IAEA
International Atomic Energy Agency
Atoms for Peace and Development

Occupational Radiation Protection during High Exposure Operations

Lessons Learnt from Occupational Radiation Protection in Past Accidents

Radiological Accidents – Goiânia Accident

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2. The emergency response
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1. Overview of the Goiânia accident

Where is Goiânia City?

- The 13th largest city in Brazil.
- The capital of Goiás State.
- Population around 1 million.

1. Overview of the Goiânia accident

What happened?

- On September 13, 1987, two men stole an orphaned radiotherapy source unit from an abandoned clinic located in 1 km northwest from Civil Plaza in Goiânia.
- In the process the ^{137}Cs was released and contaminated neighbouring people and the environment. Blue scintillation from CsCl powder caused by high gamma radiation fascinated everyone.
- On September 28, the junkyard owner's wife grew concerned about her sick relatives and took a bag of the powder to the local Sanitary Service Office by bus, contaminating additional people and facilities in the process.
- A medical physicist, that was visiting the City, has assessed, by monitoring, the scale of the accident and alerted the Regulatory Authority (**National Nuclear Energy Commission - Comissão Nacional de Energia Nuclear**).

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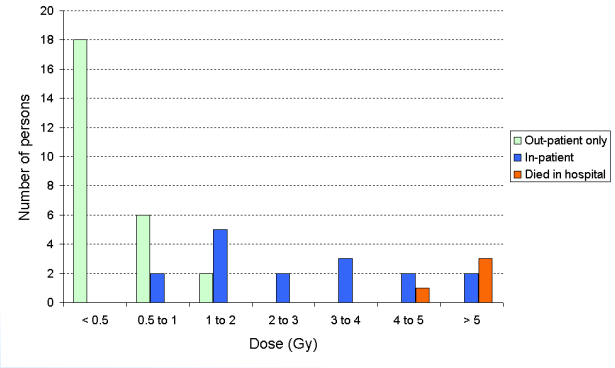
1. Overview of the Goiânia accident

What happened?

The Goiânia accident resulted in the highest recorded levels of ^{137}Cs contamination.

- 112,000 persons were monitored
- 271 people were found to be contaminated
- 20 people needed to be in-hospital treatment among them
- **4 people died**



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1. Overview of the Goiânia accident

Overview

- Type of emergency: Radiological emergency
- Threat category: IV (GS-G-2)
- Uncontrolled dangerous source
- Abandoned ^{137}Cs source for radiotherapy
- Uncontrollable radiation exposure continued from September 13th to 29th, 1987 (16 days)
- Recovery phase lasted for 6 months
- Extensive areas of the city were contaminated

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1. Overview of the Goiânia accident

- ^{137}Cs teletherapy unit was built in1971.
- Unit substituted by more modern ^{60}Co unit in 1978.
- The private clinic was moved to new premises in December 1985 taking only the ^{60}Co unit.
- The ^{137}Cs (Category 2 / IAEA RS-G-1.9) unit was left in the old clinic.
- No security guard was posted at the old clinic after January 15 1987 because of litigation issues.
- The regulatory authority did not implement an adequate inspection/inventory check for radioactive sources.

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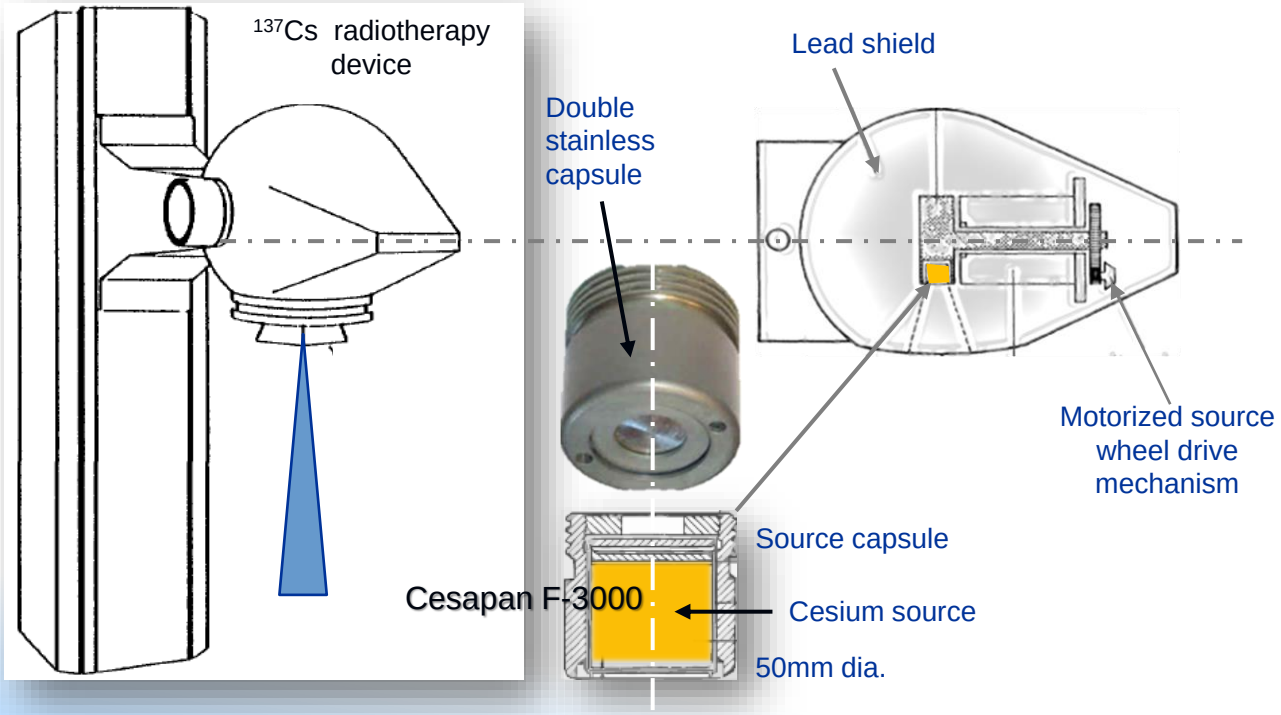
1. Overview of the Goiânia accident

The source

Radiotherapy device was designed in Italy



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1. Overview of the Goiânia accident

The source

- Chemical form: CsCl
- Physical form: Powder
- Physical size: 36.3 mm diameter x 30.0 mm height
- Radionuclide: ^{137}Cs
- Total weight: 93 g (including resin)
- Activity: 50.9 TBq
- Specific activity: 0.55 TBq/g for the source

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1. Overview of the Goiânia accident

Chronology

Sept 10 – 13: Source assembly was removed from the device and taken away

Sept 18: CsCl capsule was punctured in junkyard and sold

Sept 21: CsCl was removed from the capsule and distributed to several families

Sept 25: Rest of source assembly was sold for scrap

Sept 28: A number of people were already physically ill.

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1. Overview of the Goiânia accident

Chronology

Sept 28: The remnants in a bag was transported to the Sanitary Service Office by the junkyard manager's wife who was convinced that the glowing powder from the source assembly was causing the sickness.

Sept 29: A medical physicist who happened to be visiting Goiânia was called and confirmed the presence of a huge amount of radioactive material using a NaI(Tl) scintillation survey-meter

The remains of the ^{137}Cs teletherapy source wrapped in a cloth bag on a chair in the "Vigilancia Sanitaria"

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2. The emergency response

The quick response of CNEN afterward was worthy of praise.

•A director of CNEN was nominated Emergency Response Coordinator and went to Goiânia with two more technicians. In the following weeks, many more emergency workers arrived.

•More contaminated sites were found and a criteria of 2.5 μSv/h for evacuation was established, based on former annual dose limit of 5 mSv for public.

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2. The emergency response

The primary objectives were….

•To identify persons who had received significant doses or were contaminated and to provide the appropriate treatment.
•To identify the most contaminated locations;

•To evacuate houses where levels of radioactivity exceeded the action levels;

•To establish an exclusion zone around these most contaminated areas, preventing unnecessary access;

2. The emergency response

These objectives were achieved by October 3, with the seven most contaminated locations identified. This date could be considered as the end of the initial phase of the response considering that the major sources of hazard were under control.

2. The emergency response

Contaminated locations

Seven main contaminated areas (hot spots) were identified, evacuated and condoned off.

A : Radiotherapy clinic
C : Junk yard 1
D : Junk yard 2
E : Junk yard 3
F : Sanitary service office
H: Olympic stadium
K : Other contaminated point

2. The emergency response

Action level for evacuation

2.5 μSv/h at 1 m height at the beginning of emergency

Later

10 μSv/h at 1 m height with following conditions;

- an occupancy factor of 0.30 to 0.75;
- a distribution factor to relate the mean dose rate to the maximum dose rate (0.1 to 0.2);
- a time factor to reflect the decrease in radioactivity due, e.g. to cleaning or weathering (0.1 to 0.4);
- in each case the most conservative (highest) value was used.

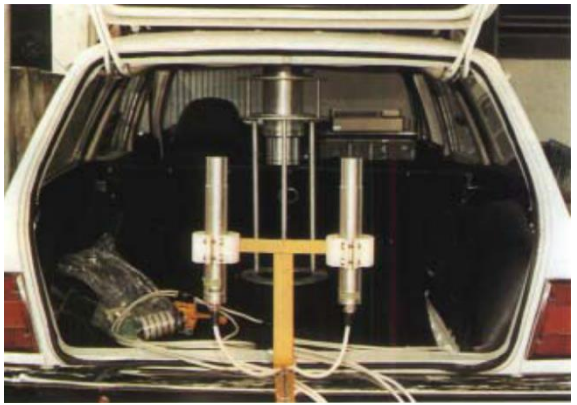
3. Radiation monitoring and protection

Site monitoring

To ensure the identification of all primary contaminated locations two techniques were employed for monitoring:

•An aerial survey of the city was carried out with 6 x 1 liter NaI(Tl) detectors mounted in a helicopter.

- Initial screening of streets in the city were carried out by a car with parts of the instruments used in the helicopter. At the same time another car with a 2” x 2” NaI(Tl) detector also surveyed different areas. More precise measurements were carried out later by a specifically designed mobile unit.



- Patients in hospital and people of contaminated houses were interviewed about their movements and visitors they had during the relevant period.

3. Radiation monitoring and protection

Monitoring and remediation in less contaminated area

- A 1 x 1 m grid was used to assess the areas for dose rate measurements and soil sampling.
- Most of the contamination was found to remain within 1.5 cm depth of the soil.
- Locations found with values above the action levels were decontaminated consisting of the removal of the upper layer of the soil and placing of new topsoil.
- To reduce the dose inside the houses, all surfaces were vacuumed with industrial vacuum cleaners with HEPA filters.
- The roofs were washed with high pressure water jets. This method proved not to be very efficient and in some cases the entire roof had to be replaced.

3. Radiation monitoring and protection

Survey meters used

Type	Num. of used	Robustness	Resilience in adverse condition	Response	Num. of failures	Failure rate
Dose rate monitor						
GM tube	27	very good	very good	very good	3	11%
Proportional counter	2	very good	acceptable	excellent	1	50%
Ionization chamber	16	very good	acceptable	poor	1	6%
Teletectors / telescopic	7	very good	acceptable	excellent	1	14%
Teletectors / articulated	3	very good	very good	good	0	0%
End window GM tube	11	very good	very good	excellent	3	27%
Contamination monitor						
Proportional counter	7	poor	good	excellent	5	71%
Side window dose GM tube	2	very good	very good	adequate	0	0%
Scintillation detector	3	very good	very good	very good	0	0%

3. Radiation monitoring and protection

Survey meters used

Surface monitoring at Olympic stadium

Roof monitoring

Scintillation survey meter designed for geological survey

3. Radiation monitoring and protection

External dosimetry

•Ambient dose rate measurement and reconstruction of the sequence of events was often useful for initial screening.

•Even considering measured dose rates and occupancy factors obtained from the patients, dose reconstruction was difficult because of complicated exposure geometries and various scenarios. Cytogenetic dosimetry was used for better estimates.

•ESR technique for bone and teeth, and TL dosimetry for relevant items was also carried out.

3. Radiation monitoring and protection

Operational protection

Because of numerous hot spots where dose rates were of the order of tens of mSv/h and some exceeded 1 Sv/h, operational dose limits were set;

- 1.5 mSv per day
- 5.0 mSv per week
- 15 mSv per month
- 30 mSv per quarter

4. The worker and members of the publics' doses

Individual monitoring for workers – External dosimetry

- 755 workers took part in the emergency operation.
- 550 of them worked on area decontamination.
- 262 of the workers had previously received training in radiation protection.
- Individual dosimetry for all workers was made by film badge.
- The film badge was changed after one month or at the end of each period of work.

4. The worker and members of the publics' doses

Dose control of workers

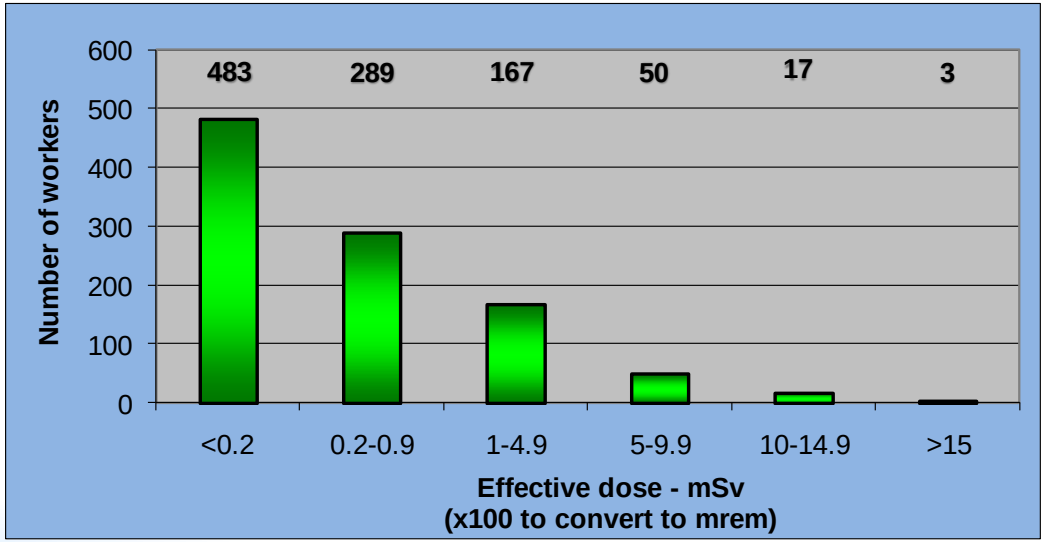
- Daily dose control of workers was mainly made using Quartz Fibre Electrometers (QFE).
- 450 QFE pens were used.
- Each worker used two QFEs (0 – 2 mGy and 0 – 50 mGy range).

- 8 of the QFEs were chosen at random for overnight calibration by ^{137}Cs.
- QFEs with calibration factors above 1.2 or below 0.8 were not used.

4. Doses to workers and members of the public

Occupational exposure (Annual dose limit of 50 mSv)

- 730 workers involved in decontamination activities – none received doses above the annual limit.
- 35 members of the public received doses above the annual limit.



4. Doses to workers and members of the public

External exposure of workers

- Much of the decontamination work was done during heavy rainstorms.
- This made it difficult to keep the daily dose limit of the workers who took part in removing contaminated mud by machines.

- The maximum dose was 4.7 mSv over 3 months work
- Of the 583 non zero accumulated dose values recorded from a total of 755 workers in the period from Sep 30th to Dec 21st, 1987:

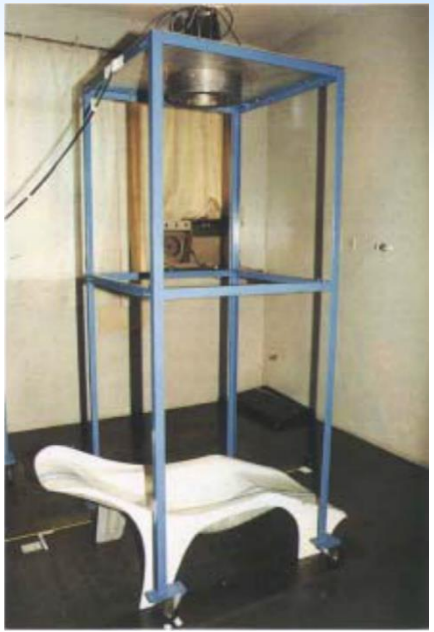
  67.6% less than 1 mSv

  100% less than 16 mSv

4. Doses to workers and members of the public

Internal dosimetry

- In vitro bioassay (excreta samples were collected in Goiânia and sent to IRD in Rio de Janeiro).
- In vivo measurements (a whole body counter was set up in Goiânia in November at the General Hospital).
- In February 1988, a bioassay laboratory was set up in Goiânia to perform in vivo and in vitro measurements during the follow up phase.



Goiânia whole body counter

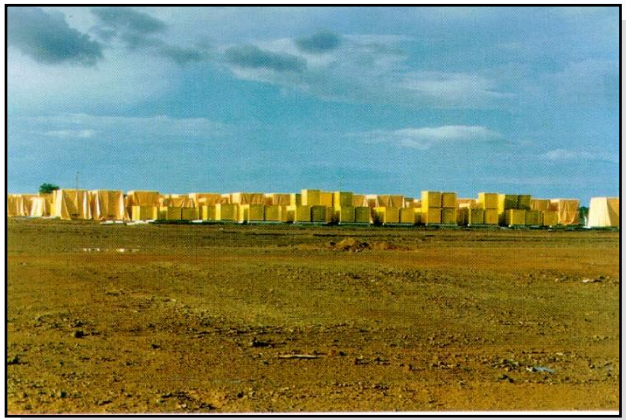
4. Doses to workers and members of the public

Individual monitoring of workers - internal dosimetry

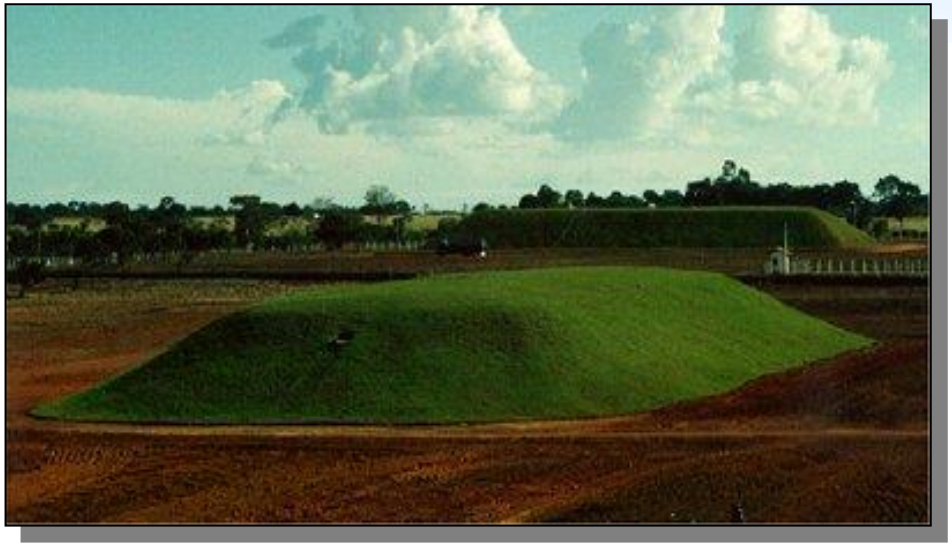
- 194 occupationally exposed persons were monitored for internal contamination at the IRD's whole body counter.
- 38 workers exceeded the MDA (74 Bq for a 30 min measurement).
- The maximum internal contamination was 2.0 ± 0.3 kBq, corresponding to a committed effective dose of about 2 µSv.

IRD's whole body counter

Temporary waste deposit



Final waste deposit – City of Abadia, Goiania



Around 3,500 m^3 of contaminated waste

5. Lessons learned

Situation of workers during emergency operations

- The public responded to the workers in protective suits with suspicion, fear, and in some cases, even physical threats.
- Workers were instructed to accept offers of drinking water and food from people's houses to increase public confidence.

- During emergency operations personnel were overworked, understaffed, and generally overwhelmed by the size of the event.
- Many personnel were radiation specialists trained to respond to accident scenarios in radiation laboratories or reactor plants.
- As a result, they were psychologically unprepared to deal with the complexity and magnitude of this accident.

5. Lessons learned

Situation of workers during emergency operations

- Extreme environmental conditions increased the workers psychological stress. Teams often worked for 15 hour shifts in 40° C.
- Personnel had to wear protective clothes and perform strenuous manual work while giving moral and psychological support to the population.
- The teams were constantly surrounded by people asking for reassurance and information.
- Over time, many responders started manifesting psychosomatic symptoms resembling acute radiation syndrome.

5. Lessons learned

• It is necessary to have confidence in the radiation detection equipment. Before use the equipment should be switched on and passed through a functional test. If no check source is available, the background reading should be noted. If there is no background or if the detector goes off scale, then the detector should be rejected or the batteries changed. Ideally the first responder will be familiar with the dose rate measuring equipment he or she is using.

• External decontamination of patients should take priority over environmental contamination considerations. Any personnel decontamination actions will not significantly increase the already existing environmental contamination.

•A major population center should have at least 10 electronic personal dosimeters available to civil defense workers that can be used immediately in the case of a large scale emergency response

5. Lessons learned

- The early assignment of a press officer for public information purposes would have allowed the radiation protection officers to concentrate on occupational radiation protection.

- The response management and teams of the authority dealing with the emergency should be previously defined as part of emergency planning and preparedness. The assigning of responsibilities in the decision processes, from planning to action and evaluation of consequences, should be very clear, and each group should know its function. If possible, teams should be formed with a leader who heads the group in normal working conditions

- In the case of a large scale accident, it will be necessary to engage the assistance of workers with no experience in radiological work. Indeed, many radiation professionals will find themselves in unfamiliar situations. Intensive training efforts for non-radiation workers should be foreseen in the case of such an accident. Procedures should be written and used in the training program so as to promote good practices

5. Lessons learned

- Suitably justified adjustments to the nationally adopted OILs may be made during the emergency on a case-by case basis.

- When setting up teams of emergency workers, it should be borne in mind that there is a need to foresee back-up teams to relieve the first team deployed. Psychological and medical support should be made available locally.

- QFDs should not be used for emergency operations unless there is no other option. Electronic personal dosimeters with alarm and visual display are recommended

5. Lessons learned

- When making surveys in the presence of members of the public, use headphones to hear the audible signal. Modern equipment has Bluetooth communication between the detector electronics and the earphones for ease of use.

- A number of surface contamination monitors should be available calibrated in terms of Bq/cm^2 per cps at least for a middle range energy beta emitter such as ^{36}Cl. Wide area calibration sources for other beta emitting radionuclides should also be available for timely calibration of the monitors

- When specifying surface contamination monitors, a number of fixed wall mounts for the equipment should be purchased to facilitate hand-foot monitoring at the exit of the controlled areas. Ideally, purpose-build hand-foot monitors would be made available

5. Lessons learned

- Considering the climatic conditions, a certain number of powered & supplied air respirators should be made available for heavy duty decontamination work. Disposable respirators are useful to avoid ingestion of radioactive material, but the protection factor is too low for most decontamination operations

- The cost of PPEs can represent a large part of the emergency budget, a line of credit with sufficient funds is necessary to be able to immediately buy the PPEs required

- Establish the dosimeter exchange frequency to be not longer than a month but at least for a period of time where the expected recorded dose will be above 1 mSv. In areas where the dose rate may increase rapidly, active dosimeters with alarms must be worn

- Ensure that all dosimeters are placed in a plastic outer protective covering before entering a contaminated area.