Radiological Threat Reduction: Dealing with Dirty Bombs

Instrumentation Seminar
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Nonproliferation and National Security Department
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What is a Radiological Dispersal Device, aka RDD or Dirty Bomb?

A little bit on radiation protection basics

Prevention of radiological terrorism

Radiological Dispersal Device Testing
  - Show some stuff blow up
  - Dispel a few myths and urban legends

Describe how a dirty bomb would affect people and the environment in terms of the science
What is a Dirty Bomb?

- It is relatively small amount or radioactive material and some explosive.
- It is “weapon of mass disruption”
  - Few if any will injured by radiation
  - A relatively small number of fatalities from the blast
  - Maybe a very expensive clean up after the initial emergency
- It is **NOT** a nuclear bomb
The Scientific Approach to Understand a Dirty Bomb

1. Identify the large sources and their chemical and physical forms
2. Blow up every combination you can think of to understand how things aerosolize (turn into dust) and determine particle size distributions of the dust - now you have the source terms
3. Plug those source terms into a model that predicts the buoyant rise from an explosion and one that is good at transporting a dust cloud on the wind (we have one, it’s called ERAD)
4. Assess the health and environmental effects
Quick review of radiation protection basics
Radiation Units

- radioactivity
  - curie (Ci) – 37 billion dis/sec, activity in 1 gram of Radium

- rad
  - absorbed dose or energy imparted to any medium, 0.01 J/kg

- rem
  - dose equivalent (rads x Quality Factor), unit of risk for people
  - Q = 1 for x or gamma, 10 for neutron, 20 for alpha

- exposure
  - roentgen (R) - X or gamma radiation in air
Benchmark Radiation Doses

- 5 rem/yr  
  Limit set by Nuclear Regulatory Commission and Department of Energy for radiation workers

- 0.1 rem/yr  
  Limit set by the Environmental Protection Agency for member of the public

- 1-5 rem  
  Guideline set by the Environmental Protection Agency to consider evacuation in an emergency
## Regulatory Limits Compared to Ranges for Acute Health Effects

- **0.015 rem**  Chest x-ray (not regulated)
- **0.1 rem/yr**  Limit for member of the public
- **5 rem/yr**  Limit for radiation worker
- **25 rads**  Temporary changes in blood
- **100 rads**  If received in less than a few hours, radiation sickness induced
- **300 rads**  Haematopoietic syndrome, survival possible with medical support
- **600 rads**  Survival not possible, palliative treatment
Radioactivity (curies) vs. Radiation (rads)
Contamination

- Contamination could occur if we come in contact with radioactive material...
- Similarly, we remove contamination by properly cleaning the contaminated area...
Properties: Penetrability

**Alpha** ($\alpha$)

**Beta** ($\beta$)

**Gamma** ($\gamma$)

*Note: aluminum sheet may be substituted here...*
Types of Radiation and Exposures

- Alpha ($\alpha$)
- Beta ($\beta$)
- Gamma ($\gamma$)
- Neutron ($n$)

Internal vs. External Exposures:
- Internal: $\alpha, \beta, \gamma, n$
- External: $\beta, \gamma, n$
Major Pathways from Dirty Bomb Release

- Inhalation (γ, α, β)
- Cloud Shine (γ)
- Deposition
- Skin (β)
- Ground
- Ground Shine (γ)
- Inhalation (γ, α, β) from Resuspended Material
Radioactive materials that are suitable for use in a Radiological Dispersal Device that would
- Contaminate a large area of high value real estate
- Contaminate a large area of high value real estate

Cost to clean up and restore

Trafficking:
Basis for Defining the Threat

Environmental Protection Agency
Intermediate Phase Protective Action Guide for Cleanup
2 rem in first year – consider relocation of the public
(a benchmark)

RDD leads to deposited radioactive material on ground

500 acres
(2 km²)
Sources in Industry, Medicine, and Commerce

- Spent Fuel Assembly: Mixture
- Irradiators: Co -60, Cs -137
- Teletherapy: Co -60, Cs -137
- Heat Sources: Sr -90, Pu -238
- Industrial Radiography: Ir -192, Co -60, Cs -137
- Brachytherapy: Ir -192, Co -60, Cs -137, I -125
- Well Logging: Am -241/Be, Pu -238/Be, Cf -252, Cs -137
- Moisture/Density: Cs -137, Am -241/Be, Ra -226/Be, Cf -252
- Industrial Gauges: Cs -137, Co -60, Am -241, Sr -90
- Calibration Sources: I -129, Cs -137, Co -60, Ra -226, Cf -252
- Consumer Products: Am -241, Ra -226
- Medical Diagnostics: Mo -99/Tc -99m

Dozens of others

Source Activity (Ci)

Radioactive Materials and Applications
Radioactive Sources Large in Ci Quantity Are Small in Size and Typically Sealed in Double Stainless Steel Containers

2,000 Ci of Sr-90 in ceramic form (about the size of an ice cube)
Examples of Sources

Large
50,000 Ci Sr-90

Large
9,000 Ci Co-60

Medium
500 Ci Cs-137

Large
200,000 Ci Co-60

Medium
20 Ci Am-241
Radiological Threat Reduction Activities

International Activities

Department of Energy is engaged with over 40 countries on radiological threat reduction activities - search, identification, recovery, security, disposition

Security enhancements for in-use sources outside the US

DOE Works closely with the International Atomic Energy Agency (IAEA), Office of Nuclear Security and Safety

DOE/BNL Working with Interpol — training, equipping front line police, and support of illicit trafficking database

At Home here in the US

Orphan Source Recovery Program – Recovery of over 10,000 high-risk radiological sources since 1993
Reducing the Threat in Over 40 Countries

Assessment Teams

- DOE Team Lead
- Security Specialist
- Material Control and Accountability Specialist
- Health Physicist for safety of the team
- Contracts specialist

- Visit sites, evaluate security and recommend security upgrades, as needed

- DOE funds the local procurement and installation of security systems
Basic Security Upgrades

Vulnerable doors/windows
Gaps/holes in roof
No intrusion detection

Before

• Reinforced sliding vehicle/personnel doors
• Windows bricked up
• Roof replaced
• Reinforced building exterior, lighting

After

Vulnerable doors/windows
Gaps/holes in roof
No intrusion detection
Security Upgrade Needed Here...

1400 Ci $^{137}$Cs
Interpol – 13 Countries

Ankara, Turkey

Sarajevo, Bosnia-H

Tirana, Albania
Interpol

Arusha, Tanzania

Bishkek
Bishkek or Bust...
# 20 Years of Radiological Dispersal Device Experiments at the Sandia National Laboratory

<table>
<thead>
<tr>
<th>Material</th>
<th>Physical Form</th>
<th># devices</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ag</td>
<td>Metal</td>
<td>17</td>
</tr>
<tr>
<td>Bi</td>
<td>Metal</td>
<td>3</td>
</tr>
<tr>
<td>Ta</td>
<td>Metal</td>
<td>1</td>
</tr>
<tr>
<td>Al</td>
<td>Metal</td>
<td>5</td>
</tr>
<tr>
<td>Stainless Steel</td>
<td>Metal</td>
<td>2</td>
</tr>
<tr>
<td>Cu</td>
<td>Metal</td>
<td>2</td>
</tr>
<tr>
<td>Co</td>
<td>Metal</td>
<td>1</td>
</tr>
<tr>
<td>Mo</td>
<td>Metal</td>
<td>1</td>
</tr>
<tr>
<td>Pb</td>
<td>Metal</td>
<td>1</td>
</tr>
<tr>
<td>U</td>
<td>Metal</td>
<td>1</td>
</tr>
<tr>
<td>Ir</td>
<td>Metal</td>
<td>3</td>
</tr>
<tr>
<td>SrTiO$_3$</td>
<td>Ceramic</td>
<td>8</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Material</th>
<th>Physical Form</th>
<th># devices</th>
</tr>
</thead>
<tbody>
<tr>
<td>CeO$_2$</td>
<td>Ceramic (2 densities)</td>
<td>7</td>
</tr>
<tr>
<td>Tb/Pd</td>
<td>Cermet</td>
<td>1</td>
</tr>
<tr>
<td>Co</td>
<td>Liquid</td>
<td>2</td>
</tr>
<tr>
<td>CsCl</td>
<td>Liquid</td>
<td>6</td>
</tr>
<tr>
<td>BaSO$_4$</td>
<td>Slurry</td>
<td>1</td>
</tr>
<tr>
<td>MnO$_2$</td>
<td>Ceramic Powder</td>
<td>4</td>
</tr>
<tr>
<td>UO$_2$</td>
<td>Ceramic Powder</td>
<td>1</td>
</tr>
<tr>
<td>CeO$_2$</td>
<td>Ceramic Powder</td>
<td>7</td>
</tr>
<tr>
<td>CeO$_2$</td>
<td>Pressed Powder</td>
<td>3</td>
</tr>
<tr>
<td>CsCl</td>
<td>Powdered salt</td>
<td>7</td>
</tr>
<tr>
<td>BaSO$_4$</td>
<td>Powdered salt</td>
<td>2</td>
</tr>
</tbody>
</table>

- More than 20 materials, 600 experiments
- More than 85 device geometries
- Funded by DOE NEST, DTRA, DOE CM, DOE international, NRC, DHS
Experimental Facilities to Characterize Aerosols from a Dirty Bomb at the Sandia National Laboratories

1000 m³ explosive aerosolization chamber

Capacity -- 0.5 lb high explosive

50 m³ full sample recovery explosive aerosolization chamber

Capacity – 1/8th lb high explosive

Fred Harper

(...We don’t blow stuff up at BNL; Fred has all the fun...)
RDD Environmental Effects

Size Matters
(particle size that is…)

Fate of the radioactive material depends on:

• Device design – resultant shock wave
• Interaction of rad material with the fireball
• Interaction of fireball with the surroundings
Characterization of Aerosolization Efficiency and Particle Size Distribution

Hanging cascade impactors and total mass samplers (< 30 μm AED)

Cyclone separators (> 30 μm and < 100 μm)

Witness wires, plates, and papers
And other strategies…
RDD Testing

(F. Harper SNL)
Some Basic Concepts

- Small particles (< 10 μm) -- primarily an inhalation problem, but can also be a shine problem

- Large particles (> 100 μm) – primarily a shine problem

- To be an inhalation problem, particles must be in the vicinity of people
Particle Size Effect
(Mike Brown, LANL)

5 micron particles lofted high into the air, 250 micron particles settle towards ground.

5 micron particles

250 micron particles
Shock Wave Effects - Simulation

Explosive

Material

ANFO - Bismuth (1dr; dx=0.05mm)
JRMERDG 10/18/05 12:52:29 CTE 0  Time=0.
Shock Wave Effects - Simulation

Explosive Material

(F. Harper SNL)
Solid fracture (energy limited spall) > 100 m

Phase change (liquid)
Phase change (vapor)

Final size distribution can be a combination of several of these peaks and can be modified by combustion and agglomeration

Stress from the Explosive Affects
Particle Size (Very Important to Know)

Particle Size

Stress

Metal

Final size distribution can be a combination of several of these peaks and can be modified by combustion and agglomeration

Solid fracture (energy limited spall)
Interactions with the Fireball Affects Particle Size

(F. Harper SNL)
Effects of Surfaces on the Fireball

(F. Harper SNL)

Steel Plate on the ground  Steel Plate 3 feet off the ground  On grass

Tests done at Sandia, with surrogates, no radioactive material
<table>
<thead>
<tr>
<th>Nuclide</th>
<th>Primary Radiation Type (half-life)</th>
<th>Primary Form</th>
<th>Size of Source for Calculation, in GBq (Ci)</th>
<th>Application that Forms the Basis for Size of Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sr-90</td>
<td>Beta</td>
<td>Ceramic</td>
<td>300,000 Ci</td>
<td>Large radioisotopic thermal generator (RTG) (Russian IEhU-1)</td>
</tr>
<tr>
<td>Cs-137</td>
<td>Beta, Gamma</td>
<td>Salt</td>
<td>200,000 Ci</td>
<td>Irradiator</td>
</tr>
<tr>
<td>Co-60</td>
<td>Beta, Gamma</td>
<td>Metal</td>
<td>300,000 Ci</td>
<td>Irradiator</td>
</tr>
<tr>
<td>Pu-238</td>
<td>Alpha</td>
<td>Ceramic</td>
<td>133,000 Ci</td>
<td>RTG used for the Cassini Saturn space probe</td>
</tr>
<tr>
<td>Am-241</td>
<td>Alpha</td>
<td>Pressed ceramic powder</td>
<td>20 Ci</td>
<td>Single well-logging source</td>
</tr>
<tr>
<td>Cf-252</td>
<td>Alpha</td>
<td>Ceramic</td>
<td>20 Ci</td>
<td>Several neutron radiography or well-logging sources</td>
</tr>
<tr>
<td>Ir-192</td>
<td>Beta, Gamma</td>
<td>Metal</td>
<td>1000 Ci</td>
<td>Multiple industrial radiography units</td>
</tr>
<tr>
<td>Ra-226</td>
<td>Alpha</td>
<td>Salt</td>
<td>100 Ci</td>
<td>Old medical therapy sources</td>
</tr>
</tbody>
</table>
Example Application of RDD Source

5000 Ci Cs-137
24 Hour Exposure
50,000 in stadium

Contours: Unmitigated Chronic Dose, rem
Source 1: 0.029 kg Cs-137
Source 2: 0.029 kg Cs-137
Explosive Release
Mass HE: 10 kg, Release hgt: 1 m
49999 exposed; 162 fatalities; 324 casualties
Population Count
Log Scale from 1 to 20
Example Application of RDD Source

Contours: Unmitigated Acute Dose, rem
Source 1: 0.029 kg Cs-137
Source 2: 0.029 kg Cs-137
Explosive Release
Mass HE: 10 kg, Release hgt: 1 m
0 exposed; 0 fatalities; 0 casualties
Population Count
Log Scale from 1 to 20

5000 Ci Cs-137
Same Source Term with Hotspot

Hotspot Version 2.05 General Explosion  May 20, 2005 01:05 PM
Plume Contour - TEDE (rem)

Inner: 2.0 rem (0.053 km²)  Middle: 1.0 rem (0.14 km²)  Outer: 0.50 rem (0.31 km²)

Source Material: Cs-137  D  30.0y
Source Term: 5.0000E+03 Ci
High Explosive: 22.00 Pounds of TNT
u (h=10 m): 2.0 m/s
Stability Class: A (Sample Time: 10.00 min)
Deposition Velocity: 1.0 cm/s
Receptor Height: 1.5 m
Inversion Layer Height: None
Wrong Assumptions, Wrong Predictions Scare People

From article published in Scientific November 2002

From the web “cobalt bomb”
Simulation of Time-Integrated Concentration (M. Brown LANL)

Airborne Plume Patterns
Comparison of dispersion of 5μm particles using from QUIC model (with and without buildings)

Mike Brown (LANL)

Transport & Dispersion

Impact of buildings on transport and dispersion

QUIC model w/ buildings

QUIC model w/ out buildings
Deposition Patterns After the Plume (1/2 mile or So)

(M. Brown LANL)
Deposition Patterns After the Plume

(M. Brown LANL)
### Realistic RDD Hazard Boundaries for Varying Device Designs

(Areas of highest concern for *Emergency Phase* response)

<table>
<thead>
<tr>
<th>Exposure</th>
<th>Consequence</th>
<th>Intermediate size source, basic engineering</th>
<th>Very large source, basic engineering</th>
<th>Very large source, sophisticated engineering</th>
</tr>
</thead>
<tbody>
<tr>
<td>Groundshine dose of 100 rad, 24-hour exposure assumed</td>
<td>Acute groundshine threshold</td>
<td>0</td>
<td>300 m</td>
<td>300 m</td>
</tr>
<tr>
<td>Inhalation dose of 100 rad to the bone marrow (30-day committed dose)</td>
<td>Acute haematopoietic syndrome threshold</td>
<td>0</td>
<td>0</td>
<td>200 m</td>
</tr>
<tr>
<td>Inhalation dose of 270 rad to the lung (30-day committed dose)</td>
<td>Acute pneumonitis threshold</td>
<td>0</td>
<td>0</td>
<td>2 km</td>
</tr>
<tr>
<td>Lifetime inhalation dose of 100 rem (50-year committed dose)</td>
<td>Chronic radiation sickness threshold</td>
<td>0</td>
<td>0</td>
<td>7 km</td>
</tr>
<tr>
<td>5 rem groundshine dose (5-hour exposure assumed)</td>
<td>Workers can work unrestricted for five hours</td>
<td>100 m</td>
<td>600 m</td>
<td>600 m</td>
</tr>
<tr>
<td>10 * ALI for inhalation</td>
<td>Use of Prussian Blue highly recommended</td>
<td>0</td>
<td>0</td>
<td>10 km</td>
</tr>
</tbody>
</table>
Realistic RDD Hazard Boundaries for Varying Device Designs  
(Areas of concern for *Intermediate Phase* response)

<table>
<thead>
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<th>Consequence</th>
<th>Intermediate size source, basic engineering</th>
<th>Very large source, basic engineering</th>
<th>Very large source, sophisticated engineering</th>
</tr>
</thead>
<tbody>
<tr>
<td>50 rem (50 year committed dose)</td>
<td>Evacuation</td>
<td>150 m</td>
<td>1 km</td>
<td>15 km</td>
</tr>
<tr>
<td>5 rem (50 year committed dose)</td>
<td>Sheltering</td>
<td>600 m</td>
<td>3.3 km</td>
<td>100 km</td>
</tr>
<tr>
<td>1 rem (50 year committed dose)</td>
<td>EPA suggests protective actions initiated</td>
<td>2 km</td>
<td>10 km</td>
<td>100 km</td>
</tr>
<tr>
<td>2 rem in one year (Derived deposition limit)</td>
<td>EPA Prescribes Relocation</td>
<td>8 km</td>
<td>100 km</td>
<td>100 km</td>
</tr>
</tbody>
</table>

Note: Scenario analysis performed with ERAD model which includes buoyant rise, small and large aerosol transport, but is not building aware.
Using Natural Boundaries for High and Medium Zone, Exits, and Monitoring Sites

- High Zone Boundary based on 1 R/hr
- Medium Zone Boundary based on natural breaks & < 10mR/hr
- Evacuees directed to triage sites away from warm zone boundary
- Triage & Monitoring sites far away from ground zero; identify & manage highly contaminated
So What Should You Do If It Happens?

- If all you know is there was a bang and some radiation, stay 500 m away and you are safe from large dose of radiation.

- If you are a first responder and you know from law enforcement intel that the source was less than 10,000 Ci, then start at 250 m away.

- Follow the directions of the Police and Firefighters, they are trained in this sort of thing, (e.g. NYPD and FDNY have put a lot of thought into managing this problem).
So What Should You Do If It Happens?

- Stay calm if you are OK from the blast and you are indoors, radiation is not a problem.

- If you run outside in the first 10-15 minutes you may encounter the undiluted radioactive dust plume.
  - That might be a bad thing, sheltering for a while is a good thing.

- Breathe through a dry cloth for 30 minutes.
So What Should You Do If It Happens?

- If you are outdoors, and you get contaminated from the dust plume, or walk through a contaminated area after the plume, you are probably already dressed for the conditions.

- Go home and remove and bag external clothes before entering the dwelling. Take a shower with warm water and soap, do not use shampoo or hair conditioner.

- Survey of clothing should be done after the Emergency Phase, i.e. with support of National Guard, etc.
Protective Equipment for First Responders Who Enter Inside 500 m (or 250 m) Zone

- Uniform
- Goggles
- Half-face Respirator (most FRs have full face)
- Gloves
- Air tanks are not necessary
  - Can move faster to rescue the injured
So What Should You Do If It Happens?

- If you did inhale the undiluted plume, medical treatment may be needed.

- Starting treatment is a medical priority, needs to be done promptly, but not an urgent medical emergency.
Conclusions

- Radiological terrorism is preventable and significant efforts are ongoing by the Departments of Energy and Homeland Security, and others. BNL makes significant contributions to those programs.

- If prevention efforts fail, the effects will result in a cleanup problem and not a big health problem.

- Few or possibly no one will receive a large radiation exposure.
Acknowledgments

Department of Energy

Defense Threat Reduction Agency

Department of Homeland Security

Nuclear Regulatory Commission