SAND2017-2348C

RDD Impact Analysis

Presented to:
Pool Re Workshop
London, U.K.
April 6, 2017

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Outline

- RDD Overview
- Atmospheric Dispersal Modeling Uncertainties
- RDD Test Cases
- Economic Impact of an RDD
- Summary

RDD Overview

Rad vs Nuclear Terrorism Risk (Notional)

Rad Terrorism-lower consequences but higher probability.

Consequences: Deaths, Destruction, Dollars

10 kiloton Nuclear Device
Prompt deaths ~100k,
Destruction ~ 1-2 km radius
Contamination ~1000 sq. km

Rad Dispersal
(~1000 Curies, CsCl)
Few radiation deaths
Contamination ~ 1 sq. km

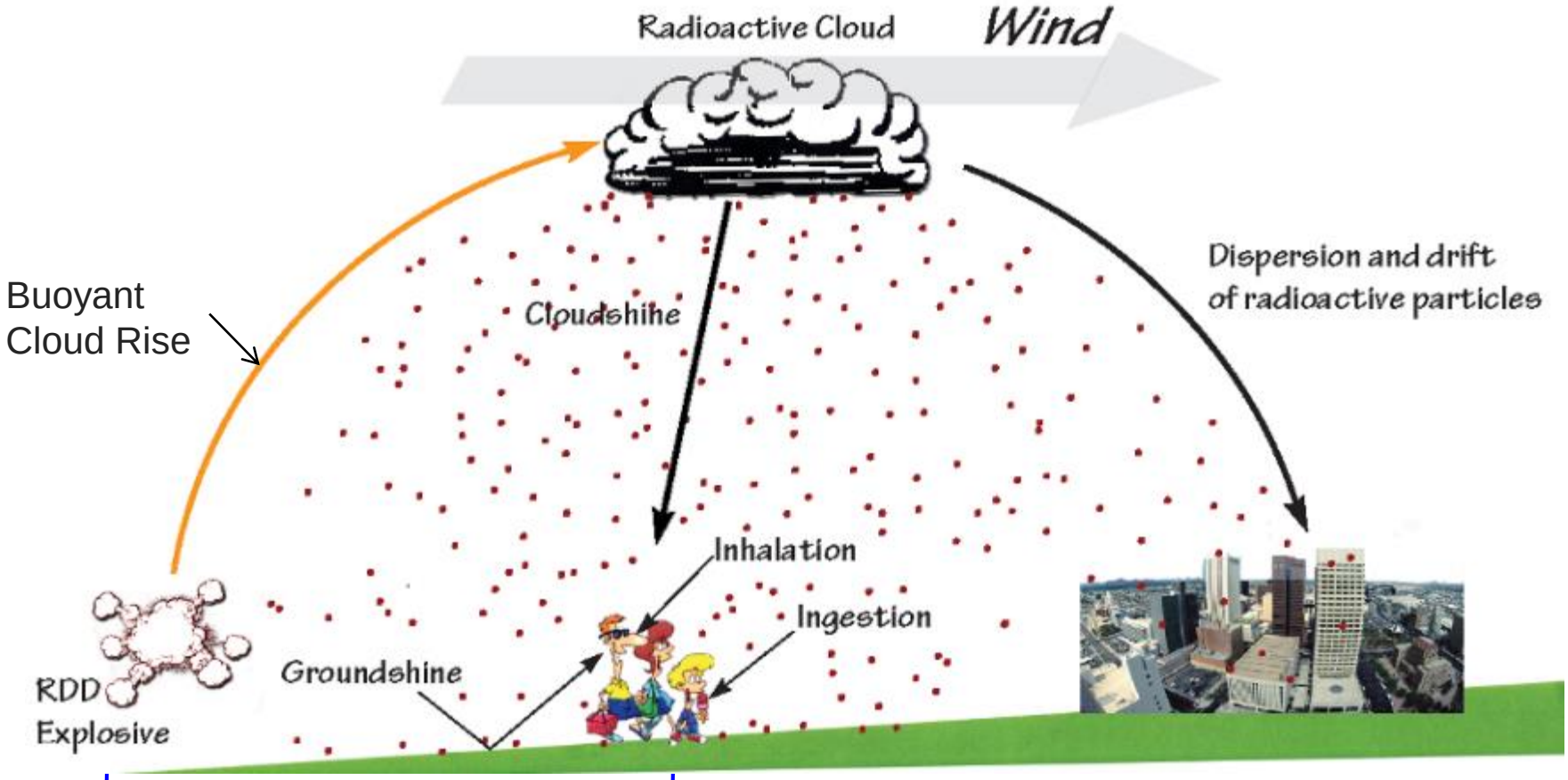
Goiania, Brazil, 1987

Probability (hard to quantify). Factors include:
Adversary Intent & Capability, Material Availability & Vulnerability, Device/Scenario "ease"

The Explosive RDD and "Area Denial"

Radioactive ground contamination can have a lasting, mass effect.

Population relocated to <u>avoid</u> radiation exposure and latent cancers.

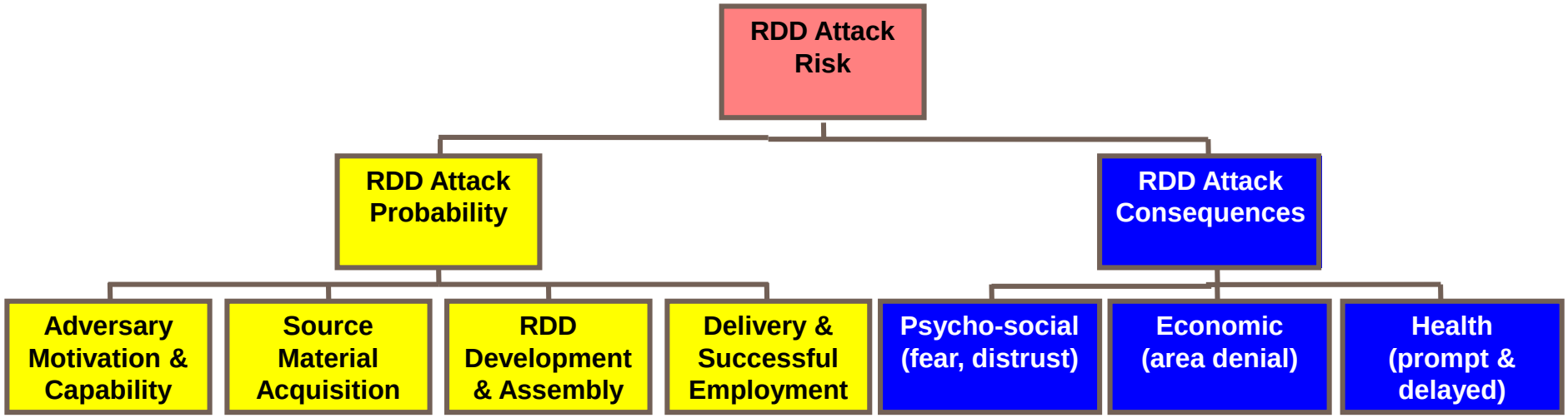


Prompt, deterministic health hazards possible out to ~100 m

Radioactive ground contamination: "area denial" out to ~ kilometers. Relocation to avoid latent cancers.

RDD Risk Elements

For a complete understanding of RDD Risk, study each box.

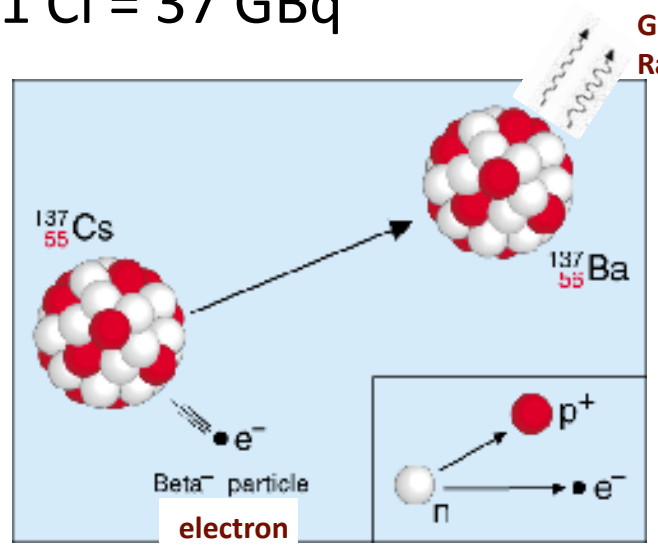


Risk-Based RDD Systems Analysis: Look for the "easy" scenarios that lead to high consequences

Radioactive Decay and Units

International unit (Bq) is very small for RDD analysis.

- 1 Becquerel (Bq) = 1 nuclear decay/sec
- Traditional Unit: Curie (Ci) where 1 Ci = 37 GBq



IAEA Categorization of Rad Materials

It is based on safety concerns, not RDD Area Denial.

Radionuclide	IAEA Category 1 (Extremely Dangerous) (Ci)	IAEA Category 2 (Very Dangerous) (Ci)	IAEA Category 3 (Dangerous) (Ci)
^{60}Co (β,γ)	810	8.1	0.81
^{137}Cs (β,γ)	2,700	27	2.7
^{192}Ir (β,γ)	2,200	22	2.2
^{241}Am (α,γ)	1,600	16	1.6

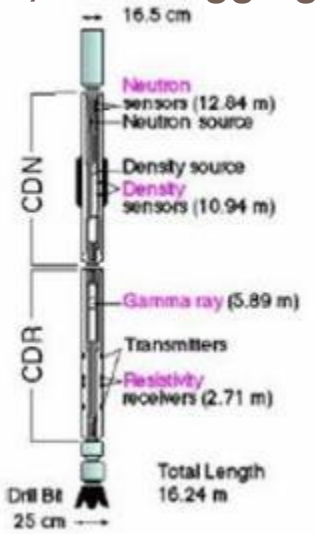
IAEA Category 1 and 2 Devices

4 radionuclides represent 99.9% of all high activity sources.

Category 1, Co-60 Teletherapy

Category 1, Cs-137 Self-Contained Irradiator

Category 2, Am-241/Be, Well Logging



Category 2, Ir-192, Radiography

Radionuclide Power to Contaminate (PTC)+

How is it calculated? Standard assumptions and basic rad-physics

- The PTC concept is an idealization that assumes "perfect", uniform dispersal
  - This removes the uncertainties associated with RDD design, weather, deployment, modeling, etc.
  - How close could an adversary get to this level depends on capability
- Typical "area denial" standards are assumed
  - Uniform contamination of 1 km^2 for "national-level event"
  - US DHS Protective Action Guide (PAG)-Relocation: 20 mSv/1st year
- An amount of radioactivity meeting those parameters is determined
  - i.e., how many curies will it take, if spread uniformly over the 1 km^2, to trigger the 20 mSv PAG?
- PTC Values
  - Cs-137: 40 Ci/km^2
  - Co-60: 10 Ci/km^2

Uniform dispersal is an idealization

1000 Ci of Cs-137

+This slide courtesy of Dr. Gus Potter, SNL

Hard Metals+

Co-60 pellets (teletherapy)

Ir-192 discs

Radionuclide Properties

Radionuclide and emission	Half-life	Specific Activity (Ci /gram)*	Dose Rate at 1 meter (rad/hr per Ci)	Chemical Form (typical)	Power to Contaminate*** PTC (Ci/km^2)	Typical Use and Activity
Co-60 (β,γ)	5.3 yr	100	1.4	Metal	10	Irradiators (~10,000 Ci)
Cs-137 (β,γ)	30 yr	20	0.38	Salt Powder	40	Irradiators (~1000 Ci)
Ir-192 (β,γ)	74 d	450	0.6	Metal	100	Radiography (~100 Ci)
Am-241/Be (α,γ, n)	433 yr	3.5	(0.005)**	Oxide Powder	< 10	Well Logging (~ 10 Ci)

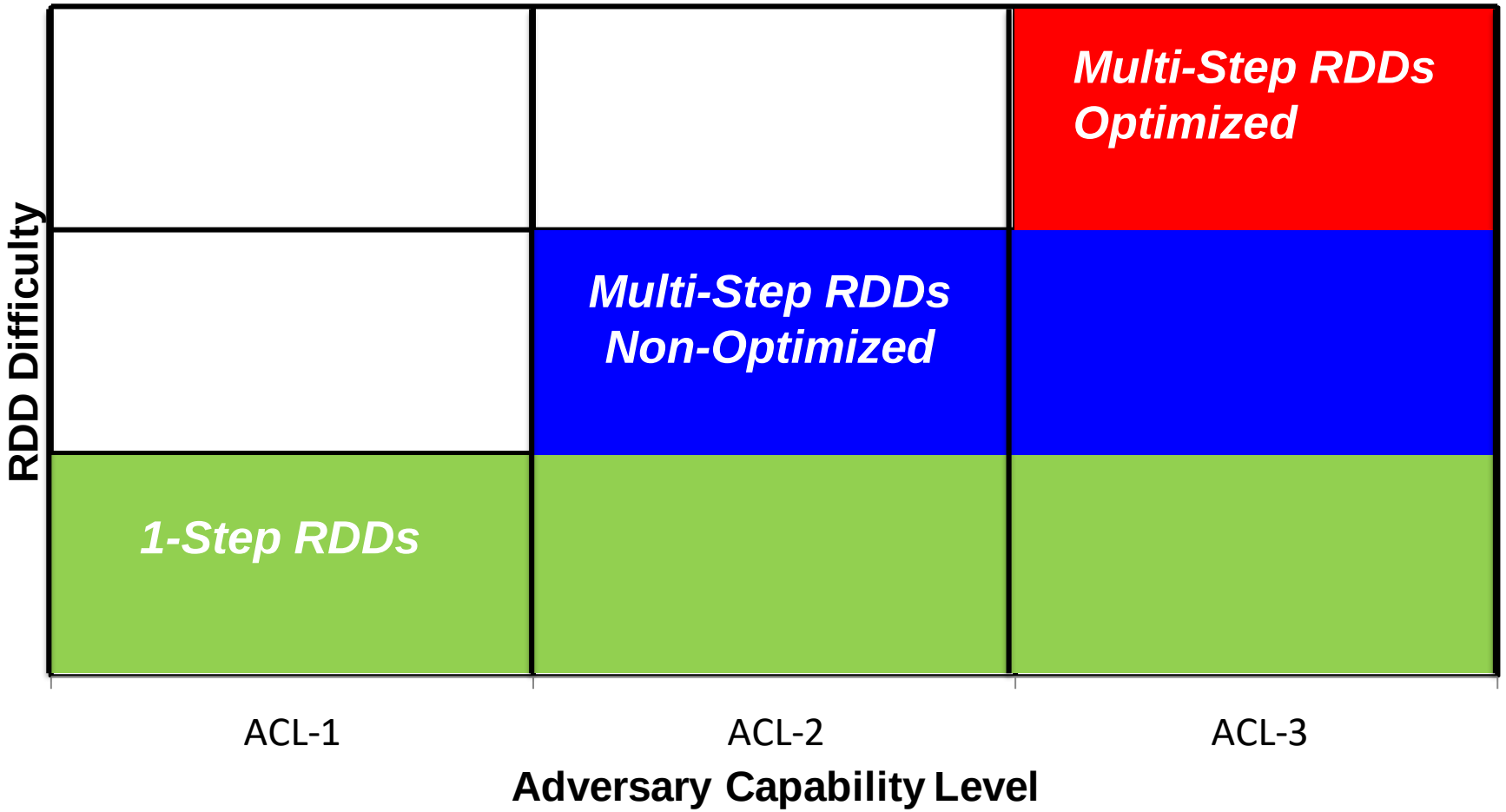
*These are typical values of specific activity found in actual use. Theoretical values (e.g. 1125 Ci/g for Co-60) are for isotopically pure materials.

**This is the dose rate per Ci at 1 m from an AmBe sealed source, encapsulated in ~ 1 mm of stainless steel.

***Radionuclide ground contamination level in Curies, uniformly spread over 1 sq. km, that would trigger EPA Relocation Protective Action Guide (PAG) of 2 rem/yr in the first year after the incident. Approximate values.

Notional Adversary Capability Levels (ACL)

As ACL increases, more difficult RDD designs are possible.



RDD Intervention/Cleanup Standards

No universal standard. ICRP recommends an "optimized process"

Event (action)	Annual Dose Threshold mSv (mrem)	Equivalent Cs-137 Ground Contamination Threshold TBq/km^2 (Ci/km^2)
US (relocation)	20 mSv in 1st year (2000)	1.5 TBq/km^2, (40)
US (long-term)	5 mSv (500)	0.37 TBq/km^2, (10)
ICRP Intervention	~ 10 mSv (1000)	0.75 TBq/km^2 (20)
ICRP (long-term)	1 mSv (100)	0.074 TBq/km^2, (2)
Natural (Cosmic+Terrestrial)	~1 mSv (100)	

- Interpretation: Intervene to relocate population when ground contamination would lead to an annual dose ≥ 20 mSv
- After cleanup the residual ground contamination should not lead to an annual dose ≥ 5 mSv

Cleanup Standards are Event Dependent

Goiania, Brazil Sept. 1987

CsCl teletherapy machine source

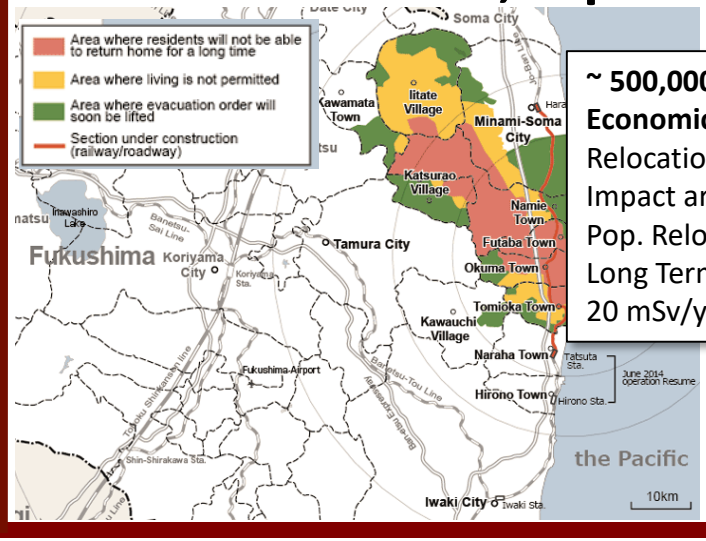
~ 1400 Ci of CsCl, partial release.
Economic Impact
Relocation criterion: ~5 mSv, 1st yr
Impact area: uneven over 1 km^2
Decon. Goal: ~1 mSv/yr after 1st yr
Pop. Relocated: 200
112,000 People Monitored

Chernobyl, USSR April 1986

~ 2,000,000 Ci Cs-137 Released
Economic Impact:
Relocation criterion: 40 Ci/km^2
~ 20 mSv, 1st yr.
Impact area: Confiscated zone~3000 km^2
Pop. Relocated:~300,000

No restrictions when < 1 mSv/yr

Fukushima, Japan March 2011

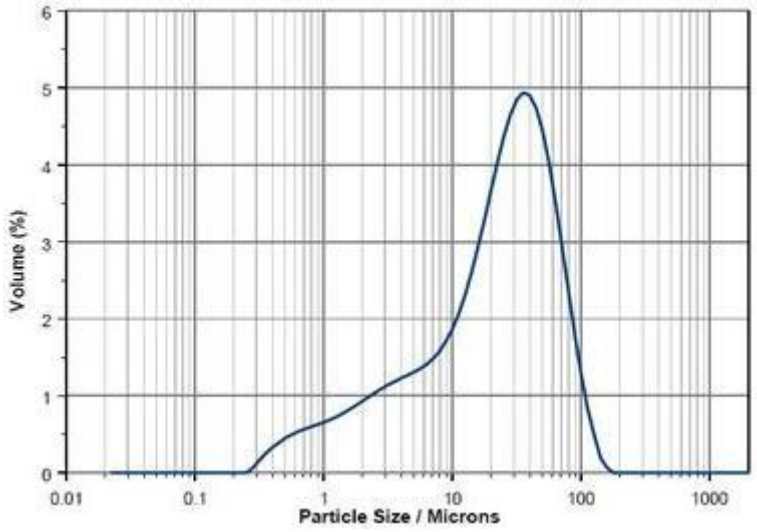


~ 500,000 Ci, Cs-137 Released
Economic Impact:
Relocation Criterion: >20 mSv, 1st yr.
Impact area ~ 1000 km^2
Pop. Relocated: ~100,000
Long Term Decon. Goal:
20 mSv/yr→10 mSv/yr→1 mSv/yr

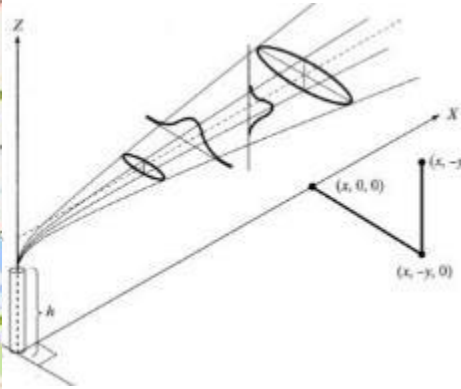
Atmospheric Dispersal: Modeling Uncertainties and Complexities

RDD Plume Uncertainties and Complexities

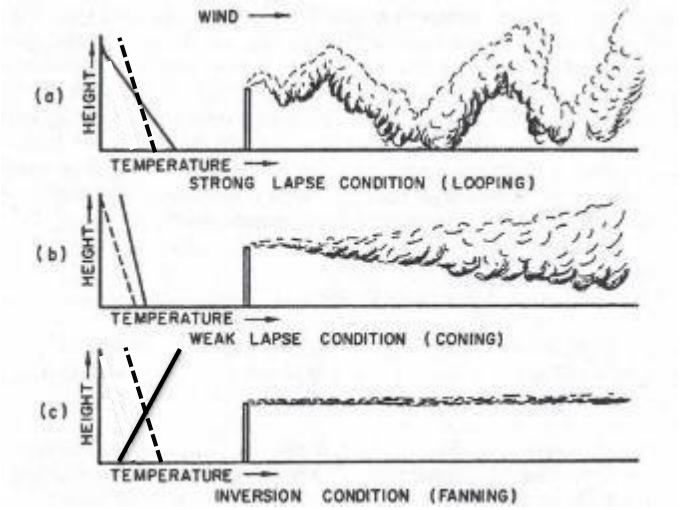
RDD Source Term Uncertainties



Met Data and Other Model Uncertainties



Inherent Uncertainty (Turbulence)

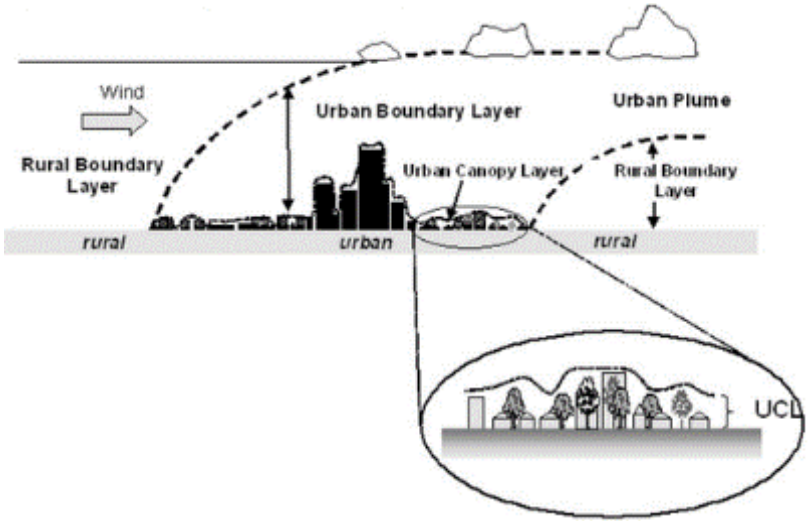


Unstable

Neutral

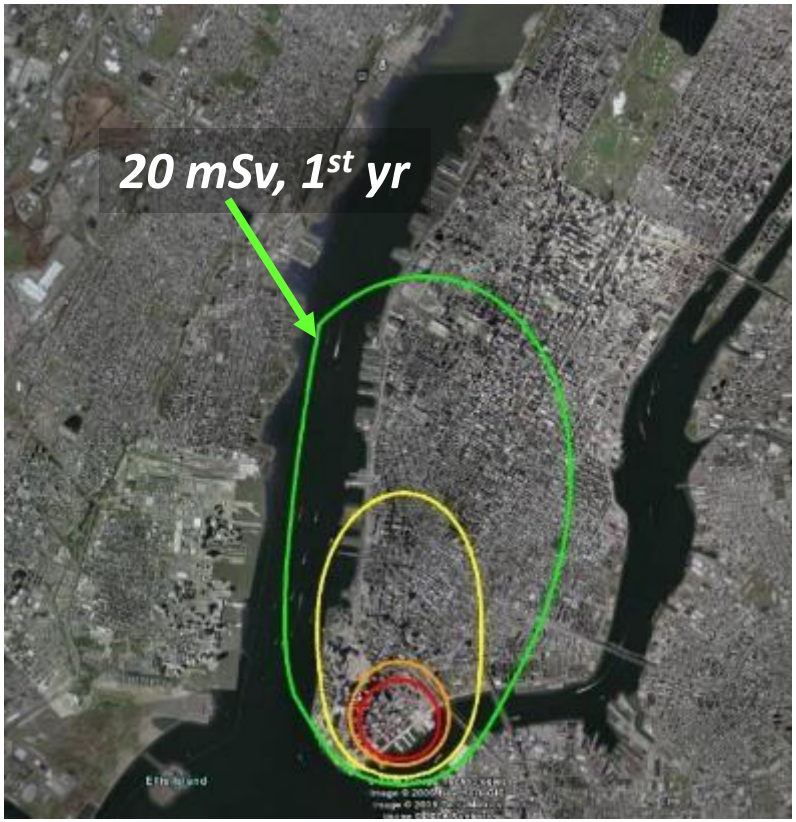
Stable

Urban Effects Uncertainties



Adversary Capability Level and Area Denial[+]

A more capable adversary could create a much larger footprint.

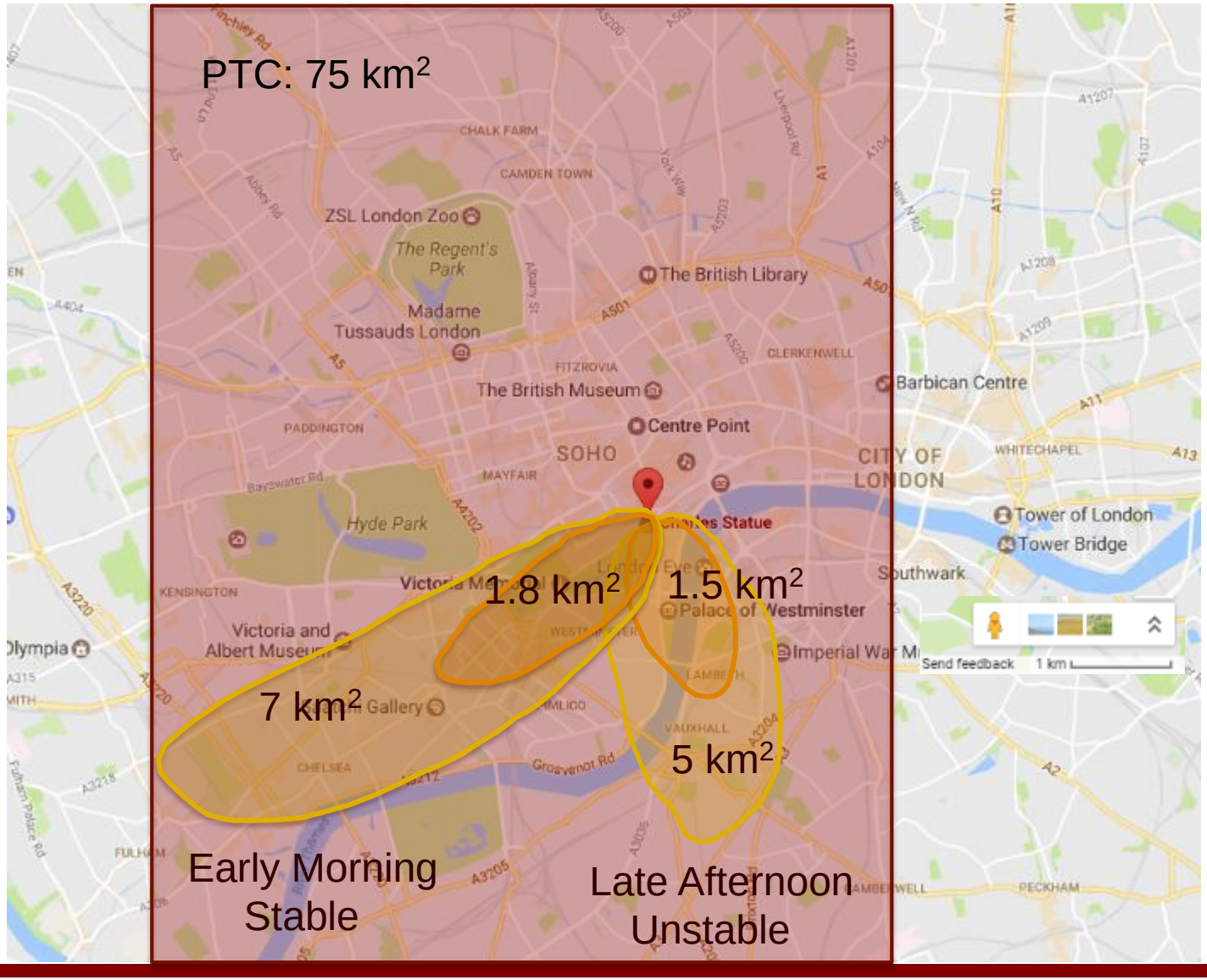


We normally use the 20 mSv contamination footprint as a baseline for area denial

[+]Images and modeling courtesy of Mr. Lawrence Trost, SNL

Summer Day in London, Wind at 3 kts

Atmospheric stability level will affect ground contamination footprint.



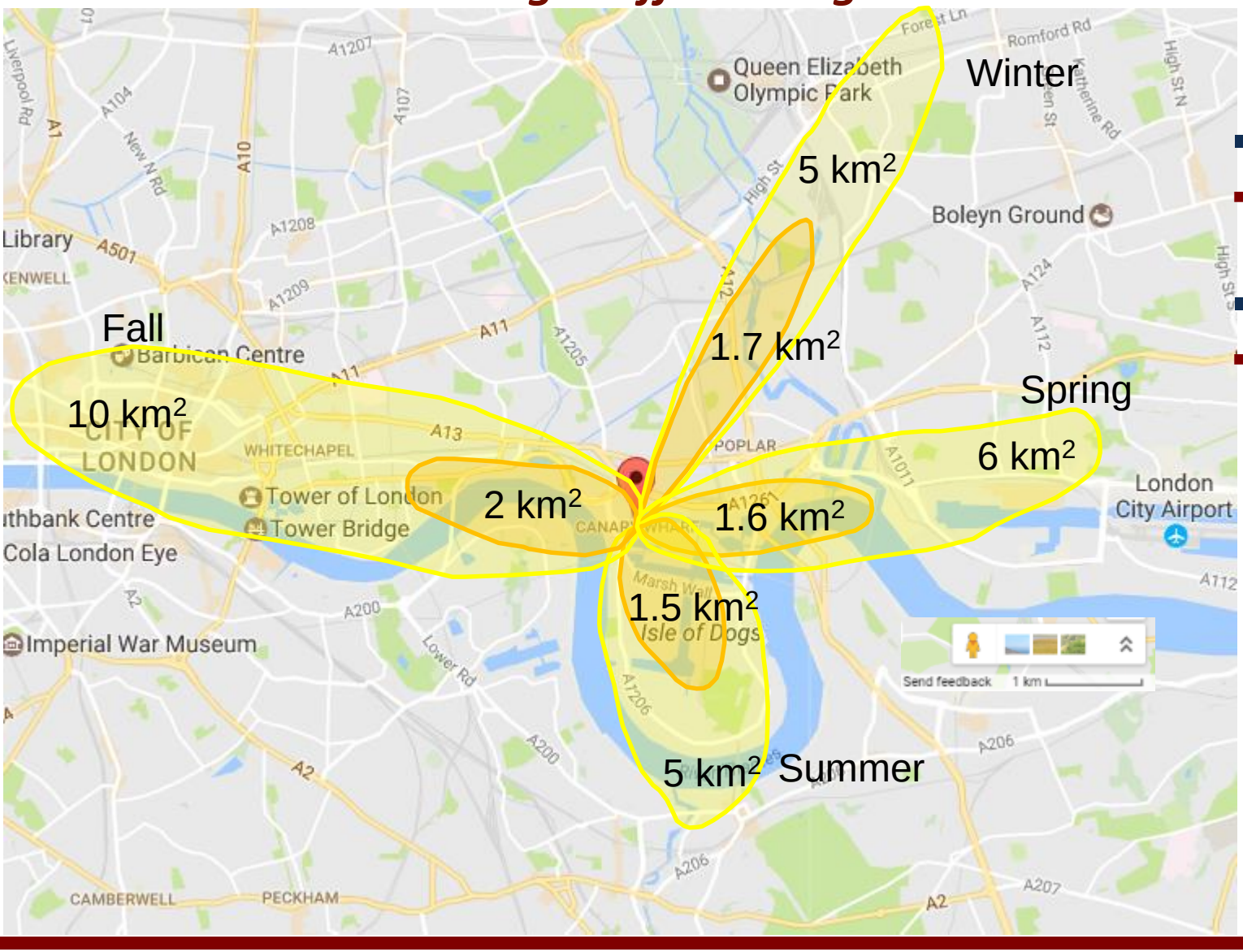
- Gold Footprint
  - Exceeds 20 mSv/yr
- Yellow Footprint
  - Exceeds 5 mSv/yr
- Red Rectangle
  - PTC

A word about urban canyon effects:

Two RDD Test Cases:
Examining the Area Denial Footprints

CsCl Blood Irradiator Source

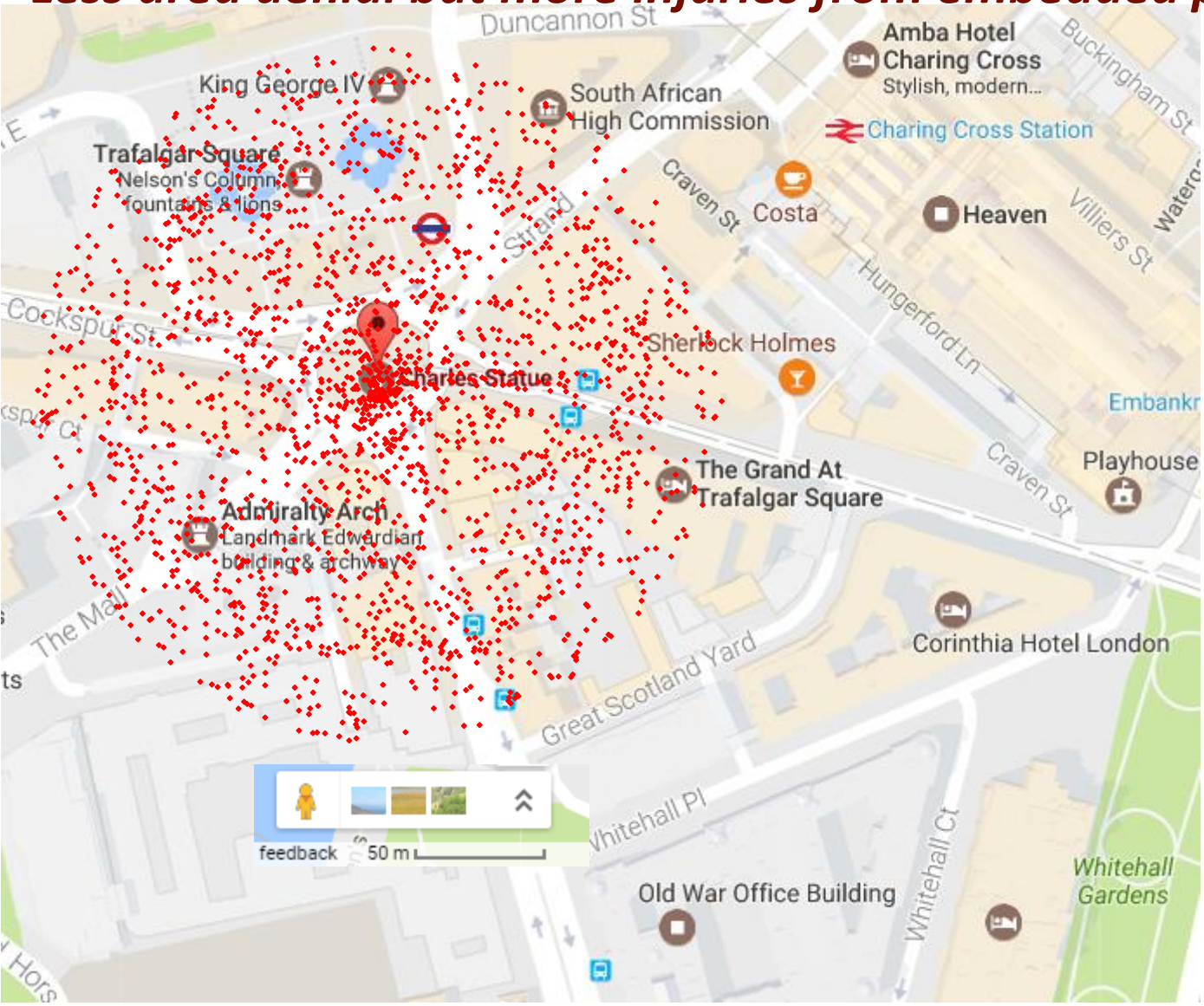
Seasonal weather changes affect the ground contamination footprint.



- Gold Footprint
  - Exceeds 20 mSv/yr
- Yellow Footprint
  - Exceeds 5 mSv/yr

Co-60 Teletherapy Source

Less area denial but more injuries from embedded pellets.

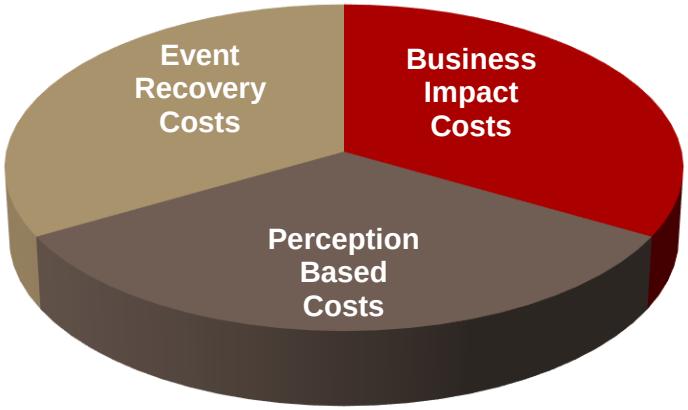


- Pellets Scatter as ballistic fragments
- ~ 100 m radius
- Embedded pellets a concern
- Entire ~100 m radius zone is hot (> 1 R/hr)

Economic Impacts of RDD Recovery

Area Denial Economic Impacts

Three distinct cost components: ERC, BIC, and PBC.



Other social costs:

- Increased fear/anxiety
- Historic buildings quarantined
- Forced relocation from homes
- Increased security/loss of freedom

- *Event Recovery Cost (ERC)* – 1 yr (typical)
  - Survey, Decontamination/Demolition, Disposal, New Construction, Relocation, Compensation, Health Care
- *Business Impact Cost (BIC)* – < 1 yr (typ.)
  - Direct – Lost GDP from business affected inside denied area
  - Indirect – Lost GDP from business affected outside denied area
  - Induced – Lost GDP from reduced spending by affected households
- *Perception Based Cost (PBC)* – can persist, many years
  - Willingness to purchase goods/services from region
  - Willingness to invest in region
  - Willingness to work in the region

Event Recovery Costs (ERC)

Sensitive to Cleanup Threshold and Decontamination Factor (DF)

Experience with Cs-137 cleanup: DF > 10 very difficult to achieve.

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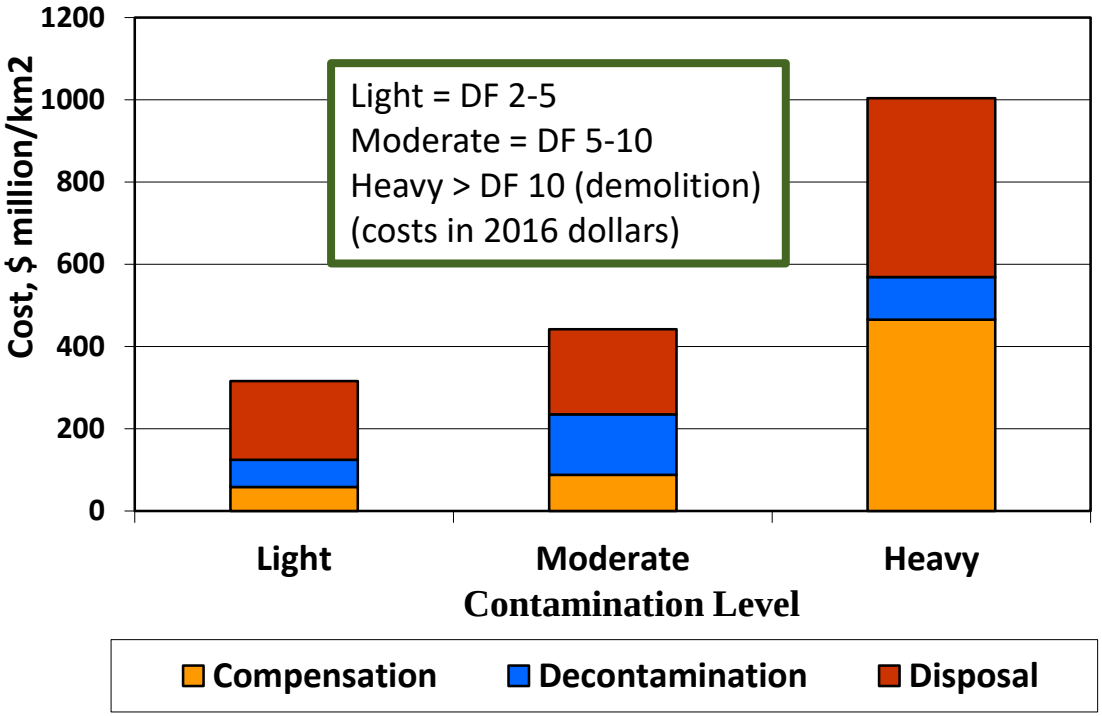
- Decontamination factor (DF): The contamination level ratio, Initial/Final
- Example 1: from US Relocation, 20 mSv → US Long-term, 5 mSv
  - DF= 20/5 = 4 (non-destructive cleanup methods are available at this DF value)
- Example 2: from 20 mSv → ICRP Long-term, 1 mSv
  - DF = 20/1 = 20 (can't achieve using standard methods, demolition or abandonment likely required)

Event Recovery Costs (ERC): An Example*

For a mixed use urban area like Albuquerque, NM.



- Manhattan vs. Albuquerque
  - Population density: ~10,000 per km^2 (Manhattan) vs. 1000 per km^2(ABQ)
  - Real estate value: $25B per km^2 (Manhattan) vs. $0.5 B per km^2 (ABQ)
- ERC ratio: Manhattan/ABQ ~ x10

* Channin and Murfin, *Site Restoration: Estimation of Attributable Costs From Plutonium-Dispersal Accidents*, SAND964957, May 1996

ERC for 1 km^2 of Manhattan with heavy contamination ~ $10 B

Published Studies on RDD Costs

- Port of Los Angeles/Long Beach (DHS/CREATE*, 2005)
  - Event Recovery Costs (ERC) not included
  - Perception Based Costs (PBC) not included
  - BIC ~ $34 B of lost output for a 4 month closure of the ports
- Downtown Los Angeles (DHS/CREATE*, 2012)
  - Event Recovery Costs (ERC) not included
  - ~ 0.3 km^2 quarantined for 1 month (for cleanup)
  - Short-run cost: BIC ~ $ 1 B of lost output for 1 month shutdown
  - Long-run cost: PBC ~ $10 B
  - Ratio PBC/BI ~ x10

BIC for 1 km^2 of Los Angeles for 1 year shutdown ~ $10's B

PBC for 1 km^2 of Los Angeles ~ $ 10's B

* Center for Risk and Economic Analysis of Terrorism Events (CREATE), a DHS Center at the University of Southern California

Public Perception of Radiation Risks

These factors will influence the perception based costs.

- Public understanding and trust in government information
- Scientific understanding of risk at low dose levels
- Personal control of risk
- Seen vs. hidden risk
- Short-term vs. long-term risk
- Media amplification

RDD Cost Summary

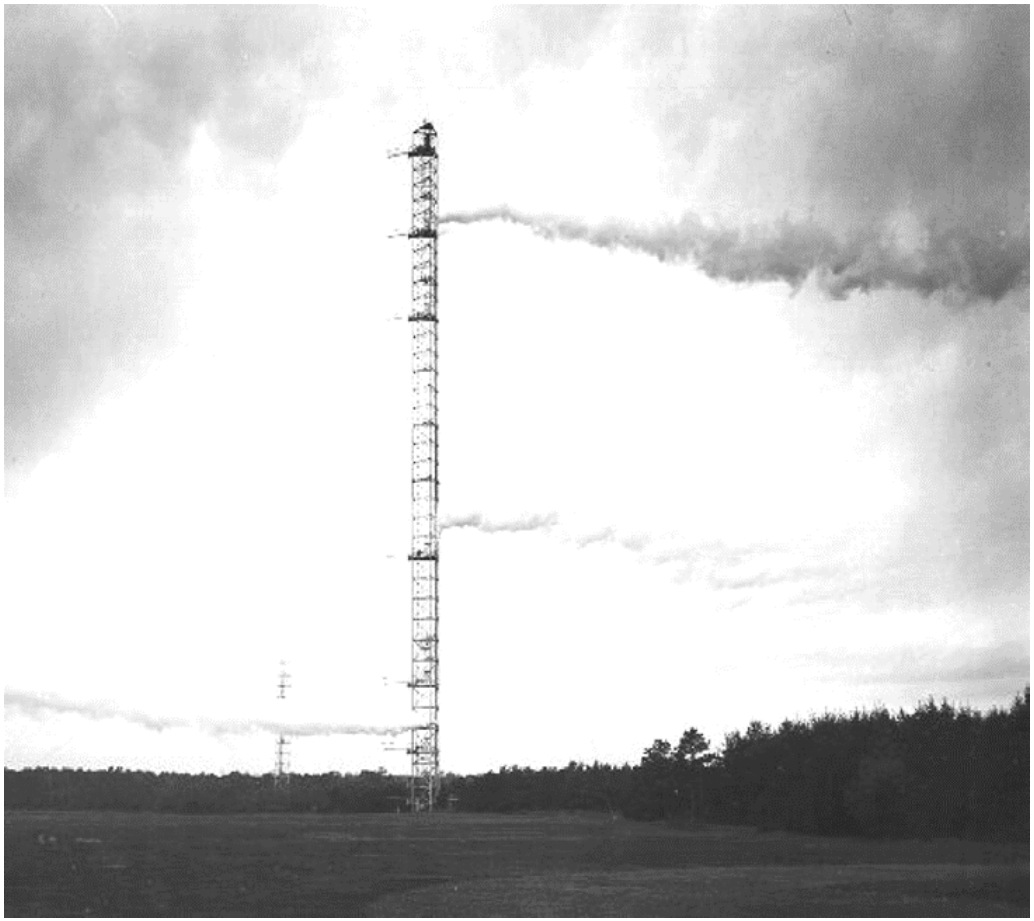
$10's of Billions for a national level area denial RDD of 1 km^2

- RDD Costs will depend on many factors:
  - Adversary capabilities, source size, radionuclide, nature of area, time it takes to recover, etc.
- Rough Order of Magnitude: ~ $10's B, each for ERC, BIC, & PBC
- Costs are sensitive to cleanup threshold, especially going < 1 mSv
  - Cs-137 (CsCl) poses special concerns
  - For Cs-137 contam. > 20 mSv/yr it will be difficult to cleanup to the ICRP desired state of 1 mSv/yr (Fukushima data shows DF's of ~ 4)
- Other societal costs are difficult to quantify but could be serious

Summary

Atmospheric Dispersal Modeling is Difficult

A multitude of uncertainties, including Mother Nature.

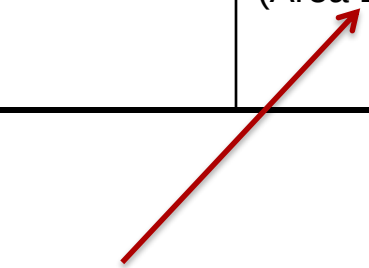


- Practical Models provide a 1st order estimate of the "average" plume
- They model the wind field and turbulence level
- They run Monte Carlo "random walks" of tracer particles (puffs) through this weather pattern and from this predict the average plume.
- From this one can estimate the RDD ground contamination footprints.

Options for Radiological Terrorism

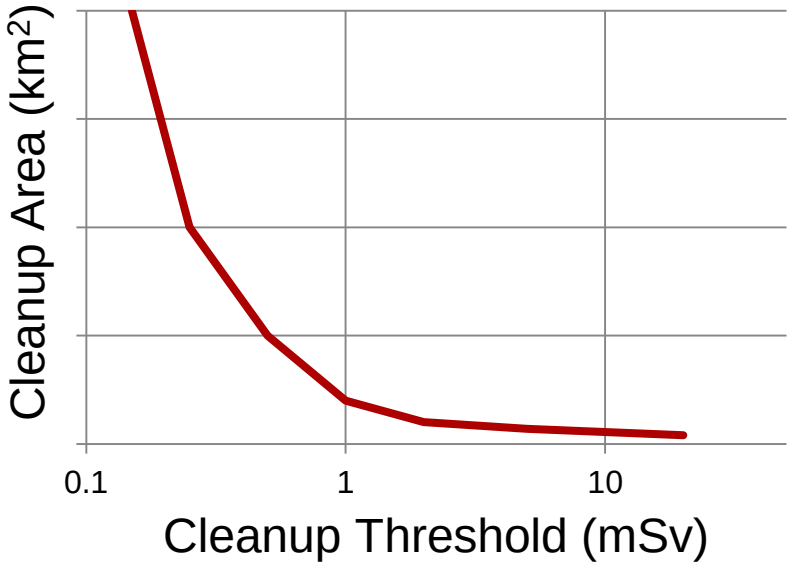
Our focus will be on the Area Denial RDD because of its persistent mass effect.

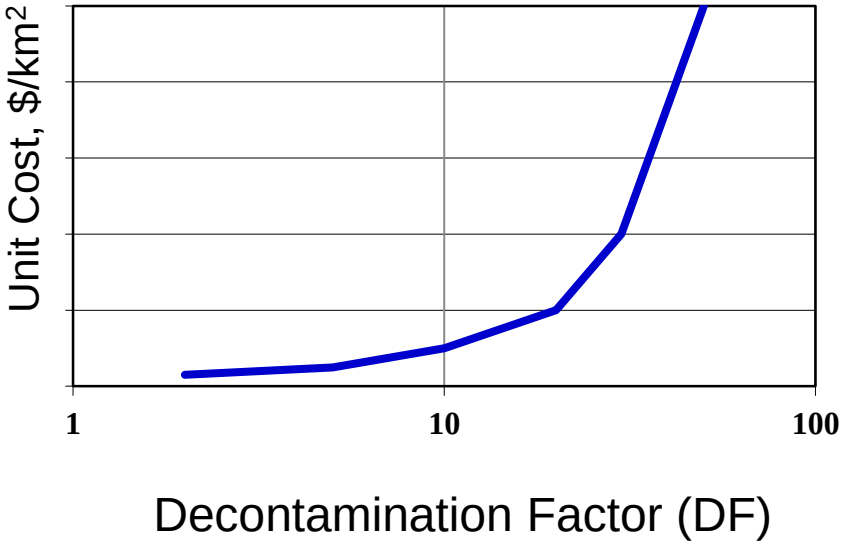
Device Type	Dispersal Form	Economic Effect	Health Effect	Comments
Radiological Exposure Device (RED)	N/A	Low	Radiation sickness	Could impact 100s; Lethality difficult; No lasting impact
Food or Water poisoning	Mix into food/water	Medium	Serious health effects to potentially thousands of victims	Could impact 1000's **Not unique**; Other poisons more readily available
"Dirty Bomb" Radiation Dispersal Device (RDD)	Many	High (Area Denial)	Few prompt health effects (some exceptions)	Persistent Mass Effect, could impact 10,000's **Unique** aspect of radiological material



Event Recovery Cost Sensitivities (Notional)

Strong sensitivity to the cleanup threshold level.

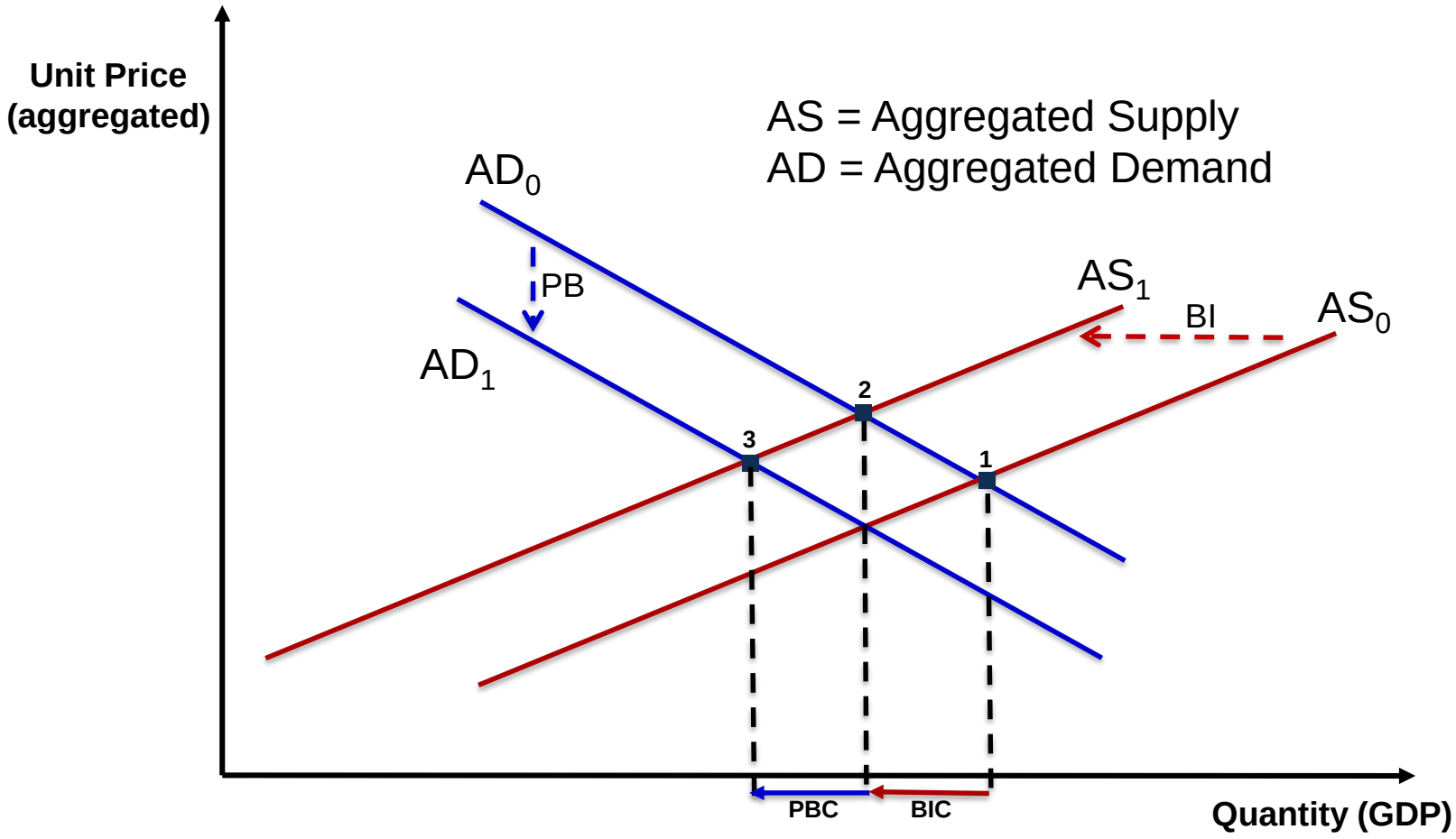




- As cleanup threshold ↓, cleanup area ↑ (new contour areas are added)
- As cleanup threshold ↓, Decon Factor (DF) ↑ (in previous select contours)
- As DF ↑in previous select contour areas, unit cleanup costs ↑ in those areas
- Thus as cleanup threshold ↓, cleanup costs ↑↑ and cleanup time ↑ ↑

Business Impact and Perception Based Costs*

BIC mainly a supply effect and PBC mainly a demand effect.



- BIC is generally short-term, the AS curve shifts back as businesses adjust
- PB can persist for years and swamp BIC (x10 or more)

* Source adaption from: J.E. Giesecke, et. al., "Assessment of the Regional Economic Impacts of Catastrophic Events: CGE Analysis of Resource Loss and Behavioral Effects of an RDD Attack Scenario, Risk Analysis, Vol. 32, No. 4, 2012.

Event Recovery Costs

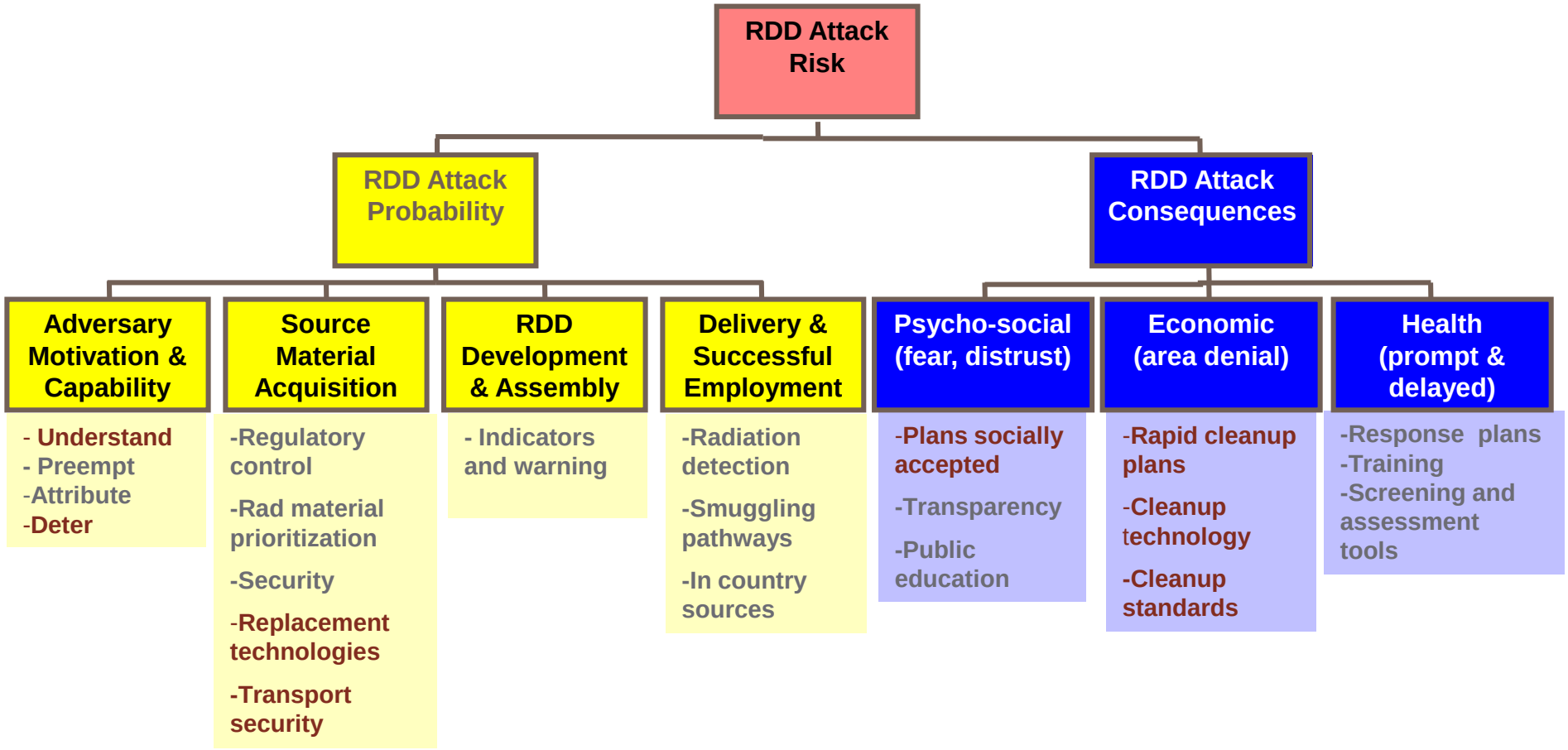
- The “Area Denial” RDD and the Cost Components

- **Event Recovery Costs (ERC)**
- Business Impact Costs (BIC)
- Perception Based Costs (PBC)

Decontamination/Demolition

Disposal

RDD Risk Reduction Countermeasures



IAEA Cat 1: Research and Blood Irradiators

Research Irradiators

- Used for research and blood irradiation
- Source activity
  - Blood irradiators: 1000–10,000 Ci (Typical~3000 Ci)
  - Research irradiators: 1000 – 50,000 Ci (Typ.~4000 Ci)
  - ~80% use Cs-137 (CsCl)
  - Rest, ~20%, use Co-60
- Found at Hospitals and Universities
- ~ 1000 CsCl irradiators in the U.S.
- Similar numbers in rest of world (~ 1000)

Blood Irradiators

IAEA Cat 1:Teletherapy & Gamma Knife

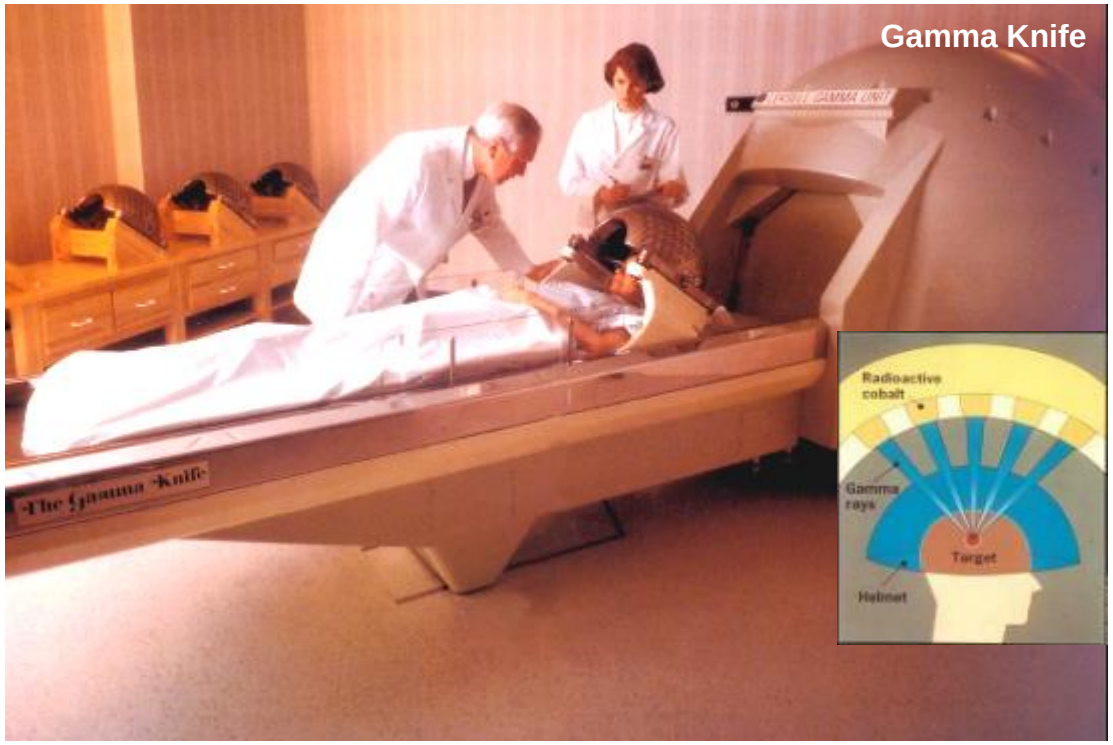


Image courtesy of Oak Ridge Associated Universities

- **Used in cancer therapy**
- **Mostly Co-60, 1000 – 15,000 Curies (Typical = 4000 Ci)**
  - High activity pellets, ~ 300 Ci/g
  - Some older units (re. Goiania) use Cs-137
- **~100 gamma knife, 10's of teletherapy units in the US**
- **~ 1000's of Co-60 teletherapy units, rest of world**

Small Co-60 pellets typically found in teletherapy/gamma knife sources