4.2)	1-2	I	38	500	1,400	10,600	500	7,420	112	954	644	1,060	140	424	Survived
4.4 (3.4-5.6)	1-2	I	41	500	2,100	21,000	756	9,900	42	177	113	1,890	189	1,050	Survived



Figure 13 - A photograph of the medical, paramedical and radiation protection team.

bone marrow to maintain within satisfactory limits, the intricate self-replication and differentiation process of stem cells.

IX - Radiation protection measures adopted during hospitalization and transfer of victims

Radiation protection measures were followed at all times during triage, transportation and medical care at hospital levels, to prevent the spread of contamination and to protect the personnel involved from unnecessary exposure. Care was taken to cover ambulance seats, stretchers and floors with plastic sheets secured by means of rubber bands. Handles and other handling devices were also covered with plastic material. Protective clothing such as caps, masks, overalls, inner and outer gloves, overshoes and plastic aprons were the principal safeguards for the attending teams during the various transportation and hospitalization procedures (Figure 13). Film-badges, TLD and direct measurement techniques were employed to monitor doses received by the medical, paramedical and radiation protection staff.

All patients, including those housed at FEBEM, were routinely monitored for quantification of internal contamination and evaluation of the effectiveness of surface decontamination and decorporation techniques (Figures 14 and 15), and 30 points on their bodies were checked every other day.

Transfer of victims from one hospital to another was always an arduous task. Aside from causing operational complications in the hospitals involved, there was the very considerable discomfort inflicted by the hot and cumbersome protective clothing, added to the fact that transfers, which obviously implied a change in the patient's state of health, made both patients and their relatives highly uneasy. Finally, transfers necessitated a massive mobilization of human and material resources: military aircrafts, equipped ambulances at both airports (Figure 16), and medical and radiation protec-

tion personnel, all of which imposed a tremendous logistic burden.

X - Aspects relating to internal contamination

As was mentioned before, about 130 individuals showed clear signs of contamination, primarily because they handled the source, or part of it, directly, thus permitting ingestion or inhalation of the cesium powder, or enabling it to penetrate through the radiation-induced injuries. The very high body-burden levels encountered in some patients represented a challenge from both medical and radiation protection standpoints. One of the victims showed an internal dose rate of 25 cGy/day, owing to internally deposited cesium. To accelerate cesium removal, on 2 October, treatment with oral Prussian Blue (Ferric Ferrocyanide) was begun in doses ranging from 1,5 to 10 g/day. In a few cases, a dose of 20 g was attempted, but due to significant gastric distress, the dose was reduced to 10 g/day. It was noted that the larger the dose of Prussian Blue the greater was the elimination of cesium through feces. As a rule, an inversion of the urine-feces ratio of cesium elimination was noticed, changing the expected 4:1 response to 1:4. These two facts allowed the medical team to conclude that Prussian Blue was efficient, from a clinical standpoint, in accelerating cesium decorporation. The biological half-life was reduced to one third of the normal value with the use of this drug.

Minor side effects were observed when full doses of the drug were administered (Table VI).

TABLE VI

Number of patients treated	Prussian Blue doses*
4	1,5 g/day
20	3 g/day
9	6 g/day
9	10 g/day

* Side effects: Constipation, epigastralgia, mild hypokalaemia

As cesium shows a behaviour similar to K, an attempt was made to stimulate its removal by means of diuretics, but the result was unsatisfactory. Eighteen patients received Furosemide (40 mg/day) or hydrochlorothiazide (50 to 100 mg/day) and remained under rigorous clinical and laboratorial monitoring in order to prevent possible side effects. The choice of diuretics was based not only on their capacity to eliminate alkaline metals (K, Cs), but also to control the hypertension diagnosed in a few of the patients. The daily bioassays of urine and feces demonstrated the inefficiency of these drugs in eliminating the nuclide, and their administration was suspended, except for those cases requiring them for other reasons.

For the same purpose, a forced fluid regimen, which consisted of 3000 ml of water or potassium-rich elements such as orange juice, was attempted. The 12 patients who were subjected to this diet (they were evaluated previously and presented normal cardiovascular and renal functions), received Prussian Blue concomitantly. It was not possible, unfortunately, to draw any conclusions as to the efficacy of this procedure for accelerating cesium removal.

It was noted that cesium migrates freely through the skin, owing to the highly soluble nature of cesium chloride. An attempt was made to stimulate its elimination through sweat induction. A joint medical program

was set up with the collaboration of a team of professionals from the Superior College of Physical Education (University of the State of Goias), aiming at developing physical activities which would best stimulate perspiration. Two methods were proposed: a) active, involving ergometric exercises, bicycles and a treadmill, which was installed in the Goiânia General Hospital, and b) passive, whereby patients underwent 20 minutes sessions in steam baths (Figure 17).

According to gross monitoring data obtained by the radiation protection teams, the two methods proved equally successful in increasing the rate of cesium elimination. Unfortunately, owing to adverse working conditions, reliable information on cesium decorporation through sweat is not available.

XI - External decontamination

Classical decontamination techniques were employed during the first two days of patient hospitalization so as to avoid further incorporation of Cs 137, to reduce the equivalent dose received by the patients and to reduce contamination of the ward. Presence of external contamination was easily verified by measuring hot spots caused by beta + gamma radiation on the skin surface. Such measurements were complicated by the high



Figures 14 and 15 - Monitoring patients for dose rate assessment. CONTAMAT and Genger Muller detectors were utilized.



Figure 15

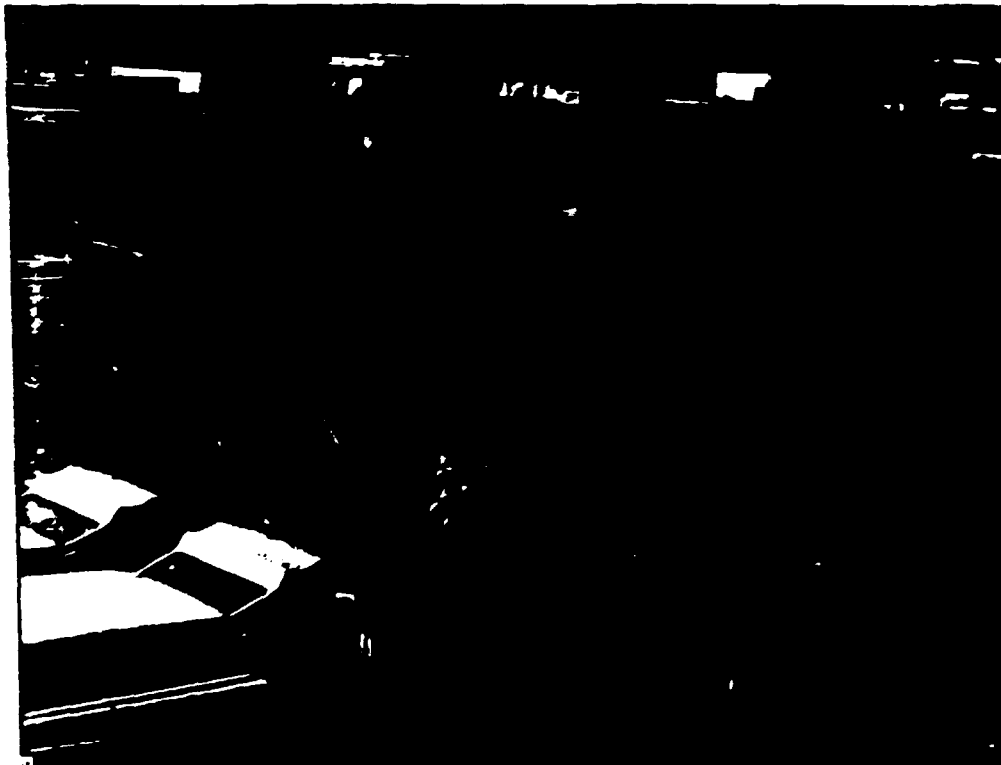


Figure 16 - Group of patients being transferred from military aircraft to ambulance at Rio de Janeiro airport. Medical and radiological personnel were needed for this operation and everyone involved wore special clothing



Figure 17 - Portable plastic steam bath installed at GGH to facilitate decontamination in internally contaminated patients. The walls and floor were protected with disposable plastic sheets.

gamma dose rate from internal contamination. The following techniques were utilized to decontaminate the patients:

a) Repeated baths in warm water with neutral soap, which reduced the contamination levels substantially;

b) Use of acetic acid for turning the cesium soluble and thus facilitating its removal;

c) Applications of titanium dioxide associated with hydrated lanolin, in cases where a great amount of radioactive material was evident on palms and on soles. Owing to its mildly abrasive action, titanium dioxide, after repeated applications, was capable of removing considerable quantities of the Cs present in nonsuperficial skin layers;

d) Additional mechanical methods for decontamination, such as callus abraders, rigid-bristle nylon brushes and pumice stone were used for patients with severe sole contamination (some individuals habitually walked barefoot and eventually developed a plantar hyperkeratosis);

e) Later, after all the above described means were exhausted, use was made of an ion-exchange resin, which exchanges cesium for potassium. The resin was

placed inside gloves and plastic overshoes, where hands or feet would remain in contact for at least 20 minutes. As a consequence, a 50% removal of residual cesium was detected.

XII - Contamination control

A control system was established by dividing the ward into three different areas (Figure 18), paying special attention in order to avoid the spread of contamination to the free areas where the whole-body counter, the offices, changing rooms and support services were installed. A control barrier was defined at the restricted area and all personnel, equipment and clothing leaving the area was monitored with a Contamat detector. Contaminated clothing used by patient and staff was processed and washed in a "hot laundry", operated by NNEC. All medical and radiation protection equipment used in the restricted areas was protected by transparent plastic bags.

An area-monitoring routine was established to measure surface and air contamination. Wipe tests and air filters were analysed and a gradual decrease in contamination in the restricted areas was obtained, mainly owing to the intensive cleaning work undertaken in those areas. Measurements were also taken in other



Figure 18 - Photograph of the Goiânia General Hospital ward
● Radiation protection control point separating free and supervised areas.

areas of the hospital (laboratories, laundry, and operating theatres), to detect and treat residual contamination. The contaminated waste (a great deal of contaminated biological waste was generated, which posed a difficult problem), was placed in 200 L steel drums. Around one drum of active waste per week was generated.

Walls, windows and the ward furnishings presented contamination owing to handling by the patients. After their discharge, conventional cleaning methods were supplemented by industrial decontamination techniques, using abrasive methods associated with titanium dioxide (TiO_2), Prussian Blue, ion-exchange resins and sometimes the actual removal of hot spots. The environment of the ward was decontaminated almost entirely to background levels.

XIII - Conclusions and recommendations

The Goiânia accident is considered the worst radiation accident to have occurred in the Western Hemisphere and is of special interest from various standpoints. The difficulties confronted by the emergency teams stemmed mainly from the delay in recognizing and identifying the nature and seriousness of the accident, associated with the fact that fragments of the cesium source were disseminated among innumerable

persons and places, thus making a proper reconstruction of the events following violation of the capsule almost impossible.

From the medical standpoint, enormous managerial difficulties were faced by the teams responsible for triage, initial treatment, transport and hospitalization, not only because of the drawbacks mentioned, but because of the large number of victims, the acute/prolonged nature of their exposure, the association of both total and local irradiations with different levels of internal and external contamination, the socio-cultural level of the victims and finally, the psychological impact of an accident of this type.

Although there is little probability of a similar accident occurring in a developed country, this possibility cannot be entirely discarded, especially when one considers that Goiânia is a relatively cosmopolitan city with an excellent medical structure and an organized and to a certain extent, sophisticated society of more than a million inhabitants.

Many lessons were learned by the professionals who worked to control the emergency situations arising from cesium effects on people and their surroundings. First among them is the necessity of including in the safety measures required for handling radioactive sources, those more comprehensive procedures already adopted in the nuclear area. We might also

enumerate the following recommendations, which could be useful to national authorities responsible for the preparation of programmes for coping with nuclear or radiological accidents:

1) Regarding organizational and logistic decisions

a) During an emergency situation, the authorities should be able to count on a well-established information network, with a thoroughly defined chain of command (flowsheet). The responsibilities inherent in the decision-making process should be very precisely indicated, not only as to plans of action, but also regarding their execution and the evaluation of their consequences. Planning should take radiological as well as nuclear accidents into account.

b) Each emergency team should have a complete understanding of its functions, and if possible, should be set up in such a manner that its leader is a person from whom the team members are accustomed to take direction during their daily work.

c) The logistics in relation to rapid mobilization of personnel and equipment is of extreme importance in cases of accidents involving large number of victims. In the Goiânia experience this became evident when the Military Air Transport system entered the scene with its vehicles and heavy equipment, well organized, secure and efficient, and assumed responsibility for transportation of the victims.

2) Regarding the responsibilities of the licensees

a) The longer it takes to identify the nature of an accident, the more serious the accident becomes, as is evidenced by this one. Therefore it is imperative that any user of radioactive material immediately informs the authorities of any irregularities involving that material. These observations apply to the use of radioactive sources in industry, medicine and research, where there is not always sufficient rigor on the part of the authorities, in controlling them.

b) A regular inspection program for radiological installations and equipment is indispensable but also should be complemented by a strong sense of civil responsibilities on the part of the licensed operators.

3) Regarding the radioactive sources

The physico-chemical characteristics of the cesium source contributed decisively to the gravity of the Goiânia event. When manufacturing such sources, this aspect should be considered, since it could have a decisive effect on the consequences of mishandling the material.

4) In regard to public information

a) An adequate system of public information, if possible of a preventive nature, should be established at once, in order to avoid panic or uncontrollable reac-

tions on the part of the population. The public should be made aware of what radiation actually is, how it can be applied, and the possible consequences of misusing it. In case of an accident, the emergency teams should give lectures in schools, churches and associations, etc., with explanations easily understood by this type of audience.

b) Personnel involved in decontamination and care of the victims (at the triage center, for example), should be trained to transmit information to the people they deal with, in a comprehensive form.

c) Information should be given regularly to the media through conversations and interviews where these professionals are given explanations about radiation in clear and understandable language.

d) In inhabited areas near nuclear or radiological installations, a complete educational program should be developed regarding nuclear energy, its benefits and its risks. Such a program should be produced under government auspices, whether the information is transmitted by nuclear specialists or by prominent figures, well known to the local population.

e) In the event of an accident, the public must be given ample information about the occurrence, as well as about the measures being taken to contain it. Categorical statements should be avoided. Collective interviews should be given and the information transmitted through an official channel.

5) Concerning medical organization

a) Irradiated patients should be treated in special hospitals, by medical and paramedical teams made up of personnel from the areas of hematology, radiotherapy, chemotherapy, surgery and intensive care.

b) Since people in these departments are not accustomed to treating radiation injuries nor to confront radiological emergencies, every hospital designated to act in such situations must provide regular training for its professionals, conducted by specialists who have had actual experience in the treatment of radiation victims.

c) A mobile medical unit which can be transported by air should be always be ready for any situation. Material and equipment necessary for bioassays and whole-body counting should be available for immediate transport in case of an event involving a considerable number of people.

d) Specialists will be required who are trained in rapid adaptation of routine hospital installations and procedures so as to deal with a radiological or nuclear emergency.

e) All emergency medical plans should be reviewed and updated periodically. Such plans should take into consideration the possible need for immediate assistance from medical and radiological specialists, local or foreign, trained in management of irradiated or contaminated patients.

f) Radiation protection equipment for hospital use should be capable of operating under adverse working

conditions. A rapid and reliable supply route is indispensable for providing large quantities of disposable surgical clothing, antibiotics, decorporating drugs, plastic material, etc.

g) Cytogenetic dosimetry associated with the recording of initial symptomatology and blood counts provide invaluable resources for estimating whole body doses, orienting triage procedures and establishing diagnosis and prognosis.

6) Training

a) Recognition of the type of injury caused by radiation depends on special training for doctors and paramedical professionals working in non-nuclear areas, as well as for those who work near nuclear or radioactive installations. Such training depends on dissemination of Government sponsored informative programs supervised by specialists in radioprotection and radiation medicine.

7) Documentation and Records

All steps taken by emergency teams during accident situations should be minutely recorded, through various forms and as early as possible. Any delay will inevitably cause loss of precious information and events will become increasingly nebulous with the passage of time.

8) Social and Psychological Support

a- In any accident situation which causes environmental contamination, or involves a great number of people, an adequate system of social and psychological support should be provided, not only for the direct victims, but for the population which is affected by it.

b- Doctors, nurses and radioprotection technicians who work in hospitals should receive psychological support during their involvement with the casualties, because of the extreme stress to which they are submitted.

XIV - Acknowledgments

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XV - Bibliography

1- Oliveira, A.R. A report of radiological accidents 1945-1985. *Radioprotection* 22: 89-135; 1987 (in French)

2- Geller, L.I. A case of acute radiation sickness in man. *Med Radiol.* 15: 23-25; 1963 (in Russian)

3- Vassileva, B.; Kruschkov, I. Suicide with Cesium 137. *Psychiat. Neurol. Med. Psychol.* 30: 116-119, 1978 (in German)

4- Beninson, D.; Placer, A.; Vander Elst, E. Study of a case of accidental human irradiation. In *Proceedings of an IAEA Symposium on the Handling of Radiation Accidents*. Vienna: IAEA 1969: 415-425 (in Spanish)

5- Collins, V.P.; Gauden, M.E. A case of child abuse by radiation exposure. In: Hubner, K.F.; and Fry, S.A. eds. *The Medical Basis for Radiation Accident Preparedness*. 1st ed. New York, NY: Elsevier. 1980: 197-203.

6- Oliveira, A.R.; Valverde, N.J.; Brandão-Mello, C.E.; Hunt, J.G. General medical and related aspects of the Goiânia accident. *Health Physics* (to be published)

7- Oliveira, A.R.; Valverde, N.J.; Brandão-Mello, C.E.; de Almeida, C.E.V.; Farina, R.; Raposo do Amaral, C.M. Skin lesions associated with the Goiânia accident. In: Ricks, R.C.; and Fry, S.A. eds. *The Medical Basis for Radiation Accident Preparedness. II: Clinical Experience since 1979*. In press.

8- Farina, R.; Brandão-Mello, C.E.; Oliveira, A.R. Medical aspects of cesium 137 decorporation: Goiânia radiological accident. *Health Physics* (to be published)

9- Hunt, J. G.; Filho, D.S.O.; Rabello, P.N.P. Radiation protection measures involving the Goiânia accident patients. Seminar on Occupational Safety held in Curitiba, Brazil, August 1988.

10- International Atomic Energy Agency. The radiological accident in Goiânia. Vienna, 1988. STI-PUB 815

11- Oliveira, A.R.; de Souza, P.C.; Tabak, D.; et al. Use of haematopoietic growth factor (rHu GM-CSF) for treating of irradiated persons: the Goiânia experience. in: *Proceedings of the European School of Haematology conference: Acute and late effects of irradiation on the hematopoietic system*, Paris, June 28-29, 1989.

12- Butturini, A., Gale, R.P.; de Souza, P.C.; et al. Use of recombinant granulocyte-macrophage colony-stimulating factor in the Brazil radiation accident. *Lancet* 8609 (2): 471-475, 1988.

13- Petterson, J.S. Perception versus reality of radiological impact: the Goiânia model. *Nuclear News* 31 (14): 84-90, 1988.

14- Valverde, N.J.; Cordeiro, J.M.; Oliveira, A.R. The acute radiation syndrome in the 137 Cs Brazilian accident, 1987. In: Ricks, R.C.; and Fry, S.A. eds. *The Medical Basis for Radiation Accident Preparedness. II: Clinical Experience since 1979*. in press.

ANNEX I

History and preliminary evaluation of the patients initially referred to the Reference Center in Rio de Janeiro

1) RSA, 22, unemployed, born in São Paulo and living in Goiânia. On 13 September 1987, together with a friend (WM), he removed the rotating assembly of the shielding head of a radiotherapy unit, and carried it in a wheelbarrow to the backyard of his home. On the same day, with the help of WM he tried to break it open. The disassembly operation took about three hours and required the use of a maul and punch to penetrate to the source contained inside. Approximately three hours after the end of the operation, he began to develop nausea, followed by vomiting (five daily episodes), which persisted during three days, with lessening intensity. One week after the initial exposure, he noticed erythema and blisters on his hands; those on his right hand appearing first. He also noticed the falling of scalp hair.

The patient's report was very meager, and he gave little cooperation during his examination, maintaining the same behaviour during his entire hospitalization period, both in Goiânia and in Rio de Janeiro. The patient had a previous psychiatric condition. He had been in daily contact with the radioactive material until 18 September, when he took the source to the junkyard belonging to patient DAF (Junkyard I), but the number of his actual contacts, or the time of their duration, he was unable to explain.

Physical examination showed him to be in poor general condition; confused, dehydrated, with sparse areas of alopecia on the scalp.

He presented disseminated versicolor ptiniasis lesions, generalized and punctuated hyperpigmentation and marked axilla pigmentation and ruptured phlyctenae. Similar lesions were present on the right forearm; a large edema and hyperemia on both aspects of the right hand, with blisters and ungueal opacification; contracture of the fifth right finger, and mild edema of the left hand. Also ulceration of the edges of the tongue and left conjunctival hyperemia were observed.

The patient was referred to the Naval Hospital on day 18 with 2.500 leukocytes per mm³ and 30.000 platelets per mm³.

2) WM, 19, unemployed driver, born and residing in Goiânia. This patient's history duplicates that of RSA, except for a more sporadic contact with the source after 13 September. Between three and four days after source manipulation, he developed nausea, followed by an episode of vomiting. Also he presented cephalaea and reported diarrhea with pasty feces. On the following day, 14 September, he noticed hyperemia on his left hand (failing to inform whether or not it was not transitory), where phlyctenae and hyperpigmentation also appeared, around 21 September. His right hand presented a similar picture. On 27 September he noticed a general falling of body hair, principally on the legs.

During the examination, he appeared cooperative and anxious. He was hydrated, with epilation areas, mainly on the legs; edema, blisters and hyperpigmentation on his hands (hyperpigmentation on the left hand was important and extended to the middle third of the forearm), hyperpigmented areas on the legs up to inguinal region and erythema from the leg to the back of left foot.

The onset time of prodromic manifestations and the patient's history justified our estimate of an acute dose

of around 3 Gy (300 rads). However, the heterogeneity of the skin lesions with areas of probable greater or lesser beta or gamma influence clearly indicated an uneven exposure, it being impossible at that time to evaluate the fractionated dose received by the patient.

The blood count did not influence our decision to have the patient transferred. The decision was based solely on the patient's history and on prodromic manifestations, physical findings and evolutionary potential.

The patient had been subjected to external decontamination (warm baths with neutral soap), at a triage center in Goiânia. He presented a dose rate of 3 mR/h on the lower abdomen.

3) LNF, 6, born and living in Goiânia. On 24 September, around 8:00 p.m., she had contact with pulverized fragments of the source which had been brought home by her father (patient IAF). During the time that she handled the powder, she ingested food, using her hands to eat. Three hours after contact, frequent vomiting began (seven or more times), which stopped by morning. On 26 September, her father noticed erythema on her left hand and left palmar region. There was no epilation history.

During the physical examination, this child was cooperative and showed a good general condition; she presented a ruptured blistering lesion of 2,5 x 1,5 cm, with erythematous base on the left palmar region.

The triage factors which led to her transfer to the Naval Hospital were the high dose rates (contact measurements) maintained even after decontamination procedures on her left hand (1.5 R/h), face (200 mR/h), thorax and abdomen (200 mR/h), as well as the history and the location of skin contamination, indicating the possibility of serious internal contamination. Evidence for this was the precocity and frequency of vomiting following exposure, although we do not exclude the possibility that vomiting was caused by gastric irritation.

This patient had received an acute, uniformly high doses (2-3 Gy), owing to severe internal contamination. In addition, she continued to be heavily irradiated, due to the presence of cesium in the interior of the body.

On admission to the Naval Hospital, the hematological counts were: leukocytes, 1200/mm³, neutrophils, 144/mm³ and hemoglobin, 11,2 g/dl.

4) IAF, 40, odd job man, born and living in Goiânia, the father of LNF. On 24 September, having obtained powdered fragments of the radioactive source from his brother, DAF, he brought them home. The powder, wrapped in paper, was equivalent to a teaspoonful, and it was kept for about 15 minutes in the left pocket of his trousers. Also, the patient had had brief contacts, of undetermined frequency and duration, with the source itself during the time it remained in DAF's house.

On 25 September, he noticed hyperemia and phlyctenae on his left thigh, as well as in the bend of his left elbow. He had no prodromic manifestations and appeared to be well during examination, except for a 4 x 4,5 cm lesion, with scars, and ruptured phlyctenae in the bend of his left elbow. There were shallow ulcerations in the left palmar region.

The history and physical examination indicated the possibility of a low whole-body dose, probable internal contamination, radiodermatitis with good evolutionary potential and external contamination (70 mR/h on the left hand and 120 mR/h on the right after decontamina-

tion. The patient was transferred to the Naval Hospital as a psychological support measure for his daughter, who was interned there.

5) DAF, 36, owner of Junkyard I, born and living in Goiânia. On 18 September, at 04:00 p.m., he bought and at the same time took delivery of the source from RSA, and put it in a dump in his yard. From 9:00 p.m. on that same day until 2:00 p.m. on 21 September, he kept it in his house, where he was exposed to it in various manners. On 2 September, at about 3:00 p.m. he used tools to withdraw "luminous fragments" from the source capsule. On 22 September, around 6:00 p.m., nausea and vomiting began.

The patient was in fair general condition; axillary temperature 37.8°C, hypohydrated, with painful deglutition because of tongue and oropharynx ulcerations. He complained of pain and presented edema on his hands, with hyperemia and blisters on his fingertips. Hyperpigmentation on the right malar region was also noticed. Alopecia caused fallen scalp hair on his pillow. The blood count on admission showed 700 leukocytes/mm³, 357 neutrophils/mm³ and 63.000 platelets/mm³.

The patient was triaged for transfer to the Naval Hospital, as his history indicated fractionated but significant exposure. Also taken into account were the clinical findings described above (mouth ulceration, fever, radiodermatitis). His alcoholic past history was considered in the triage and was, in our opinion, a potential synergic factor for a bad evolution.

Following conventional decontamination, external contamination was 30 mR/h on the right hand and 4 mR/h on the left. Until the time of his transfer he was treated with parenteral hydration and analgesics.

6) EF, 46, public functionary, born and living in Goiânia. On 25 September he obtained from his brother a "piece of stone", given to the brother by DAF. He put it in the right hand pocket of his trousers, where it remained for about an hour. Afterwards, he left the fragment on a bedside table.

Around two hours after contact with the material, he felt a strong pain in the leg and on the following day he noticed hyperemia on the latero-external aspect of the right thigh, which evolved with hyperpigmentation and phlyctenae subsequently ruptured by the patient himself. New blisters appeared and on 29 September, the patient was subjected to surgical debridement under general anaesthesia at the Queimados (Burn) Hospital in Goiânia.

During the examination we observed a 5,5 x 6 cm erythematous lesion, painful, with apparent granulation, on the lateral aspect of the right thigh.

External monitoring indicated 0,7 mR/h for the injured region and his blood count was normal on admission. The patient was treated with analgesics and triaged into the Naval Hospital because of the severity of his radiodermatitis.