

# The Unintended Consequences of the Linear Non-Threshold Model and the 2-rem PAG



PRESENTED BY

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# There are different views of biological effects of low levels of radiation to healthy individuals.

Epidemiologist

“Data is *consistent* with the LNT.”

Medical professional

“Diagnostic and therapeutic doses are not adding additional cancer risk.”

Biologist

“Adaptive response is real.”

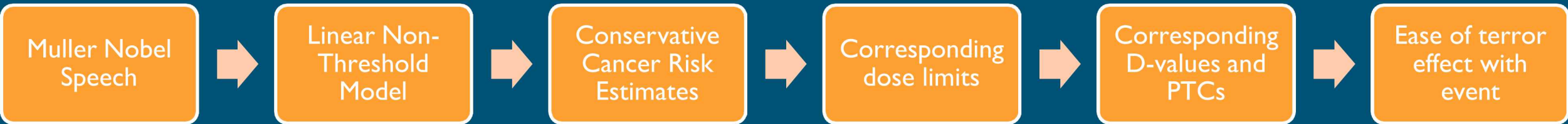
Health Physicist

“I’m not sure...”

Dosimetrist

“Show me the bodies...”

# The Muller statement drove radiation standards to accumulated dose with continuous exposure expected.



1946

Nobel Prize in Physiology or Medicine, Hermann Muller: “In this situation we can, however, draw the practical lesson, from the fact of the great majority of mutations being undesirable, that their further random production in ourselves should so far as possible be rigorously avoided.”

1956

National Academy of Sciences, The Biological Effects of Atomic Radiation:

- “Anything that adds radiation to this naturally occurring background rate causes further mutations and is genetically harmful.”
- “There is no minimum amount of radiation which must be exceeded before mutations occur.”
- “The harm is cumulative...”

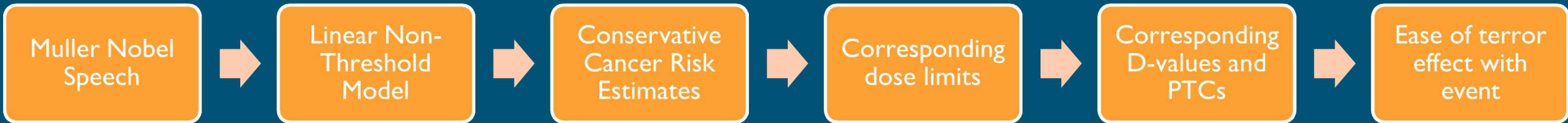
1958

Recommendations of the ICRP (ICRP-1):  $D=5(N-18)$

1959

Report of Committee II on Permissible Dose of Internal Radiation (ICRP-2): “The MPC values based on a critical organ are set by the requirement that the dose rate (rems/week) after 50 years of occupational exposure shall not exceed the values...”

# Radiation standards morphed to annual (perceived) risk as defined by effective and committed dose.



1977

1979

2007

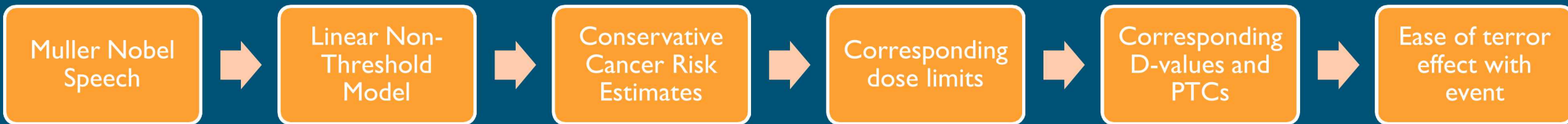
Recommendations of the ICRP (ICRP-26): "...any necessary exposures are kept as low as is reasonably achievable..."

- Effective dose equivalent concept (not named)

Limits for Intakes of Radionuclides by Workers (ICRP-30):  
 "Committed Dose Equivalent (H<sub>50</sub>), the total dose equivalent averaged throughout a tissue in the 50 years after intake of a radionuclide into the body."

Dangerous Quantities of Radioactive Material (IAEA D-Values): The D-value is that quantity of radioactive material, which, if uncontrolled, could result in the death of an exposed individual or a permanent injury that decreases that person's quality of life.

# Minimization of risk as defined by safety standards used to define security standards.



1992

2008

2010

Manual of Protective Action Guides and Protective Actions for Nuclear Accidents (EPA-400-R-92-001): Relocate the general population,  $\geq 2\text{rem}$

NRC and DHS Need to Take Additional Steps to Better Track and Detect Radioactive Materials (GAO-08-598): For purposes of illustration, we calculated how large an area might be sufficiently contaminated using IAEA category 1, 2, and 3 quantities of cesium-137

The 2010 Radiation Source Protection and Security Task Force Report: (Significant RDD) this means a device with sufficient radioactive materials to contaminate approximately 1 km<sup>2</sup> of the environment to the ... [PAG] relocation guideline of 2 rem in the first year

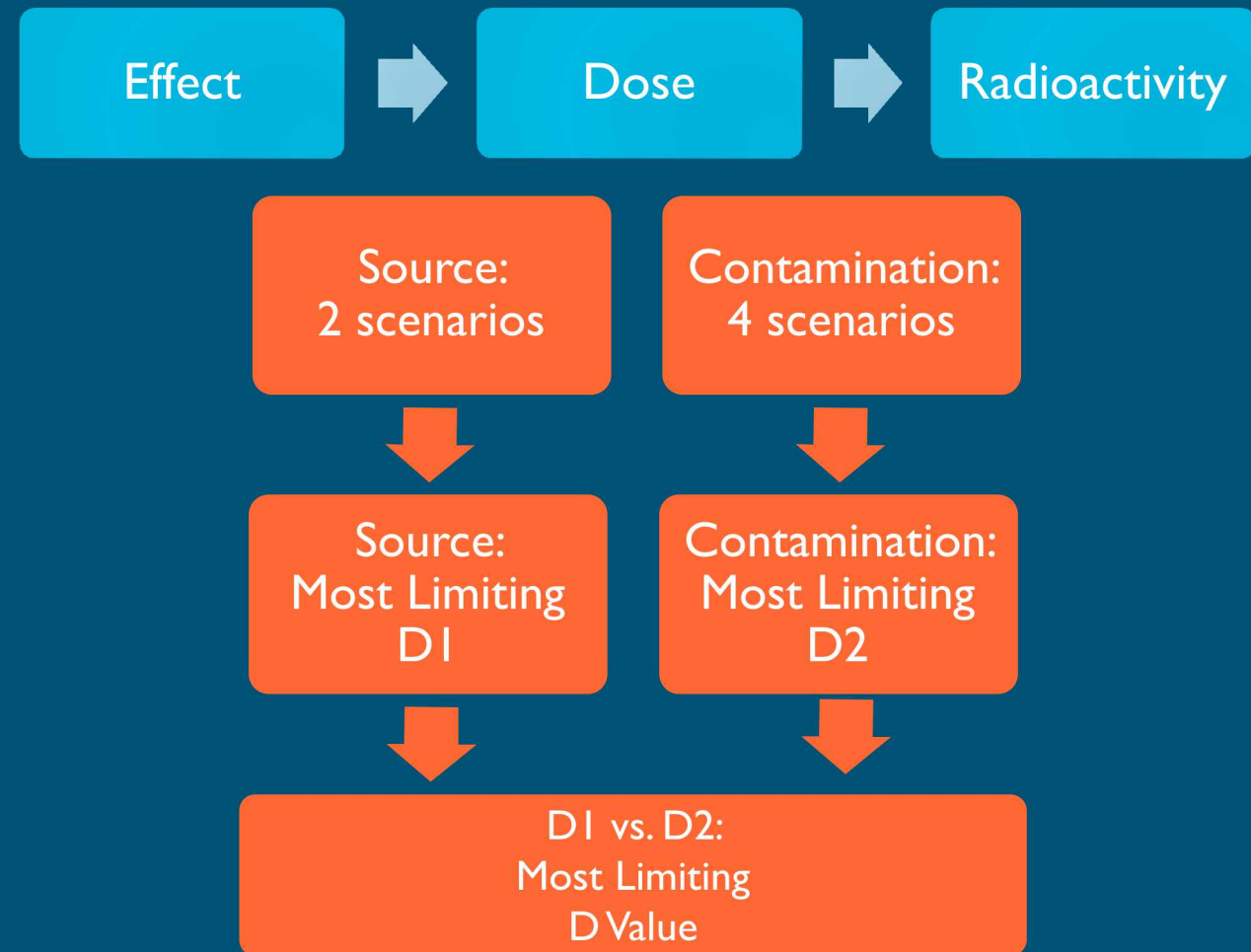
IAEA D-values now used to set security requirements for radioactive sources (IAEA COC, 10CFR37).

D-values are used in the assignment of security categories (C1 – C5) and associated requirements.

D-value stands for “dangerous quantity”

Evaluations were made to deterministic effects:

- “Fatal effects are those that, if developed, lead to death”
- “Non-fatal effects are those that reduce the quality of life and are organ or tissue specific”
- Thoracic lung evaluation based on lung cancer (stochastic)



The GAO and Radiation Source Protection task force have promoted the “power to contaminate” concept.

## TWO MEANINGS:

### I. Original (see table):

Area that could be contaminated by even dispersion of category value to 2-rem in the first year EPA relocation PAG.

### II. More commonly used:

Amount of radioactivity that, if evenly dispersed, would contaminate 1 km<sup>2</sup> to the 2-rem in the first year EPA relocation PAG.

FRMAC  
language:

$DRL_{Dp}$  – deposition derived response level (activity/area) corresponding to the 2-rem in the first year EPA relocation PAG.

Table 3: Potential Contamination from an RDD

Thresholds for concern (based on 1 year of exposure)	Amount of radioactive material (cesium-137)		
	Category 3 threshold (2.7 curies)	Category 2 threshold (27 curies)	Category 1 threshold (2,700 curies)
EPA recommends relocation (2 rem) <sup>a</sup>	15.1 acres	150.7 acres	15,012 acres
Potential observable health effects (100 rem)	0.3 acre	3 acres	300 acres

In the security space, there are four radionuclides of concern that represent four different potential consequences.

$^{137}\text{Cs}$ : easily dispersible



D=2.7 Ci

PTC=42 Ci

$^{60}\text{Co}$ : hard metal, pellets

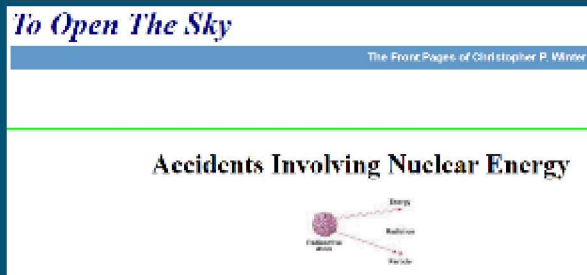


D= 0.81 Ci

PTC=11 Ci



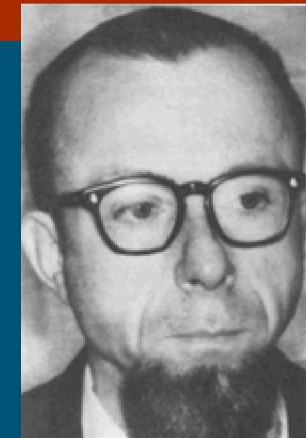
$^{192}\text{Ir}$ : hard metal



D=2.2 Ci

PTC=100 Ci

$^{241}\text{Am}$ : inhalation hazard



D=1.6 Ci

PTC=4 Ci

May 2002:

Gu Jiming, a nuclear scientist in Guangzhou, China, attacks a business rival with pellets of Iridium-192. Gu uses forged papers to obtain an industrial machine holding the pellets, then places them above the ceiling panels in the hospital office of his rival. The victim soon reports memory loss, fatigue, appetite loss, headaches, vomiting, and bleeding gums. Another 74 staff members at the hospital, including one pregnant woman, also develop symptoms. Gu is convicted 29 September 2003 and given a suspended death sentence (life in prison.) An assistant is sentenced to a 15-year prison term.

9 Large  $^{137}\text{Cs}$  sources are used nationally and internationally in blood and research irradiators.

Physical and chemical properties – large quantities in soluble salt due to chemistry of Ba, small sources vitrified.

Economic consequences have been studied and are significant – Goiânia also.

Risk assessment identified vulnerabilities which resulted in in-device-delay program.

USG/private program for replacement of blood and medical research irradiators.



10  $^{60}\text{Co}$  is mostly used in gamma knives and panoramic irradiators.

In common use worldwide for teletherapy, gamma knife, panoramic irradiators.

Hard “tra

In medical  
approxim

Can disp

Easy to f



# 11 Thefts of $^{192}\text{Ir}$ sources are common with vehicles.

2<sup>nd</sup> hardest metal known  
(osmium is #1)

In solid disc form within  
pig tail

Extremely difficult to  
disperse ballistically or  
otherwise

Exposures can occur due  
to high radioactivity —  
cascade of 2 – 3 gammas

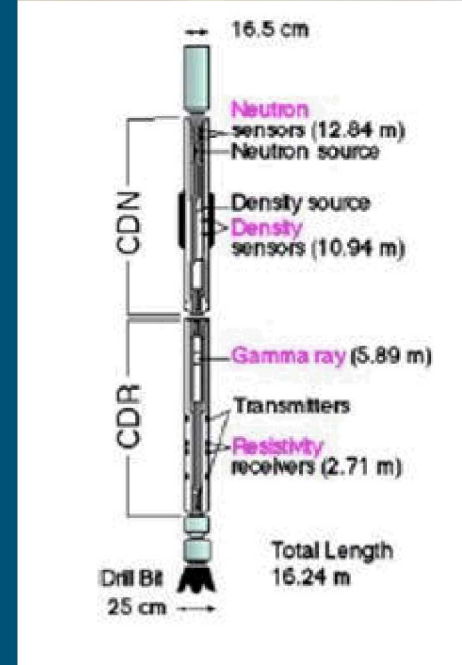


Neutron sources of  $^{241}\text{AmBe}$  are common in the oil and gas industry, used for well logging.

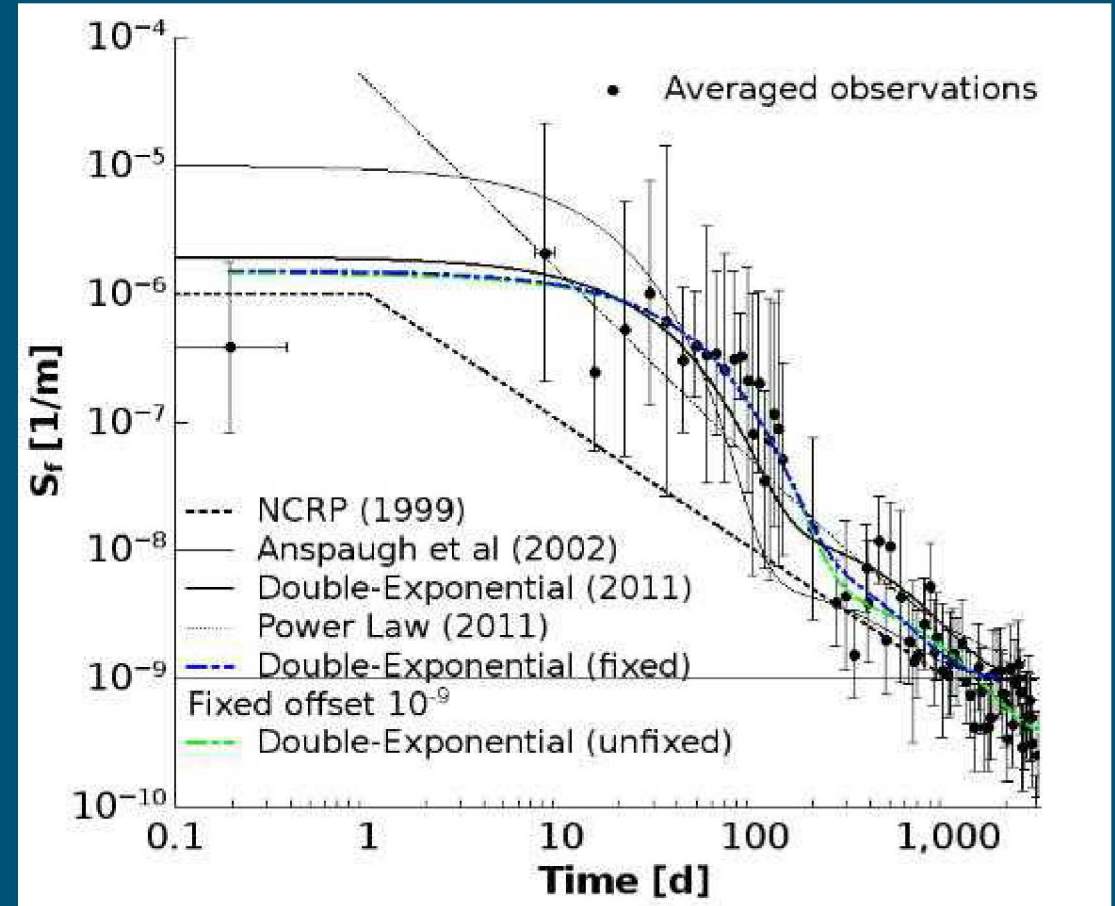
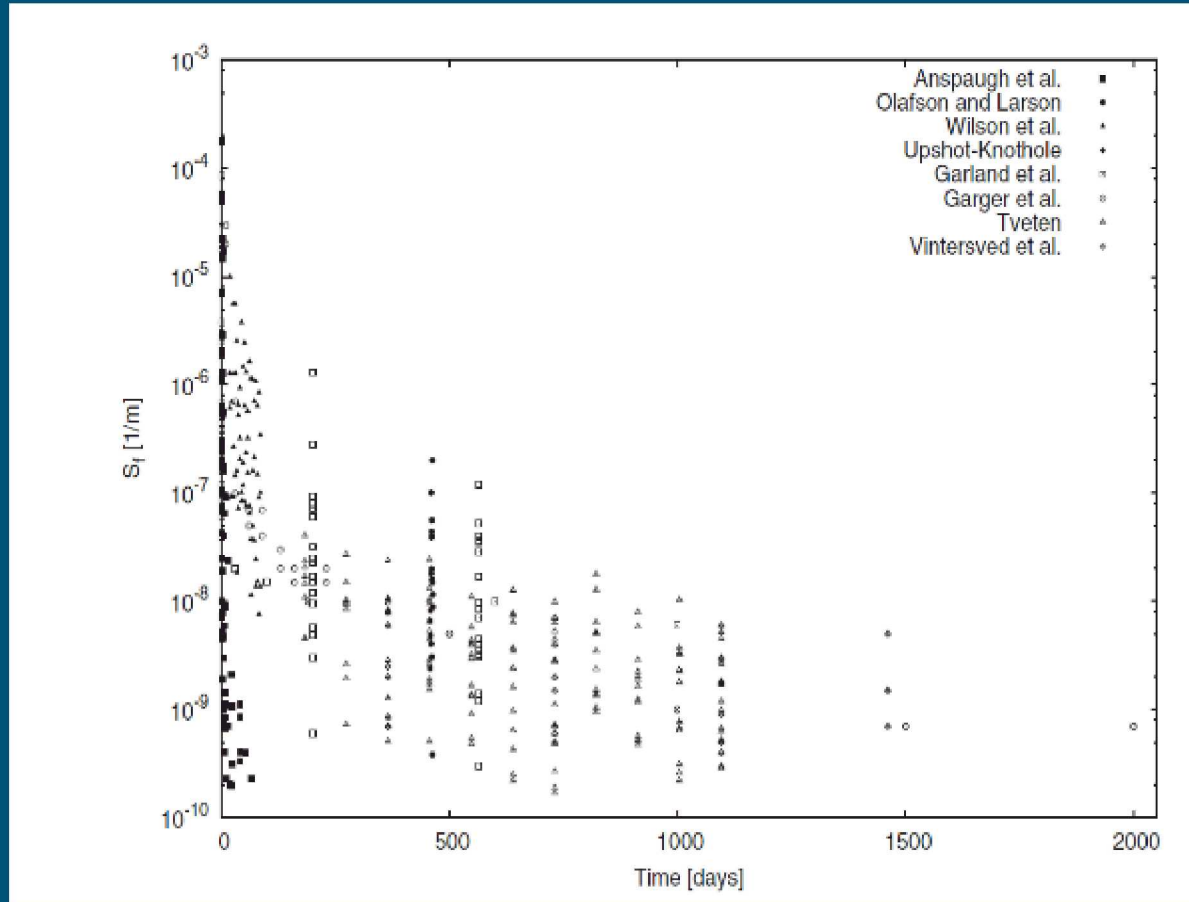
Powder is easily dispersible, Am assumed to separate from Be, many oxidation states (like Pu), but  $\text{AmO}_2$  most common

With 5.5 MeV alpha (vs. 60 keV gamma), inhalation hazard

Resuspension assumed in calculation of 2-rem PAG



Prospective dose calculations from  $^{241}\text{Am}$  are difficult due to the lack of proper science behind resuspension models.



# The 2-rem PAG clearly does not compare consequences between the radionuclides of interest.

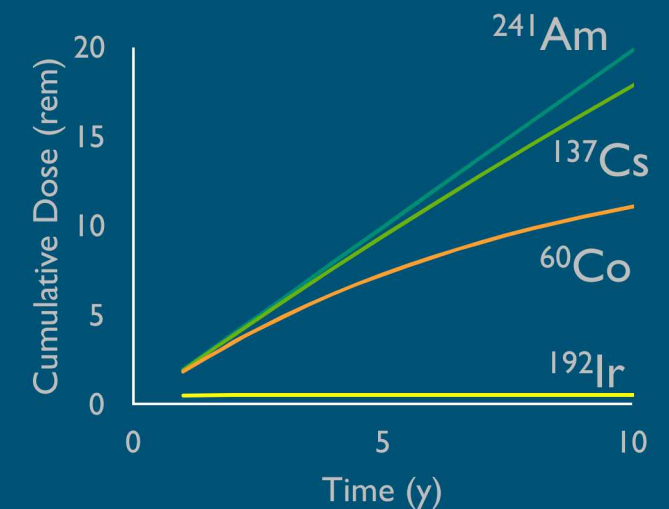
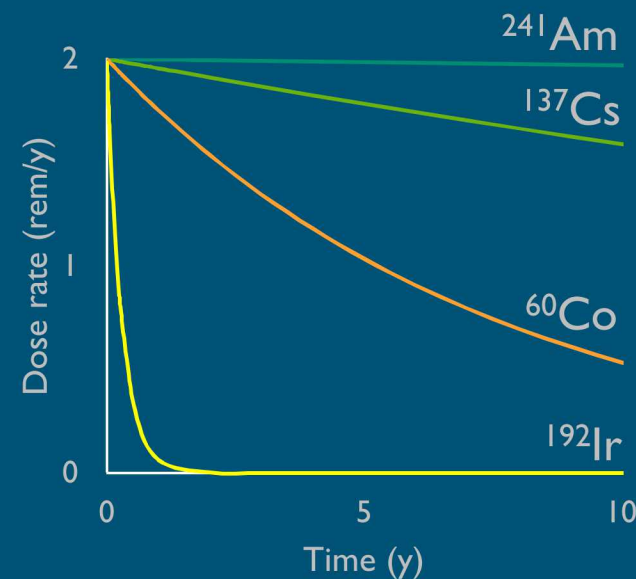
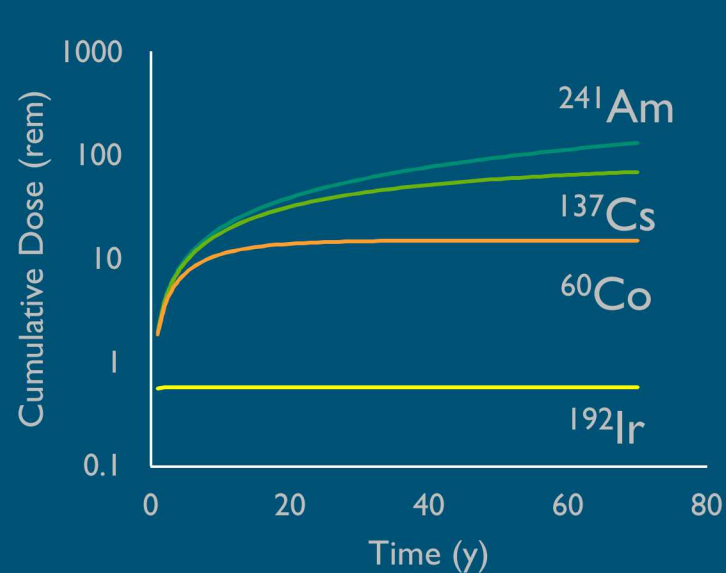
The LNT does not consider dose rate, but cumulative dose, justifying the combination of internal and external dose (TEDE).

Dose rate is reduced over time by mechanical and physical processes (only half-life is expressed here).

If the LNT is real, the 2-rem PAG would result in vastly different risk depending on the half-life of the radionuclide, among other properties.

Using BEIR VII (LNT) at 2 rem:

- 0.16% excess cancer risk, 45% base risk
- 0.08% excess cancer death risk, 22% base risk



# Neither PTC nor D-value concepts addresses security risk.

## Power to Contaminate

Treats all radionuclides the same  
Begins with 2-rem EPA relocation PAG  
Assumes uniform spread over 1 km<sup>2</sup>  
Radioactivity amount that meets this is PTC

## D-Values

Evaluates individual radionuclides based on specific safety-based scenarios  
2 source scenarios:

- “pocket”
- “room”

4 contamination scenarios:

- “inhalation”
- “ingestion”
- “contamination”
- “immersion”

## Likely Consequences

<sup>192</sup>Ir: Direct exposure  
<sup>60</sup>Co: Ballistic projection  
<sup>137</sup>Cs: Contamination and groundshine  
<sup>241</sup>Am: Contamination and resuspension

# The process of environmental cleanup is expected to be successful without consequence.

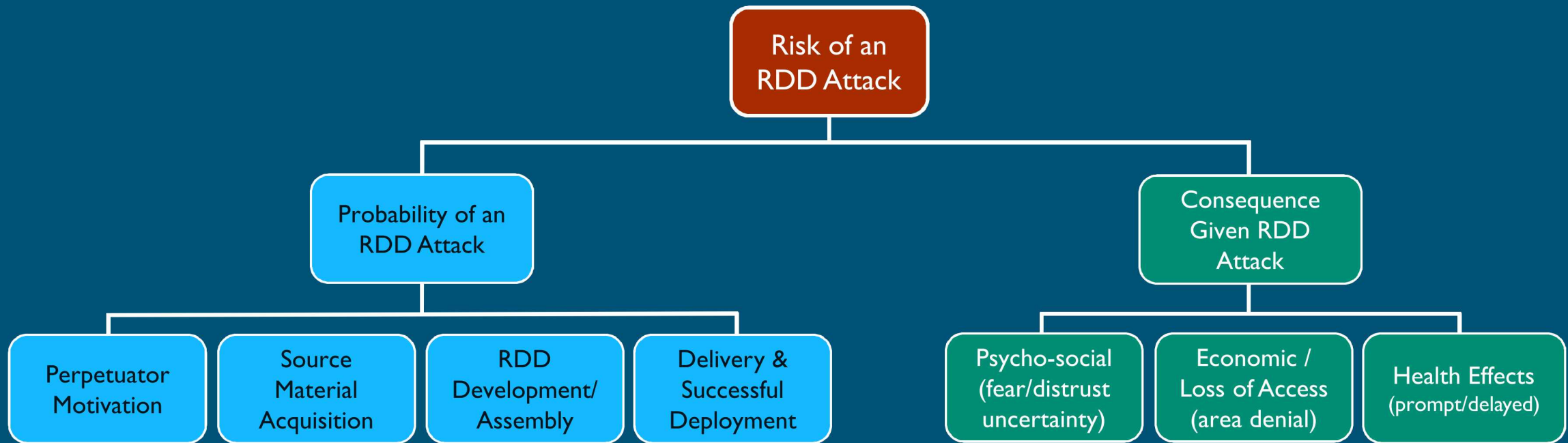
## Cleanup process NOT without consequences:

- Disposal of non-hazardous waste soil
- Industrial accidents — Enewetak
- Transportation of waste
- Low limits (e.g., 15 mrem/yr) that probably overestimate true dose
- Loss of topsoil — 3 years to recover 5 in. with active management
  - Topsoil is the upper, outermost layer of soil, usually the top 5 inches (13 cm) to 10 inches (25 cm). It has the highest concentration of organic matter and microorganisms and is where most of the Earth's biological soil activity occurs. Topsoil is composed of mineral particles, organic matter, water, and air.



*Cost less than \$100 billion*

A proper paradigm for risk from the use of radioactive sources must include probability and consequences.



# Evaluation of consequences should take into account such material chemical and physical properties as

## Material considerations:

Is the material physically dispersible?

- $^{137}\text{CsCl}$ : yes
- $^{192}\text{Ir}$  metal: no

Are there chemical considerations that affect the consequences?

- $^{137}\text{Cs} \rightarrow ^{137\text{m}}\text{Ba} \rightarrow ^{137}\text{Ba}$ : exothermic reactions
- $^{241}\text{AmO}_2$ : soil?
- CsCl absorption

## Economic and physical consequences:

What will cleanup entail:

- Cleanup levels
- Decontamination
- Destruction of structures

Could there be radiation-induced illness?

Is there an increased cancer risk (i.e., is the LNT real?)

## Psychosocial consequences:

What are the consequences of enforced actions like relocation?

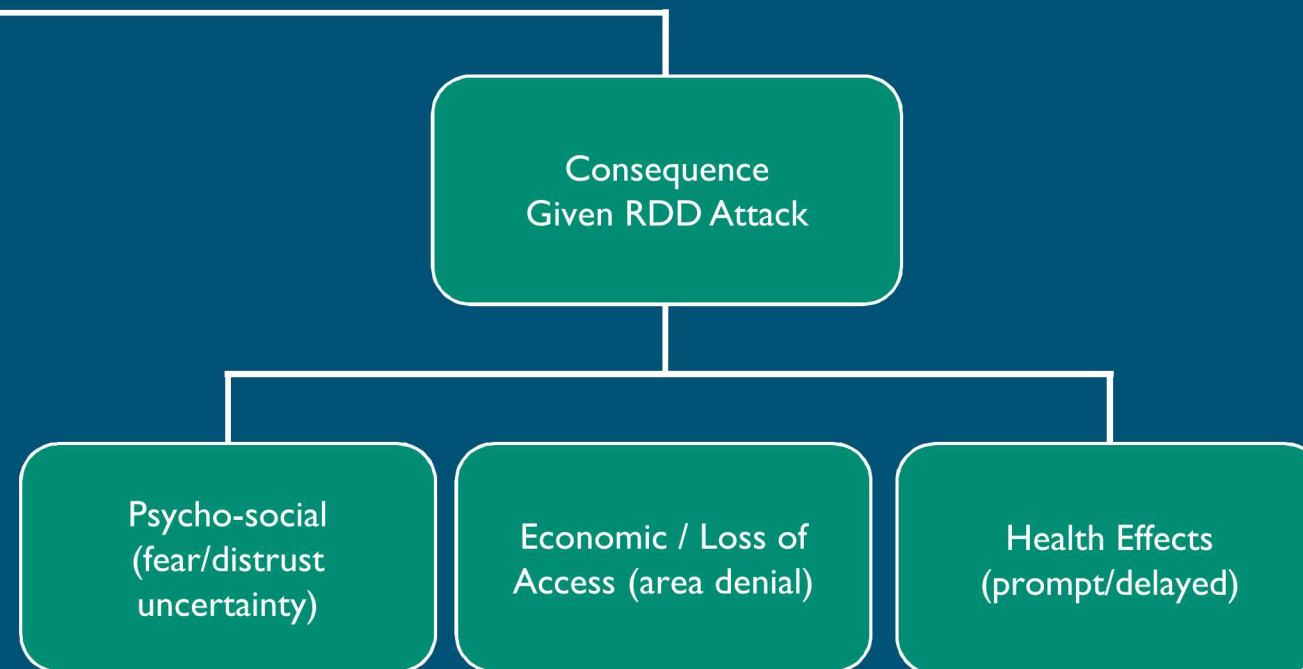
What will be the unintended consequences of years of radiation fearmongering and overprotection?

Probability considerations should include material security, dose rates from sources at risk, and ability to move to target.

Can the material truly be exploited based on its physical location and facility's security posture?

Are the dose rates such that the adversary be deterred or physically harmed?

Can the source be moved to the target without detection?



The LNT and decades of overprotection can only increase the harm to victims, responders, and the public.



	Description	Factor of Conservatism
a)	Application to a specific practice	3
b)	Conversion to Activity Concentration	3 - 15
c)	Practical measurement margin	1.5 - 2.5
d)	Sum of fractions	1.2 - 2
e)	Activity distribution	2 - 5
Cumulative Impact (Range)		33 - 1125
<b>Typical Cumulative Impact</b>		<b>100 - 1000</b>

## Doing it the right way is the best for everybody.

Do away with the 2-rem relocation PAG.

Balance all risks appropriately inclusive of that from radiation exposure.

Don't be over-conservative with prospective dose calculations.

Stop overprotection in all aspects of radiation protection.

Resolve the LNT controversy — especially between the adaptive response and epidemiological views.

**Remember:** we can only measure exposure to individuals, not dose.