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Radiation Accidents, Medical Highlights (Selections from the REAC/TS Registry)

AFFRI Scientific MEIR Course
USUHS, Bethesda, MD, July–Aug, 2008

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Dose Criteria for Designation as a Radiation Accident

| Condition | Criteria rem (mSv) |
|--|--|
| 1. Dose to whole body; active blood - forming organs or gonads | 25 (250) |
| 2. Dose to skin of whole body or extremities | 600 (6,000) |
| 3. Dose to other tissues or organs from external source | 75 (750) |
| 4. Internal Burdens | 1/2 NCRP maximum organ burden |
| 5. Medical Misadministration | All misadministrations, provided they also result in a dose (if a radiation source) or a burden (if a radiopharmaceutical), equal to or greater than the criteria for conditions 1,2,3, or 4 above |

Source: ERDA/NRC 1974

What Causes Radiation "Accidents"?

Usually Human Error

- ✓ Lost or mishandled sources
- ✓ Medical misadministration
- ✓ Bypassing Interlocks
- ✓ Failure to use criticality control
- ✓ Calibration/programming errors
- ✓ Inadequate radiation protection programs, supervision/quality control, and training/written procedures
- ✓ Human factors

REALITY: MAJOR RADIATION "ACCIDENTS" WORLDWIDE (1944-DEC 2007): "CLASSIFICATION BY DEVICE"

Radiation Devices 319

| | |
|------------------|-----|
| Sealed Sources | 210 |
| X-ray Devices | 83 |
| Accelerators | 25 |
| Radar Generators | 1 |

Radioisotopes 93

| | |
|-----------------------|----|
| Diagnosis and Therapy | 38 |
| Transuranics | 28 |
| Fission Products | 11 |
| Tritium | 2 |
| Radium Spills | 1 |
| Other | 13 |

Criticalities 20

| | |
|---------------------|---|
| Critical Assemblies | 8 |
| Reactors | 6 |
| Chemical Operations | 6 |

Total 432

Source: REAC/TS Registry

Things To Consider

- There Are Different Types and Extents of Radiation Injury, Depending on the Accident Scenario.
 - ✓ Whole Body Irradiations
(WBI vs TBI)
 - ✓ Partial Body Irradiations (PBI)
 - ✓ Local Radiation Injury (LRI)
 - ✓ Internal Contamination from Radioisotopes
- There May be Acute and Chronic effects.

An Industrial Radiography Example

:Location

Yanango, 42 megawatt hydroelectric plant,
located 300 km east of Lima, Peru.



Device

^{192}Ir "gamma camera" with a 1.37 TBq (37 Ci) source



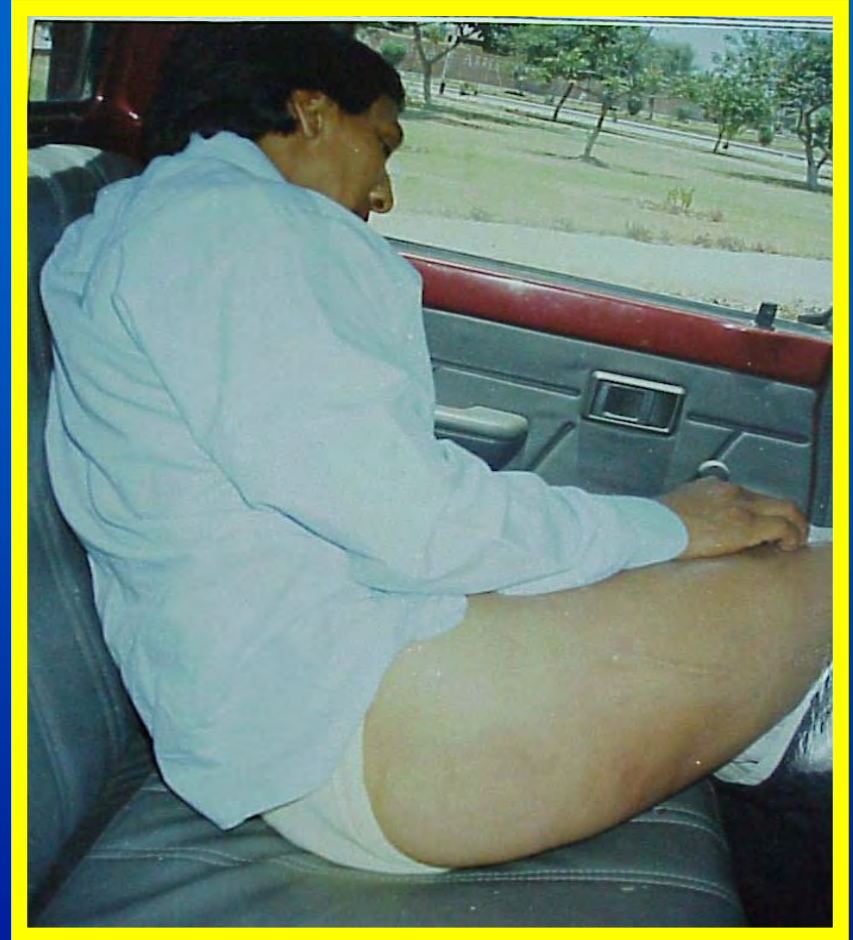
Dose Rates

For a 30 Ci ^{192}Ir radiography source

| <i>Distance</i> <i>[cm]</i> | <i>Dose Rate</i> <i>[rad/min] or [cGy/min]</i> |
|--------------------------------|---|
| Surface | 36,000 |
| 1 | 2,400 |
| 2 | 600 |
| 3 | 267 |
| 4 | 150 |
| 5 | 96 |

Medical

- 37 year old male put source in his pocket with ~6 hour exposure .
- Initial symptoms of nausea / vomiting and one episode of diarrhea.
- Erythema on upper posterior thigh
- Admission.
- T_x - IV fluids, 500mg Cipro bid, 8mg dexamethasone tid, Naprosyn-like pain meds





D+2 (Feb 22, 1999)

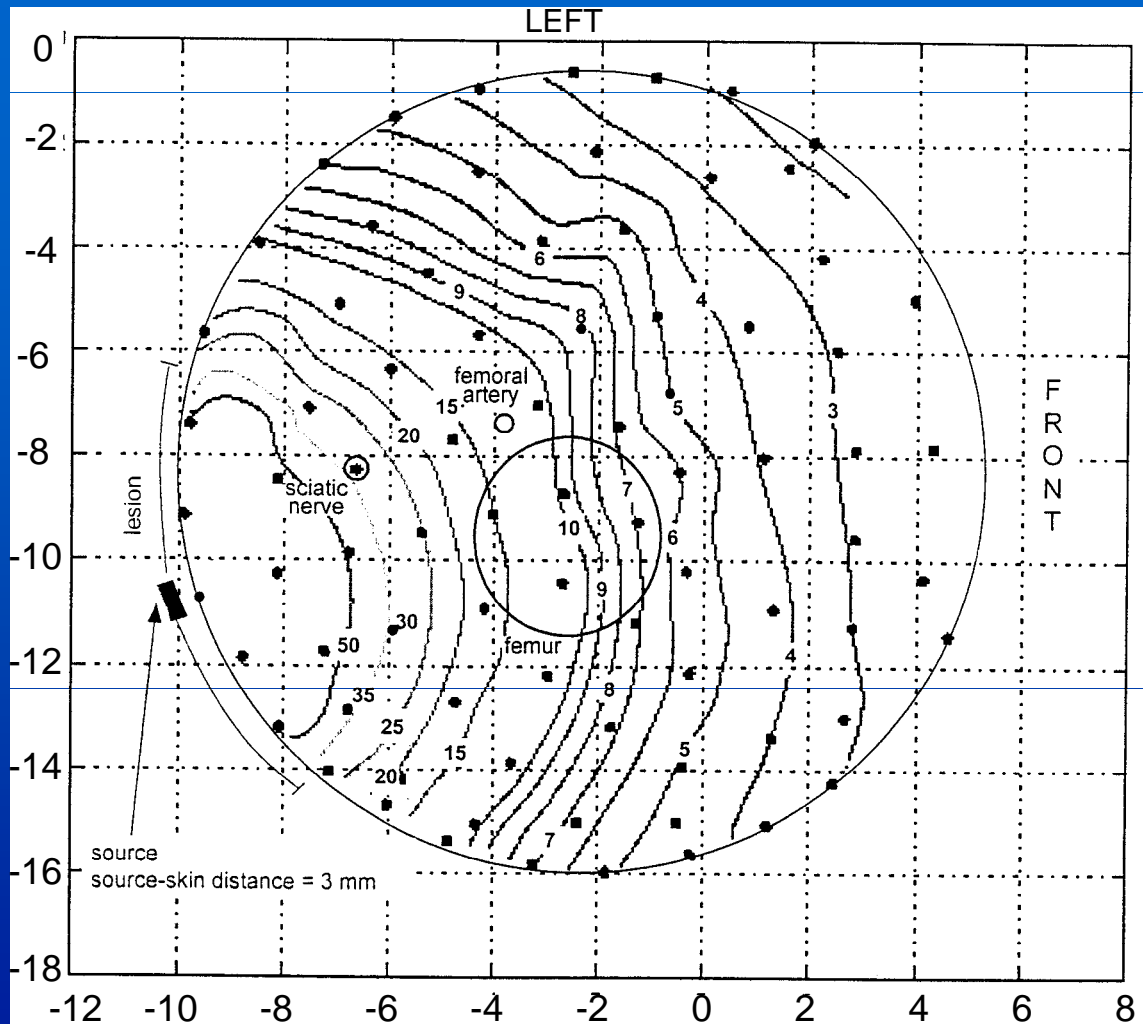
Blistering, vesicular
lesion with inflammatory
halo

D+5 (Feb 25, 1999)

Clindamycin 300mg tid
started & Cipro ↑ 750mg
bid

Absorbed doses in Gy

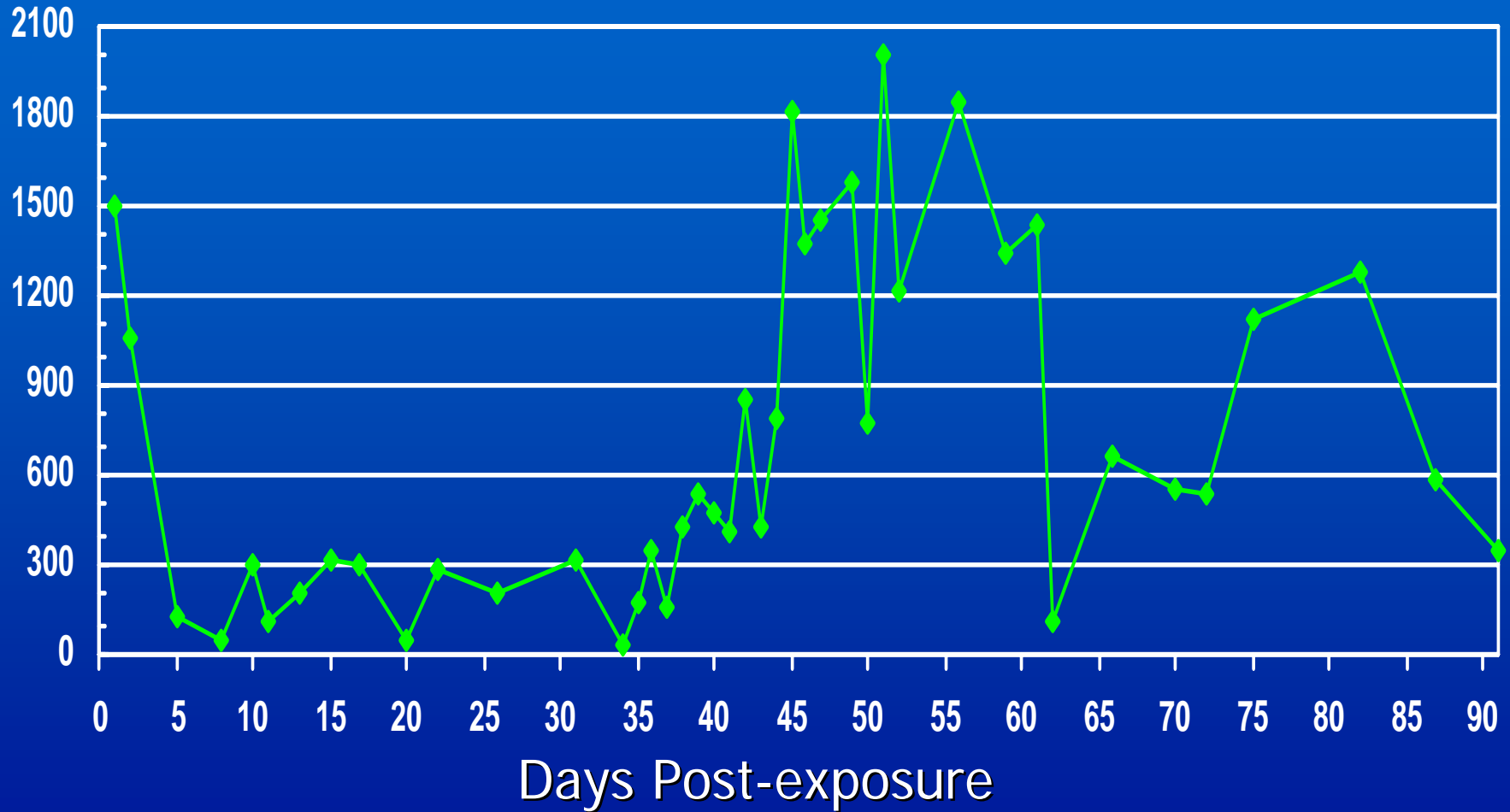
Normalized to 30 Gy at the rim of the lesion (radius = 5 cm)

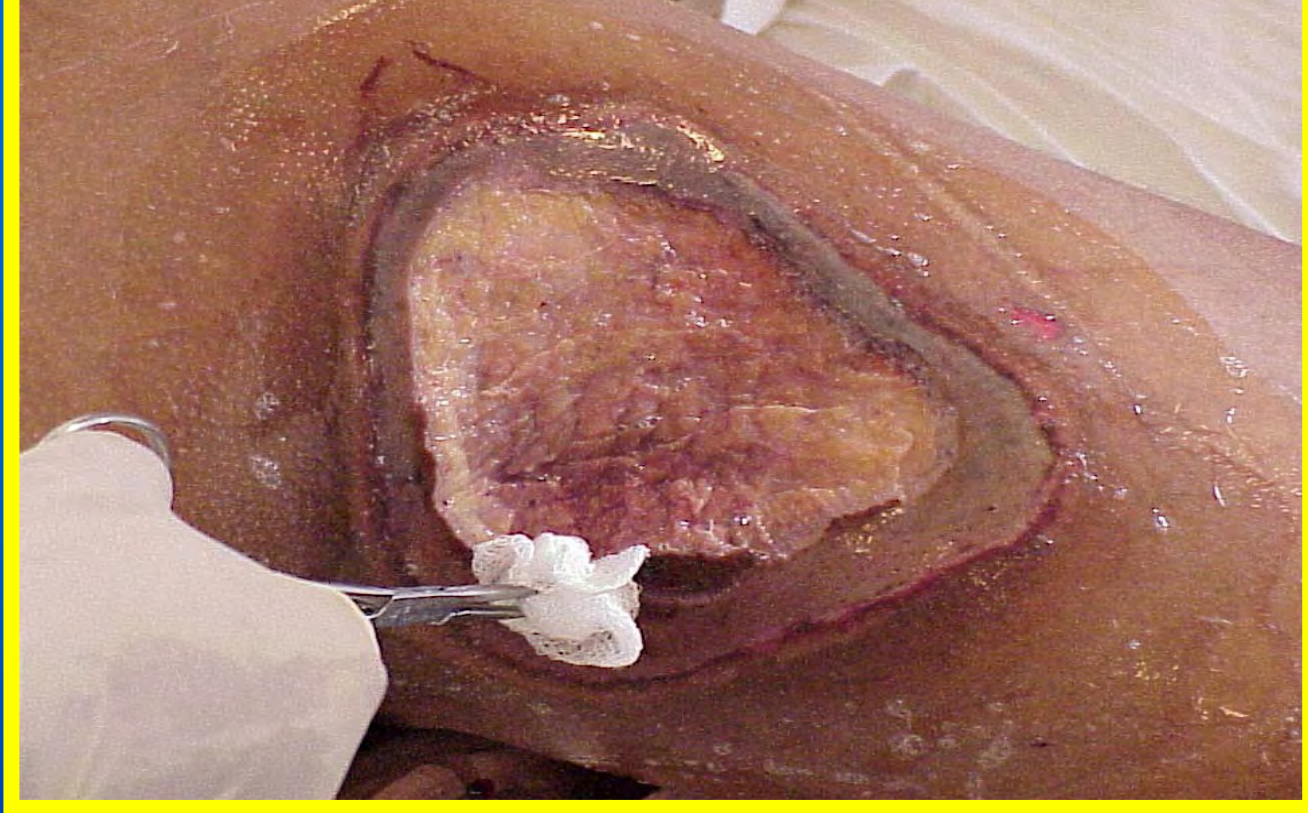


Absorbed dose distribution for horizontal cross-section at source level with source-skin distance of 3 mm

Lymphocyte Kinetics

Absolute





D+28 19 March 1999 Ulcerative lesion 2cm deep
- continues to expand.

D+32 Increasingly painful. Morphine infusion
started. Radiation-induced sciatic
neuropathy.

D+39 First febrile episode.

Others Potentially Affected

- Workers at site
- 15 passengers on the mini-bus with the welder as he went home
- Immediate family at the residence
 - wife and 3 children ages 10, 7, and 18 months - no hematological changes observed in wife or children though wife did develop skin lesion

Examples of Accidents Involving Fissile Materials:

- Criticality Accidents
- Nuclear Reactor Accidents
- Nuclear Weapon Accidents
- Nuclear Industry/Lab Accidents

Criticality Comments

- A chain reaction is necessary for a criticality (sustained nuclear fission reaction) to occur
- Subcritical System → Safe Storage
- Critical System → Nuclear Reactor
- Supercritical System → Nuclear Weapon

Criticality does NOT equal Nuclear Detonation

*Radiological Concerns for Criticality Accidents**

- Immediate:
 - prompt neutron & gamma exposure
- Short-term:
 - Release of ^{131}I
- Long-term:
 - Releases of ^{90}Sr , ^{137}Cs , ^{235}U , ^{239}Pu

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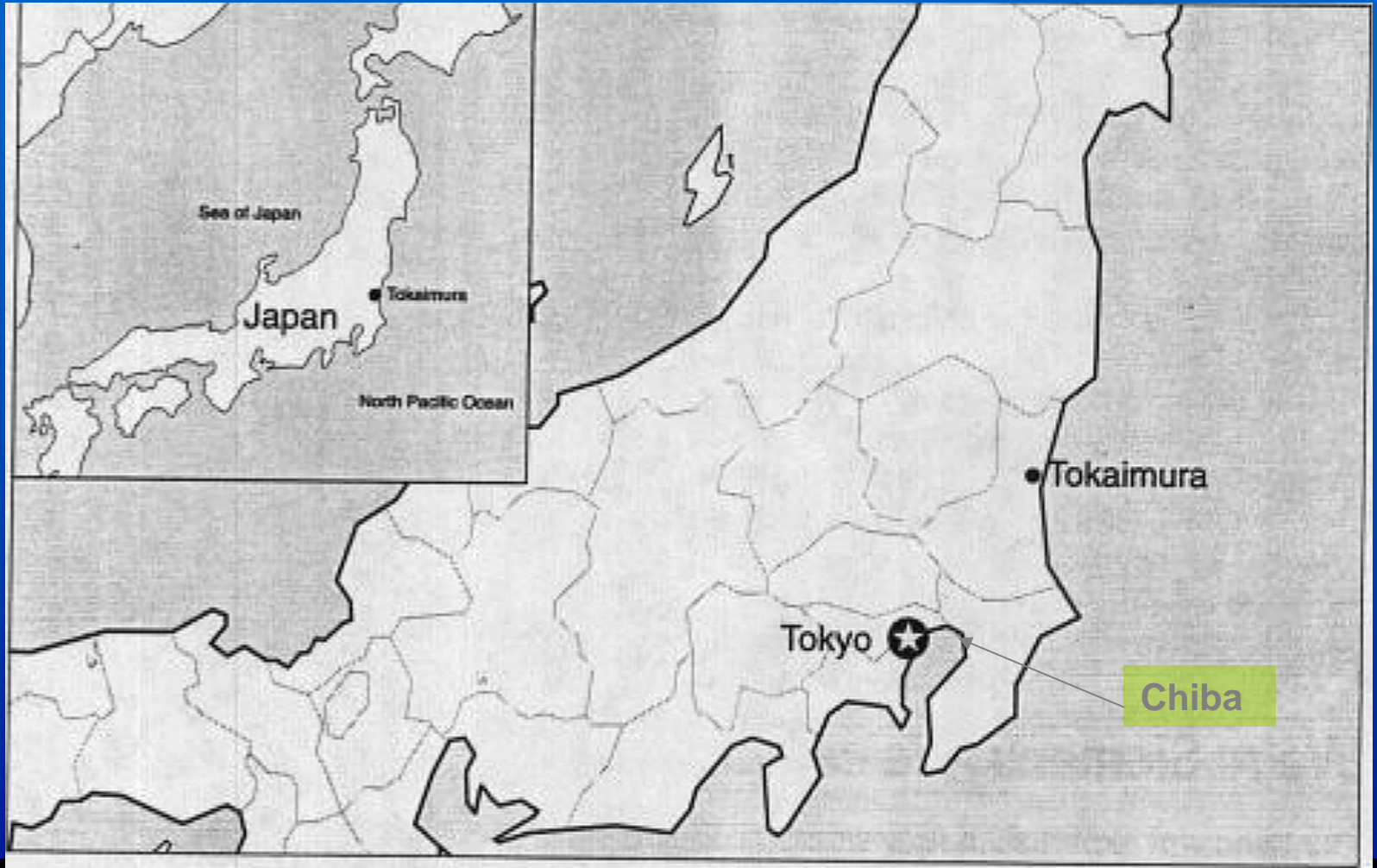
*Critical assembly, operating reactor, weapon detonation

Notable Criticality Accidents

| Year | Location | Fatalities |
|------|-------------------|---------------|
| 1945 | Los Alamos | 1 |
| 1946 | Los Alamos | 1 |
| 1958 | Oak Ridge | 0 |
| 1958 | Los Alamos | 1 |
| 1961 | Idaho Falls | 3 (trauma) |
| 1964 | Rhode Island | 1 |
| 1979 | Three Mile Island | 0 |
| 1986 | Chernobyl | 28 (2 trauma) |
| 1999 | Tokai-Mura | 2 |

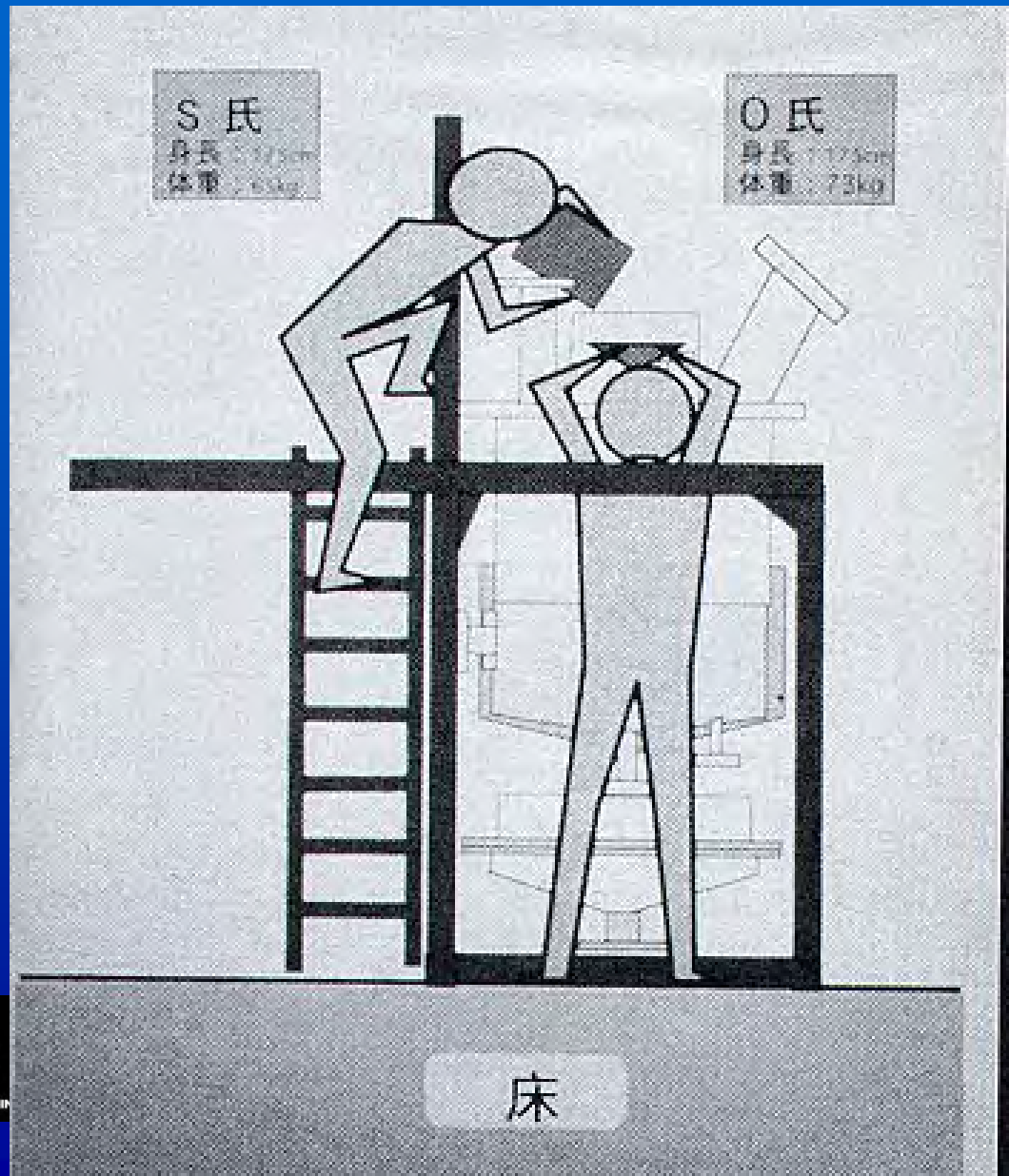


Tokaimura, Japan Map



The location of Tokaimura, Japan—site of the September 30 criticality accident

Positions of Workers



Follow-up: Mr. O

- Severe skin damage over more than 50% of body
- Losing 2 L of fluid per day through diarrhea, although not bloody
- One episode of cardiac arrest in early December, but resuscitated
- Died from massive organ failure December 21, 1999, 82 days post-exposure

Follow-up: Mr. S (con't)

- Antibiotic-resistant pneumonia contracted in March, 2000 (160 d post exposure)
- Pulmonary edema, placed on ventilator
- Intermittent kidney failure in April, 2000, treated by dialysis
- Oral mucositis and tissue shrinkage, could not swallow or open eyes, on parenteral nutrition
- Died of multiple organ failure April 27, 2000, 210 days post exposure

Doses based on symptoms

- Mr. O: marrow ablation, severe gastrointestinal syndrome, survival for 82 days with expert medical care:
absorbed dose = 10 (+/- 2) Gy
- Mr. S: recoverable marrow damage, mild gastrointestinal syndrome, pulmonary fibrosis, survived 210 days:
absorbed dose = 6 (+/- 1) Gy
- Mr. Y: minor marrow damage
absorbed dose = 2 (+/- 0.5) Gy
- Skin doses for Mr. O & S > 20 Gy

Calculated Absorbed Doses

- Absorbed doses were calculated to be:
 - Mr. O: 5.4 neutron + 8.5 gamma = 14 Gy
 - Mr. S: 2.9 neutron + 4.5 gamma = 7.4 Gy
 - Mr. Y: 0.8 neutron + 1.3 gamma = 2.1 Gy
- The total absorbed doses (neutron + gamma) can also be bracketed by the clinical findings

Initial Dose Estimates, Gy

| Method | Mr. O | Mr. S | Mr. Y |
|--------------------------------------|-------|-------|-------|
| Na-24 blood (n only) | 9.1 | 5.0 | 1.2 |
| Rings+dicen. (γ equiv.) | 21 | 6.6 | 2.8 |
| PCC (γ equiv.) | > 20 | 7.8 | 2.6 |
| Na-24 WBC (n only) | | | 1.6 |
| Lymphocyte counts (γ eq.) | >10 | 6-10 | 1-4.5 |

ARS: Dose-Mortality Relationship

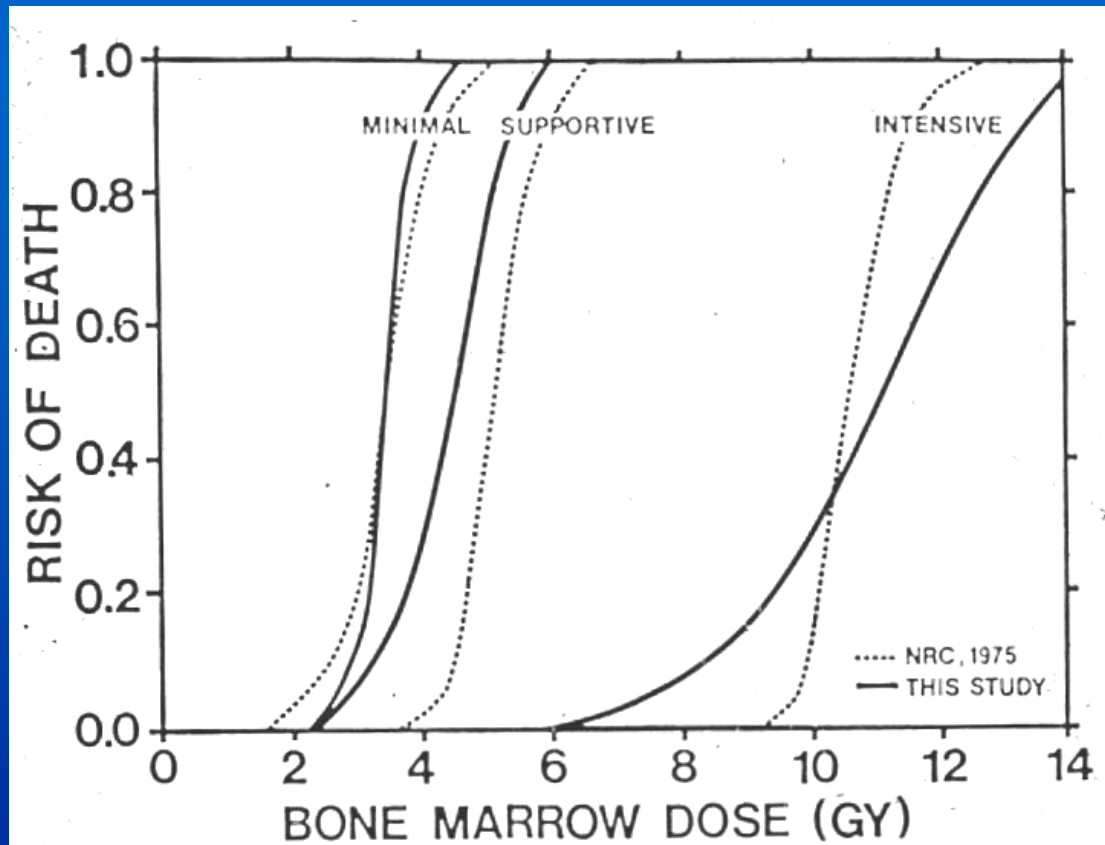


Figure 1.18 Dose-mortality relationships for irradiation of bone marrow; from NRC, 1975, and from this study.

Reactor Accidents

- Loss of Coolant Accident (LOCA)
- Pipe breaks in the primary loop remove cooling water from the core, leading to an increase in core temperature
- Fuel rods fail, releasing volatile radionuclides (iodine, cesium, etc.)
- Core meltdown—all the way to China?

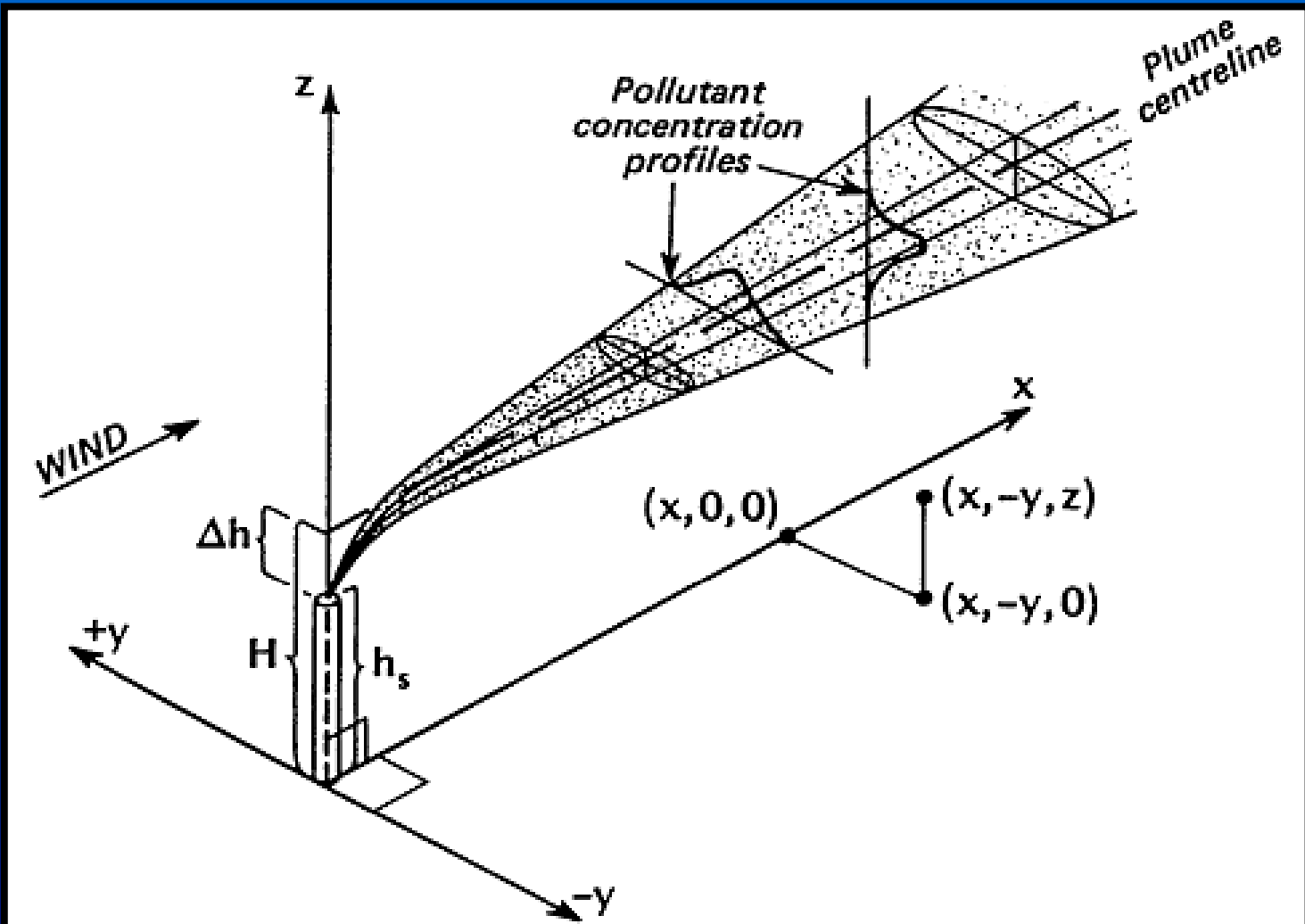
What Really Happens

- Fuel expands, reducing reaction rate
- Reactor scrams with gravity-induced lowering of control rods
- Emergency core cooling system activates and floods core
- Even if core does melt, containment systems works, as at TMI

Accident response

- Independent of the type of accident:
 - determine and control hazards to responders & victims
 - assess, treat, evacuate victims
 - implement further control procedures
 - assess personnel exposures
 - monitor clean-up
 - verify clean-up effectiveness

Plume Dispersion



Exposure Pathways

- External dose from plume overhead (cloud shine) or material on ground (ground shine)
- Internal dose due to inhaling materials directly from plume or from stirred dust
- Ingestion of contaminated materials in the form of food or water

Protective Actions Available to the Public

- Sheltering
- Evacuation
- Stable Iodine Prophylaxis
- Other actions to reduce dose

Guidance for Population Protection: 1st Principle

- Intervention to avoid serious prompt health effects should be carried out as a first priority
 - serious prompt health effects may be expected in susceptible populations at doses > 1 Gy (100 rad), and in all at doses > 2 Gy (200 rad) (whole-body)
 - evacuation is usually the only effective intervention measure in high dose situations

Guidance for Population Protection: 2nd Principle

- Protective actions to avoid delayed health effects should be initiated when they will produce more good than harm in the affected population
 - iodine prophylaxis in case of radioiodine releases
 - sheltering in place, evacuation, or temporary relocation

Guidance for Population Protection: 3rd Principle

- These actions should be introduced and withdrawn at levels that produce a maximum net benefit to the population
 - guidelines available from USEPA, IAEA, and IRPA
 - may well be driven primarily by logistical considerations (e.g., availability of transport, availability of temporary shelters, etc.)

Guidelines for Protective Actions

- Early phase: initiation of release to about 4 days
- Evacuate to avoid TEDE of 1 - 5 rem
- Shelter in place if equal or greater protection afforded by doing so
- Administer KI to prevent thyroid dose of 25 rem

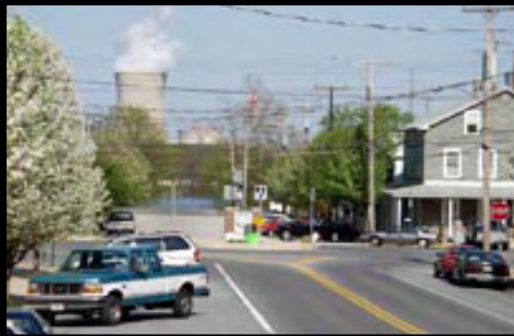
Intermediate Phase PAG's

- Intermediate phase: source or release is under control, and additional protective actions are being implemented; weeks to months
- Relocate to avoid 2 rem TEDE or 100 rem to skin in first year
- Apply dose reduction techniques (e.g., decontamination, hot spot removal) if less than 2 rem TEDE anticipated in 1st year

Logistical Requirements for Later Protective Actions

- Temporary relocation:
 - Transportation
 - Housing & furnishings
 - Security
 - Decontamination equipment & waste disposal
- Permanent resettlement:
 - Transportation
 - Housing & furnishings
 - Security

Three Mile Island



Three Mile Island

- Unit 2 feedwater pump tripped at 4:00 a.m. on March 28, 1979
- Reactor scrammed 8 seconds later
- Pressure relief valve stuck open, so ECCS water lost
- Pressurizer (only way of controlling water level and pressure in primary loop) filling up, so high pressure injection pumps shut down

TMI, con't

- State route 441 closed at 12:45 p.m.
- Everything fairly calm the next day
- Because of confusion and concern over the “hydrogen bubble”, evacuation advised for pregnant women and preschool children with 5 miles at 12:30 on March 30
- Schools closed and further evacuation planned
- Supplies of KI shipped in

TMI, con't

- NRC did not share info that hydrogen bubble was really not a threat
- Many families, including health care providers, left on their own
- Schools reopened April 4
- 5-mile evacuation advisory withdrawn on April 9
- Final clean-up cost was \$1E9

Figure 31. Radiation Hotspots Resulting From the Chernobyl' Nuclear Power Plant Accident



Possible Consequences of Reactor Plumes

- *Psychological*
 - Effects on individuals
 - Effects on families/co-workers
 - Effects on the general population
 - Effects on emergency response personnel
 - Effects on health-care personnel
- *Environmental*
 - Contamination of air, water, land
 - Waste management
 - Food chain
- *Economic*
 - Use loss
 - Import/export restrictions
 - Clean-up costs
- *Legal*
 - Impact on regulatory agencies
 - Damages and legal costs
 - Medical/legal uncertainties

Notable Weapons Accidents

- Palomares , Spain - January, 1966
- Thule, Greenland - January, 1968
- Damascus, Arkansas - September, 1980

Am-241 Inhalation ,Case Study

- Two workers were transferring ^{241}Am from a shipping barrel to a disposal container.
- The workers were wearing respiratory protection.
- But, a supervisor was also present, and not wearing respiratory protection.

Am-241 Case Study (continued)

- On exit, all three workers were noted to be contaminated – and room air samples were positive for alpha.
- Lung count bioassay was advised and performed the next day - all 3 patients were positive.
- 24 hr urine and fecal bioassay collections were advised and begun.

Day 1 Bioassay results

- Patient #1 (supervisor, male):
 - Lung content: 400 Bq
 - Urine: 1 Bq per day
- Patient #2 (female):
 - Lung content: 200 Bq
 - Urine: 0.12 Bq per day
- Patient #3 (male):
 - Lung content: 50 Bq
 - Urine: 0.06 Bq per day

Initial Intakes and Effective Dose Estimates

- Patient #1: 1.8 kBq, 210 mSv
- Patient #2: 0.63 kBq, 73 mSv
- Patient #3: 0.15 kBq, 17 m S v (?Stop DTPA?).
- Chelation Rx begun on day 2 with Ca-DTPA for the males and Zn-DTPA for the female, and continued daily with Zn-DTPA for 5-6 days.
- Bioassay measurements /DTPA Rx s/ dose aversion continued.

Case Involving Tritium Exposure (H-3)

- The physician on-call in the Poison Control Center is paged for a call for assistance.
- Six male teens at a university dormitory facility have broken open an exit sign, releasing approximately 10 Ci of tritium to the local environment.
- A radiological survey finds the highest levels of tritium to be on the public telephone (157,000 dpm). Urine samples are taken from all six teens and sent for tritium bioassay.

H-3 case

- From liquid scintillation counting at a laboratory, the highest urine value is found to be 6.5 $\mu\text{Ci/L}$ in a 17 year-old male.
- Using the rule of thumb that 1 $\mu\text{Ci/L}$ peak tritium concentration in urine corresponds to an integrated whole-body dose of 10 mrem (NCRP 65), the maximum estimated CEDE dose is approximately 65 mrem (0.65 mSv) whole body.
- Prior to receiving the urine bioassay results, all teens were instructed to increase oral hydration to 3-4 l/d for 7 days.

Radiotherapy Accident

HDR source unknowingly broke off inside one of the catheters. Patient was transferred from the cancer treatment center back to the nursing home with the catheters in place. A second HDR treatment was scheduled the following week.

PATIENT ABSORBED DOSE ESTIMATES FOR 4.22 CURIE Ir-192 SOURCE OVER 92.75 HRS

| | | |
|-----|---------------------------------|------------------------|
| 1. | Rectum (closest point) | 7,770 Gy (770,000 cGy) |
| 2. | Bladder (closest point) | 2,080 Gy |
| 3. | Small bowel (closest point) | 330 Gy |
| 4. | Small bowel (median point) | 95.8 Gy |
| 5. | Left kidney (median point) | 36.7 Gy |
| 6. | Right kidney (median point) | 31.2 Gy |
| 7. | Bone Marrow (L1 Vertebral Body) | 19.7 Gy |
| 8. | Heart (median point) | 9.4 Gy |
| 9. | Lung (median point) | 6.1 Gy |
| 10. | Brain (median point) | 0.9 Gy |

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CONCLUSIONS

- **No acute radiation effects seen in staff, other patients, or visitors**
- **Cytogenetic studies performed at REAC/TS (ORISE) in Oak Ridge, TN demonstrated that a certain group of staff and patients had a significant number of chromosomal abnormalities in peripheral lymphocytes**
- **The patient involved in the accident experienced severe acute radiation syndrome and the radiation accident was the cause of death**

Goiania, Brazil

^{137}Cs Accident September 13, 1987



Cesium-137



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Skin lesion initially diagnosed incorrectly



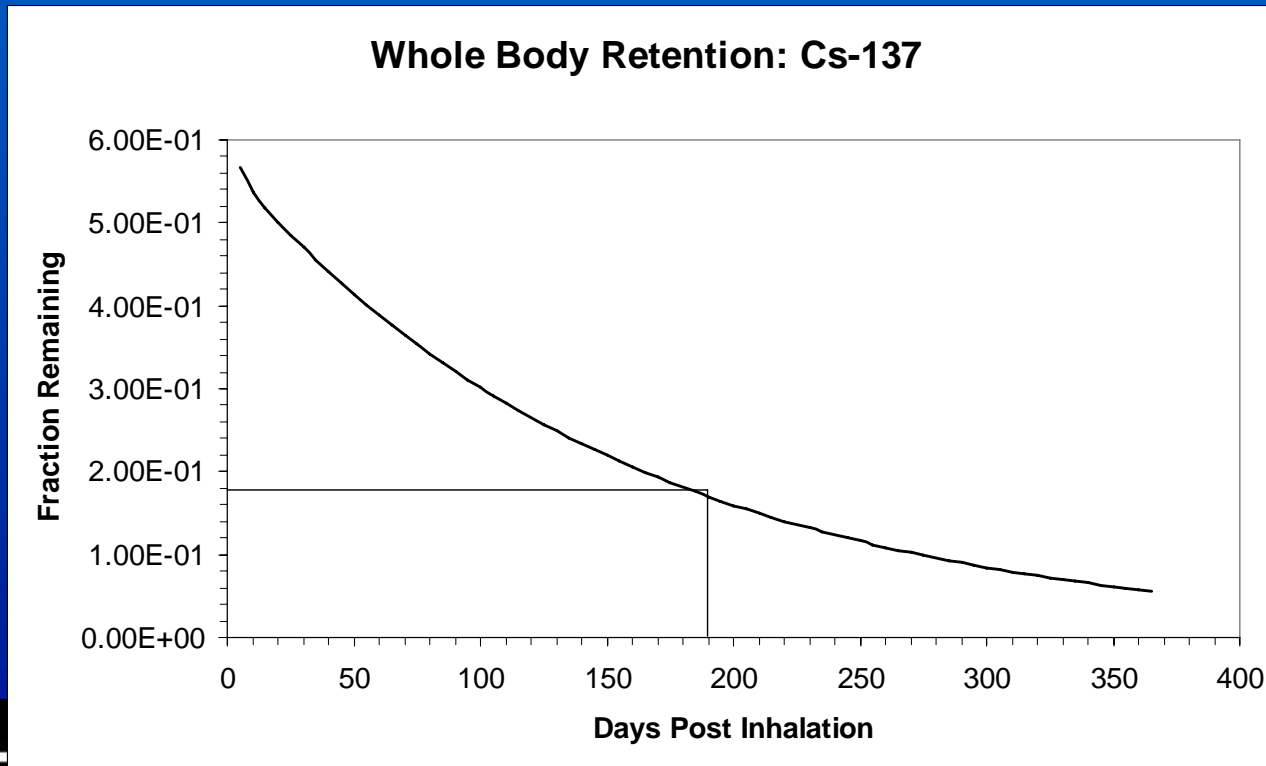
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Individual Monitoring

- 112,000 people were screened
- 249 contaminated people:
 - 120 people had their clothes and shoes contaminated;
 - 129 people had external and internal contamination

HOW MUCH INTAKE and WHAT IS THE DOSE (CEDE)?

Step 1) Estimate the Intake Using Intake Retention Fractions.



At 190 days
about 18% of
Cs-137
Remains in
whole body.

Assume Measured 1.48 MBq [40 uCi] of Cs-137 at 190 Days

Intake (Inhalation) = $1.48 \text{ MBq} / 0.18 = 8.2 \text{ MBq}$

[$40 \text{ uCi} / 0.18 = 222 \text{ uCi}$]

Step 2) Compare to Annual Limit on Intake (ALI).

ALI = 7.4 MBq [200 uCi] for Cs-137

(Gives 0.05 Sv [5 rem] CEDE)

So individual has 110% of ALI and

Dose of 0.55 Sv [5.5 rem].

Initial Internal Contamination Measurements

| Range Bq | Range $\mu\text{Ci}/\text{mCi}$ | No. of Persons |
|-----------------|------------------------------------|----------------|
| 10^4 - 10^5 | 0.27 - 2.7 μCi | 11 |
| 10^5 - 10^6 | 2.7 – 27 μCi | 15 |
| 10^6 - 10^7 | 27 – 270 μCi | 23 |
| 10^7 - 10^8 | 270 μCi – 2.7 mCi | 20 |
| 10^8 - 10^9 | 2.7 – 27 mCi | 7 |
| 10^{10} | 27 mCi | 1 |
| Total | | 67 |

Results of Initial Cytogenetic Dosimetry

| Range [Sv] | No. of Persons | Relative Frequency [%] |
|------------|----------------|------------------------|
| 0 – 0.5 | 43 | 61.43 |
| 0.5 – 1.0 | 8 | 11.43 |
| 1.0 – 2.0 | 6 | 8.57 |
| 2.0 – 3.0 | 5 | 7.14 |
| 3.0 – 4.0 | 0 | 0 |
| 4.0 – 5.0 | 3 | 4.29 |
| 5.0 – 6.0 | 3 | 4.29 |
| 6.0 – 7.0 | 2 | 2.58 |
| Total | 70 | 100.00 |

Goiania Data

Table 2: Cesium-137 Effective Half-life During and After Treatment with Insoluble Prussian blue

(In Days, by Age, and Dose of Insoluble Prussian blue)

| Group | Age (Years) | Insoluble Prussian blue dose (grams/day) | No. of Pts. | During Insoluble Prussian blue Treatment - ^{137}Cs $T_{1/2}$ | Off Insoluble Prussian blue Treatment - ^{137}Cs $T_{1/2}$ |
|-------------|-------------|--|-------------|--|---|
| Adults | > 18 | 10 | 5 | 26 ± 6 days | 80 ± 15 days (all 21 adult patients) |
| Adults | > 18 | 6 | 10 | 25 ± 15 days | |
| Adults | > 18 | 3 | 6 | 25 ± 9 days | |
| Adolescents | 12 -14 | < 10 | 5 | 30 ± 12 days | 62 ± 14 days |
| Children | 4 - 9 | < 3 | 7 | 24 ± 3 days | 42 ± 4 days |

Acute Clinical Outcomes

Individual Radiological Information (approximate)

| | |
|----------------------|--|
| MF1 | 5.7 Gy (died) |
| DF | 7 Gy (lived) Possibly spent more time outside (fractionated) |
| MA1 | 10 MBq (270 µCi) intake, 4.3 Gy external (cytogenetics) |
| IS | 4.5 Gy (died) Probable very acute dose. |
| AS | 5.3 Gy (died) Probable very acute dose. |
| LF2 | 1GBq (27 mCi) intake, 6 Gy external (died) |
| GS | 100 MBq (2.7 mCi) intake, 3 Gy, significant burn on shoulder |
| ⁶⁵ Dr. PM | 1.3 Gy, negligible intake (left source in bag) |

The logo for 'reacts' features the word in a white, lowercase, sans-serif font. The letters are superimposed on a light blue world map, which is centered within a dark blue oval. The entire graphic is set against a solid blue background.

reacts

Thank you!
Questions?

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reacts

RADIATION EMERGENCY ASSISTANCE CENTER/TRAINING SITE ■ OAK RIDGE, TENNESSEE

ORISE