Radiation sources: Lessons from Goiânia

An impressive co-operative response helped limit the accident's consequences and document the lessons learned

On 13 September 1987, a shielded, strongly radioactive caesium-137 medical source was removed from its housing in a teletherapy machine. The machine had been left in a clinic abandoned by the Instituto Goiano de Radioterapia in Goiânia, the capital of the State of Goias in Central Brazil.

By 18 September, the source assembly had been broken out of its protective shielding and sold to a scrap metal dealer. On 21 September, the source capsule, previously damaged, was broken open. Fragments of the source were distributed to other areas of the city. Many people were directly irradiated by the source and were externally and internally contaminated by caesium-137. Several persons became ill and sought medical attention.

Finally, on 28 September, a medical physician in Goiânia recognized the characteristic symptoms of radiation overexposure. A physicist who was consulted the next day detected high radiation levels and promptly notified Goias health authorities, who then contacted Brazil's National Nuclear Energy Commission (CNEN). The Goias officials then evacuated the affected areas and began to identify those persons who had been seriously exposed.

CNEN immediately sent an advance team to Goiânia to help treat affected persons and to control contaminated areas. CNEN mobilized substantial additional resources and an emergency response centre was set up to co-ordinate activities.

(Brazil informed the IAEA of the emergency and requested assistance under the new Convention on Assistance in the Case of a Nuclear Accident or Radiological Emergency. The IAEA arranged for assistance by US medical experts, for assistance from IAEA technical co-operation experts and the provision of dosimeters, and for the provision of monitoring equipment from France, the Federal Republic of Germany, Hungary, Israel, the Netherlands, and the United Kingdom. Separately, Argentina, France, the Federal Republic of Germany, the Soviet Union, the United Kingdom, and the United States provided other experts and equipment directly to Brazil.)

Twenty persons in all were hospitalized. Despite intensive medical care, four of them died. Twenty-eight had been seriously contaminated. Over the next two months, a contamination monitoring station set up in a stadium screened more than 112 000 people. Hundreds had to be decontaminated.

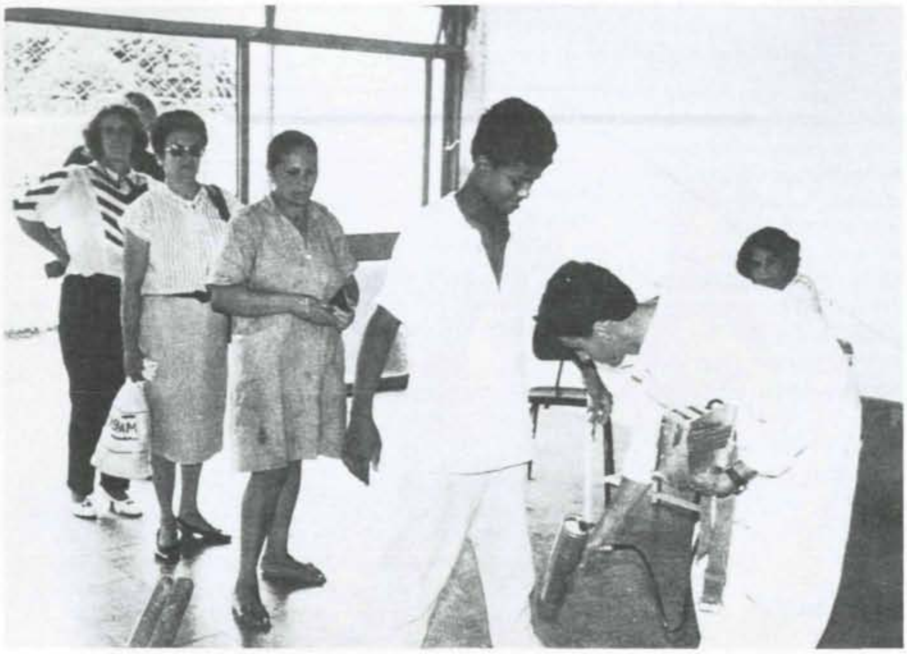
Once the seriousness of the accident had been recognized, the most severely contaminated areas were identified and closed off within a day. The highest radiation levels were reduced substantially by shielding the areas affected. Within two weeks, all the contaminated areas had been identified and isolated and the cleanup had begun.

By late October, waste from the major decontamination work began to be moved to a site designated by Goias State 20 kilometres from Goiânia. By mid-December, restrictions on the main contaminated areas of Goiânia had been lifted. More than 3000 cubic metres of waste were removed and stored at the new repository.

In all, more than 700 workers participated in the response, including CNEN staff and personnel from the Brazilian army, NUCLEBRAS, FURNAS, the State of Goias, and private companies. Worker doses during the operation were held to an average of about 20% of annual occupational limits.

Details of the accident, the response to it, and lessons learned have recently been published by the IAEA in the report ***The Radiological Accident in Goiânia.**** *The report is based on a review meeting of experts held in July 1988 in Rio de Janeiro under the joint organization of CNEN and the IAEA. The following summation is drawn from that report.*

* *The report is available from the IAEA Division of Publications. See the* ***Keep abreast*** *section for ordering information.*



In Goiânia, authorities designated a nearby Olympic Stadium as a staging area for isolating patients and screening others for contamination. Shown here are some people being monitored. (Credit: CNEN)

The accident

It is now known that at about the end of 1985, a private radiotherapy institute, the Instituto Goiano de Radioterapia in Goiânia, Brazil, moved to new premises, taking with it a cobalt-60 teletherapy unit and leaving in place a caesium-137 teletherapy unit without notifying the licensing authority as required under the terms of the institute's license. The former premises were subsequently partly demolished. As a result, the caesium-137 teletherapy unit became totally insecure. Some time later, in September 1987, two people entered the premises and, not knowing what the unit was but thinking it might have some scrap value, removed the source assembly from the radiation head of the machine. This they took home and tried to dismantle.

In the attempt, the source capsule was ruptured. The radioactive source was in the form of caesium chloride salt, which is highly soluble and readily dispersible. Contamination of the environment ensued, with one result being the external irradiation and internal contamination of several persons. Thus began one of the most serious radiological accidents ever to have occurred.

After the source capsule was ruptured, the remnants of the source assembly were sold for scrap to a junkyard owner. He noticed that the source material glowed blue in the dark. Several persons were fascinated by this and over a period of days friends and relatives came and saw the phenomenon. Fragments of the source the size of rice grains were distributed to several families. This proceeded for five days, by which time a number of people were showing gastrointestinal symptoms arising from their exposure to radiation from the source.

The symptoms were not initially recognized as being due to irradiation. However, one of the persons irradiated connected the illnesses with the source capsule and took the remnants to the public health department in the city. This action began a chain of events which led to the discovery of the accident.

A local physicist was the first to assess, by monitoring, the scale of the accident and took actions on his own initiative to evacuate two areas. At the same time, the authorities were informed, upon which the speed and the scale of the response was impressive. Several other sites of significant contamination were quickly identified and residents evacuated.

The human consequences

Shortly after it had been recognized that a serious radiological accident had occurred, specialists — including physicists and physicians — were dispatched from Rio de Janeiro and São Paulo to Goiânia. On arrival, they found that a stadium had been designated as a temporary holding area where contaminated and/or injured persons could be identified. Medical triage was carried out, from which 20 persons were identified as needing hospital treatment.

Fourteen of these people were subsequently admitted to the Marcilio Dias Naval Hospital in Rio de Janeiro. The remaining six patients were cared for in the Goiânia General Hospital. A whole-body counter was set up to assist in the bioassay programme and to monitor the efficacy of the drug Prussian Blue, which was given to patients in both hospitals to promote the decorporation of caesium. Cytogenetic analysis was very helpful in distinguishing the severely irradiated persons from those less exposed who did not require intensive medical care.

Decontamination of the patients' skin and dealing with desquamation from radiation injuries and contaminated excreta posed major problems of care. Daily hae-

The accident in Goiânia in perspective

Considerable information has been documented about accidents since 1945 with significant overexposure to radiation. Most of the accidents at nuclear facilities occurred early in the development of the applications of nuclear energy. Some were criticality accidents and several were at experimental reactors. Although the incidence of radiation accidents in nuclear facilities has decreased considerably over the years, the number of such accidents elsewhere has risen. Several accidents have affected members of the public. Some resulted in deaths when control was lost over high strength sources, which, unrecognized for what they were, ended up in the public domain.

The general picture seems clear and well documented, even though some serious radiation accidents (for example, hand exposures of industrial radiographers) may not have been reported and, to that extent, information that would be useful for preventing similar accidents is unavailable. In comparison with the number of deaths caused by other types of industrial accidents every year, those due to accidental radiation exposure reported worldwide over 40 years are not many. However, the relatively good safety record for applications of radiation gives no grounds for complacency, especially where practicable, effective steps can be taken to reduce the risks of such accidents.

Serious radiation accidents reported, 1945–1987

Type of facility	No. of events	Overexposures	Deaths
Nuclear facilities	27 (34%)	272 (64%)	35 (59%)
Non-nuclear facilities			
Industry	42 (52%)	84 (20%)	20 (34%)
Research	7 (9%)	10 (2%)	– (–)
Medical	4 (5%)	62 (14%)	4 (1%)
	80 (100%)	428 (100%)	59 (100%)

An overexposure is taken here as exposure of the whole body, blood-forming organs, or other critical organs to 0.25 Sv or more; of skin to 6 Sv or more; other external exposure of 0.75 Sv or more; and internal contamination of half or more of the "maximum permissible organ burden". (The concept of the "maximum permissible organ burden" has now been superseded by the concept of the "annual limit of intake".) The table excludes patient-related events and off-site exposures at Chernobyl.

Fatal radiation accidents reported, 1945–1987

Year	Location	Radiation source	Fatalities: Worker	Fatalities: Public
1945	Los Alamos, USA	Critical assembly	1	
1946	Los Alamos, USA	Critical assembly	1	
1958	Vinca, Yugoslavia	Experimental reactor	1	
1958	Los Alamos, USA	Critical assembly	1	
1961	Switzerland	Tritiated paint	1	
1962	Mexico City, Mexico	Lost radiography source		4
1963	China	Seed irradiator		2
1964	Fed. Rep. of Germany	Tritiated paint	1	
1964	Rhode Island, USA	Uranium recovery plant	1	
1975	Brescia, Italy	Food irradiator	1	
1978	Algeria	Lost radiography source		1
1981	Oklahoma, USA	Industrial radiography	1	
1982	Norway	Instrument sterilizer	1	
1983	Constituyentes, Argentina	Research reactor	1	
1984	Morocco	Lost radiography source		8
1986	Chernobyl, USSR	Nuclear power plant	29	
1987	Goiânia, Brazil	Stolen teletherapy source		4
Total: 17 events with 59 fatalities			40	19

Note: The table refers to reported accidents in nuclear facilities and non-nuclear facilities in industry, research, and medicine (excluding patient-related events).

Sources: "The Medical Basis for Radiation Accident Preparedness" (Proc. REAC/TS Int. Conf. Oak Ridge, TN, 1979) (Hübner, K.F., Fry, S.A., Eds), Elsevier North Holland, New York (1980); United Nations Scientific Committee on the Effects of Atomic Radiation, *Ionizing Radiations: Sources and Biological Effects,* 1982 Report to the General Assembly, United Nations, New York (1982).

— Information and tables are excerpted from the IAEA's *Nuclear Safety Review for 1987,* copies of which are available from the IAEA Division of Publications. See the *Keep Abreast* section for ordering information.

Contaminated items being removed. (Credit: CNEN)

matological and medical examinations, good nursing care and bioassay of blood cultures contributed to the early detection and therapy of local systemic infections.

Four of the casualties died within four weeks of their admission to hospital. The post mortem examinations showed haemorrhagic and septic complications associated with the acute radiation syndrome. The best independent estimates of the total body radiation doses of these four people, by cytogenetic analysis, ranged from 4.5 gray (Gy) to over 6 Gy. Two patients with similar estimated doses survived. A new hormone-like drug, granulocyte macrophage colony stimulating factor (GMCSF), was used in the treatment of overexposed persons, with questionable results. Within two months, all surviving patients in Rio de Janeiro were returned to the Goiânia General Hospital, where decorporation of caesium continued until it was safe to discharge them from hospital.

Many individuals incurred external and internal exposure. In total, some 112 000 persons were monitored, of whom 249 were contaminated either internally or externally. Some suffered very high internal and external contamination owing to the way they had handled the caesium chloride powder, such as daubing their skin and eating with contaminated hands, and via contamination of buildings, furnishings, fittings, and utensils.

More than 110 blood samples from persons affected by the accident were analysed by cytogenetic methods. The frequency of chromosomal aberrations in cultured lymphocytes was determined and the absorbed dose was estimated using *in vitro* calibration curves. The dose estimates varied from zero up to 7 Gy. Statistical analysis of cells with chromosomal aberrations indicated that some individuals had incurred non-uniform exposures. Highly-exposed individuals are still being monitored for lymphocytes carrying cytogenetic aberrations.

Urine samples were collected from all individuals potentially having internal contamination and their analysis was used as a screening method. Urine and faecal samples were collected daily from patients with internal contamination. Intakes and committed doses were estimated with age specific mathematical models. The efficacy of Prussian Blue in promoting decorporation of caesium was evaluated by means of the ratio of the amounts of caesium excreted in faeces and in urine. A whole-body counter was set up in Goiânia, and the effect on the biological half-life of caesium in the organism of the dosage of Prussian Blue administered to patients was estimated.

Environmental contamination

The environment was severely contaminated in the accident. The actions taken to clean up the contamination can be divided into two phases: the first phase corresponds to the urgent actions needed to bring all potential sources of contamination under control, and was in the main completed by 3 October, but elements of this phase persisted until Christmas 1987, when all the main contamination sites had been dealt with. The second phase, which can be regarded as a remedial phase aiming to restore normal living conditions, lasted until March 1988.

The primary objectives of the urgent response were to prevent high individual radiation doses that might bring about non-stochastic effects; to identify the main sites of contamination; and to establish control over these sites. In the initial response, all actions were aimed at bringing sources of actual exposure under control, and this took three days.

Initial radiation surveys were conducted on foot over the contaminated areas. Seven main foci of contamination were identified around the junkyards concerned, some of them with dose levels of up to 1 sievert per hour at one meter.

An aerial survey by a suitably equipped helicopter confirmed that no major areas of contamination had been overlooked. Over a period of two days, all of the more than 67 square kilometers of urban areas of Goiânia were monitored. The extents of the seven known principal foci were confirmed and only one previously unknown site, giving rise to a dose rate of about 20 millisievert (mSv) per hour at one metre, was discovered.

It was possible for lesser areas of contamination to have been missed, especially in the vicinity of the heavily contaminated areas around the main foci. A complementary system of monitoring covering large areas, although limited to roads, was put into practice. This system used detectors mounted on and in cars, and 80% of the Goiânia road network, over 2000 kilometres, was thus covered. The main foci of contamination were the junkyards and residences where the integrity of the source capsule was breached; these covered an area of about one square kilometre.

Action levels in this initial response were set for control of access (10 mSv per hour); for evacuation and prohibited access (2.5 mSv per hour and later 10 mSv per hour for houses, and 150 mSv per hour for unoccupied areas); and for workers participating in accident management (dose limits and corresponding dose rates per day, week, and month). In total, 85 houses were found to have significant contamination, and 200 individuals were evacuated from 41 of them. After two weeks, 30 houses were free for reoccupation. It should be emphasized that these levels, which correspond roughly to the lowest values of the intervention levels recommended by the International Commission on Radiological Protection and the IAEA (non-action levels), were extremely restrictive, owing to political and social pressures.

Subsequently, the dissemination of contamination throughout the area and the hydrographic basin was assessed. A laboratory was set up in Goiânia for measuring the caesium content of soils, groundwater, sediment and river water, drinking water, air, and foodstuffs. Countermeasures were only necessary, however, for soil and fruit within a 50-metre radius of the main foci.

The subsequent response, consisting mainly of actions undertaken for recovery, faced various difficulties in surveying the urban area and the river basin. These were compounded by the heavy rain that had fallen between 21 and 28 September, which had further dispersed caesium into the environment. Instead of being washed out as expected, radioactivity materials were

Control, safe use, and disposal of radiation sources

The use of radiation sources of various types and activities is widespread in industry, medicine, research, and teaching in virtually all Member States of the Agency. Loss of control of radiation sources can give rise to unplanned exposures to workers, patients, and members of the public, sometimes with fatal results. Examples are the events in Mexico in 1983-1984, Morocco in 1984, and the recent accident in Brazil in 1987.

Agency programmes aimed at reducing the likelihood of such events have been ongoing for some time; for example the Waste Management Advisory Programme (WAMAP) missions and the Radiation Protection Advisory Teams (RAPAT). However, the events of 1987 have prompted renewed efforts towards improving the control over sealed sources in Agency Member States.

In late 1987, the Agency introduced new programmes to enhance its efforts towards providing practical help to Member States in the control of sources while in use and in the management of the sources at the end of their useful lives. Assistance in this latter area will be given in two main ways:

- Short-term assistance in waste disposal. In the short term, prompt action may be justified in a few Member States which have no capability at present for the safe management and disposal of radiation sources. These special cases are considered to be identified through WAMAP or RAPAT missions reports. The Agency is planning to institute discussions on this and other related subjects with Member States, including countries which are supplying radiation sources.
- Promotion of national waste management capabilities. The Agency will provide guidance on procedures for the collection and immobilization of sources and, as necessary, safe storage and eventual disposal. Emphasis is placed on standardization of designs and procedures, as for example in the provision of plans and designs for immobilization and storage facilities. A pilot demonstration of many of these techniques has been designed; this will be conducted in late 1988 in conjunction with a WAMAP mission. Preparations were made to make a video film to illustrate the techniques for use as part of the guidance material and also for use in training courses.

As part of decontamination efforts, an excavator removes a radiation "hot spot" in a house before demolition. (Credit: CNEN)

deposited on roofs, and this was the major contributor to dose rates in houses.

Levels of contamination in drinking water were very low. The groundwater was also found to be free of contamination, except for a few wells near the main foci of contamination with concentrations of caesium just above the detection level.

The main countermeasures undertaken during this remedial phase were the decontamination of the main sites of contamination (including areas outside the main foci), of houses, of public places, of vehicles, and so on. For decontamination at the main foci, heavy machinery was necessary to remove large amounts of soil and for demolishing houses. Large numbers of various types of receptacles for the waste also had to be constructed. In addition, a temporary waste storage site had to be planned and built. This was done by the middle of November, and decontamination of the main foci and remaining areas was carried out from mid-November up until the end of December 1987.

The investigation levels selected for considering the various actions corresponded to a projected dose of 5 mSv in the first year and a long-term projected dose of 1 mSv per year in subsequent years. The work included the demolition (and removal) of seven houses and the removal of soil. Areas from which soil was removed were covered with concrete or a soil pad. In less contaminated places, the main source of exposure was contaminated dust deposited on the soil; after removal of the soil layers where necessary, surfaces were covered with clean soil. Of 159 houses monitored, 42 required decontamination. This decontamination was achieved by vacuum cleaning inside and by washing with high pressure water jets outside. Various procedures for chemical decontamination proved to be effective, each adapted to the circumstances, the material concerned, and the level of radioactivity.

The action levels for these remedial actions were selected under strong political and public pressures. The levels were set substantially lower than would have resulted from an optimization process. In most cases, they could be regarded as more applicable to normal situations than to an accident recovery phase.

After the Christmas holidays in December 1987, the areas of lower dose rate surrounding the main foci were decontaminated. There was no need for heavy machinery, and optimization procedures were developed and adopted. This stage lasted until March 1988.

From its inception, the response generated large quantities of radioactive wastes. A temporary waste storage site was chosen 20 kilometres from Goiânia. Wastes were classified into non-radioactive (below 74 kilobecquerels per kilogram), low level (below 2 mSv per hour) and medium level (between 2 and 20 mSv per hour). Various types of packaging were used, according to the levels of contamination. The packaging of wastes required 3800 metal drums (200 litres), 1400 metal boxes (5 tonnes), 10 shipping containers (32 cubic metres) and six sets of concrete packaging. The temporary storage site was designed for a volume of waste of 4000—5000 cubic metres, encapsulated in about 12 500 drums and 1470 boxes.

The final total volume of wastes stored was 3500 cubic metres, or more than 275 lorry loads. This large volume is directly attributable to the restrictive action levels chosen, both in the emergency period and in the recovery phase. The economic burden of such levels, especially in the latter phase, is far from insignificant.

A sampling system was built to monitor the run-off (including rainwater) from the platform on which the wastes were placed. The best estimate of the radioactivity accounted for in contamination is around 44 terabecquerels (1200 curies), compared with the known radioactivity of the caesium chloride source before the accident of 50.9 terabecquerels (1375 curies). No decision has yet been made on the final disposal site for the waste.

Observations and recommendations

Very often reviews of radiological accidents serve only to call attention to what is already well known. Many observations and recommendations emerged from the review of the accident in Goiânia. However, observations made here do not necessarily refer to the specific circumstances of the accident.

On the subject of the potential occurrence of such accidents, one major observation is that nothing can diminish the responsibility of the person designated as liable for the security of a radioactive source. Radioactive sources that are removed from the location defined in the process of notification, registration, and licensing can present a major hazard. Means to preclude such breaches of care should therefore be ensured by the person liable for a radioactive source, and these should include verification procedures and appropriate security arrangements. Although the regulatory system is a check on the effectiveness of the professional and management system, it should be emphasized that regulatory and legal control cannot and must not detract from managerial responsibility.

In order to facilitate the discharging of responsibility by the person liable for a radioactive source, suitable ways of complying with regulatory requirements should be specific, simple, and enforceable. In particular, good communication is required among all concerned in implementing and enforcing radiological protection requirements.

Recognition by the general public of the potential danger of radiation sources is an important factor in lessening the likelihood of radiological accidents. Due consideration should be given to a system of markings for radiation hazards that would be recognizable to the wider public.

The physical and chemical properties of radioactive sources are very important in relation to radiological accidents. They should be taken into account in the licensing for manufacture of such sources, in view of the potential influence of these properties on the consequences of accidents with, and in the misuse of, sources.

If, all precautions notwithstanding, an accident does occur and a radiological hazard is foreseen, there should be a well understood chain of information and command. In this regard, it is worth mentioning that preparations to respond to radiological emergencies should cover not only nuclear accidents but the entire range of possible accidents entailing radiation exposure.

Medically, experience in Goiânia confirmed in general the adequacy of presently available diagnostic techniques, antibiotics, and methods for platelet separation and transfusion. In addition, it demonstrated the usefulness of cytogenetic dose estimates and the remarkable efficacy of Prussian Blue in eliminating internal contamination by caesium-137.

The treatment of casualties of radiological accidents is extremely varied and complex. They must be cared for in hospitals by staff who are engaged on a daily basis in the haematological, chemotherapeutic, radiotherapeutic, and surgical treatment of patients at risk from cancer, immunosuppression, and blood dyscrasias. Generally, medical personnel and facilities are not prepared for dealing with radiation injuries and radiological emergencies. Provision should be made in radiological emergency plans for immediate assistance from medical specialists trained to handle such patients. Recognition of the nature of radiation injury, however, depends on the education of non-nuclear workers as well as on trained health professionals, all of whom are dependent upon widely disseminated educational programmes.

On the subject of dealing with the environmental contamination due to an accident, it is worth noting the issue of decisions on intervention levels. There is usually a temptation to impose extremely restrictive criteria for remedial actions, generally prompted by political and social considerations. Such criteria, however, impose a substantial economic and social burden in addition to that caused by the accident itself, and this is not always warranted.

Finally, it is worth mentioning that an accident should be documented as soon as possible, since the facts tend to become blurred with the passage of time. Dissemination of information to the communications media, the public and, indeed, the response force is especially important. In particular, the response teams should receive support in administration and public information appropriate to the scale of the emergency. Major emergencies require prompt on-site administrative and public informational support. All individuals who are likely responders to radiological emergencies should undergo training, both formal and in drills, appropriate to their likely functions.

Lessons learned by the Brazilian National Nuclear Energy Commission (CNEN)

- A radiological accident entailing contamination due to the breaking up of a radioactive source can be aggravated if much time elapses before the discovery of the accident.
- The physical and chemical properties of a radioactive source are important factors in an accident. The records of sealed sources should contain that information. It is suggested that physical and chemical properties of sources should be taken into account in the licensing for manufacture of such sources, emphasizing the possible consequences of accidents or misuse.
- An adequate system of information is essential to avert panic on the part of the public. In general, the public should be made aware of what radiation is and of its applications. A booklet explaining the special terms and units related to radiation should be available to the communications media. In the event of a radiological emergency, a group should be set up to present information in the legislative assembly, schools, churches, and community associations, and so on, as well as to the news media. Personnel working in decontamination and attending to casualties should be instructed on how to convey information comprehensibly to the population. Their contacts with the individuals affected in the accident in Goiânia proved very important: people would gauge the seriousness of contamination by the reactions of the workers. The people most affected by the accident would judge whether their houses were really free of contamination by whether the CNEN personnel accepted water or coffee from them.
- An adequate system of social and psychological support should be provided following a radiological accident causing serious contamination. The psychological support should be provided to those individuals directly and indirectly affected and the personnel working in response to the emergency. Psychologists should be available for counselling, joining the group responsible for making quick decisions and planning action to be taken, and evaluating the possible stress to the casualties.
- The effectiveness of international assistance following a radiological accident depends on the infrastructure of the country concerned. The emergency training courses co-ordinated by the IAEA should be held in developing countries and not only in developed countries where facilities are available and work well. In general, these programmes deal with emergencies responded to by strong organizations under a priori known conditions. In many countries, circumstances are very different, equipment is diverse, the climate is adverse, and matters are administered differently.
- A mobile system of first aid transportable by air should be available at all times.
- The IAEA should maintain a record of radiological equipment available. Customs regulations should be amended to facilitate the import and re-export of material and/or equipment. The IAEA should have a set of radiological equipment at hand ready to be shipped and should establish a regional centre for emergency attendance in every continent.
- Instrumentation should be capable of being adjusted to withstand field conditions, so that it can be used in high humidities, high temperatures, and unstable environmental conditions. Personnel using instruments should be trained to be able to obtain a clear indication of dose-rate response for a wide range of doses; and to know the most suitable equipment in different conditions and its calibration factors.
- Records of available personnel resources according to field of work should be kept. Experts from the IAEA, in each area of action, should be available to be contacted in the event of an emergency to give support to the local radiological protection teams. These experts should be ready to advise actively in decision making and on intervention measures, and to participate in all the work that needs to be done. The experience of the accident in Goiânia indicated that supposedly 'better' reports had in fact been prepared by specialists who had not participated in the response.
- The provision of a temporary waste storage site near the area affected by a radiological accident is considered indispensable. A delay in the decision, usually a political one, on where to construct a site, could permit greater dispersion of radioactive material in the environment.
- An infrastructure of civil engineering personnel should be available to participate in decontamination work.
- For decision making and the organization of working teams following a radiological accident, the hierarchy should be well defined. The assigning of responsibilities in the decision process, from planning to action and evaluation of consequences, should be very clear, and each group should be sure of its function. If possible, teams should be formed with a leader who heads the group in normal working conditions.
- In general, a programme of inspection of radiological equipment and facilities is very important; however, it is only effective if coupled with some kind of enforcement system, such as assigning civil or professional liability in licensing sources.