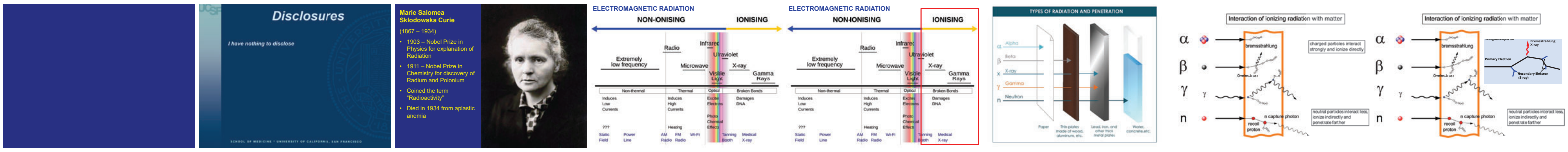
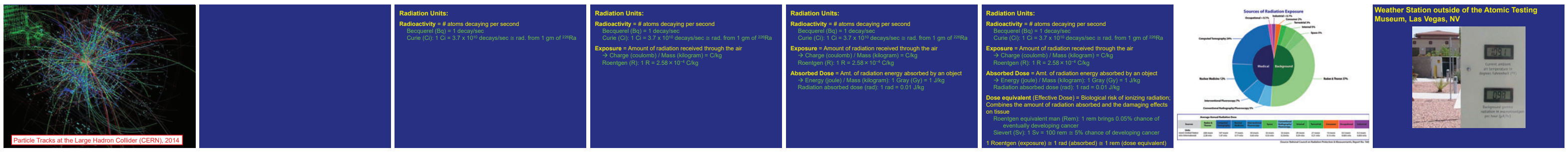
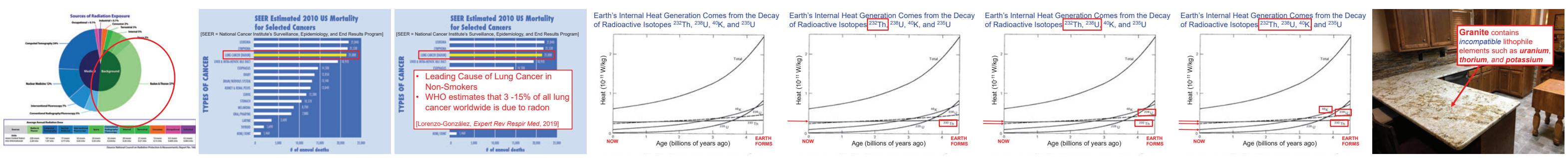
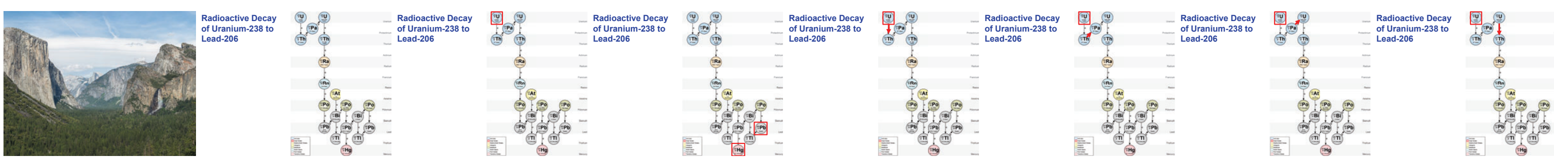
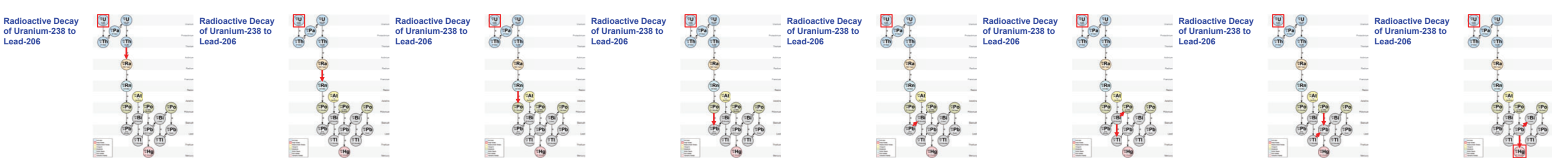

Disclosures
I have nothing to disclose
Marie Salomea Skłodowska Curie
ELECTROMAGNETIC RADIATION
NON-IONISING
IONISING
Interaction of ionizing radiation with matter

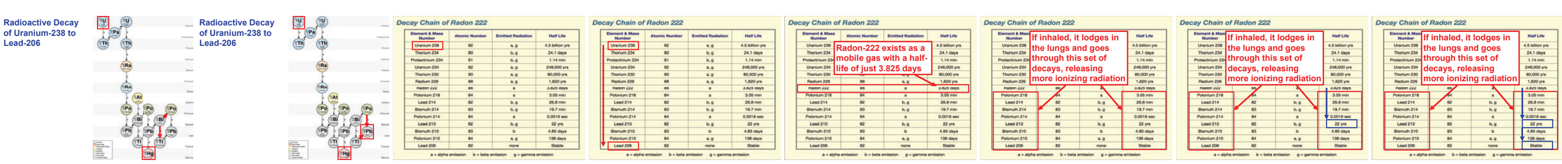

Particle Tracks at the Large Hadron Collider (CERN), 2014
Radiation Units:
Weather Station outside of the Atomic Testing Museum, Las Vegas, NV

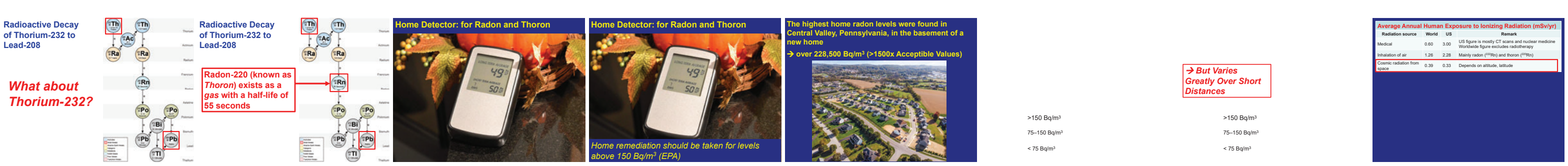

Weather Station outside of the Atomic Testing Museum, Las Vegas, NV
9.8 μR/hr = 0.82 mS/yr (slightly higher than the global average from cosmic and terrestrial sources)
Average Annual Human Exposure to Ionizing Radiation (mSv/yr)


SEER Estimated 2010 US Mortality for Selected Cancers
Leading Cause of Lung Cancer in Non-Smokers
WHO estimates that 3 -15% of all lung cancer worldwide is due to radon
Earth's Internal Heat Generation Comes from the Decay of Radioactive Isotopes
Granite contains incompatible lithophile elements such as uranium, thorium, and potassium


Radioactive Decay of Uranium-238 to Lead-206


Radioactive Decay of Uranium-238 to Lead-206


Radioactive Decay of Uranium-238 to Lead-206
Decay Chain of Radon 222
Radon-222 exists as a mobile gas with a half-life of just 3.825 days
If inhaled, it lodges in the lungs and goes through this set of decays, releasing more ionizing radiation


Radioactive Decay of Thorium-232 to Lead-208
What about Thorium-232?
Radon-220 (known as Thoron) exists as a gas with a half-life of 55 seconds
Home Detector: for Radon and Thoron
Home remediation should be taken for levels above 150 Bq/m³ (EPA)
The highest home radon levels were found in Central Valley, Pennsylvania, in the basement of a new home
over 228,500 Bq/m³ (>1500x Acceptable Values)
But Varies Greatly Over Short Distances
Average Annual Human Exposure to Ionizing Radiation (mSv/yr)

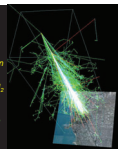
Cosmic Rays: Mostly Ultra-high energy protons from extra-solar system sources (e.g., supernova explosions)

Cosmic Ray Showers

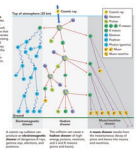
Cosmic Ray Showers

Most health hazards from secondary radiation

→ *Collision of cosmic rays with N_2 and O_2 to form high-energy muons, neutrons, electrons, pions, X-rays, protons*

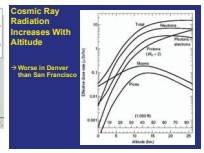


Cosmic Ray Showers



Cosmic Ray Radiation Increases With Altitude

→ Worse in Denver than San Francisco



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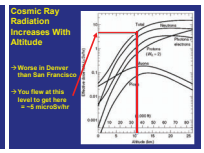
→ Worse in Denver than San Francisco

→ You flew at this level to get here ≈ 6 microSv/hr



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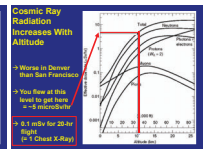
→ 0.1 mSv for 2b-hr flight (≈ 1 Chest X-Ray)



Radiation Exposure: Worse in Space

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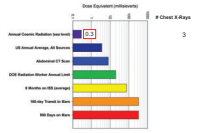

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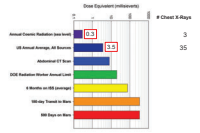

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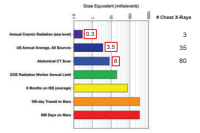

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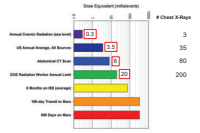

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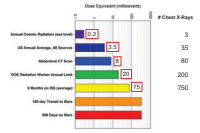

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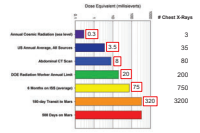

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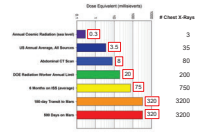
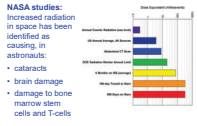
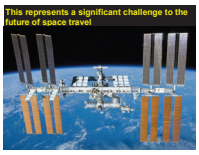


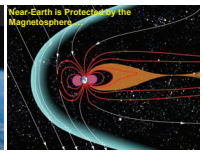
Radiation Exposure: Worse in Space

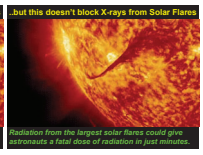
NASA studies: Increased radiation in space has been identified as causing, in astronauts:

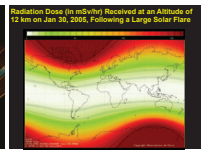
- cataracts
- brain damage
- damage to bone marrow stem cells and T-cells

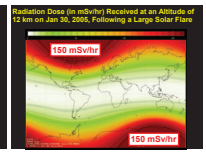


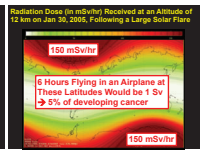


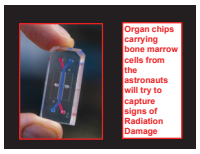












[Dolgin, Science, 2026]

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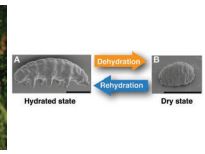
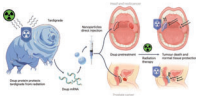
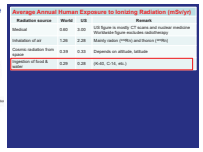


Dsup may also help avoid damage to sensitive healthy tissue during Radiation Treatment of Cancers



[Kirtane et al., *Nature Biomedical Engineering*, 2025]



Average Annual Human Exposure to Ionizing Radiation (mSv/yr)

Radiation source	World	US	Remark
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Consumer items	–	0.13	Cigarettes, air travel, building materials, etc.
Occupational exposure	0.005	0.005	Worldwide is mostly radon in mines US is mostly due to medical and aviation workers
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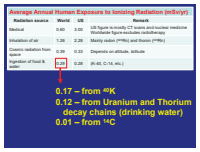

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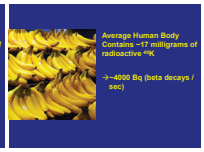
0.17 – from ^{40}K
0.12 – from Uranium and Thorium decay chains (drinking water)
0.01 – from ^{14}C

Average Human Body Contains ~17 milligrams of radioactive ^{40}K



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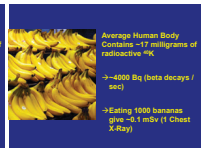
→ ~4000 Bq (beta decays / sec)



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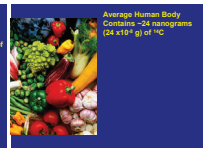
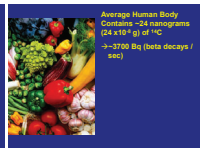
→ ~4000 Bq (beta decays / sec)

→ Eating 1000 bananas give ~0.1 mSv (1 Chest X-Ray)



Average Human Body Contains ~24 nanograms (24 x10⁻⁹ g) of ^{14}C



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→ Important for Evolution!

^{14}Carbon has a half-life of only 5730 years, so why is there any left?

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→ *Made in atmosphere from COSMIC RAYS and solar activity (turning ^{14}N to ^{14}C)*

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Uranium Concentration in Common Materials

USGS

Uranium Oxide (U_3O_8), Found Naturally in Uranium Ore Rocks at Very Low Concentrations (0.05% – 0.30%)

Open-air uranium ore mining pit, Namibia)

Coal Fly Ash → Concentrated Levels of Uranium and Thorium

Kingston Coal Fly Ash Slide

Kingston, Tennessee, December, 2008

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NRC Occupational Dose Limits

Whole Body (TEDE)	50 mSv/yr
Any Organ (TODE)	500 mSv/yr
Skin (SDE)	500 mSv/yr
Extremity (SDE)	500 mSv/yr
Lens of Eye (LDE)	150 mSv/yr
Embryo/Fetus of DPW	5 mSv/yr
Member of the Public	1 mSv/yr

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Nevada Nuclear Test Site

Estimated per capita Iodine-131 thyroid doses from 1951-1962 U.S. atmospheric nuclear tests at the Nevada Test Site (National Cancer Institute)

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Nuclear Power Use Over Time

Nuclear Accidents:

→Over 100 since 1957 (mostly in the US)

→Best known:

1) Three-mile Island, Pennsylvania, March 28, 1979
2) Chernobyl, Ukraine, April 26, 1986
3) Fukushima, Japan, March 11, 2011

Three-mile Island (PA), March 28, 1979

Loss of coolant and partial core meltdown due to operator errors

→ Small release of radioactive gases. No deaths.

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Chernobyl, Ukraine, April 26, 1986

→Core Meltdown

→Evacuation of 300,000

→Radioactive material dispersed across Europe

→56 dead at site

→10-20 mSv (over 20 years for inhabitants)

→Estimate of 16,000 deaths from dispersed radioactivity

Fukushima, Japan, March 11, 2011

→ Tsunami from earthquake flooded failsafe electronics in basement

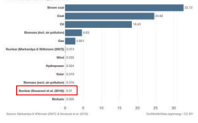
→ Meltdowns and evacuations

→ Total local doses were 1 – 15 mSv

→ 167 cleanup workers received doses above 100 mSv

→ 0 immediate deaths

→ Estimated ~1,500 deaths from exposure over 80 years



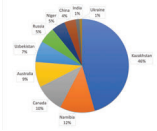
Average Annual Human Exposure to Ionizing Radiation (mSv/yr):

Radiation source	World	US	Remark
Medical	0.60	3.00	US figure is mostly CT scans and nuclear medicine Worldwide figure excludes radiotherapy
Inhalation of air	1.26	2.28	Mainly radon (^{222}Rn) and thoron (^{220}Rn)
Cosmic radiation from space	0.39	0.33	Depends on altitude, latitude
Ingestion of food & water	0.29	0.28	(K-40, C-14, etc.)
Terrestrial radiation from ground	0.48	0.21	Depends on soil and building material
Consumer items	–	0.13	Cigarettes, air travel, building materials, etc.
Occupational exposure	0.005	0.005	Worldwide ave. is 0.7 mSv, mostly radon in mines US is mostly due to medical and aviation workers
Atmospheric nuclear testing	0.005	–	0.11 mSv in 1963, declining since, higher near sites
Chernobyl accident	0.002	–	0.04 mSv in 1986, declining since, higher near site
Nuclear fuel cycle	0.0002		Up to 0.02 mSv near sites, excludes occupational
Other		0.003	Industrial, security, medical, educational, research
Total	3.01	6.24	**mSv/person per year = 62 Chest X-Rays**

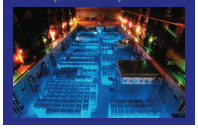
Concentrating uranium ore into pure uranium oxide (U_3O_8) ("yellowcake")

A uranium "pellet," enriched in ^{235}U, ready for a reactor fuel rod

Uranium Production, by Country (2022)



Used control rods are "hot" and need to cool down for ~5 years before they can be removed



Nuclear Waste Storage: Covert, Michigan

In the U.S., Military Radioactive Waste is Buried Deep in the *Waste Isolation Pilot Plant*, East of Carlsbad, NM (Within a NaCl Salt Deposit)

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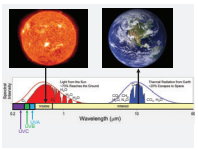
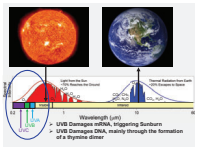
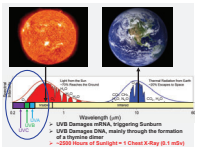
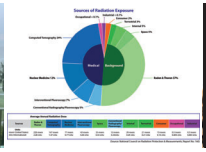




- UVB Damages mRNA, triggering Sunburn
- UVB Damages DNA, mainly through the formation of a thymine dimer



- UVB Damages mRNA, triggering Sunburn
- UVB Damages DNA, mainly through the formation of a thymine dimer
- ~2000 Hours of Sunlight = 1 Chest X-Ray (0.1 mSv)



Radioactive Decay of Uranium-235 to Lead-207

What about Uranium-235?

Radioactive Decay of Uranium-235 to Lead-207

Radon-223 exists as a gas with a half-life of just 3.96 seconds!