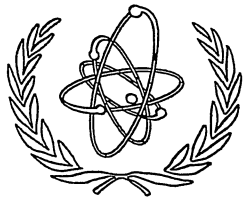
RADIOLOGICAL ACCIDENTS



BACKGROUND



SYLLABUS

- λ Introduction
- λ Types of radiological accidents
- λ Where they can happen
- λ Accident consequences
- λ Statistics of radiological accidents
- λ Examples
  - Goiânia accident
  - San Salvador accident
  - Tammiku accident
- λ Lessons learned
- λ Conclusions



INTRODUCTION

- λ The use of sources of radiation in different fields of practice other than in reactors is growing daily
- λ Despite safety precautions in design and operations accidents involving radiation sources do occur more frequently than reactor accidents
- λ Unlike reactor accidents, the impact of any such accidents generally affect only a small number of people; however, the impact on these few people may be serious



TYPES OF RADIOLOGICAL ACCIDENTS

- λ Radiological accidents can be classified in the following categories:
  - accidents with radiation sources or material
  - accidents outside the country with trans-boundary effects, and
  - nuclear powered satellite re-entry

Accidents with Radiation Sources or Material

- λ found radioactive material or contaminated areas or items
- λ lost or missing sources
- λ unshielded sources
- λ accidents in a laboratory, industrial or research facility
- λ transport accidents
- λ dispersion of alpha emitters

WHERE THEY CAN HAPPEN?

- λ Medical institutions
- λ Industrial facilities
- λ Research and educational institutions
- λ Transport involving radioactive material
- λ (Nuclear fuel cycle)
- λ Where else?

Medical Institutions

Use	Sources	Dose rates or activity	Exposure	Endangered area
Theraphy departments	Co-60 Cs-137	1 – 10 Sv/h in vicinity	External	Therapy rooms
Applicators	Cs-137, Ir-192, Ra-226, P-32, Sr-90, I-125	Order of 10 MBq (mCi)	External Internal	Therapy or nuclear med. area
Nuclear medicine	I-131, I-123, Tc-99m, Xe-133	Order of 10 MBq (mCi)	External Internal	Storage, nuclear med. area, hospital
X-ray machines, Accelerators	X-rays, electrons	Less than 1 Sv/h	External	Radiology or therapy rooms

Industrial Facilities

Use	Sources	Dose rates or activity	Exposure	Endangered area
Flow, friction, wear, thickness, densities, sterilization	Co-60, Cs-137, Ir-192, neutrons, Am-241, Po-210	More than TBq (100 Ci)	Mostly external Internal	Individual hazards, room, facility contamin.
X-ray machines, sterilizers, accelerators	X-rays, α, β, γ Co-60, Cs-137	Up to 10 PBq (1 MCi)	External	Facility
Satellites, navigation buoys, weather stations	Pu-238, Sr-90	Large activities	External Internal	Large areas, isolated locations
Luminiscent materials	Pr-147, H-3, Ra-226	Up to 10 TBq (kCi)	Internal	Facility and surrounding area

Research and Educational Institutions

- Departments of physics, nuclear engineering and life sciences:

Radiation sources: H-3, C-14, Co-60, X-rays, alpha, beta, gamma, accelerators, neutron generators, microscopes, X-ray crystallography

- Activities and dose rates: various
- Type of exposure: external and internal
- Most likely size of radiation area: facility and surrounding area; irradiation of hands and/or fingers from X-ray crystallography units

Research and Educational Institutions (Cont.)

- Research reactors: power levels up to 10 MW
  - Radiation sources: fission products, neutrons, fissile materials, transuranics
  - Activities: several 10 TBq (thousands of Ci)
  - Type of exposure: external and internal
  - Most likely size of radiation area: several km^2

Transport Involving Radioactive Material

- Approximately 2.5 million packages of radioactive materials are shipped only in the USA each year
- Transport accidents have caused no serious radiation overexposure
- Transport of fuel
  - Radiation sources: enriched uranium
  - Activities: several 10 PBq (million of Ci)
  - Type of exposure: internal, external
  - Most likely size of radiation area: several km^2

Transport Involving Radioactive Material

- Radiopharmaceuticals
  - Radiation sources: I-131, Tc-99m, Xe-133 and others
  - Activities: several 10 TBq (thousands of Ci)
  - Type of exposure: external, internal
  - Most likely size of radiation area: transport, terminals, roads

Where Else?

- At military premises
- Anywhere: terrorist activities or illicit trafficking in radioactive materials

Accidents Outside the Country with Trans-boundary Effects

- Severe accidents in nuclear installations may have consequences that might affect countries far from accident country
- The most significant threat from such accidents is due to contamination of the environment (deposition); deposition is highest if rain is present at the time of plume passage
- Regardless of the actual threat, the perception of the threat conveyed by the media is in itself a significant consequence

Nuclear Powered Satellite Re-entry

- Nuclear power sources are used in space vehicles such as satellites and deep space probes
- Plutonium, a component of radioisotopic thermoelectric generators and heating units is of special interest
- Satellites may also contain radioactive materials in the form of a small nuclear reactor

Nuclear Powered Satellite Re-entry (Cont.)

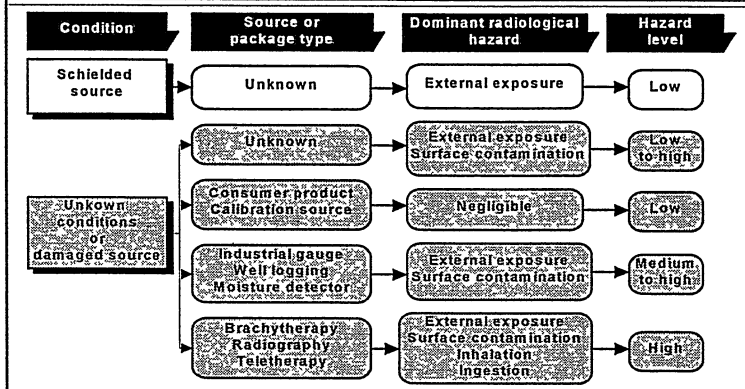
- Accidental re-entry as a result of loss of control of a space vehicle may lead to impact on the earth's surface and the spread of contamination
- Launch accidents do not usually present a significant hazard

WHAT CAN HAPPEN

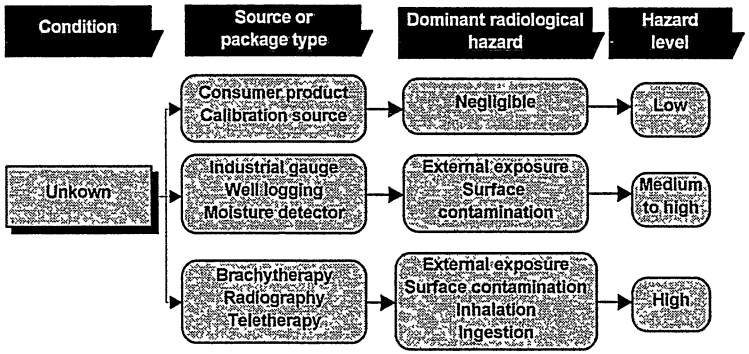
λ **Possible radiological hazards:**

- External irradiation
- Internal contamination through inhalation or ingestion
- Contamination of environment

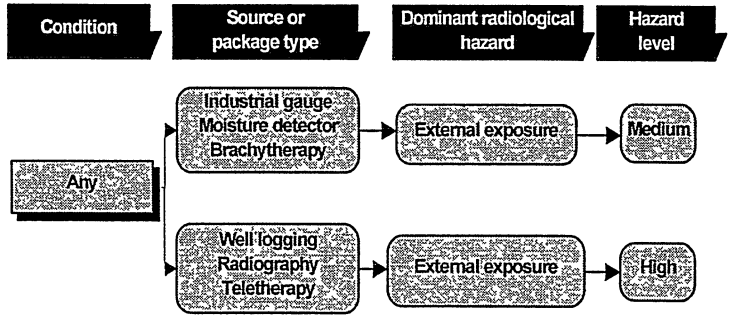
Found Source of Contamination



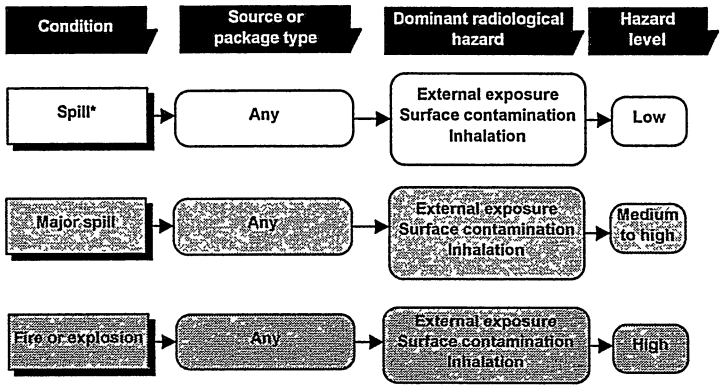
Missing Source



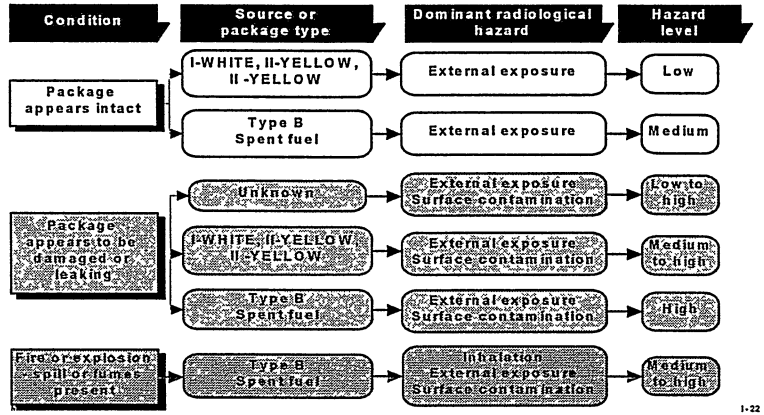
Unshielded Source



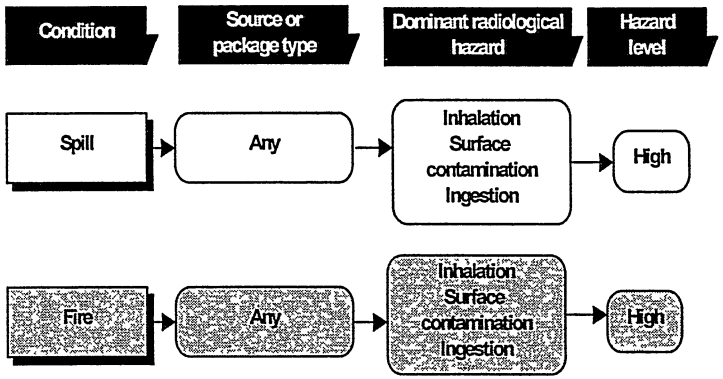
Laboratory Accident



Transport Accident



Dispersion of Alpha Emitters



HISTORY OF RADIOLOGICAL ACCIDENTS

- Accidents involving the serious overexposure of persons are in fact rare
- Early mishaps were reported shortly after the discovery of X-rays and radioactivity in 1895
- First case of skin injury due to radiation was reported in 1896

Causes

Most human radiation injuries since then have resulted from:

- the mishandling of industrial sealed radioisotope sources or
- inadvertent exposure to X-rays used for quality control

Statistics

- 392 major accidents have been registered since 1944 (until September 1997) [DOE-REAC/TC]
  - 133492 persons involved
  - 3008 significantly exposed by DOE/NRC Accident Dose Criteria
  - 113 fatalities

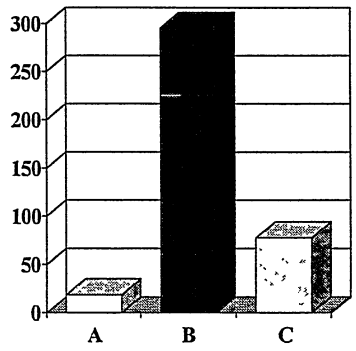
Statistics (cont.)

- 392 major radiation accidents may be classified regarding the practice into:

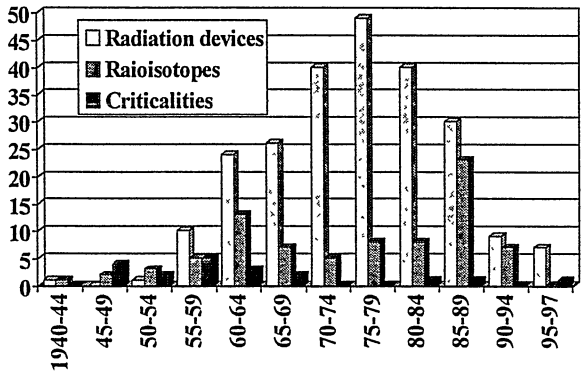
A. Criticalities.....19

B. Radiation devices....295

C. Radioisotopes..... 78

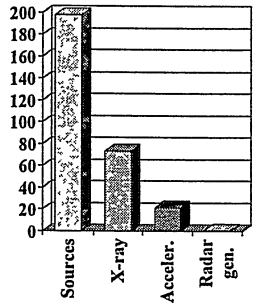


Frequency distribution



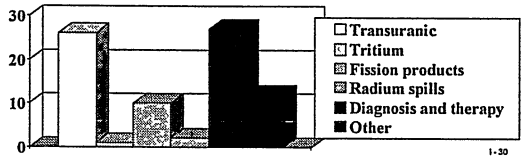
Radiation devices

- λ Sealed sources 198
- λ X-ray devices 74
- λ Accelerators 22
- λ Radar generators 1



Radioisotopes

- λ Transuranic 26
- λ Tritium 1
- λ Fission products 10
- λ Radium spills 2
- λ Diagnosis/therapy 27
- λ Other 12



EXAMPLES

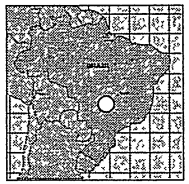
- λ Goiânia accident
- λ San Salvador accident
- λ Tammiku accident



THE RADIOLOGICAL ACCIDENT

GOIÂNIA, Brazil

Where did the accident occur?



- Goiânia - the Capital of Goiâs State, Brazil
- Population - about one million
- Accident area - poor section of the city
- Facility - abandoned premises of a radiotherapy institute

What Happened?

- End of 1985 a private radiotherapy institute moved to new premises, leaving in place a Cs-137 teletherapy unit without notifying the licensing authority
- The former premises were subsequently partly demolished
- September 13, 1987 two persons entered the premises, removed the source assembly from the radiation head of the machine
- They took the source assembly home and tried to dismantle it
- In the attempt, the source capsule was ruptured

The source

Nuclide	Cs-137
Activity (Sept.87)	50.9 TBq (1375 Ci)
Chemical form	CsCl
Physical form	powder
CsCl mass	93 g
Cs-137 mass	19.3 g
Physical half-life	30 years

How the Accident Was Discovered

- After the source capsule was ruptured, the remnants of the assembly were sold as scrap to a junkyard
- Fragments of the source the size of rice grains were distributed to several families
- In five days a number of people were showing gastrointestinal symptoms from exposure to radiation
- One of the irradiated persons connected the illnesses with the source capsule, and took the remnants to the public health department
- This action began a chain of events which led to the discovery of the accident

Main Countermeasures

- λ Medical triage
- λ Monitoring of the people and survey the environment
- λ Medical treatment of the irradiated/contaminated persons
- λ Actions to bring sources of exposure under control
- λ Decontamination of the main sites of contamination (houses, public places, vehicles, etc.)
- λ Demolition and removal of houses
- λ Removal of contaminated soil

Main Consequences

- λ 4 fatalities
- λ Persons contaminated
- λ The environment severely contaminated
- λ Large quantities of radioactive wastes generated
- λ The economic burden
- λ Substantial psychological impact on population

Basic Facts

λ Individuals surveyed	=	112,800
λ Persons contaminated	=	271
■ clothing and shoes	=	120
■ internal and external	=	151
λ Local radiation injuries	=	28
λ Hospitalization	=	20
λ Bone marrow failure	=	4
λ Acute radiation syndrome	=	8
λ Fatalities	=	4

Basic Facts (cont.)

- ❖ Decontamination of the city
- λ 730 workers
- λ 98 houses, of which:
  - ■ 41 were evacuated
  - ■ 6 were demolished
  - ■ 53 were repaired
- λ 58 different public places decontaminated, including pavements,squares, shops and bars
- λ 64 vehicles

Basic Facts (cont.)

- Waste storage site:
  - 20 km from the city
  - designed to accommodate 4,000-5,000m3 of waste
- Types of waste packaging used:
  - 4,500 metal drums (200L)
  - 1,400 metal boxes (5 tonnes)
  - 10 shipping containers (32m3)
  - 6 sets of concrete packaging
- Volume of waste stored: 3,500 m^3, or more than 275 construction lorry loads

Lessons Learned

- An adequate system of information is essential to avert panic
- Emergency workers should be instructed on how to convey information to the population
- The effectiveness of international assistance following a radiological accident depends on the infrastructure of the country concerned

Lessons Learned (cont.)

- In most countries circumstances are very different, equipment is diverse, the climate can be adverse and matters are administered differently
- For assistance, appropriate international bodies should consider documenting available monitoring equipment

Lessons Learned (cont.)

- Customs regulations:
  - amended to facilitate the import and return of goods
- Monitoring equipment to be used in the field should be capable of being adjusted for use in:
  - high humilities/temperatures and unstable environmental conditions
- Civil engineering infrastructure:
  - available for decontamination and reconstruction operations

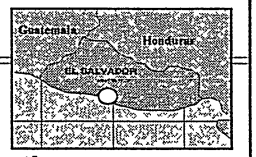
Accident Conclusions

- λ Radioactive sources that are removed from the location designated in the process of notification, registration and licensing can present a serious hazard
- λ Nothing can diminish the responsibility of the person designated as liable for the security of the radioactive source
- λ Recognition by the general public of the potential danger of radiation sources is an important factor in lessening the likelihood of radiological accident
- λ Considerations should be given to markings for radiation hazards that would be recognizable to the wider public
- λ The treatment of causalities of radiological accidents is extremely varied and complex

THE RADIOLOGICAL ACCIDENT

SAN SALVADOR
El-Salvador

Basic Facts



- λ Accident Location: San Salvador, the capital of the Republic of El Salvador
- λ Facility: an industrial irradiation facility
- λ Date: 5 February 1989
- λ Source: Co-60 in a movable source rack
- λ Activity: 0.66 PBq (18 kCi) at the time of the accident

Irradiation Facility

- λ In the irradiator, the product packages to be sterilized are loaded into large product boxes and moved by pneumatic cylinders to a centrally located, vertical rectangular source rack
- λ The source rack contains Co-60 source elements in the form of rods in 'source pencils'

First Event

- The source rack became stuck in the irradiation position on Sunday 5 February
- The operator bypassed the irradiator's already degraded safety systems, and entered the radiation room (first alone) with the two other workers to free the source rack manually

Second Event

- Probably on Thursday or Friday (10 February) some of the pencils fell from the upper source module into the pool
- Four of the pencils from the top module, an active source pencil and tree dummy pencils, were subsequently found to have fallen into the radiation room; the others had fallen into the pool

Salvador5.tif

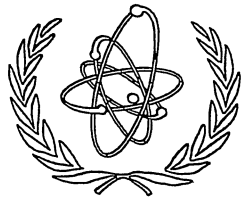
Major Cause and Consequences

- Major Cause: operator error, component failure, procedural failure
- Consequences:
  - Tree workers developed the acute radiation syndrome; legs and feet of two were amputated
  - One died six and a half months after the accident, his death being attributed to residual lung damage due to irradiation

Conclusions

- There was no regulatory control of radiological protection matters nor any readily available expertise in El Salvador
- Operators trained by the supplier of the irradiators had left at an early stage and subsequent training was only oral and informal
- The company did not implement measures detailed in notices from supplier to upgrade safety of the facility
- The installed safety systems had degenerated or been bypassed over the years

THE RADIOLOGICAL ACCIDENT



TAMMIKU
Estonia

Basic Facts

- Accident location: Tammiku, Estonia
- Facility: Radioactive Waste Repository
- Date: 21 October 1994
- Source: Cs-137
- Activity: uncertain; between 150 GBq to 7.4 TBq (estimates based on dose rate measurements)

What Happened?

- Three brothers visited the waste disposal facility in the early hours of the morning
- One of them found the metal container and passed it to his brothers
- Two cylinders fell out of the open tube in the container; one he picked up and placed in his pocket (that was the radioactive source)

What Happened? (Cont.)

- They returned home after taking the container and some barrels
- A few hours after the unauthorized entry into the repository one of the brothers began vomited repeatedly
- Sometime that day the source was placed in a drawer in the kitchen

What Happened? (Cont.)

- λ 25 October: one brother was hospitalized with a severe injury to his leg; he did not reveal what happened
- λ 2 November he died; the course of the death was not associated at that time with radiation exposure
- λ 16 November the family's pet dog (4 month old, staying mainly in the kitchen) died; previously the dog had been vomiting and blood was present in the dog's urine

What Happened? (Cont.)

- λ 17 November: the stepson was admitted to hospital with severe burns to his hands
- λ These were diagnosed as radiation induced and the police were notified; rescue actions were initiated that limited the further extent of the consequences

Conclusions and Lessons Learned

- λ The waste disposal facility at Tammiku was not suitable for the storage or disposal of radioactive sources
- λ The security of the facility was inadequate
- λ National regulatory authorities shall keep adequate records of the types of radioactive sources that are present in their countries
- λ National regulatory authorities shall require users of radioactive sources to keep comprehensive records of all the sources in their possession

LEARNING FROM EXPERIENCE

- λ Much can be learned from past experience
  - ■ Competent authority should organize collection of histories of accidents
  - ■ National competent authorities should periodically publish reviews of reports; the international community can learn from national experience

LEARNING FROM EXPERIENCE (Cont.)

- The following factors contribute considerably in the reduction of radiation accidents:
  - awareness of hazards associated with the use of radioactive sources and appropriate surveillance by the management
  - employment of well trained and competent personnel especially suited for these jobs

LEARNING FROM EXPERIENCE (Cont.)

- periodic maintenance and testing of the equipment used for radiation exposure
- maintenance of proper inventory of sources, their whereabouts and the exposures given with these sources
- use of suitable monitoring equipment during each operation

Lessons learned

- An analysis of radiation accidents indicate that human error and equipment error are the main causes of these accidents
- The general tendency is for a person who does a routine job repeatedly will overlook some basic requirements for a proper work practice and this may result in an unusual situation leading to an accident
- Inadequate training, ignorance, failure to monitor and failure to maintain the equipment are other main factors contributing to the human error

CONCLUSIONS

- Be prepared
- Co-ordination of response is critical - know who is in charge
- Ensure authorities are defined in advance
- Integrate radiation emergency response with conventional response systems
- Prompt recognition and notification of an accident
- Prompt activation and appropriate response
- Public information
- Maintain credibility in the authorities
- Training and exercises matter

Conclusions (Cont.)

- In many non-reactor radiological emergencies, the hazard due to radiation is often less than conventional hazards present (e.g. fire, chemicals)
- The non-radiological aspect of a radiological emergency usually take precedence: saving lives, treating injuries, fighting fires, protecting critical equipment and safety of personnel are priorities
- Once non-radiological situations have been stabilized, immediate steps must be taken to minimize the radiological risk to the public, the emergency workers, and the environment