The Socrates Award Lecture 2003

Risk Analysis of Radiological Dispersal Devices

Professor Greg Möller
University of Idaho
Moscow, Idaho USA

Learning Objectives

- Review the history and potential use of "radiological dispersal devices" (RDDs)
  - Dirty bombs
- Examine commercial radionuclide sources
- Examine the health consequences of radionuclide exposure
- Formulate a risk analysis for commercial source RDD use
- Examine the 1987 Goiania, Brazil incident

Learning Objectives

- Explore a hypothetical RDD incident and subsequent risks and protective actions
- Examine the conclusions concerning RDD health risk and psychosocial impacts

Radiological Dispersal Device

- A radiological dispersal device is any device that is able to spread radioactive material through explosion
- This device would not yield a nuclear explosion, but would disseminate material causing destruction, damage, or injury by means of radiation produced by the decay of the source material
- The US secretly experimented with this concept from 1940-1953

US Radiological Warfare History

- Radiological warfare (RW) began with the Manhattan Project in 1942
- Two years earlier, the National Academy of Sciences urged the US military to develop radioactive fission products to be used as nuclear bombarding projectiles.
- The first of three reports states that radioactive material could be carried by aircraft, and dispersed as bombs over an enemy territory
- The committee chair, Arthur Holly Compton, gave radiological warfare priority among the possible advantages of atomic energy

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US RW History

- In 1943, when development problems plagued the readiness of the atomic bomb, RW became a contingency
- A declassified letter written by Robert Oppenheimer, director of the Los Alamos Laboratory to Enrico Fermi made a novel proposal: suggested using strontium-90 (a high energy beta emitter) to irradiate the German food crops and water supply

US RW History

- New information on the health effects of radiation was being developed; suggested potential as a weapon
- Following WWII, RW was examined in numerous studies (Operation Crossroad, Green-Run tests, Dugway)
- Results: no practical military purpose
- In 1946, the Manhattan Project announced a program to distribute radionuclides for non-military utilization in scientific, industrial, and medical applications

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Commercial Radionuclide Sources

- Not included in the present analysis:
- Military weapons, nuclear power plant (including wastes)
- Smaller sources: pharmaceuticals, smoke detectors, lab waste

- Included:
- Medicine – teletherapy
- Food – irradiation
- Industrial – radiography
- Power – thermoelectric generators

Comprehensive Review of Commercial Radioactive Sources at Risk for RDD Use

- This work of Ferguson *et al.* (MIIS) concludes that RDDs are not generally WMD and acute lethality potential is very limited
- Suggests that only a few types of sources represent the greatest threats
  - These are typically the sources under the highest levels of regulatory control in advanced countries.
  - Since most radioactive source production and distribution is limited to a short list of vendors, the report observes that commercial recipients can be actively monitored and regulated.
- The analysis observes several weaknesses in current radioactive source management and suggests enhanced surveillance, identification, and disposal of orphaned and disused sources, and additional global controls.
- Concludes that the risk of RDD use will never be eliminated, but mitigation of the potential impact through source control, public education, and training of emergency response personnel is possible with increased attention to this threat.

Recent Concerns

- 1987, Goiania, Brazil: Scrap removal of Cesium-137 from an abandoned teletherapy unit
- 1996, Moscow, Russia: Islamic militants from the breakaway province of Chechnya planted an Cesiium-137 RDD in Moscow's Izamilovo Park
  - Source came from a teletherapy instrument used to treat cancer
- 2003, Amiriya, Iraq: Looting of Cobalt-60 from a former military testing site.

RDD Considerations

- Size and radioactivity of the source material
- Accessibility of the source material
- Shielding requirements
- Energy of the emitted radiation can be shielded by materials of sufficient thickness and density
  - Gamma emitter, Co-60 → lead, concrete
  - Beta emitter, Sr-90 → plastic
- Shielding requirements and accessibility limit the practical potential for some sources, even in terrorist RDD applications

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Units: Common vs. SI

- Rad (radiation absorbed dose) → Gray (Gy)
  - One gray is equivalent to 100 rads
- REM (radiation equivalent dose) → Sievert (Sv)
  - One sievert is equivalent to 100 rem.
- Curie (Ci) (radioactivity measure) → Becquerel (Bq)
  - There are 3.7 x 10^{10} Bq in one curie

Shielding Requirements Limit Portability

- For gamma sources: the higher the activity, the more shielding you require to transport the source.

Small radiography sources:
• typically 0.1 Ci to 200 Ci.
• 30 – 50 Lbs

Medium radiography sources:
• Hundreds of Ci
• 200 - 400 Lbs

Large industrial source:
• 9,000 Ci
• 3 tons of shielding

High Activity Radioactive Material

Fuel Assembly

- Spent Nuclear Fuel & High Level Waste
- Radioisotope Thermoelectric Generators (RTG)
- Medical & Radiographic sources

Radioisotope Thermoelectric Generators (RTG)

Self heated Plutonium 238

- The heat generated by the radioactive decay is used to generate electricity
- Used when maintenance free power is needed for decades (satellites, ocean bottom, and arctic applications)
- RTGs most often made from Sr-90 (0.46 kW/kg) or Pu-238 (0.54 kW/kg).

Portable Radiography Sources

- “Top strength” industrial radiography sources can burn fingers and cause radiation sickness within a few minutes.
- Effects drop off dramatically with distance. Outside of 3 meters, acute effects rare even after hours of exposure.
- Sources are constructed to meet rigorous testing standards. A typical source is encapsulated in two (2) TIG welded Stainless Steel Capsules.
- Source Material itself is often metal (Cobalt or Iridium) or embedded on non-soluble ceramics or “microspheres” to prevent inhalation of radioactive material if the source encapsulation is breached.

Facility Based Irradiators

- These sources can have 10 to 100 times more radioactivity than radiography sources
- Found in food irradiators, medical sterilizers, etc.
- The shielded enclosures that hold the sources weigh more than a ton.
- Difficult to remove source from the facility or equipment.

Risk of Use Quotient

- Increased risk is proportional to increased source activity and increased accessibility
- Increased risk is inversely proportional to shield container mass

Risk of use quotient (RUQ)

$$= \log\left[\frac{(\text{source activity}) \times 10^{-12}, \text{Bq}}{\text{shield container mass, kg}} \times \frac{\text{kg}}{\text{Bq}} \times \text{accessibility factor}\right]$$

- Source activity = assume large
- Accessibility = ranked 1-10
- Shield container mass
  = calculated

Industrial Radiography

Isotope / absorber	Source activity Bq	Container mass kg	Accessibility factor 1-10	Risk-of-use quotient RUQ
^{192}Ir	3.70×10^{12}			
Lead		68	5	-0.57
Concrete		89	5	-0.68
^{60}Co	3.70×10^{12}			
Lead		432	5	-1.4
Concrete		1355	5	-1.9

Medical Teletherapy

Isotope / absorber	Source activity Bq	Container mass kg	Accessibility factor 1-10	Risk-of-use quotient RUQ
^{60}Co	7.40×10^{13}			
Lead		1141	8	-0.28
Concrete		5171	8	-0.94
^{137}Cs	7.40×10^{13}			
Lead		326	8	**0.26**
Concrete		1355	8	-0.36

Irradiator Facility

Isotope / absorber	Source activity Bq	Container mass kg	Accessibility factor 1-10	Risk-of-use quotient RUQ
^{60}Co	3.70×10^{14}			
Lead		1517	1	-0.61
Concrete		8771	1	-1.3
^{137}Cs	3.70×10^{14}			
Lead		432	1	-0.07
Concrete		2513	1	-0.83

RTG

Isotope / absorber	Source activity Bq	Container mass kg	Accessibility factor 1-10	Risk-of-use quotient RUQ
^{90}Sr	1.11×10^{16}			
Lead		6	10	**4.3**
Perspex		7	10	**4.2**

External Exposures

- Focused radiation or localized contamination can result in radiation effect to specific areas on the body

- Whole body exposure can result from:
  - A passing radioactive cloud or smoke
  - A large, distant point source
  - Exposure from contamination deposited on the ground

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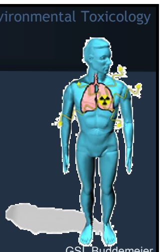
Internal Exposures



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- Once radioactive material is deposited in the body, it can expose the person from within.
- The magnitude of the dose will depend on many factors:
  - How much material was deposited
  - How it got into the body (ingestion, inhalation, absorption, or injection)
  - Chemical form of the radioactive material
  - The radiation it produces
  - How quickly it decays
  - How quickly the body eliminates the material

Internal Exposures

- Dose from internal depositions are usually expressed by summing dose that will be received over the next 50 years from a one time internal deposition
  - Referred to as Committed Effective Dose Equivalent (CEDE)
  - This dose calculation/estimate takes into account internal exposure factors
  - Even with a large CEDE, there may or may not be acute effects from the exposure

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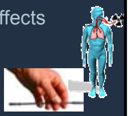
Types of Exposure & Health Effects



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- **Acute Dose**
  - Large radiation dose in a short period of time
  - Large doses may result in observable health effects
    - Early: Nausea & vomiting
    - Hair loss, Fatigue, & medical complications
    - Burns and wounds heal slowly
  - Examples: Medical Exposures and accidental exposure to sealed sources
- **Chronic Dose**
  - Radiation dose received over a long period of time
  - Body more easily repairs damage from chronic doses
  - Does not usually result in observable effects
  - Examples: Background Radiation and Internal Deposition

The Human Factor

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- Concerns about radiation and contamination often produce an exaggerated emotional response.
  - Can't detect it with our 5 senses
  - Associated with cancer
  - Reminiscent of "cold war" fears
  - Science difficult to understand
  - Out of our control
- Possible results may be…
  - Unexposed people saturating the medical community
  - Health and economic effects from long term anxiety or depression in the community

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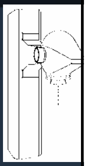
A Case Study: Goiania, Brazil 1987



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- When a hospital changed locations, a radiation therapy unit was temporarily left behind.
- Scrap metal hunters found the unit and dismantled it for scrap metal (~ Sept 18th).
- The 1.4 kiloCi (1,400 Ci) Cs-137 source containment was breached during the process.
- Pieces of source distributed to family and friends.
- Everyone was impressed by "the glowing blue stones." Children and adults played with them.
- Serious radiological accident recognized on Sept 29th when Acute Rad. Syndrome symptoms where seen by med. staff.

Initial Response

112,000 people (10 % of Goiania's population) were surveyed at an Olympic Stadium.

- 250 were identified as contaminated
- 50 contaminated people were isolated in a camping area inside the stadium for more detailed screening
- 20 people were hospitalized or transferred to special housing with medical and nursing assistance
- 8 patients transferred to Rio de Janeiro Hospital
- Residential contamination survey was initiated

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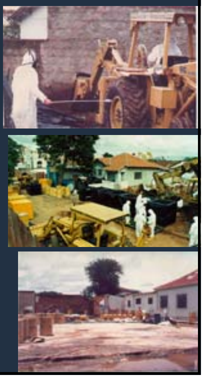
Early Consequences



- Widespread contamination of downtown Goiania
- 85 residences found to have significant contamination (41 of these were evacuated and a few were completely or partially demolished)
- People cross-contaminated houses 100 miles away
- Hot Spots at 3 scrap metal yards and one house

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Radiation Injuries and Uptake

- 4 fatalities (2 men, 1 woman and 1 child)
- 28 patients had radiation induced skin injuries (they held/played with the source for extended periods)
- 50 people had internal deposition (ingestion)

Goiania Conclusions

Dosimetric and medical aspects of the radiological accident in Goiânia in 1987

IAEA

- Long and expensive clean-up effort.
- Profound psychological effects such as fear and depression on large populations
- Isolation and boycott of goods by neighbors

Radiological Considerations for Public Protective Actions

- EPA-established radiological ***public*** dose action levels to facilitate decision making
- Based on projected dose levels at which specific protective actions are warranted to reduce or eliminate the dose ***which is yet to be received***
  - Early Phase
    - Actions that need to be initiated quickly
    - Dose projected to those standing outside over the first 4 days
    - Evacuation, sheltering, administration of stable iodine
  - Intermediate Phase
    - Actions can be taken weeks to months after the accident
    - Dose projections to those living in the contaminated areas
    - Relocation, actions to avoid ingestion of contaminated foods

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Protective Action Guides (PAG)

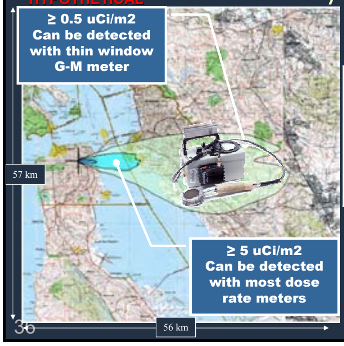
- Early Phase
  - 4 day exposure to cloud (“plume”) immersion, cloud inhalation, groundshine, and resuspension:
    - 1 REM: consider evacuation or sheltering
    - 5 REM: consider evacuation
    - 25 REM Thyroid Dose: consider administration of stable iodine
- Intermediate Phase
  - Exposure to groundshine and resuspended material
    - 2 REM in first year, 0.5 REM in “second” year, 5 REM in first 50 years are levels at which relocation should be considered
  - Dose from ingestion
    - Expressed as deposition Derived Response Levels (DRL/DIL)
    - “Preventative” levels: 0.5 REM (1.5 REM Thyroid Dose)
    - “Emergency” levels: 5 REM (15 REM Thyroid Dose)

As an Example, if Brazil’s Source was used as a “Dirty Bomb”

- This model makes unrealistic assumptions:
  - The source was 100% aerosolized
  - Lots of explosives (> 10 sticks of dynamite)
  - Presumes exposed populations “stood outside” during the 4 day exposure period
- Despite the accident in Brazil, sources of this strength are very difficult to obtain.

San Francisco Example: Ground Contamination Can be Detected East of Berkeley Hills

HYPOTHETICAL



≥ 0.5 uCi/m2 Can be detected with thin window G-M meter

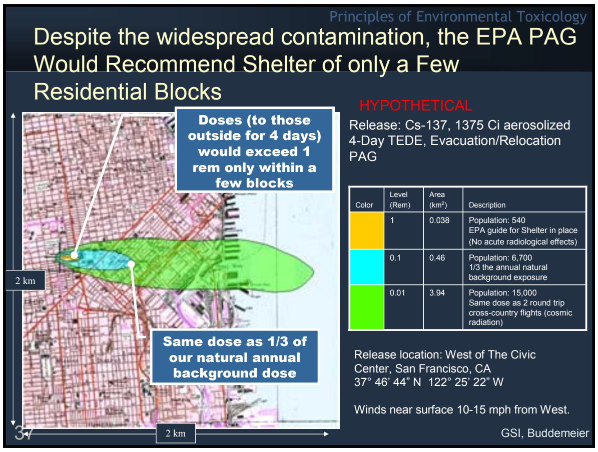
≥ 5 uCi/m2 Can be detected with most dose rate meters

Release: Cs-137, 1375 Ci aerosolized, Deposited Contamination

Color	Level (uCi/m^2)	Area (km^2)	Description
🟦	50	1.99	Population: 14,000 Take measures to prevent cross contamination
🟦	5	24.43	Population: 24,000 Detectable with “hot dog” GM
🟩	0.5	361.9	Population: 534,000 Detectable with “Pancake” GM

Release location: West of The Civic Center, San Francisco, CA
37° 46’ 44” N 122° 25’ 22” W

Winds near surface 10-15 mph from West.



Despite the widespread contamination, the EPA PAG Would Recommend Shelter of only a Few Residential Blocks

Doses (to those outside for 4 days) would exceed 1 rem only within a few blocks

Same dose as 1/3 of our natural annual background dose

HYPOTHETICAL

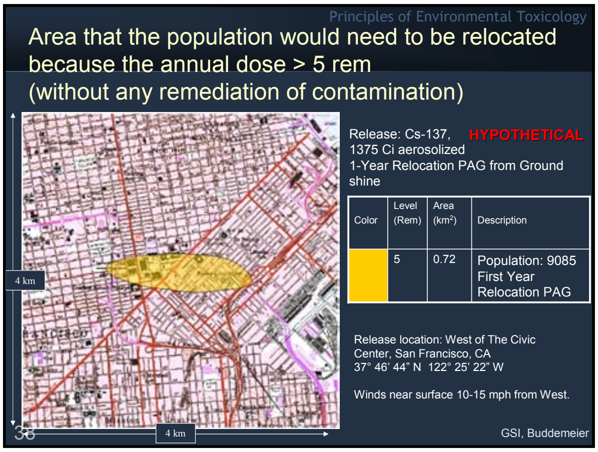
Release: Cs-137, 1375 Ci aerosolized
4-Day TEDE, Evacuation/Relocation PAG

Color	Level (Rem)	Area (km^2)	Description
🟧	1	0.038	Population: 540 EPA guide for Shelter in place (No acute radiological effects)
🟦	0.1	0.46	Population: 6,700 1/3 the annual natural background exposure
🟩	0.01	3.94	Population: 15,000 Same dose as 2 round trip cross-country flights (cosmic radiation)

Release location: West of The Civic Center, San Francisco, CA
37° 46’ 44” N 122° 25’ 22” W

Winds near surface 10-15 mph from West.

GSI, Buddemeier



Area that the population would need to be relocated because the annual dose > 5 rem (without any remediation of contamination)

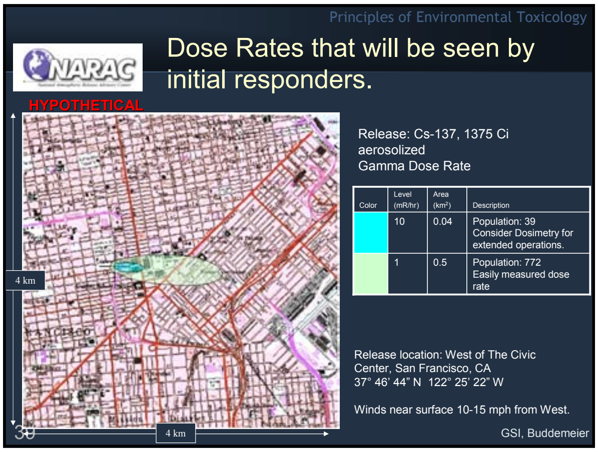
Release: Cs-137, HYPOTHETICAL
1375 Ci aerosolized
1-Year Relocation PAG from Ground shine

Color	Level (Rem)	Area (km^2)	Description
🟨	5	0.72	Population: 9085 First Year Relocation PAG

Release location: West of The Civic Center, San Francisco, CA
37° 46’ 44” N 122° 25’ 22” W

Winds near surface 10-15 mph from West.

GSI, Buddemeier



Dose Rates that will be seen by initial responders.

HYPOTHETICAL

Release: Cs-137, 1375 Ci aerosolized
Gamma Dose Rate

Color	Level (mR/hr)	Area (km^2)	Description
🟦	10	0.04	Population: 39 Consider Dosimetry for extended operations.
🟩	1	0.5	Population: 772 Easily measured dose rate

Release location: West of The Civic Center, San Francisco, CA
37° 46’ 44” N 122° 25’ 22” W

Winds near surface 10-15 mph from West.

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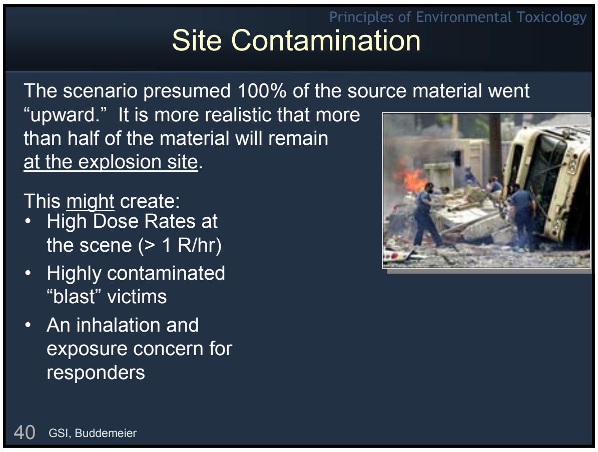

Site Contamination

The scenario presumed 100% of the source material went “upward.” It is more realistic that more than half of the material will remain at the explosion site.

This might create:

- High Dose Rates at the scene (> 1 R/hr)
- Highly contaminated “blast” victims
- An inhalation and exposure concern for responders

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RDD Conclusions

- A “Dirty Bomb” is conventional explosives combined with radioactive material with the intention of spreading the radioactive material over a relatively large area.
- This is **NOT** a nuclear explosion, the radioactive material does not enhance the explosion.
- Very few deaths would be expected from acute radiological exposure (the greatest hazard would likely be from the effects of the conventional explosives).
- The contamination will hamper emergency response efforts and can delay hospital treatment.
- Widespread contamination can deny the use of facilities and areas and have a significant psychological impact on the exposed population.

RDD Conclusions

- High activity sources can cause health effects, but only to those in close proximity.
- Acute health effects from distributed radioactive material unlikely without prolonged, high-concentration exposure.
- Radiation or contamination will hinder response efforts.
- Denial of facilities and areas will have a major cost effect
- Public anxiety and it’s effects may be the primary lasting health effect.

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