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Radiological Terrorism and RDDs A Risk-Based Approach

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Sandia National Laboratories

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ASTAR

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Outline

- Radiological Terrorism and the Concept of Risk

  Risk = Probability x Consequence

- The Basic Physics of Explosive Dispersal
- Major Radioactive Materials (Radionuclides) of Concern
- Radiation Dispersal and Area Denial
- Radiation Sealed Sources and Devices in Use
- Summary

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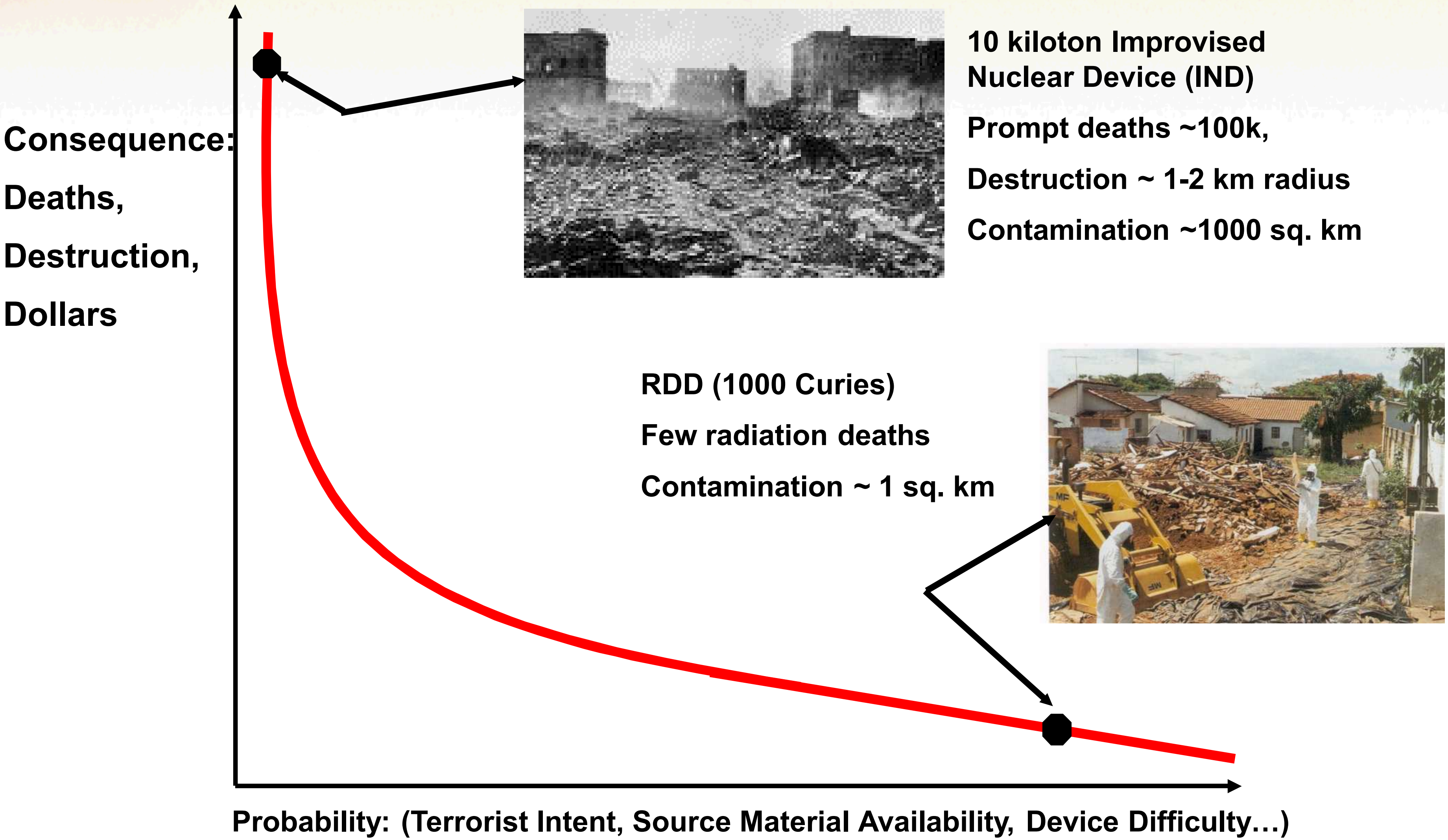
Options for Radiological Terrorism

Device Type	Dispersal Form	Economic Effects	Health Effects	Comments: Impact
Radiation Exposure Device (RED)	N/A	Low-Medium	Deterministic and stochastic health effects	Could impact 100's to 1000's; No lasting economic impact
Rad-Food Dispersal (RFD)	Dissolve or mix	Medium to High	Serious deterministic health effects possible	Could impact 100's to 1000's; Other poisons more readily available?
Radiation Dispersal Device (RDD)	Many	Medium to Very High due to "Area Denial"	Few (if any) deterministic health effects; Latent cancer risk (stochastic) drives population relocation	Could impact 1000's to 10,000's; **Unique** aspect of radiological Material

Risk = Probability x Consequences



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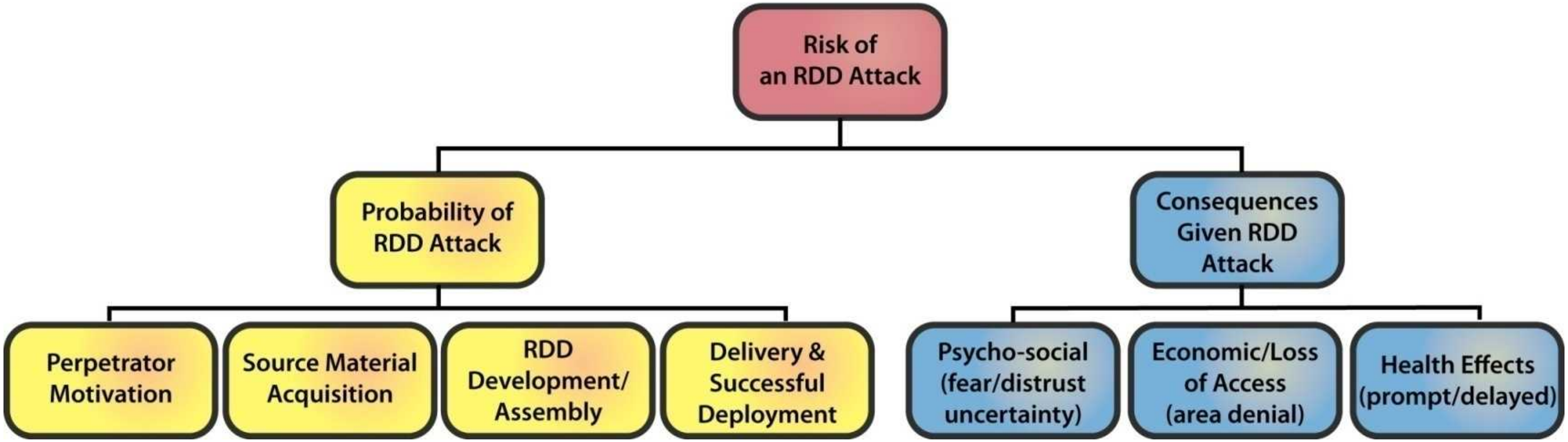
Public Perception of Risk

- Public's perception of risk often differs from mathematical 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

- RDD's seem to hit all of the public's hot buttons

RDD Risk Elements



A rad-terrorism systems analyst studies all of the major building blocks of risk

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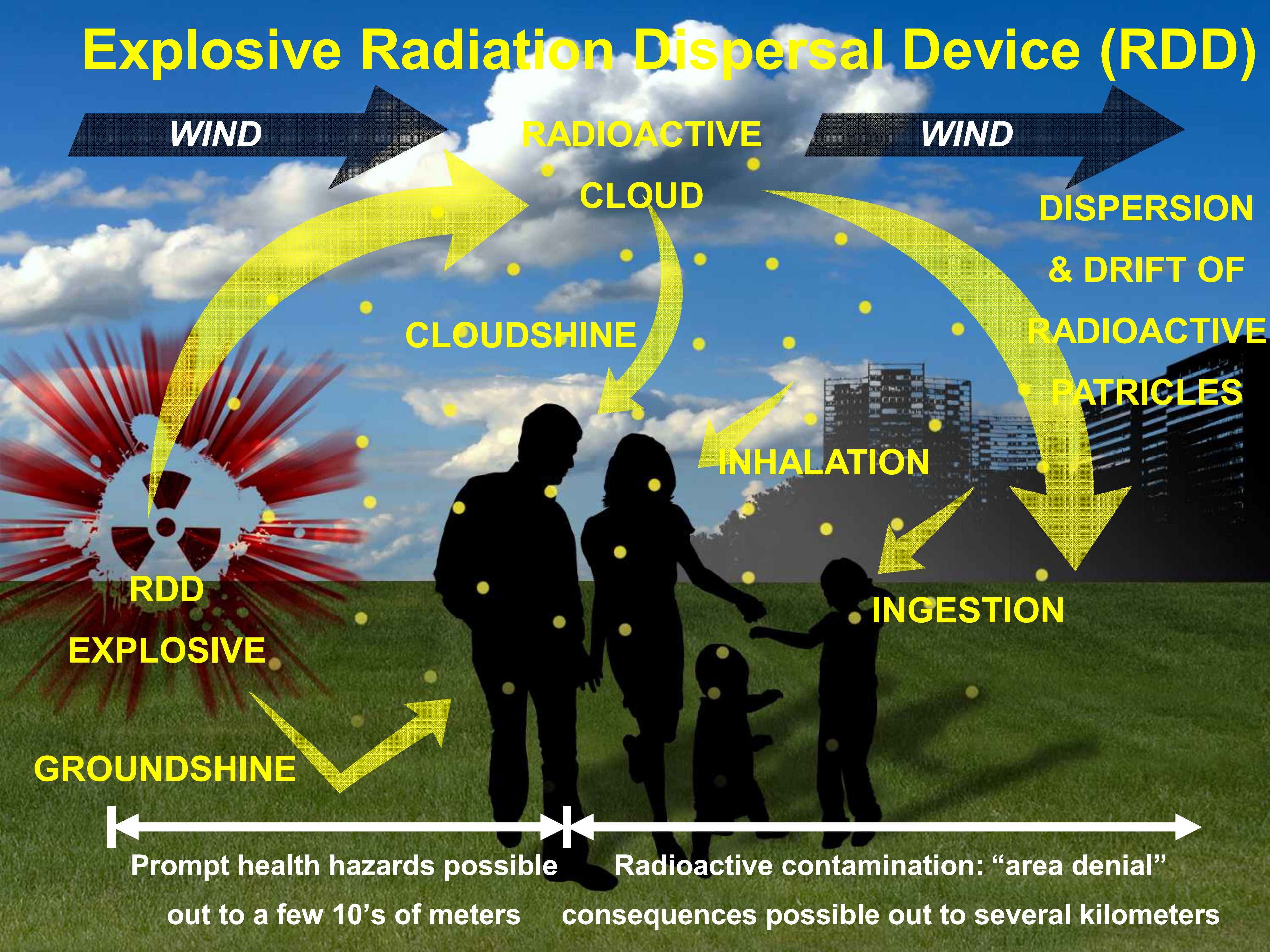
Explosive Radiation Dispersal Device (RDD)
WIND
RADIOACTIVE
CLOUD
WIND
DISPERSION
& DRIFT OF
RADIOACTIVE
PATRICLES
CLOUDSHINE
INHALATION
INGESTION
RDD
EXPLOSIVE
GROUNDSHINE
Prompt health hazards possible
out to a few 10's of meters
Radioactive contamination: "area denial"
consequences possible out to several kilometers

Different Methods of Dispersal

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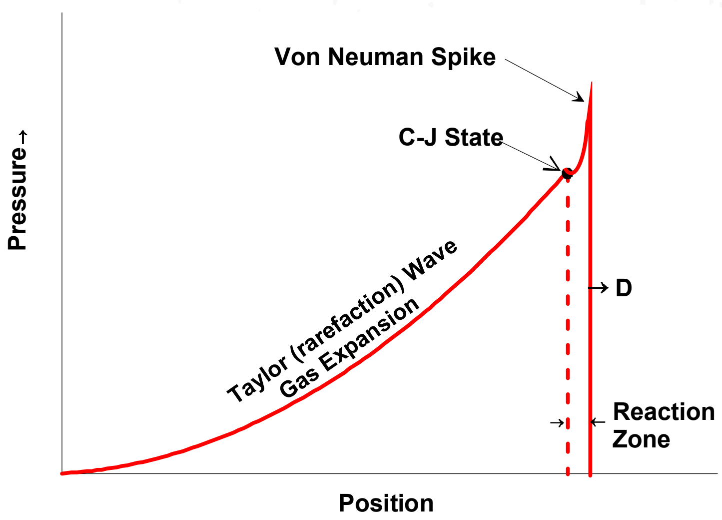
Property of Explosives

EXPLOSIVE	ρ_0 (g/cm^3)	D (km/s)	P_{CJ} (Gpa)	Temp (ºC)
Nitroguanidine	0.195	2.7	0.63	d. 232
HMTD *	0.88	~4.5	~4	d. 75
ANFO (5.8% FO) *	0.82	4.55	5.5	m. 170
TATP *	~.92	~5.3	~5.8	m. 91
90% Peroxide, neat *	1.395	4.76	6.87	b>100
AN/NM (70/30)*	~1.05	5.3	~7.3	b.101**
Ureanitrate *	1.59	4.7	9.3	m. 152
NM	1.133	6.299	13.4	b. 101
highest Vel Dynamite	~1.2	6.9	~14	d. 55
lowest Vel Dynamite	~1.2	1.1	~0.4	d. 55
70% HP/propanol *	1.38	6.81	15.6	b>100
TNT	1.64	6.95	19	m. 81
PETN	1.53	7.49	22.5	m. 140
Pentolite (50/50)	1.644	7.52	25.2	m. 81
Nitroglycerine	1.596	7.7	25.3	d. 55
Comp C-4	1.6	8	25.6	d. 205
RDX	1.6	8.13	26	d. 205
Comp-B	1.67	7.868	27.2	m. 81
Octol (75/25)	1.8	8.55	30.65	m. 81
HMX	1.89	9.11	39	d. 285

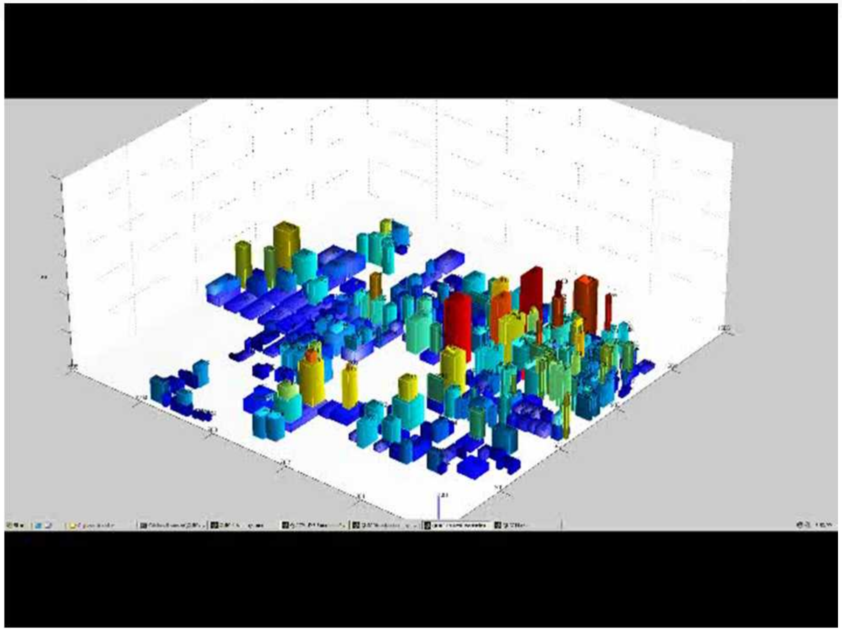
*-HME, b: boils, d: decomposes, m: melts

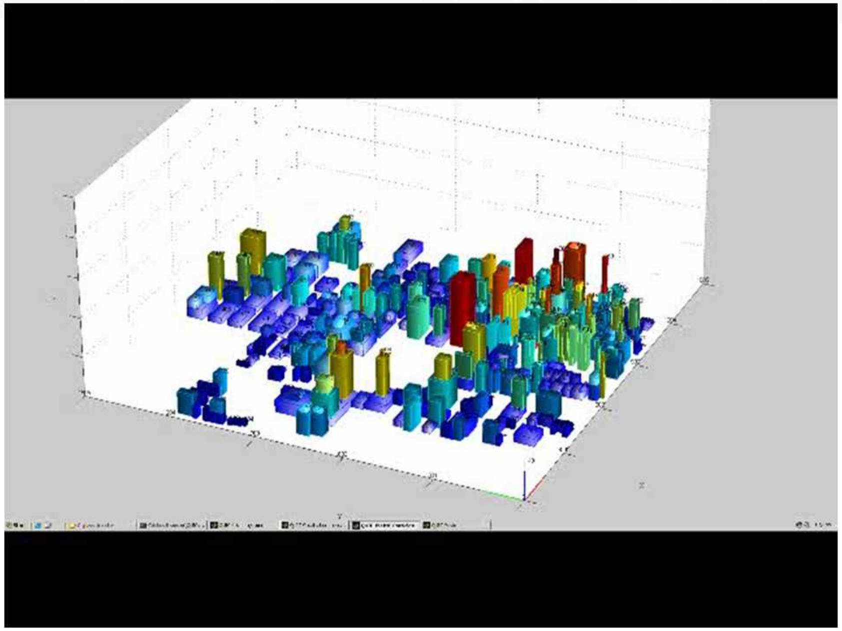
**NM boils off (~101°C) then AN melts (~170°C)



- **High explosives generate shock waves**
- **The shock pressure (P_{CJ}) of an explosive is a measure of the explosive ability to break-up and disperse materials**

The Physics of Explosive Dispersal





- **The extent of the dispersal and ground/surface contamination depends on the local weather (wind speed, atmospheric stability)**

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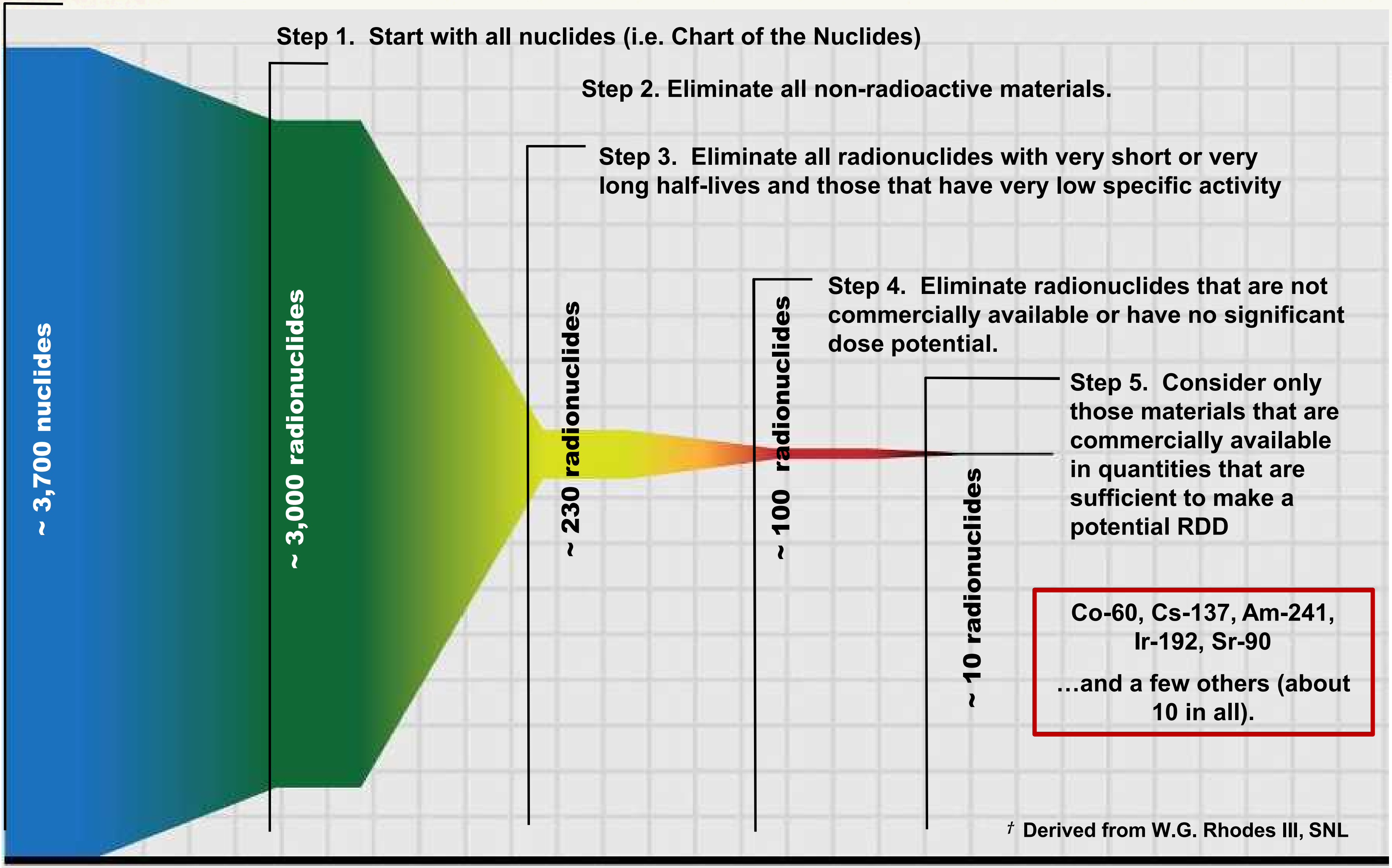
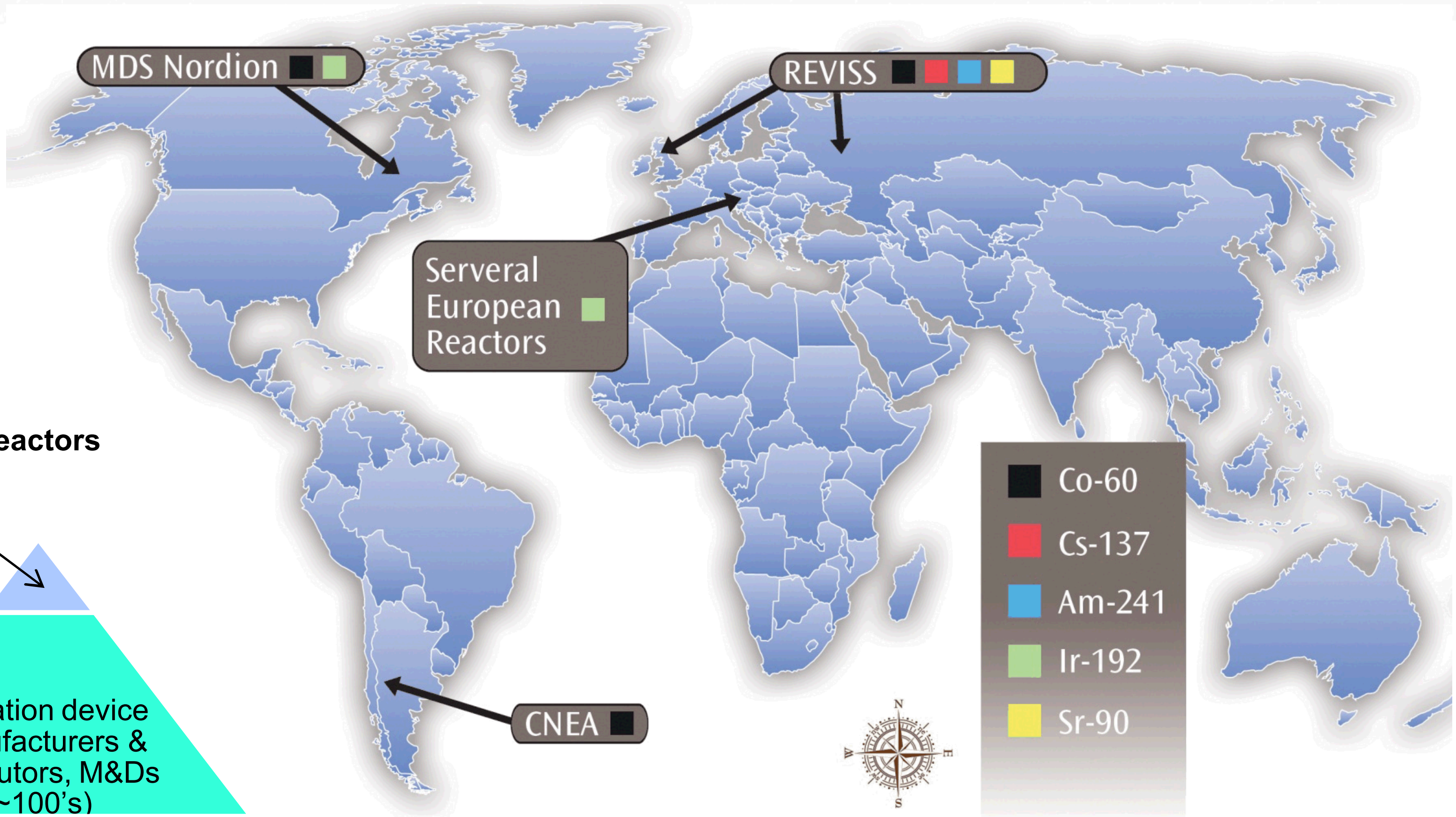
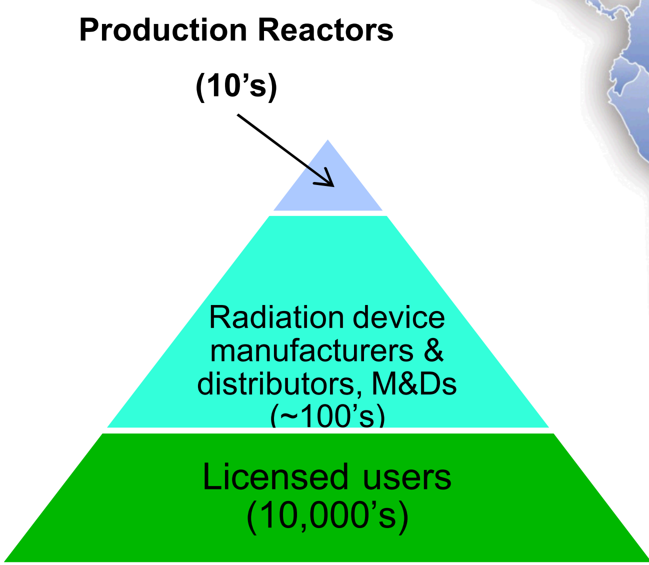
Radionuclide Down-Selection†



Major Producers of Radionuclides, Sealed Sources and Devices †





† Derived from (Van Tuyle, LANL, 2003)

Radionuclides Properties

Radionuclide and emission	Half-life	Chemical Form (typical)	Specific Activity (Ci/g) pure / typical	Dose Rate at 1 meter rem/hr per Ci	Area Denial Potential (Ci/km^2) Needed to Trigger EPA Reloc. PAG	Typical Use and Ci Quantity Used
Co-60 (β,γ)	5.3 yr	Metal	1130/100	1.2	10	Irradiators (≥1000 Ci)
Sr/Y-90 (β)	29 yr	Ceramic $SrTiO_3$	140/34	Bremsstrahlung (pure beta)	100	RTGs (≥10,000 Ci)
Cs-137 (β,γ)	30 yr	Salt Powder	87/20	0.35	40	Irradiators (≥1000 Ci)
Ir-192 (β,γ)	74 d	Metal	9200/450	0.6	100	Radiography (~100 Ci)
Am-241 (α,γ)	430 yr	Oxide Powder	3.5	0.003	40	Well Logging (~ 10 Ci)

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Rad-Material Quantity: Area Denial

- **EPA Protective Action Guideline (PAG) for Relocation**
  - Basis: limiting the exposed population equivalent dose to 2 rem in 1-year (stochastic latent cancer risk basis ~ 10^{-3} per rem)
  - For Cs-137, Relocation PAG triggered at contamination ~ 40 Ci/km^2
- **Urban area population ~ 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 (assuming uniform dispersal)
    - Potential Relocation~100,000's inhabitants
    - National level event

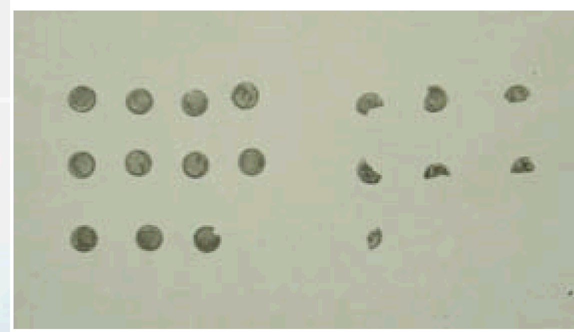
Note: <u>Uniform</u> dispersal is not feasible

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

Liquids and Powders

Courtesy of Fred Harper, SNL

Courtesy of Mike Edenburn, SNL

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

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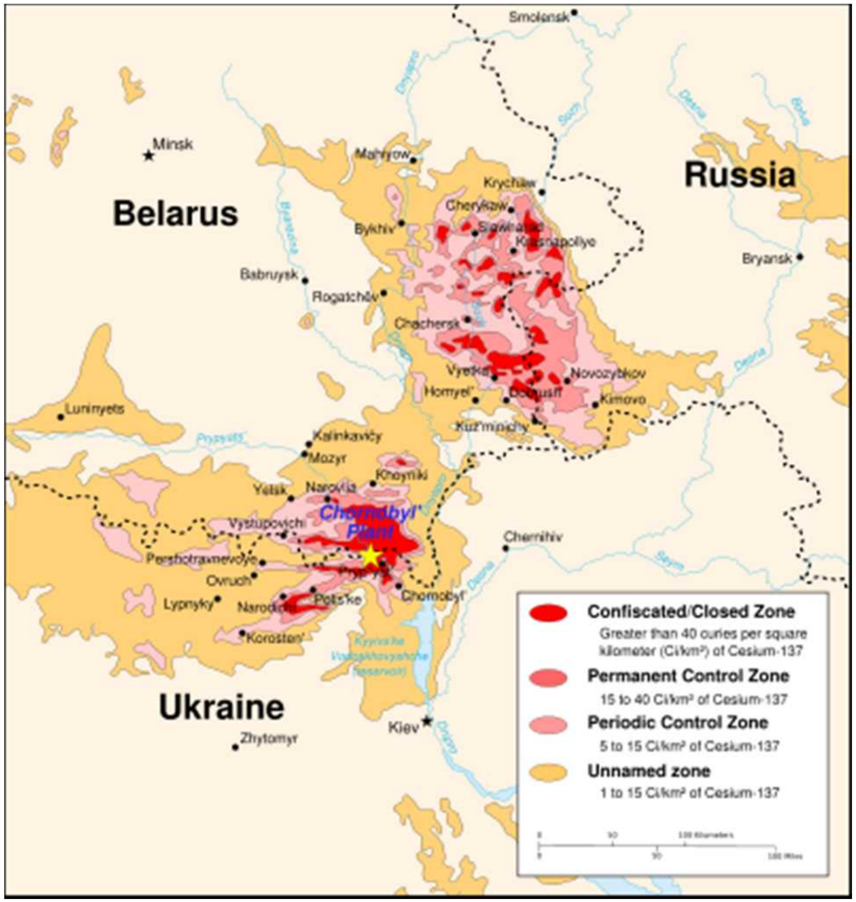
Past Experience with Cs-137

- 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

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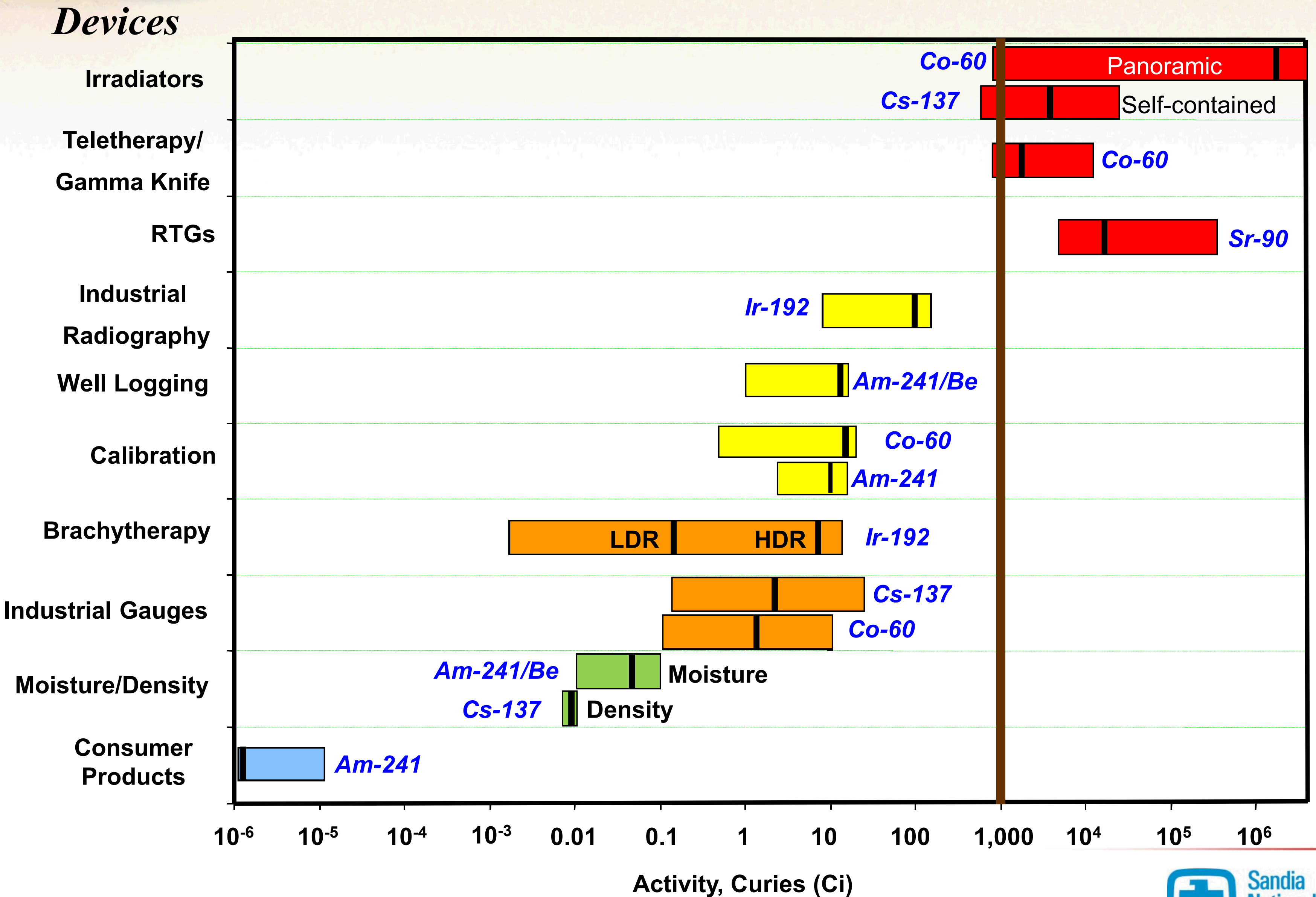
Radiation Devices & Activity Ranges†



† Derived from IAEA Categorization of Sources

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Radioisotope Thermoelectric Generator (RTG)

- From 1970 to 2000, these devices were used to power lighthouses, navigational beacons, and other remote monitoring sites in Russia and the Former Soviet Union (FSU).
- Typical RTGs contain between 25,000 to 325,000 Ci of Strontium-90.
- Multiple attempts to steal non-ferrous metals in these devices.
- US and partners plan to have all Russian RTG's removed/secured by 2016

Strontium cores from RTGs on the Kola Peninsula

Russian Sr-90 RTG

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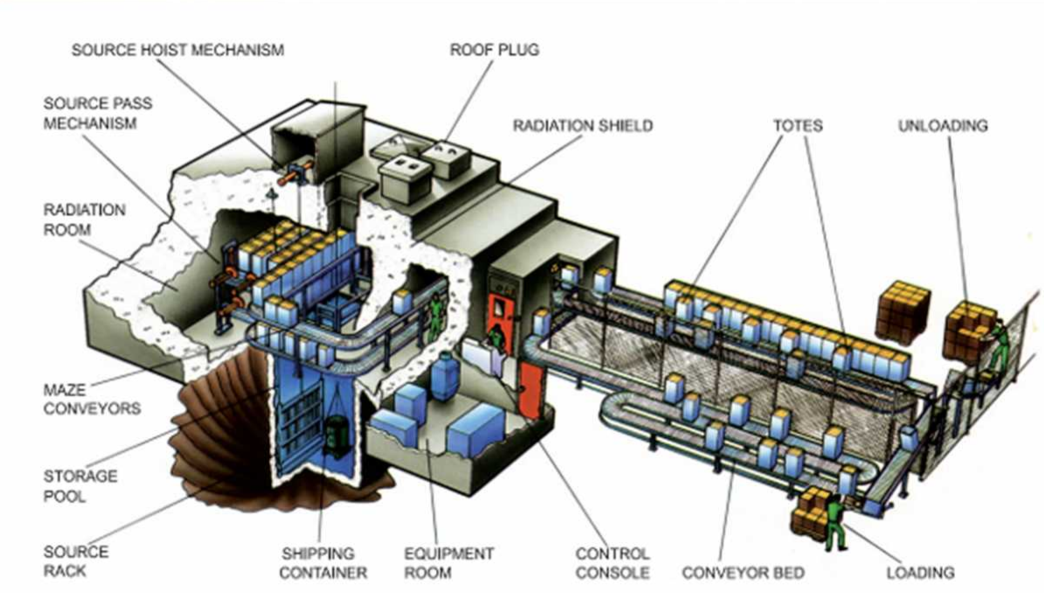
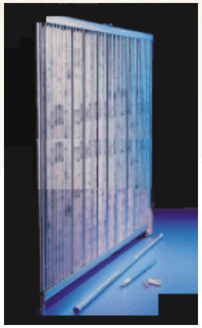
Co-60 Panoramic Irradiators

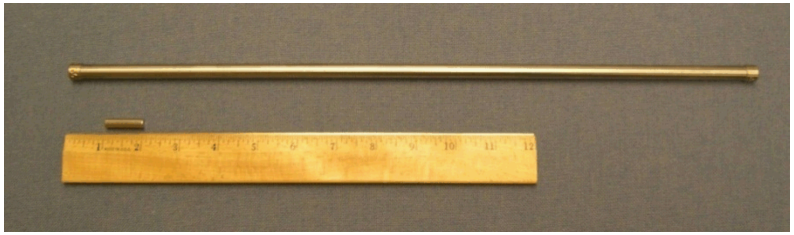


Panoramic irradiators use Co-60 pencils in a flat panel array containing > 1 MCi



Co-60 flat panel array containing > 1 MCi

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

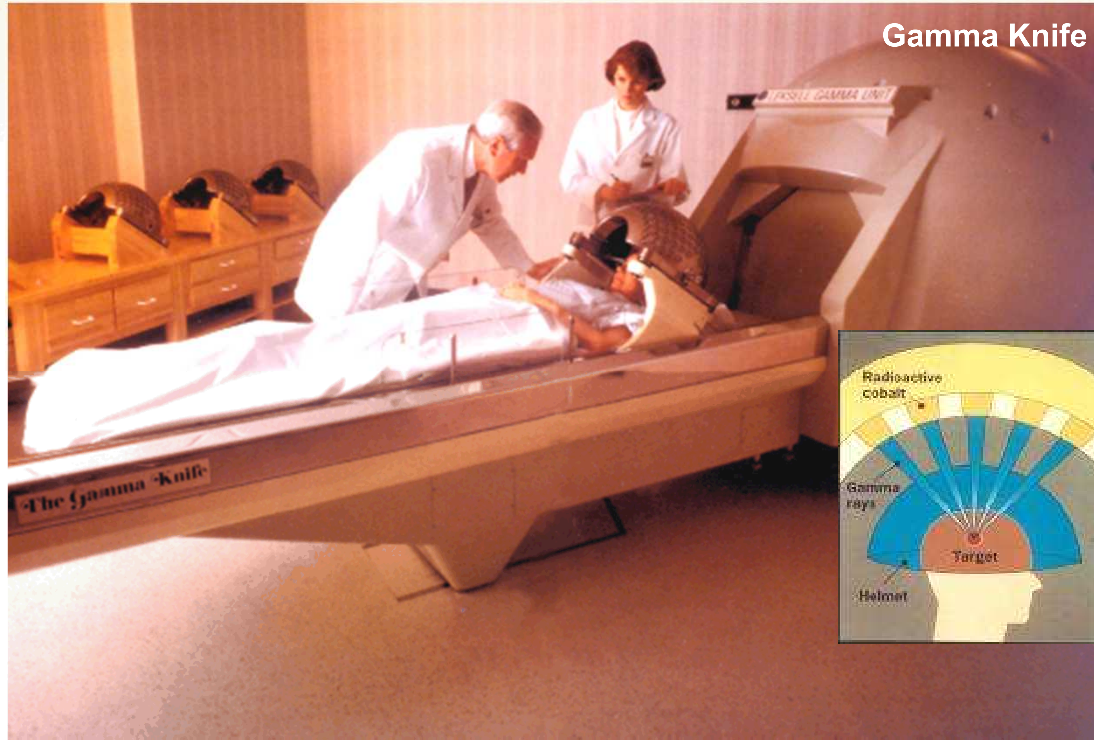


Standard Co-60 pencil and slug

- **Use to sterilize medical supplies, food, etc.**
- **~ 60 facilities in US, same for rest of world**
- **Co-60 shipments to US from Canada**
- **~100 shipments to US per year, 250,000 Curies per shipping cask**

Teletherapy & Gamma Knife Devices

Image courtesy of Oak Ridge Associated Universities

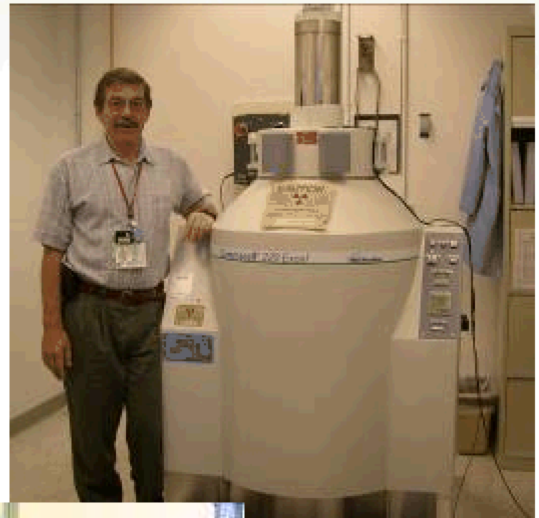


- **Used in cancer therapy**
- **Mostly Co-60, 1000 – 15,000 Curies**
  - High activity pellets, ~ 300 Ci/g
  - Some older units (re. Goiania) use Cs-137
- **~100 gamma knife, 50 teletherapy in the US**
- **~ few 1000 teletherapy units overseas**

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

Self-Contained Irradiators

Research



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.
- ~ 600 additional CsCl irradiators worldwide

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Risk Assessments: The Swiss Cheese Model

Urban Area Facility:
Hospital, University, Research Institute

RDD Source
Location: US or Foreign

Radiation Source Size:
1 Ci, 10 Ci, 100 Ci, 1000 Ci, > 1000 Ci

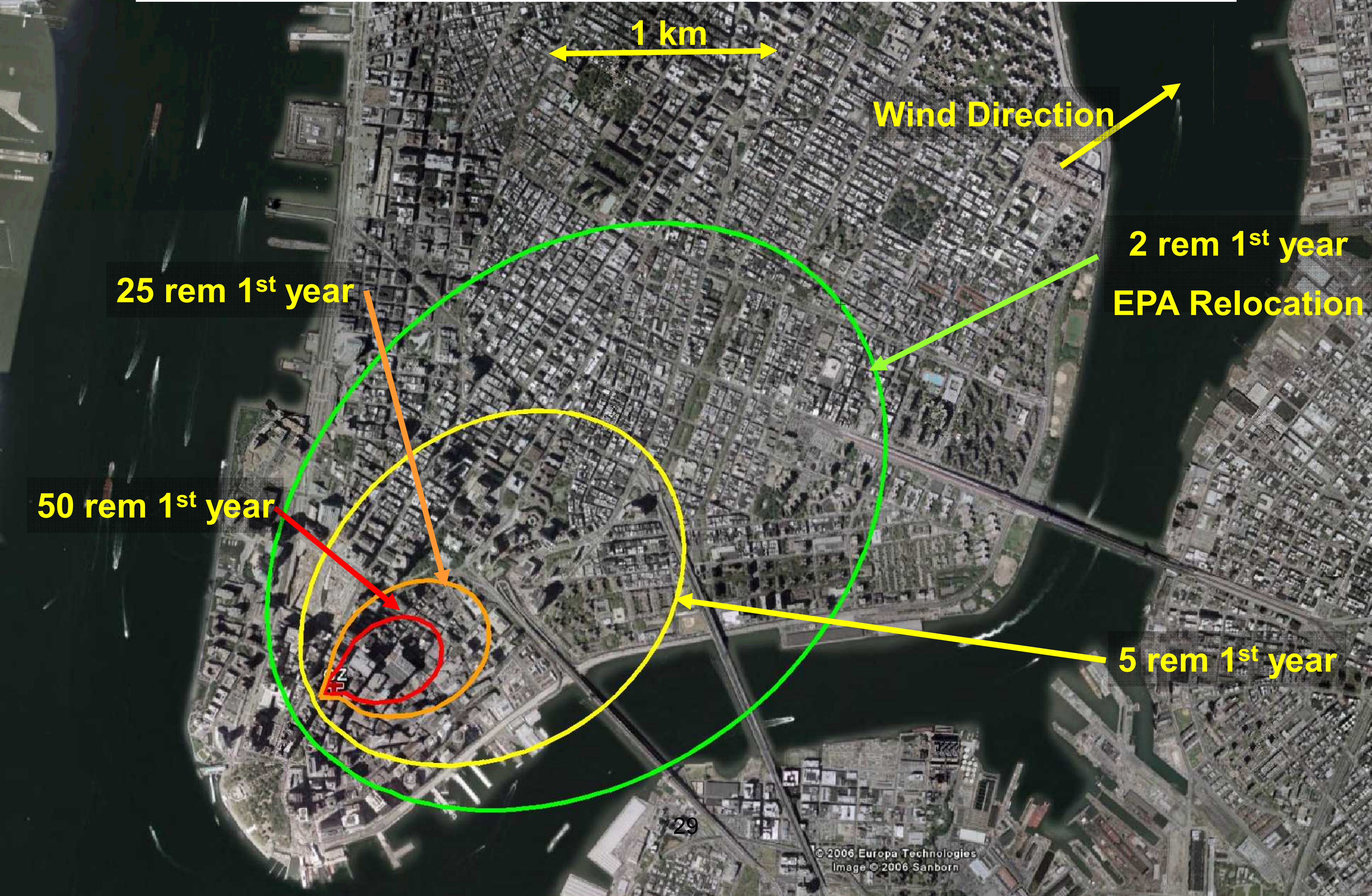
RDD Risk

US Source Location:
Urban area or remote

Security Culture at Facility:
University: Academic Freedom

Radiation Source Physical/Chemical Form:
Hard metal, powder, solubility

Possible Consequence of a Large RDD



RDD Risk Reduction Countermeasures

Risk of an RDD Attack

Probability of RDD Attack

Perpetrator Motivation
- -Infiltrate
- -Preempt
- -Negotiate
- - Attribute

Source Material Acquisition
- -Source term prioritization
- -Regulatory control
- -Physical security
- -Replacement technologies
- -Disposal sites
- -Transport security

RDD Development/ Assembly
- -Indicators
- --Special tools
- --Special skills

Delivery & Successful Employment
- -Radiation detection at:
- --PODs, POEs
- --Smuggling pathways
- -In country sources

Consequences Given RDD Attack

Psycho-social (fear, distrust)
- -Plans socially accepted
- -Transparency
- -Public education

Economic (area denial)
- -Rapid cleanup plans
- -Cleanup technology
- -Cleanup standards

Health (prompt, delayed)
- -Response plans
- -Med stockpile
- -Trained specialists
- -Screening and assessment tools

The RDD risks are manageable

Summary

- The Risk Based Approach and RDDs
- Area Denial is Based on EPA Relocation Protective Action Guideline (Relocation PAG ~ 2 rem in the first year)
- Radioactive Materials of Concern: Just a Few (Cs-137, Co-60, Am-241, Ir-192)
- Consequences of an Area Denial RDD Are:
  - Economic Dislocations
  - Psycho-social
  - Few deterministic health effects
- Questions?

Backup

Radiation and Radioactivity

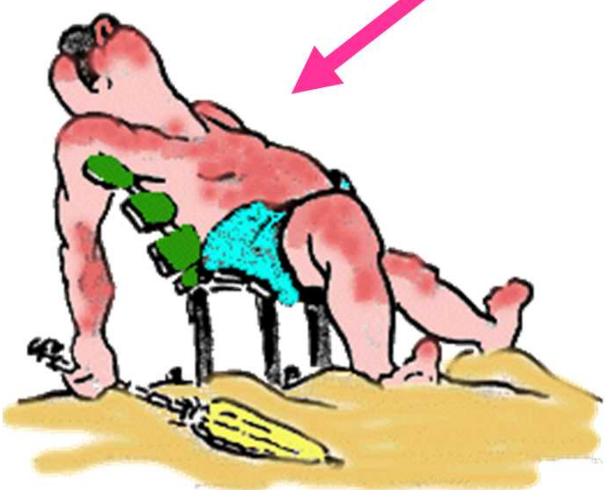
- **Ionizing Radiation – particles or energy emitted from an atom (in an attempt to reach stability) which are capable of ionizing other atoms.**
- **Radioactivity (Activity) – rate of decay**
  - **Curie (Ci): 3.7×10^{10} decays per second**
  - **Becquerel (Bq): One decay per second**
  - **Specific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

Prefixes and Typical Range of Radiation Source Activity

Prefix	Definition	Symbol
Tera	Trillion, $1x10^{12}$, 1E12, 1,000,000,000,000	TCi
Giga	Billion, $1x10^{9}$, 1E9, 1,000,000,000	GCi
Mega	Million, $1x10^{6}$, 1E6, 1,000,000	MCi
kilo	thousand, $1x10^{3}$, 1E3, 1,000	kCi
None	$1x10^{0}$, 1E0, 1	Ci
milli	thousandth, 10^{-3}, 1E-3, 0.001	mCi
micro	millionth, 10^{-6}, 1E-3, 0.000001	µCi
nano	billionth, 10^{-9}, 1E-3, 0.000000001	nCi
pico	trillionth, 10^{-12}, 1E-3, 0.000000000001	pCi

Radiation Exposure and Contamination: Two Different Things

Exposure



Contamination

Contamination is radioactive material where it's not wanted. For an RDD, the ground <u>contamination</u> will drive population relocation to avoid exposure and dose to the population

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