Nuclear Detonation Response Training

Radiation Basics

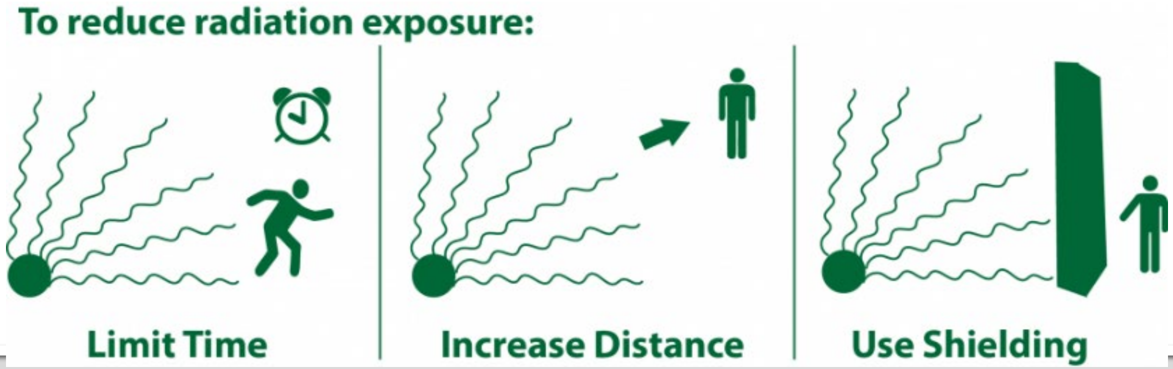
July 2025

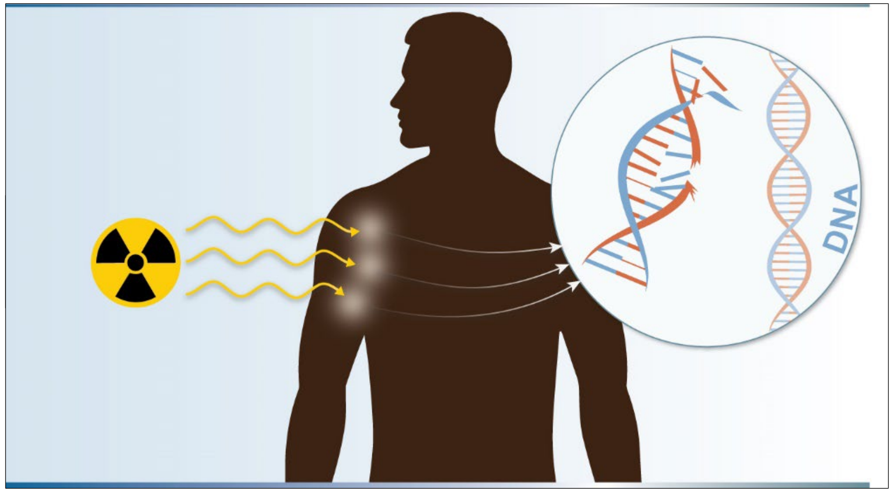
Brooke Buddemeier
Certified Health Physicist
Global Security

Prepared by LLNL under Contract DE-AC52-07NA27344.

Pop Quiz!

- What is radiation?
  - Heat, light, any movement of energy through space
- What is Ionizing radiation?
  - Radiation that can break chemical bonds, damaging DNA causing cell damage and mutations
- How do we detect radiation?
  - Detection and monitoring equipment
- How do we protect ourselves from radiation?
  - Time, Distance, and Shielding





Case Study: Radioactive Source Theft Event in Mexico (December 2013)

- Retired 3,000 curie (111 terabequerels) Co-60 teletherapy source being transported to disposal site was stolen during transport at gunpoint on 2 December 2013
- Considered Category 1 (“extremely dangerous to the person”) by the IAEA.
  - “If not safely managed or securely protected, the source would be likely to cause permanent injury to a person who handled it or who was otherwise in contact with it for more than a few minutes.”
  - “It would probably be fatal to be close to this amount of unshielded radioactive material for a period in the range of a few minutes to an hour.”
- If sold as scrap metal, could significantly contaminate recycled metals and end up in consumer products. Could be mis-used to expose or contaminate the public.
- **<u>Unshielded</u>** source recovered in a corn field on 11 December 2013

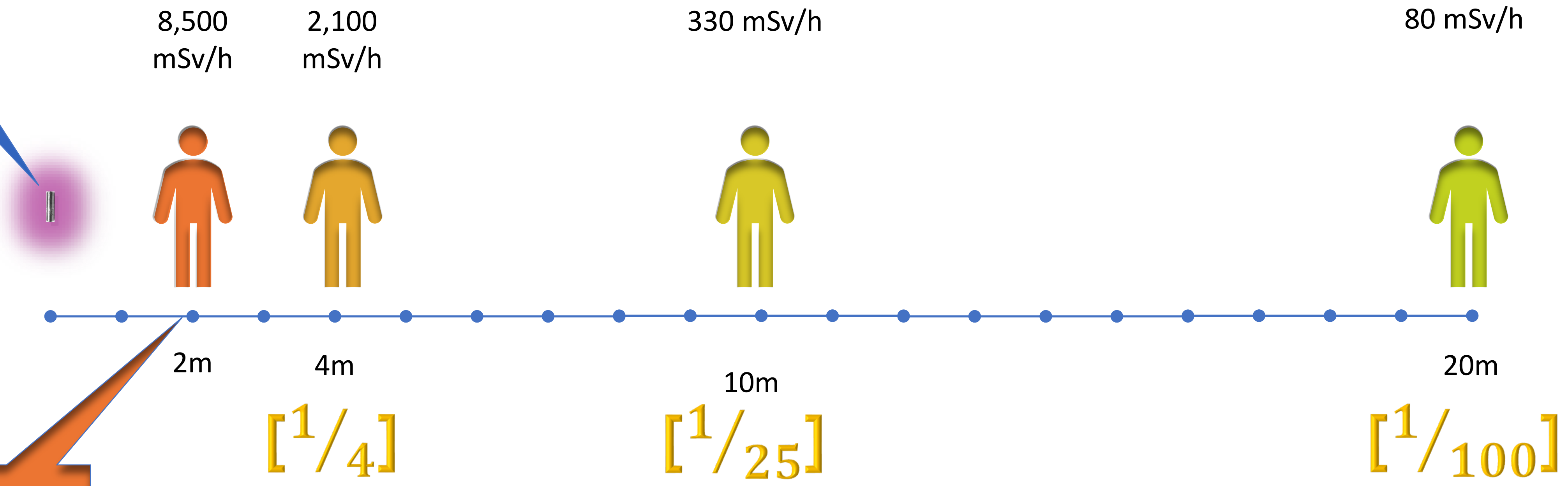
“Recovering a source of that level of intensity is not making enchiladas,” Juan Eibenschutz, executive director of the Nuclear Security and Safeguard Commission

Photo CREDIT: Shelby Leonard/LANL

Exposure Considerations (3,000 Ci Co-60)

3 000 Ci (111 TBq) Co-60

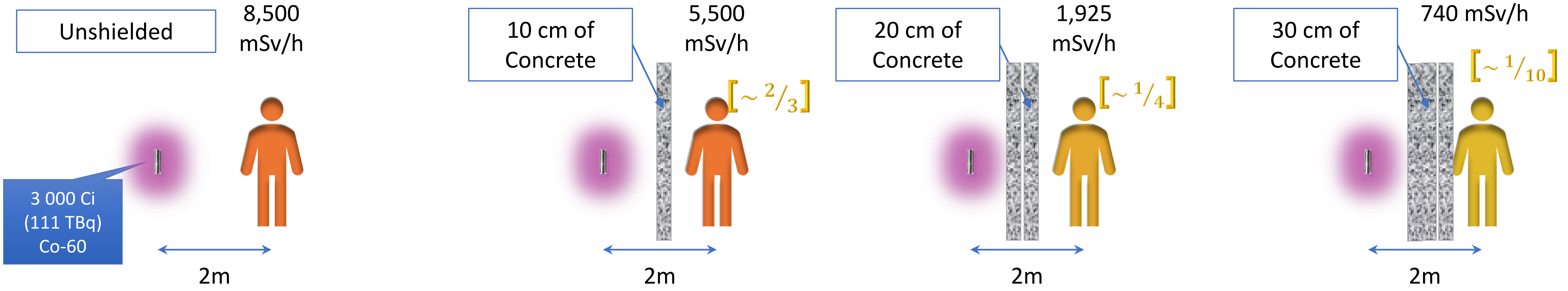
“It would probably be fatal to be close to this amount of unshielded radioactive material for a period in the range of a few minutes to an hour.”



Lethal in 30 min

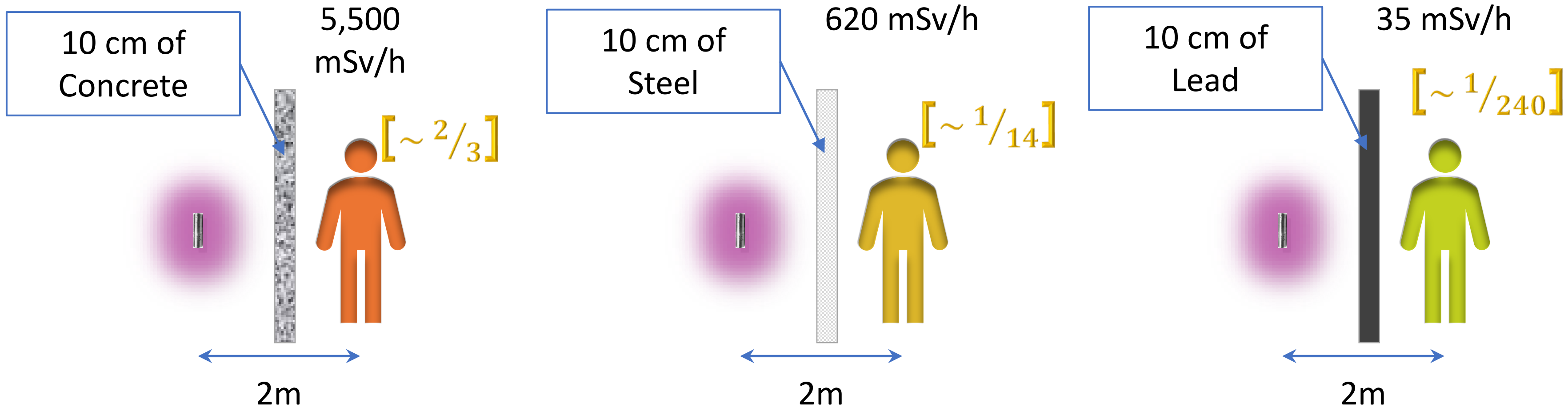
500m was used as an exclusion zone for recovery operations of the 3,000 curie (111 terabequerels) Co-60 source. Dose rates at that distance were ~ 0.025 mSv/h (25 µSv/h or 2.5 mR/h).

Shielding Examples (3,000 Ci Co-60)



The more mass between you and the source, the lower the dose rate. This can be done with:

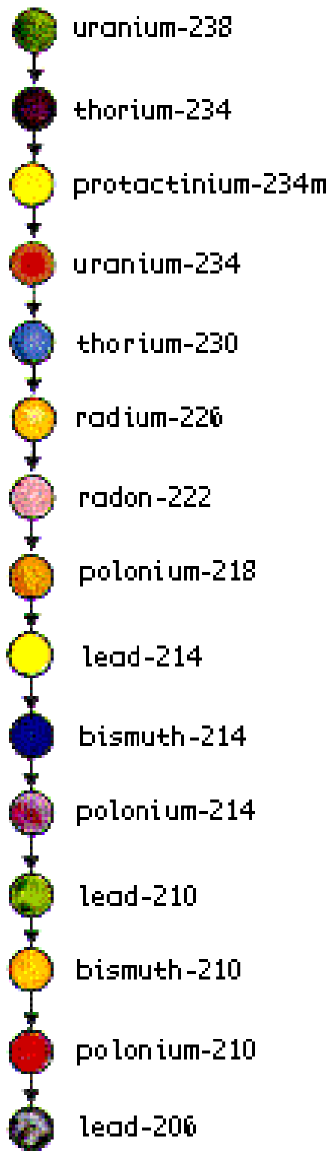
- Thicker walls
- Denser materials



Unstable Atoms Decay

- The number of “decays” that occur per unit time in the radioactive material tell us how radioactive it is. Units include:
    - Curies (Ci),
    - decays per minute (dpm), and
    - Becquerels (Bq or decays per second).
- When an unstable atom decays, it transforms into another atom and releases its excess energy in the form of radiation
- Sometimes the new atom is also unstable, creating a “decay chain”

1 Ci = that quantity of radioactive material in which 37 billion atoms are transformed per second – $3.7x10^{10}$ disintegrations per second (Bq)



Radiation Forms

- When unstable atoms transform, they often eject particles from their nucleus. The most common of these are:
    - <u>Alpha Radiation</u>

      High energy, but short range (travels an inch in air, not an external hazard)

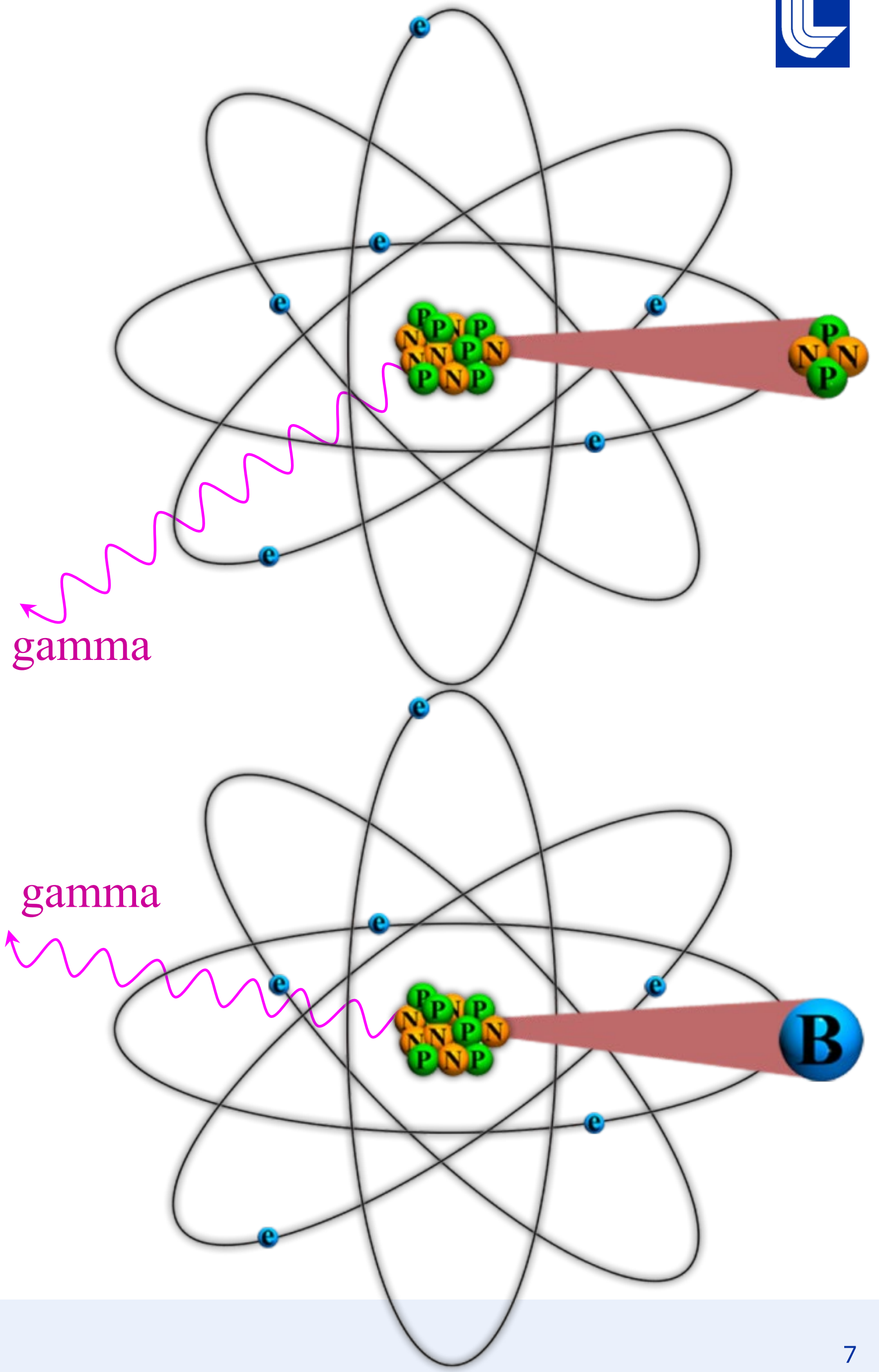
    - <u>Beta Radiation</u>

      Longer range (10 – 20 feet in air) and can be a skin and eye hazard for high activity beta sources.

The "new" nucleus that is formed during the particle emission is often left in an "excited" state, which is why…

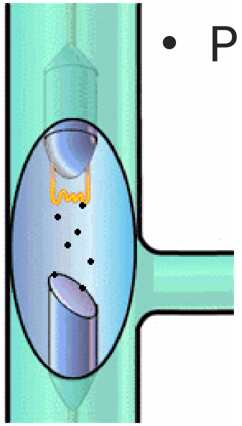
- Gamma Rays (photons)

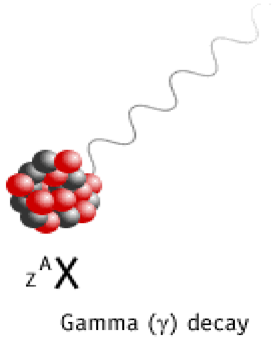
  are produced <u>along with</u> **particle radiation**. This "penetrating" electromagnetic radiation (like light, but with more energy) is an external hazard and can travel 100s of feet in air.

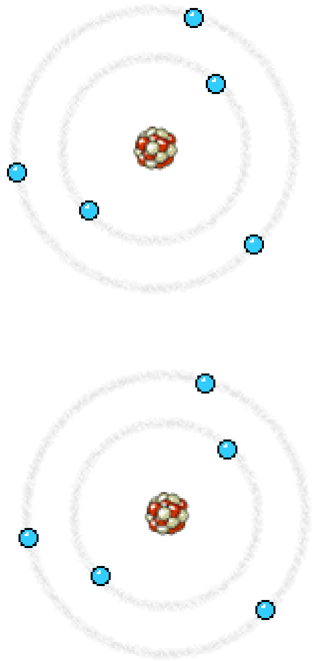


Gamma rays vs. X-rays

- Gamma rays come from the nucleus, usually after a particle (i.e., α, β) decay leaves the nucleus in an excited state.
- X-rays come from the electron cloud of an atom. X-rays can be made many ways:
  - Atomic de-excitation after decay
  - External radiation knocks out an election
  - Projectile electron is redirected / slowed by the nucleus (Bremsstrahlung radiation)







The latter two production methods can be done with machines (X-ray machines)

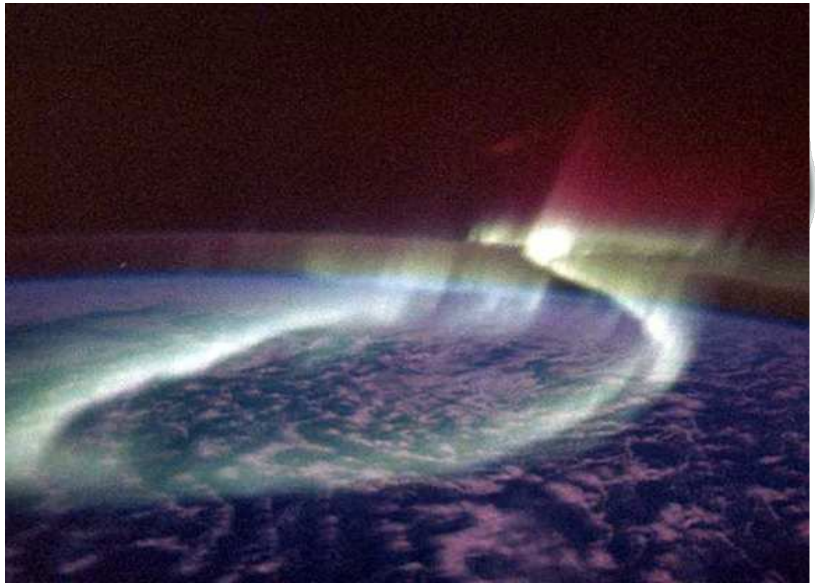
Radioactive Material and Radioactivity

- The radioactivity level of any given amount of radioactive material is constantly decreasing
- The “Half-Life” describes how quickly Radioactive Material decays away with time.
- It is the time required for half of the unstable atoms to decay.

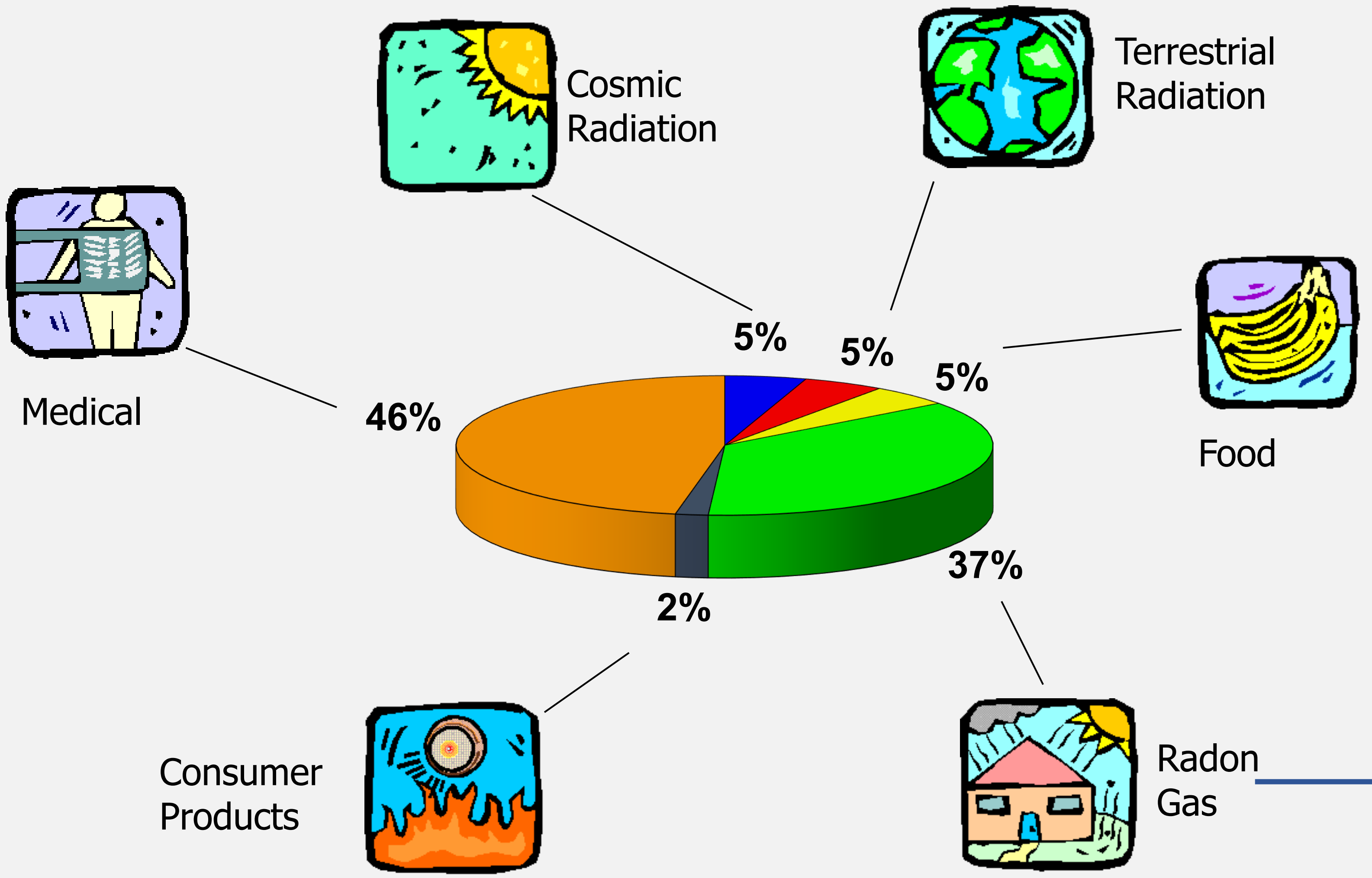
Some radioactive isotopes and their half-life	
Isotope	**Half-Life**
Nitrogen-16	7 seconds
Technetium-99m	6 hours
Thallium-201	73 hours
Cobalt-60	5 years
Cesium-137	30 years
Americium-241	432 years
Uranium-238	4.5 billion years

Radiation and Radioactive Material are a Natural Part of Our Lives

- We are constantly exposed to low levels of radiation from outer space, earth, and the healing arts.
- Low levels of naturally occurring radioactive material are in our environment, the food we eat, and in many consumer products.
- Some consumer products also contain small amounts of man-made radioactive material.



U.S Annual Average - 620 mrem



type of radiation	nuclide	half-life
	uranium-238	4.47 billion years
α		
	thorium-234	24.1 days
β		
	protactinium-234m	1.17 minutes
β		
	uranium-234	245000 years
α		
	thorium-230	8000 years
α		
	radium-226	1600 years
α		
	radon-222	3.823 days
α		
	polonium-218	3.05 minutes
α		
	lead-214	26.8 minutes
β		
	bismuth-214	19.7 minutes
β		
	polonium-214	0.000164 seconds
α		
	lead-210	22.3 years
β		
	bismuth-210	5.01 days
β		
	polonium-210	138.4 days
α		
	lead-206	stable

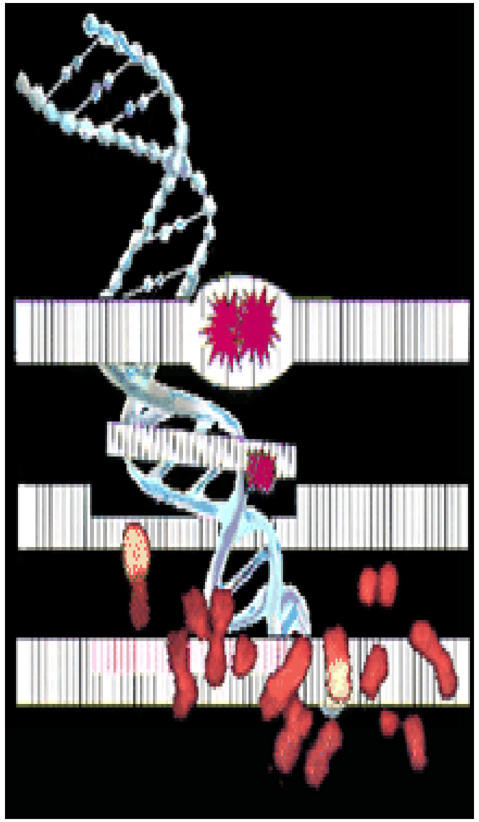
The Amount of Radiation Produced by Different Radionuclides is Related to Decay Rate NOT Size

- **Specific activity** is the amount of radioactivity in a gram of material.
- Radioactive material with long half-lives have low specific activity.

1 gram of Cobalt-60 has the same activity as 1,730 tons of natural Uranium

Our Bodies Are Resilient

- DNA damage is most important and can lead to cell malfunction or death.
- Our body has ~ 60 trillion cells
  - —Each cell takes "a hit" about every 10 seconds, resulting in tens of millions of DNA breaks per cell each year.
  - —BACKGROUND RADIATION causes only a very small fraction of these breaks (~ 5 DNA breaks per cell each year).
- Our bodies have a highly efficient DNA repair mechanisms



At HIGH Doses, We KNOW Radiation Causes Harm

- High Dose effects seen in:
  - Radium dial painters
  - Early radiologists
  - Atomic bomb survivors
  - Populations near Chornobyl
  - Medical treatments
  - Criticality accidents

- In addition to radiation sickness, increased cancer rates were also evident from high level exposures.

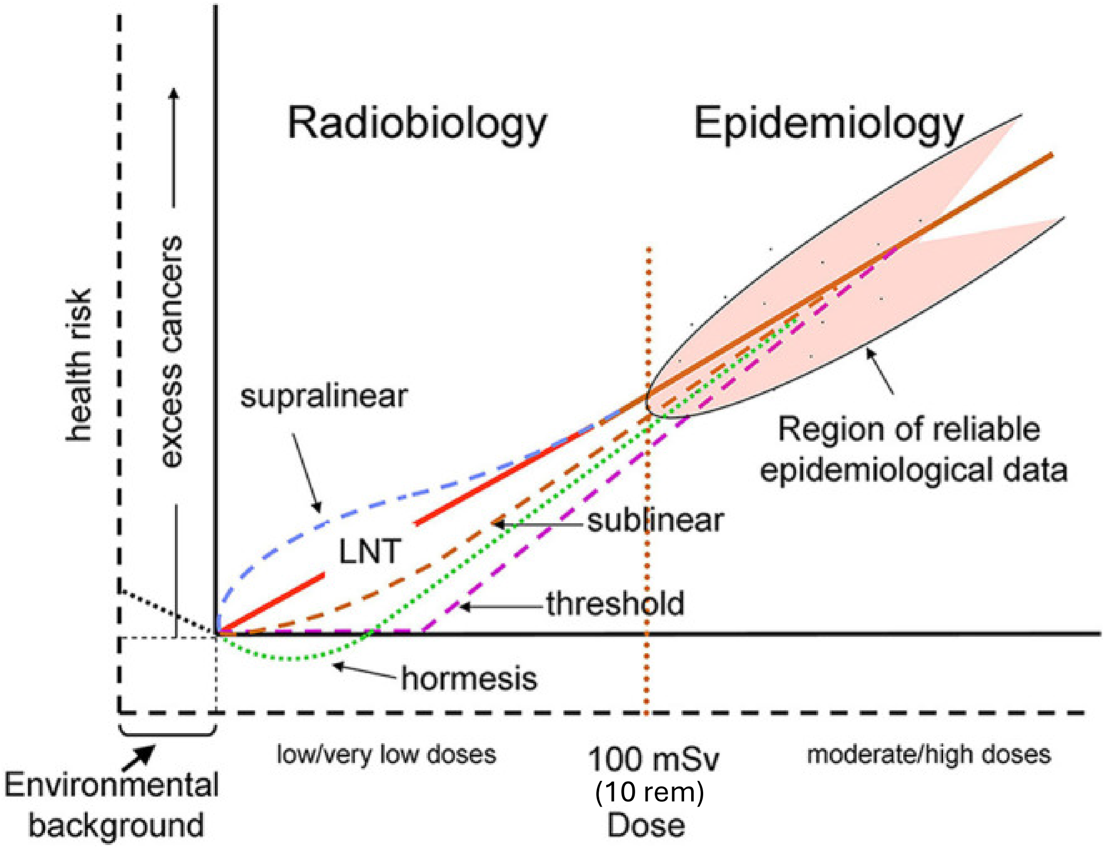
At LOW Doses, We PRESUME Radiation Causes Harm

Below 100 mSv (10 rem) the risks of health effects are either too small to be observed or are nonexistent.

Several different possible dose-response relationships are shown.

We presume there may be some small increased risk, even if not measurable, and that the risk is proportional to the dose.

This conservative approach is known as the ***Linear, No Threshold Model***.



The Bad News: Radiation is a carcinogen and a mutagen

The Good News: Radiation is a <u>very weak</u> carcinogen and mutagen!

Image credit: Belli M, Indovina L. The Response of Living Organisms to Low Radiation Environment and Its Implications in Radiation Protection. Frontiers in Public Health. 2020; 8:601711

Dose Rate vs. Dose

- <u>Dose</u> describes the amount of radiation energy deposited in the body

    Measured in:
    Sieverts (Sv) or Gray (Gy)
    For fallout: 1 Sv ~ 1 Gy
    1 Sv = 1000 mSv
    1 Sv = 100 cSv (100 rem)

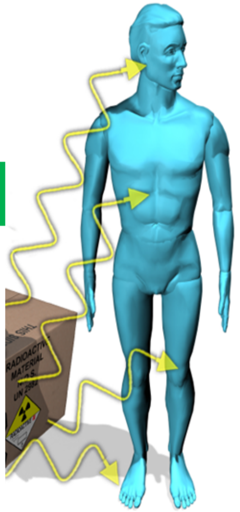
Dose

- The <u>Dose Rate</u> describes how quickly the energy is being deposited

    Measured in:
    mSv/h
    mGy/h

Radiation Exposures (mGy or mSv)

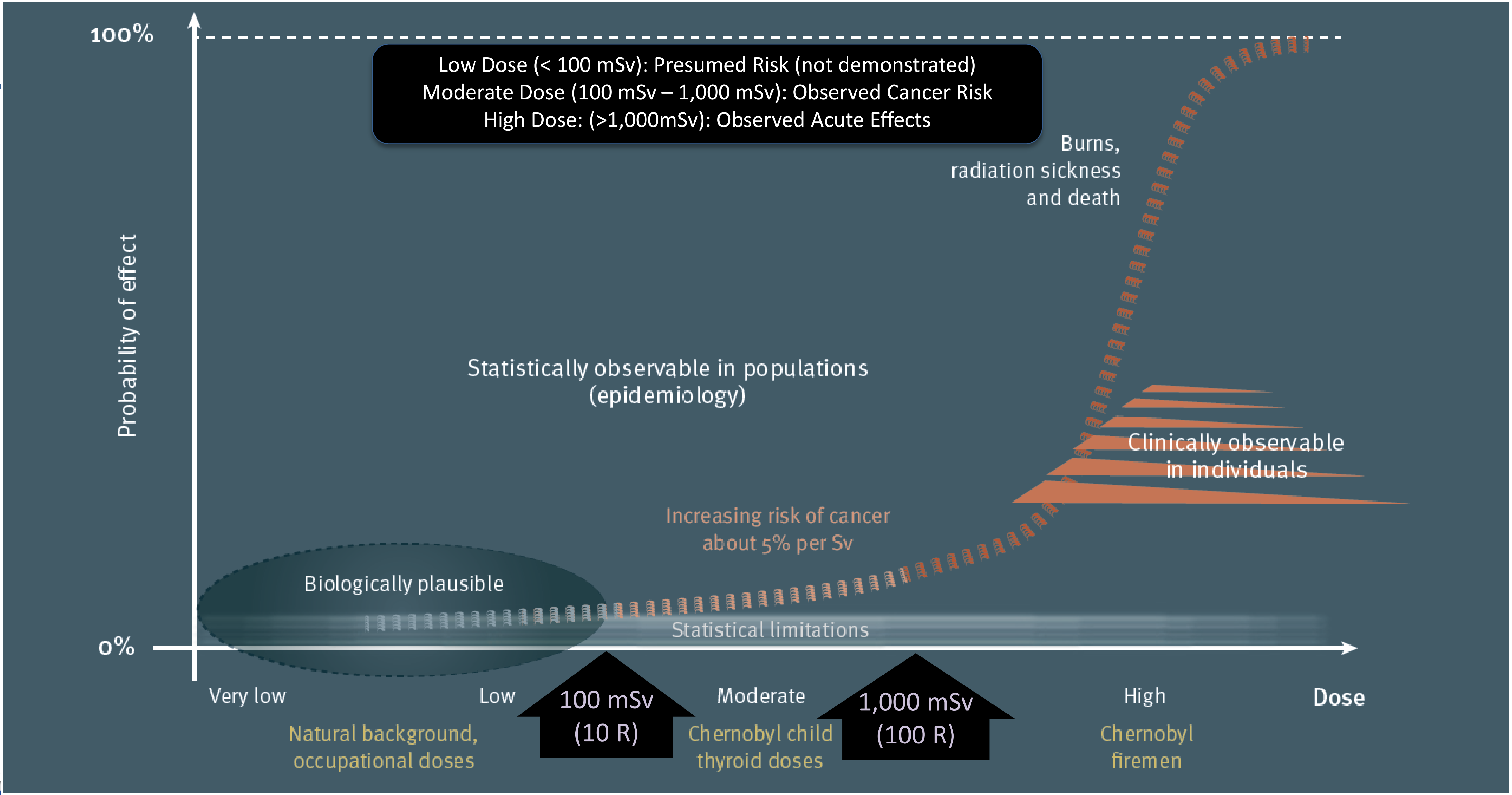
High Dose		**Acute injury or death and higher risk of cancer later in life**
	10,000	Likely fatal within days
	6,000	With medical care, would kill 50% of people within 60 days
	4,000	Without medical care, would kill 50% of people within 60 days
	1,000	Mild signs of Acute Radiation Syndrome. 5% increased cancer risk
Moderate		**No Immediate symptoms. Increased risk of cancer later in life**
	500	NCRP Decision dose for withdrawing responders
	250	EPA reference level for life saving activities
	100	Cancer risk statistically observable
Low Dose		**No symptoms. No detectable cancer risk**
	75	Whole Body CT Medical Exam (average)
	50	Annual radiation worker reference level (US)
	20	Average annual worker reference level (IAEA)
	3	Average annual US background radiation dose
	0.03	Chest x-ray



Doses are often in mGy for Moderate/High Dose, & mSv for Low Dose. For external photon radiation, 1 mGy ~ 1 mSv

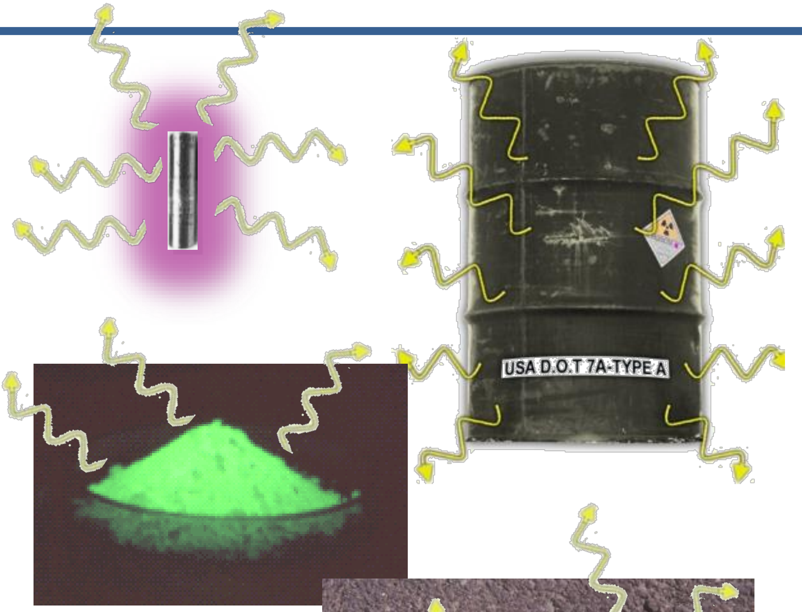
Relationship of radiation doses and health effects

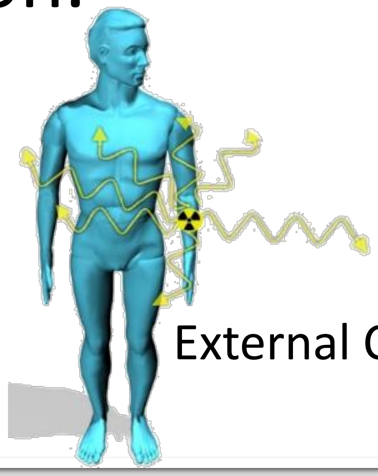
UNEP; RADIATION EFFECTS and SOURCES
http://www.unscear.org/unscear/en/publications/booklet.html?print



Radiation is energy; Contamination is material

- Exposure to ***Radiation*** will **<u>not</u>** contaminate you or make you radioactive.
- ***Contamination*** is loose radioactive material spilled someplace you don't want it.
- Radioactive contamination emits radiation.
- Contact with ***Contamination*** can contaminate you with the material.





External Contamination

Summary of Radiation Hazards (1 of 2)

- Radiation is energy given off by unstable atoms and some machines.
- Radioactive material contains unstable atoms that give off radiation when they "decay."
- Contamination is unsealed (loose) radioactive material spread someplace where you don't want it.
- Being exposed to radiation does not make you radioactive

Summary of Radiation Hazards (2 of 2)

- Radiation damages our cell’s DNA, fortunately our body has very efficient repair mechanisms.
- Large acute doses of radiation (more than 1,000 mSv) can cause sickness or even death. The severity of the effects are proportional to the dose.
- All exposures to presumed to increase the risk of cancer. The amount of “increased risk” is proportional to exposure.

Quiz: Evaluate the Following Statement

Radioactive Contamination is Highly Dangerous and Requires Extraordinary Protective Measures

Fact 1

"Skin or wound contamination is never immediately life threatening to affected people or medical personnel"
~ International Commission on Radiological Protection, report # 96

Quiz: Evaluate the Following Statement

Decontamination of the Patient is the Highest Medical Priority

Fact 2

"rescue and medical emergencies take precedence over radiological concerns"

"..radioactive material contamination rarely represents an immediate danger to the health of the victim or the responder. This reduces the immediacy of the need for decontamination and allows the emergency response community greater flexibility in selecting decontamination options"

~ National Council on Radiation Protection and Measurements, Commentary # 19

Quiz: Evaluate the Following Statement

You need "special skills" to handle radioactive patients

Fact 3

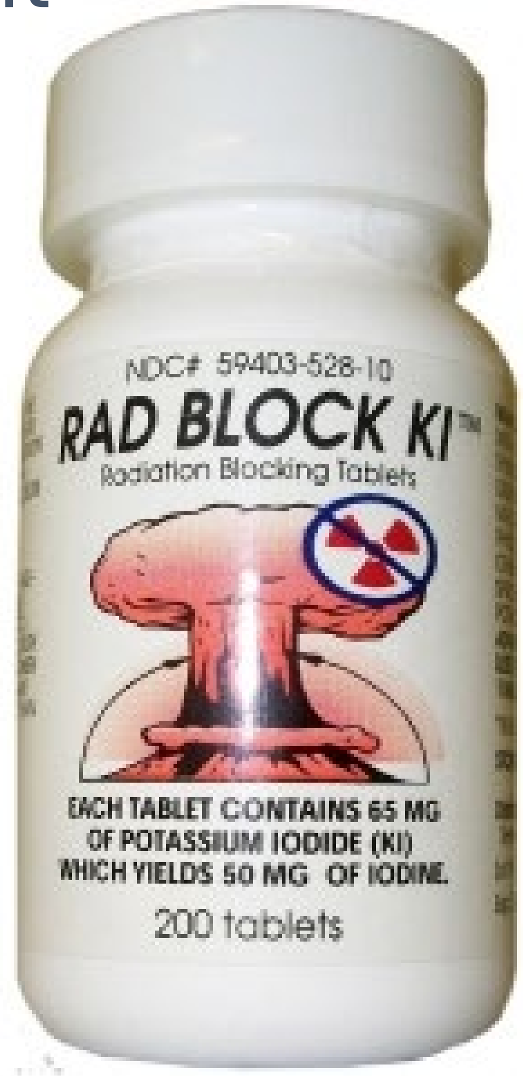
“Universal precautions (i.e., standard hospital personal protection procedures) in the emergency room are generally sufficient for treatment of victims of nuclear and radiological incidents”

~ National Council on Radiation Protection and Measurements, Commentary # 19

- Radioactivity can be easily and immediately measured with radiation meters (e.g., Geiger counters) are needed.
  - They are easy to use
  - Many hospitals already have them
  - Most fire departments now have meters
- Contamination surveys are easily taught and easily performed

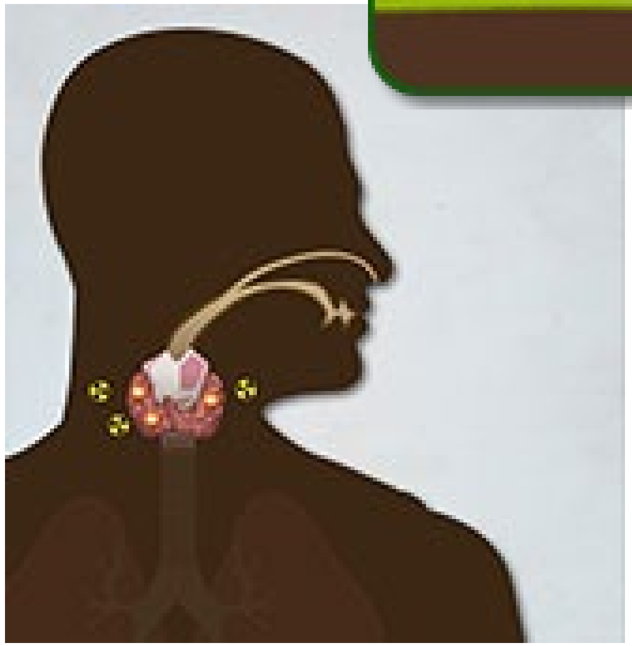
Quiz: Evaluate the Following Statement

Potassium Iodine (KI) Blocks Radiation from Nuclear Detonations



Get the (KI) Facts!

- **Potassium Iodine (KI) only reduces the absorption of radioactive Iodine into thyroid.**
- For a Nuclear Detonation, radioactive Iodine is NOT a significant hazard compared to external radiation.
- KI can be effective for nuclear power plant accidents which are more likely to release significant quantities of radioactive iodine (among other radionuclides).
- When a person takes KI, the stable iodine in the medicine gets absorbed by the thyroid, the thyroid gland becomes "full" and cannot absorb any more iodine, stable or radioactive. It is most effective when taken just before inhaling or ingesting radio-iodine, embargoing contaminated foodstuffs can be just as effective.



Radiation Exposures (mGy or mSv)

High Dose

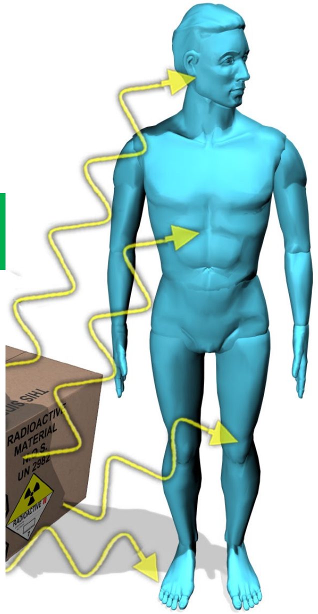
Acute injury or death and higher risk of cancer later in life

10,000	Likely fatal within days
6,000	With medical care, would kill 50% of people within 60 days
4,000	Without medical care, would kill 50% of people within 60 days
1,000	Mild signs of Acute Radiation Syndrome. 5% increased cancer risk

Moderate

No Immediate symptoms. Increased risk of cancer later in life

500	NCRP Decision dose for withdrawing responders
250	EPA reference level for life saving activities
100	Cancer risk statistically observable



Low Dose

No symptoms. No detectable cancer risk

75	Whole Body CT Medical Exam (average)
50	Annual radiation worker reference level (US)
20	Average annual worker reference level (IAEA)
3	Average annual US background radiation dose
0.03	Chest x-ray

Doses are often in mGy for Moderate/High Dose, & mSv for Low Dose. For external photon radiation, 1 mGy ~ 1 mSv

Radiation Exp

High Dose

Acute injury or death and hi

1000	Likely fatal within days
600	With medical care, woul
400	Without medical care, w
100	Mild signs of Acute Radi

Moderate

No Immediate symptoms. I

50	NCRP Decision dose for
25	EPA reference level for li
10	Cancer risk statistically

Low Dose

No symptoms. No detectab

7.5	Whole Body CT Medical
5	Annual radiation worker
2	Average annual worker r
0.3	Average annual US back
0.003	Chest x-ray

Doses are often in rad for Moderate/High Dose, & rem fo