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Options for Radiological Terrorism
A Risk-Based Approach

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ASTAR

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Basic Concepts

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Radiation and Radioactivity

- Ionizing Radiation – particles or energy emitted from an atom (in an attempt to reach stability) which are capable of ionizing other atoms.
- Radioactivity (Activity) – rate of decay
  - Curie (Ci): 3.7×10^{10} decays per second
  - Becquerel (Bq): One decay per second
  - Specific Activity: activity per unit mass (Ci/g or Bq/g)
- Radiation dose- exposure of an object (person) to ionizing radiation produces a radiation absorbed dose.

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Options for Radiological Terrorism

Device Type	Dispersal Form	Economic Effects	Health Effects	Comments
Radiation Exposure Device (RED)	None	Low	Serious deterministic health effects possible (radiation sickness)	Could impact hundreds; No lasting economic impact
Rad-Food Dispersal (RFD)	Dissolve or mix	Medium	Serious deterministic health effects possible (radiation sickness)	Could impact thousands; Other poisons more readily available?
RDD for "Area Denial"	Many	High	Few (if any) deterministic health effects; Latent cancer risk (stochastic) drives population relocation	Could impact tens of thousands; **Unique** aspect of radiological Material

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Using Risk to Study Radiological Terrorism
Risk = Probability x Consequence

Risk = Probability x Consequences

Consequence: Death, Destruction, Dollars

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

RDD (1000 Curies)
Few radiation deaths
Contamination~ few sq. km

Event Probability: (Terrorist Intent, Source Material Availability, Device Difficulty…)

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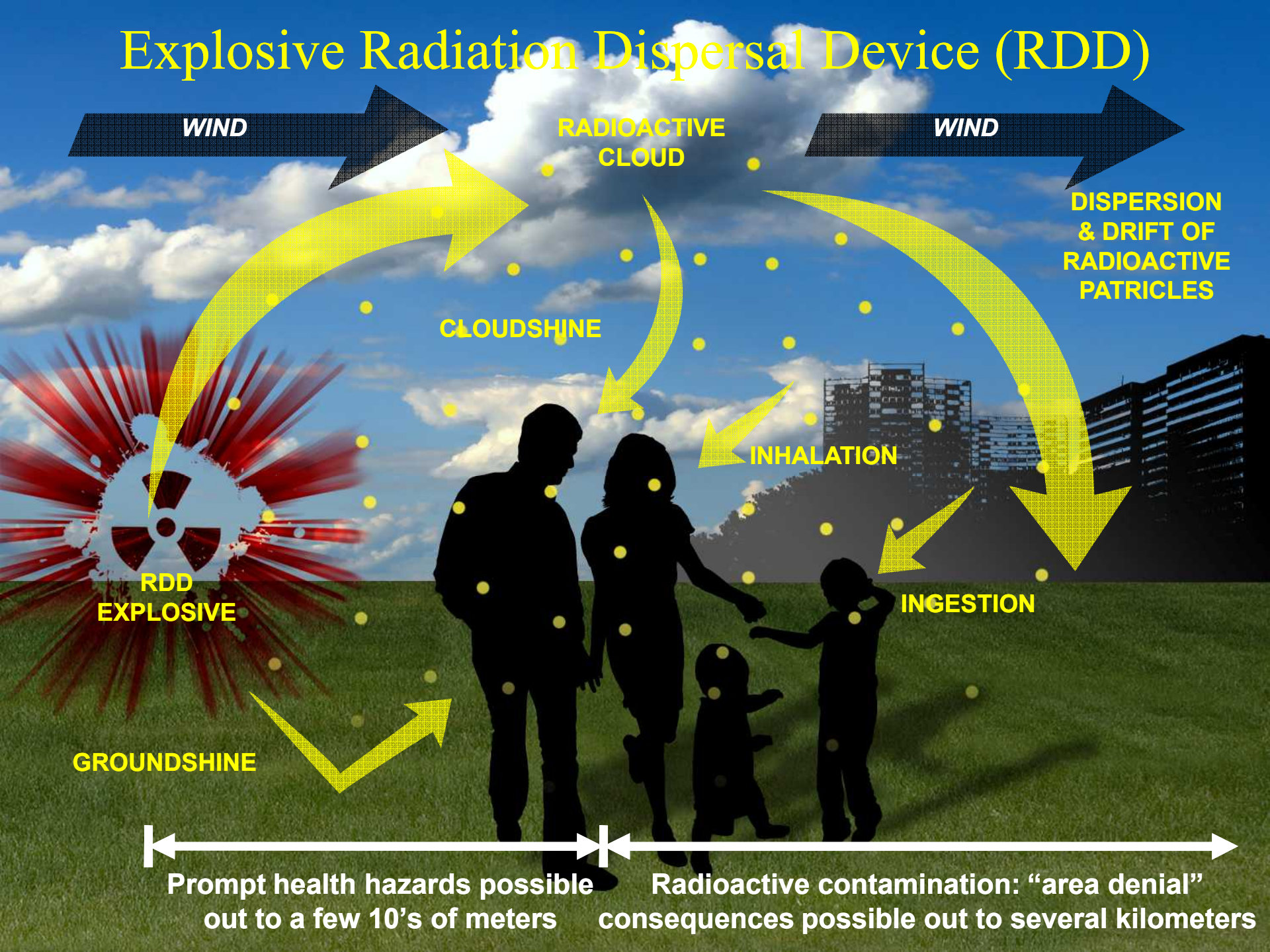
Public Perception of Risk

- Public's perception of risk can exceed actual risk
  - Understanding of risk
  - Trust in government information
  - Short-term vs. long-term risk
  - Personal control of risk
  - Benefit/cost of risk
  - Seen vs. hidden risk
  - Equitable sharing of risk

Explosive Radiation Dispersal Device (RDD)



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Different Methods of Dispersal

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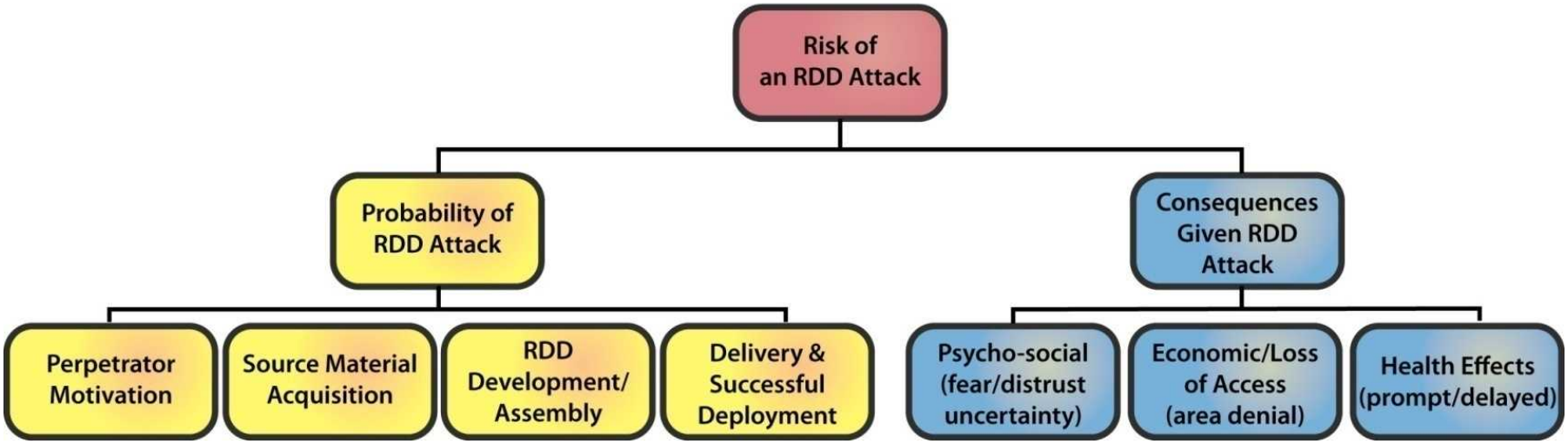
RDD Risk Elements



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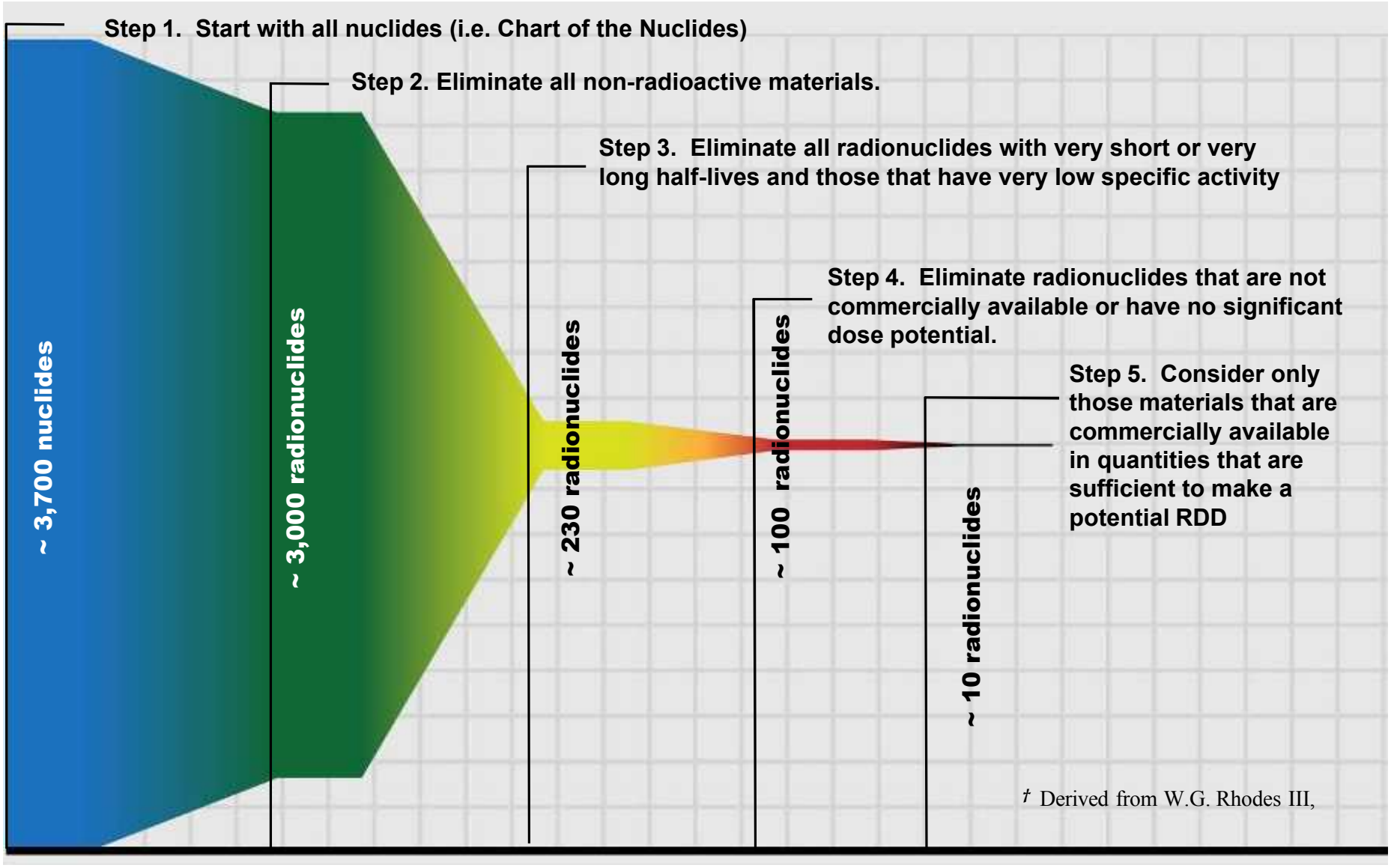
Radioactive Materials of Concern: There are Just a Few

Radionuclide Down-Selection†



† Derived from W.G. Rhodes III,

Origins of Radioactive Source Material

Reactor-Produced

Fission Products
- **^{137}Cs**
- **^{90}Sr**
- ^{125}I, ^{131}I

Activation
- **^{60}Co**
- **^{192}Ir**

Actinide Product
- **^{241}Am**
- ^{238}Pu
- ^{252}Cf

Accelerator-Produced

Short-lived Species
- ^{11}C
- ^{13}N
- ^{15}O

Naturally-Occurring

Primordial
- ^{238}U, ^{235}U
- ^{232}Th
- ^{40}K

Primordial Progeny
- ^{226}Ra
- ^{222}Rn, ^{220}Rn
- ^{210}Po

Cosmic Ray Spallation
- ^{3}H
- ^{14}C

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Radionuclides Properties

Radionuclide and emission	Half-life	Chemical Form	Specific Activity Ci/g (Approximate)	Area Denial Potential: EPA Relocation PAG Triggered (Approximate)	Typical Use and Ci quantity used
Co-60 (β,γ)	5.3 yr	Hard Metal	100 Ci per g	10 Ci per sq. km	Irradiators (>1000 Ci)
Cs-137 (β,γ)	30 yr	Salt powder	20 Ci per g	40 Ci per sq. km	Irradiators (>1000 Ci)
Am-241 (α,γ)	430 yr	Oxide Powder	3 Ci per g	40 Ci per sq. km	Well Logging (10 Ci)
Ir-192 (β,γ)	74 d	Hard Metal	500 Ci per g	100 Ci per sq. km	Radiography (100 Ci)

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How Many Curies are Needed for Area Denial? Use EPA Protective Action Guide for Relocation (A Stochastic Based Risk Assessment by EPA)

Large Area Denial RDD: Material Quantity

- Use EPA Protective Action Guideline (PAG) for Relocation
  - Basis: limiting the exposed population equivalent dose to 2 rem in the first year
  - Designed to limit risk of latent cancers to the exposed population
  - For Cs-137, Relocation PAG is triggered at ~ 40 Ci/km^2 ground contamination

- High population density urban area ~ 10,000 inhabitants per sq. km
  - A large section of Manhattan (25 sq. km) would require **1000 Ci**
    - 40 Ci/km^2 x 25 km^2 = 1000 Ci
    - ***Potential Relocation of several hundred thousand inhabitants***
    - ***National level event***

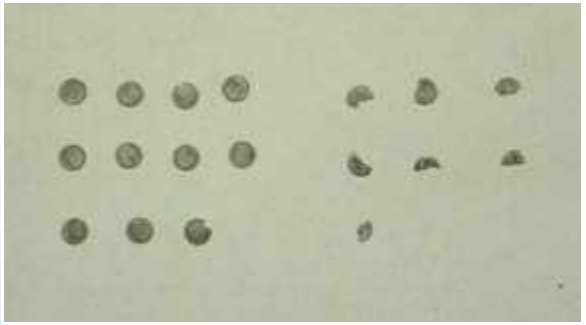
- *Important note: It is difficult to achieve a uniform dispersal*

Hard Metals

Co-60 slugs (large irradiators)

Co-60 pellets (teletherapy)

Ir-192 discs



Photos courtesy of Fred Harper and Eric E. Ryder, Sandia Labs

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Liquids and Powders

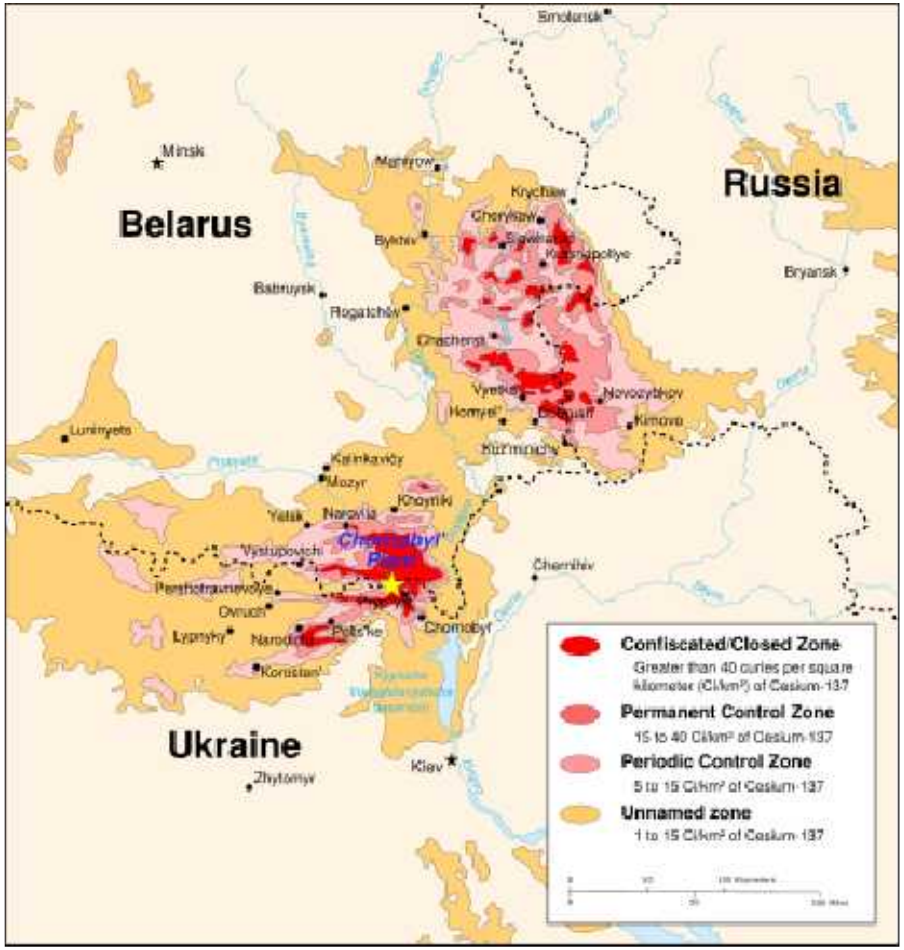
Courtesy of Fred Harper, Sandia Labs

Courtesy of Mike Edenburn, Sandia Labs

- Cs-137 physical form: salt (CsCl) pressed powder
- Am-241 physical form: oxide (AmO_2) pressed powder

Past Experience with Cs-137

- Chernobyl, USSR April 1986
  - 2 Million Ci, Cs-137



- Goiania, Brazil Sept. 1987
  - 1400 Ci, Cs-137 (CsCl)


Cs-137 teletherapy machine


70 g Cs-137 resulted in 40 tons of rad-waste

Source: The Radiological Accident in Goiania, IAEA 1988

Compare to 1983 Juarez Incident, Co-60

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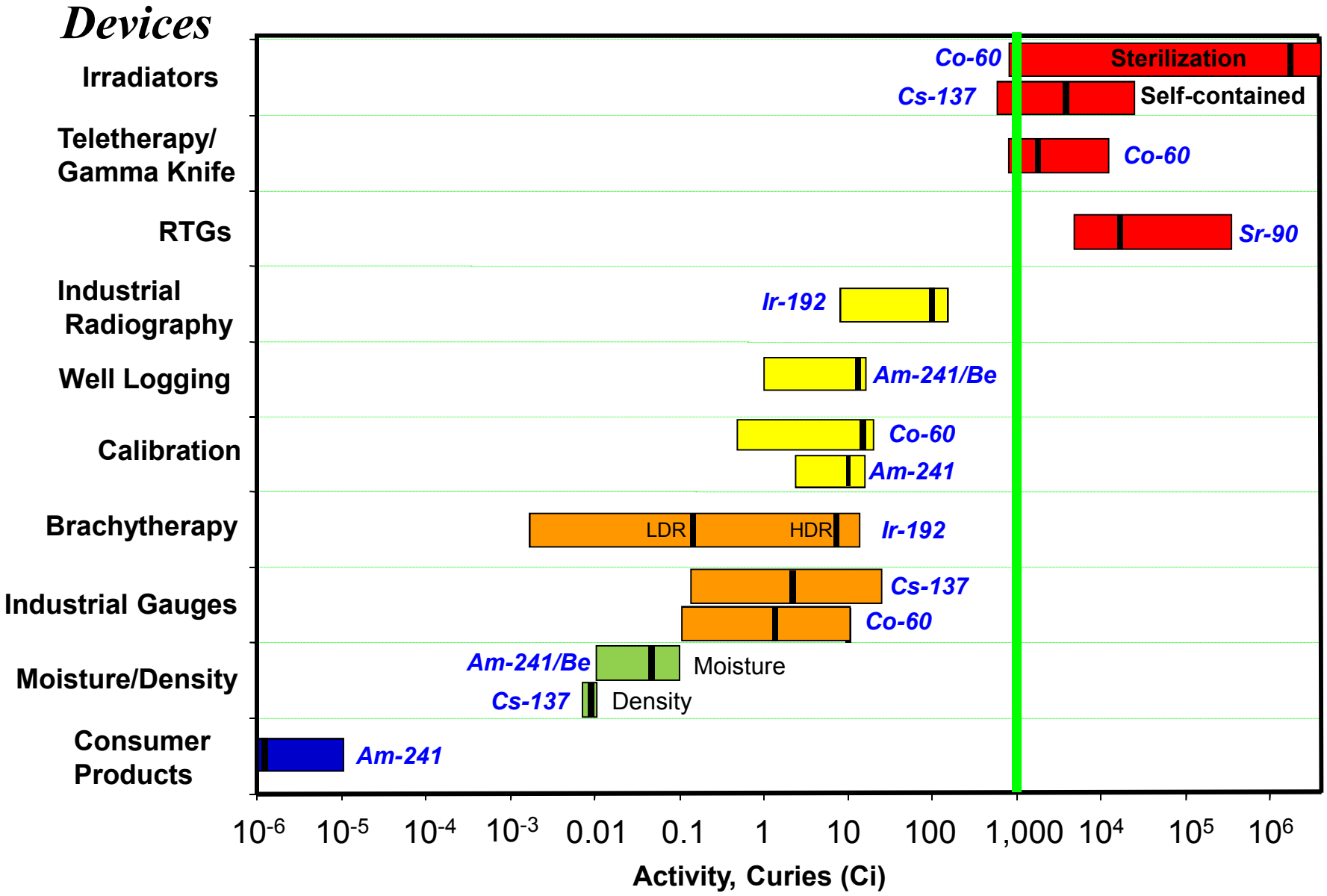
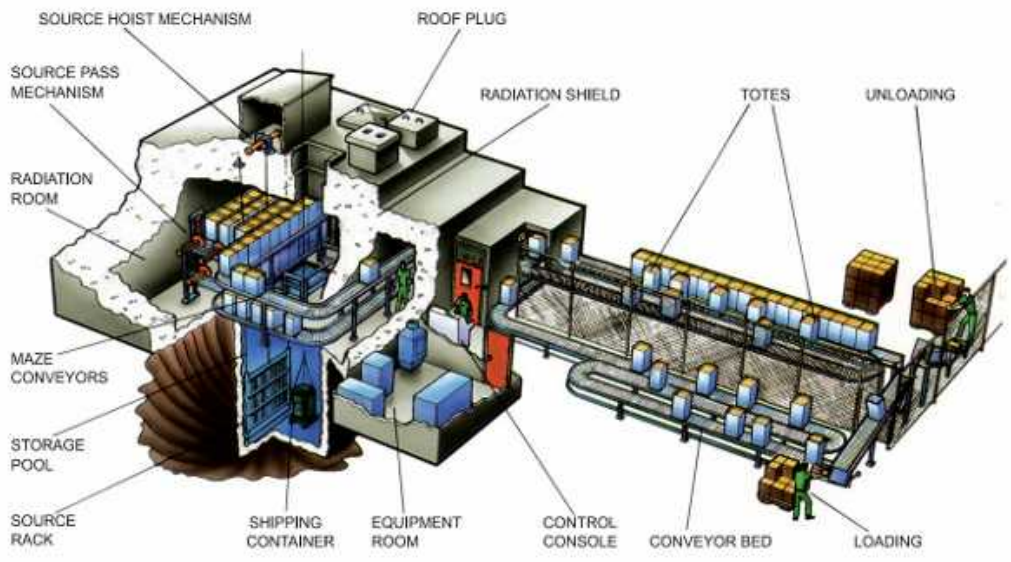
Radiation Devices & Activity Ranges

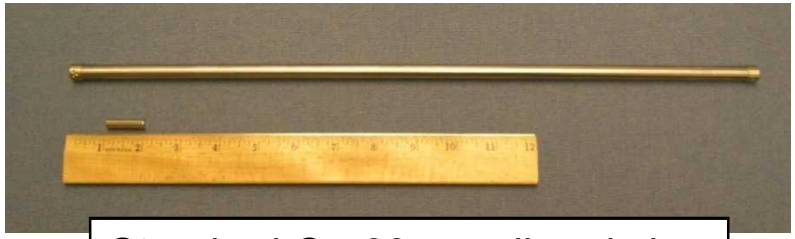


Panoramic Irradiators



Transport of Co-60 pencils from Canada to the U.S. for use in panoramic irradiators

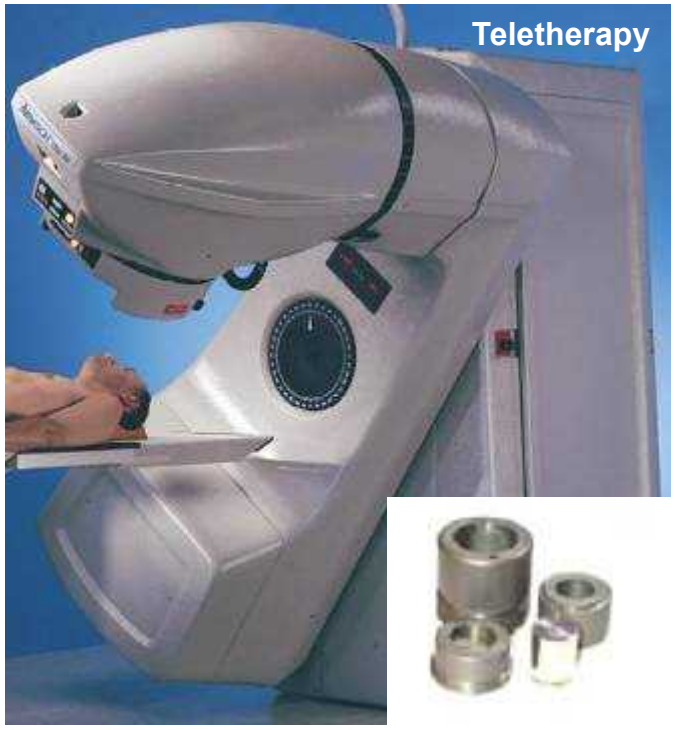
Panoramic irradiators use Co-60 pencils in a flat panel array containing > 1 MCi



Standard Co-60 pencil and slug

- 250,000 Curies per shipping cask
- ~100 shipments to US per year

Teletherapy & Gamma Knife Devices



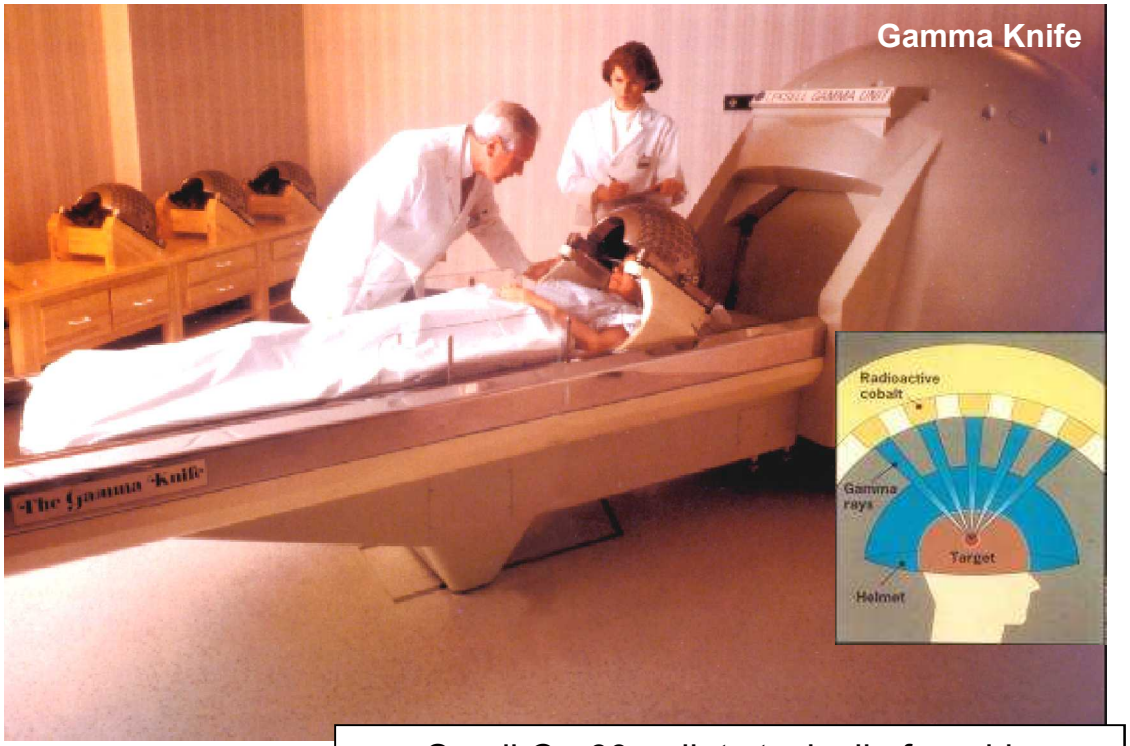
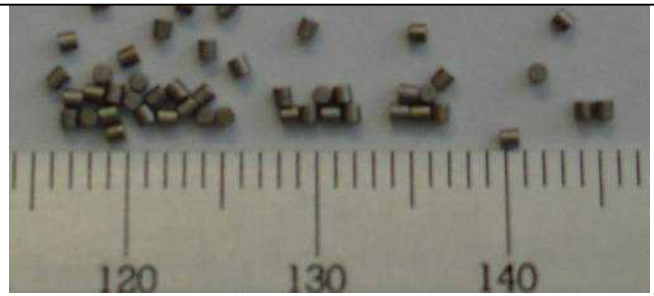


Image courtesy of Oak Ridge Associated Universities

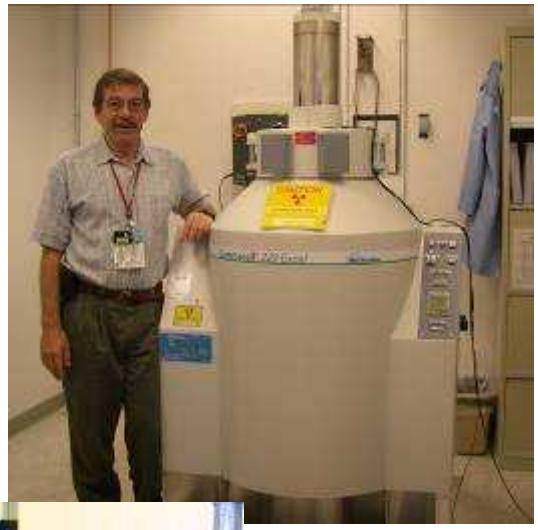
- Used in cancer therapy
- Mostly Co-60, 1000 – 15,000 Curies
  - (some older teletherapy machines use Cs-137).
- Major manufacturers: Elekta, MDS Nordion
  - US inventory ~100 gamma knife, 50 teletherapy
  - A few thousand teletherapy units overseas

Small Co-60 pellets typically found in teletherapy/gamma knife sources (minor scale is mm)



Self-Contained Irradiators

Research Irradiators



Blood Irradiators

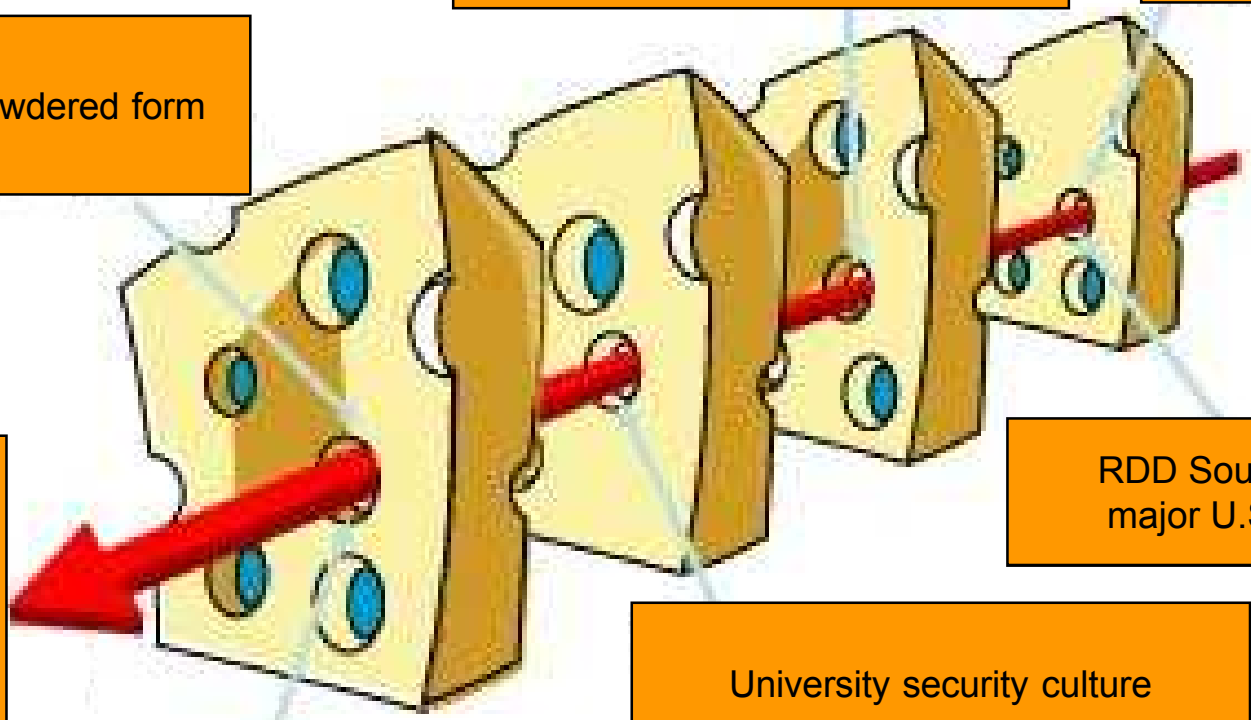
- Used for research and blood irradiation
- Source activity
  - Blood irradiators: 1000 – 10,000 Ci
  - Research irradiators: 1000 – 50,000 Ci
  - ***Most machines use Cs-137 (CsCl)***
  - Some use Co-60
- Found at Hospitals and Universities
- ~ 1000 machines in the U.S.
- ~ 500 additional CsCl irradiators worldwide

Loopholes Through the Layered Defense

RDD Source at university

RDD Source In the U.S.

Source material in powdered form



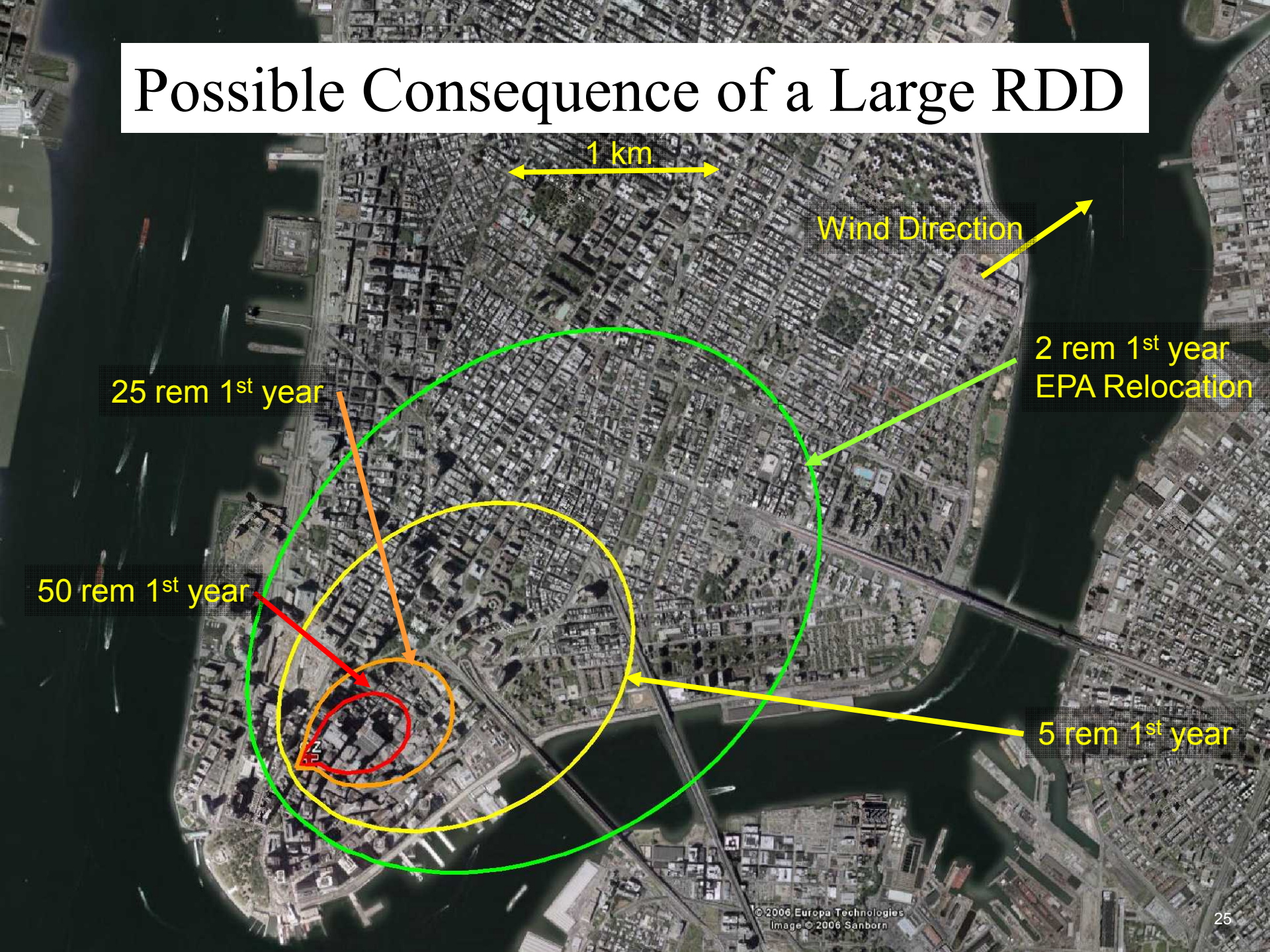
"Effective" RDD

RDD Source in major U.S. city

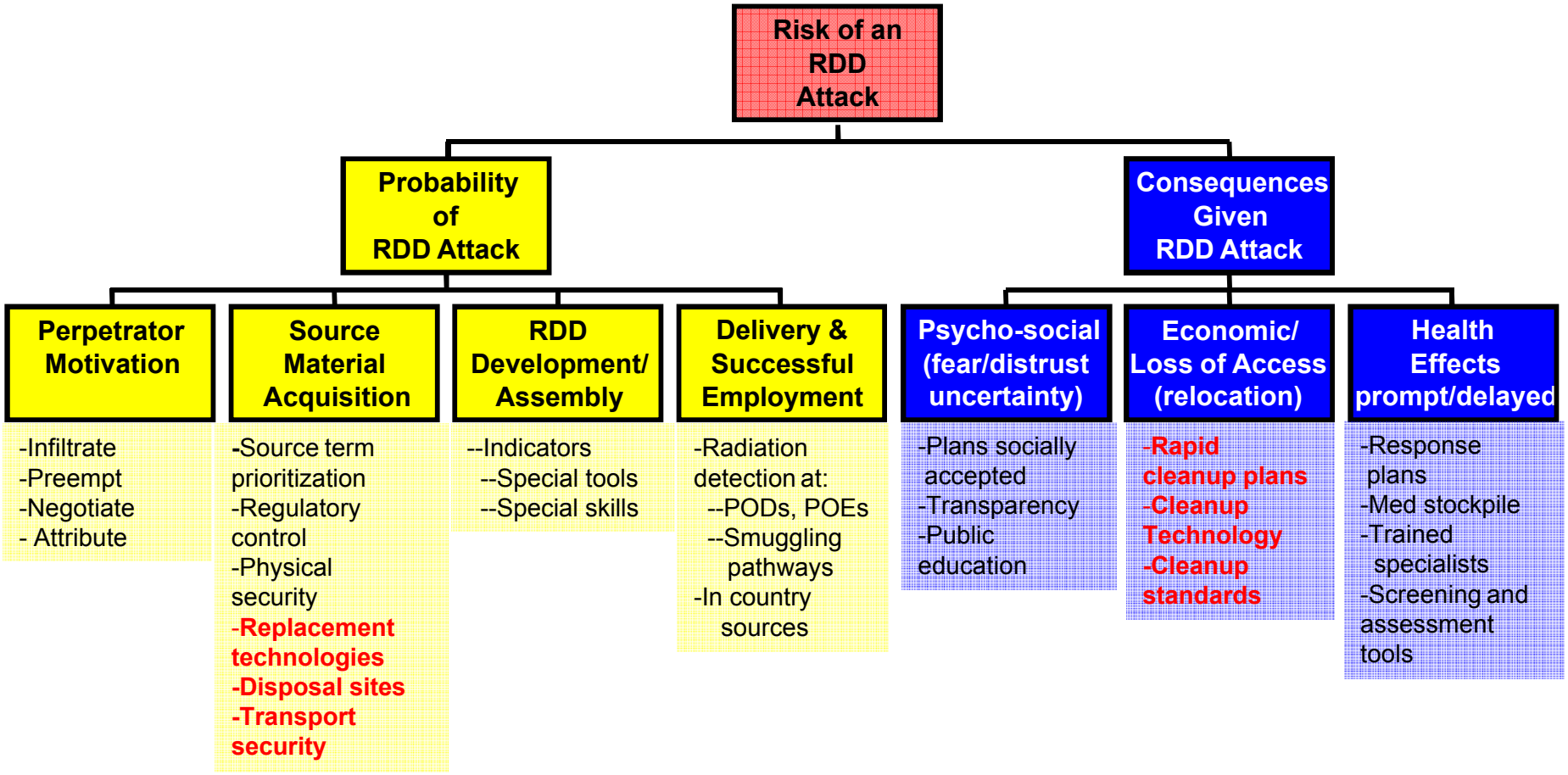
University security culture

Large Source (~1000 Ci)

Possible Consequence of a Large RDD



RDD Risk Reduction Countermeasures



- The RDD risks are manageable

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Summary

- The Risk Based Approach and RDDs
- Area Denial is Based on EPA Relocation PAG
- Radioactive Materials of Concern: Just a Few
- Consequences of an Area Denial RDD Are:
  - Economic Dislocations
  - Psycho-social
  - Few deterministic health effects
- Questions?