Radioactive Materials: Regulators, Health Impacts

“During the whole of the next day we proceeded on our journey through this interminable gallery, arch after arch, tunnel after tunnel.”

—Henry Lawson in “Journey to the Center of the Earth” by Jules Verne.

Radioactive Material Regulators

Who's in Charge?
U.S. Nuclear Regulatory (NRC) Commission (http://www.nrc.gov/)

Chairman Christopher T. Hanson

***Issues licenses.**
***Enforces standards.**
***Regulates possession, transportation, and disposal of commercial radioactive wastes.**

Radioactive Material Regulators

U.S. Department of Energy (U.S. DOE)
(https://www.energy.gov/)

***Conducts research and development for waste disposal.**

***Assists LLRW disposal programs.**

***Manages defense-related (transuranic) wastes**

***Slated to manage used nuclear fuel disposal sites when and if they open.**

***Manages surplus plutonium.**

Secretary Jenny Granholm

Radioactive Material Regulators

U.S. Environmental Protection Agency (EPA)

http://www.epa.gov/

***Provides radiation protection standards**

***Risk assessments of radionuclides in soil, water, air, and food.**

***NCR regulates waste disposal using U.S. EPA criteria.**

Michael S. Regan

Radioactive Material Regulators

U.S. Department of Transportation

https://www.transportation.gov/

Regulates the transportation of radioactive materials, low-level radioactive wastes, transuranic wastes, spent nuclear fuel, and hazardous wastes.

Pete Buttigieg


Nuclear Regulatory Commission...
• Enforces standards
• Grants or denies licenses
• Inspects
• Regulates shipping casks
• Interacts with State, Tribal, and Local authorities
Department of Energy...
Designs, constructs, and operates a repository
Department of Transportation...
• Regulates transportation of waste
• Enforces requirements on shippers, routing, and vehicles
• Interacts with State, Tribal, and Local authorities
Environmental Protection Agency...
• Establishes standards

Regulation in Illinois

In Illinois, we have the Division of Nuclear Safety (DNS) which is part of the Illinois Emergency Management Agency (IEMA).

***Inspect radioactive material licensees.**

***Inspect and register medical radiation equipment.**

***Monitor the 11 power reactors at the 6 power plants for electricity (such as LLRW).**

***Escort used nuclear fuel shipments.**

https://iema.illinois.gov/

Radioactive Materials and Health

Acute radiation symptoms

Nausea, vomiting, diarrhea, bleeding, coma, and then death.

Gamma Radiation

Erythema (skin redness).

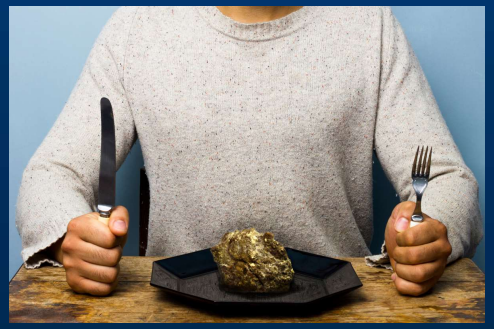
Ulceration (skin sores that heal slowly—if at all).

Tissue necrosis (dead skin).

Uranium and Health Issues

Uranium is present in most naturally occurring solid and liquid media in trace concentrations.

We ingest and inhale uranium from the air, water, food, and soil. People consume about 1 to 2 micrograms (0.6 to 1.0 picocuries) of natural uranium every day with their food.



Uranium and Health Issues

When we consume uranium, we also consume the daughter-decay products:

$^{238}U \rightarrow {}^{234}U \rightarrow {}^{230}Th \rightarrow {}^{226}Ra \rightarrow {}^{222}Rn \ldots$

$^{232}Th \rightarrow {}^{228}Ra \rightarrow {}^{228}Th \rightarrow {}^{224}Ra \rightarrow {}^{220}Rn \ldots$

In drinking water, most occur in the pCi/L-level.

What happens next?

Uranium and Health Issues

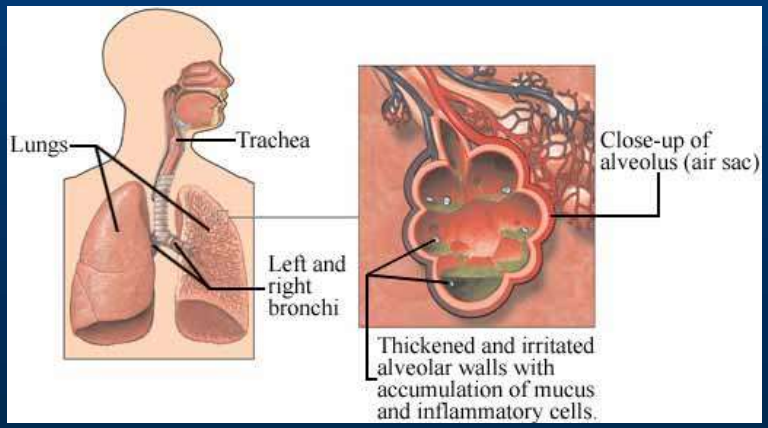
Absorption of U from the intestinal tract may range from < 0.2% to 3%.

The rest of the U leaves the body in feces.

About 90% of the absorbed U will be eliminated by the kidneys while the remainder will accumulate in the skeleton with a biological half-life of about 300 days.

Radioactive Wastes and Health

If you breathe uranium particles, the smaller particles are inhaled down to the lower part of your lungs. Depending on the solubility of the particle, they may dissolve slowly, they remain there for years, causing most of the radiation dose to the lungs from the inhaled uranium.



Uranium and Health Issues

Most people have a very small amounts of uranium, about 1/5,000th of the weight of an aspirin tablet, in their bodies, mainly in their bones.

From the Agency for Toxic Substances and Disease Registry (ATSDR), an agency of the U.S. Department of Health and Human Services.

http://www.atsdr.cdc.gov/

Occupational Exposure

No definitive evidence has been found that links human deaths to uranium exposure.

Among uranium miners, death rates from diseases of the cardiovascular system and the urogenital system were decreased when compared to other populations.

Occupational Exposure

Uranium miners have greater-than expected rates of death from lung cancer; however, attributed to the radiological effects of radon and its decay products, which are progeny of uranium and, therefore, present in uranium mines.

Radium and Health Issues

Radiotoxicity of radium

^{226}Ra yields 1 Ci per gram of metal.

^{228}Ra yields 280 Ci per gram of metal.

99% of all radium is ^{226}Ra which emits 4.8 MeV energy of alpha particles.

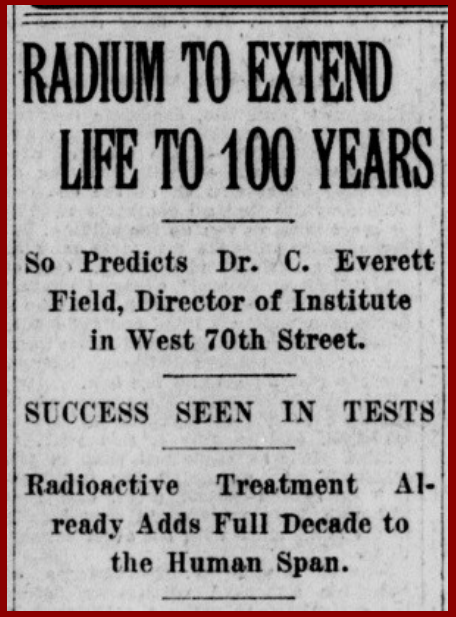
Radium and Health Issues

About 80% of ingested Ra will leave the body in feces. The remaining 20% will enter the bloodstream.

Like calcium, a large fraction is preferentially deposited in bone and teeth. Release from bones in humans takes years, if not a lifetime.

Radium and Health Issues

During the early part of the 20th century in the U.S., radium was thought to be a cure for "high blood pressure, cancer, goiter, stomach trouble, arthritis, female troubles, rheumatism, kidney trouble, constipation . . ."



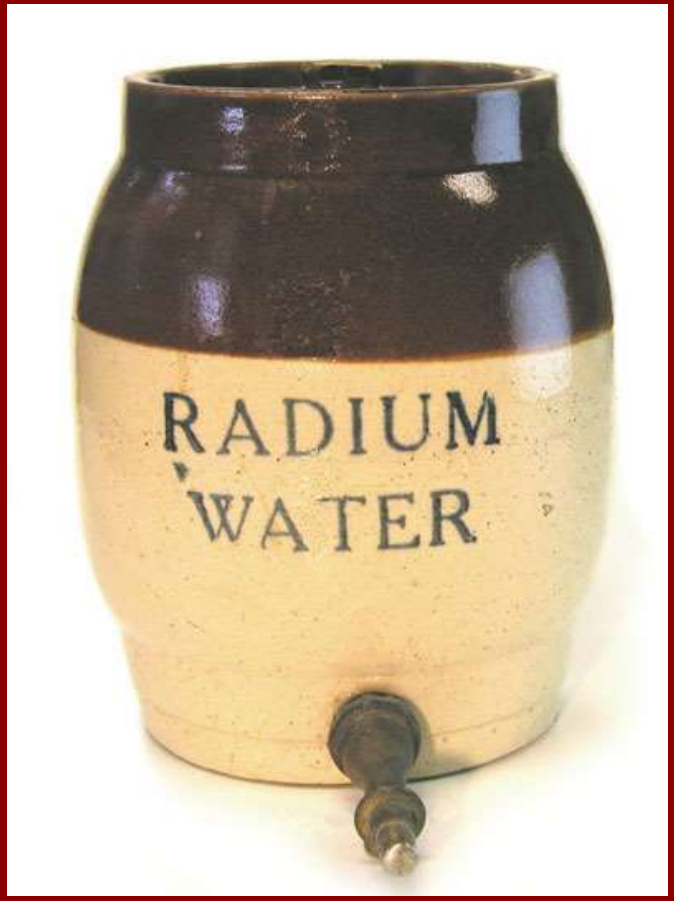
RADIUM TO EXTEND LIFE TO 100 YEARS

So Predicts Dr. C. Everett Field, Director of Institute in West 70th Street.

SUCCESS SEEN IN TESTS

Radioactive Treatment Already Adds Full Decade to the Human Span.

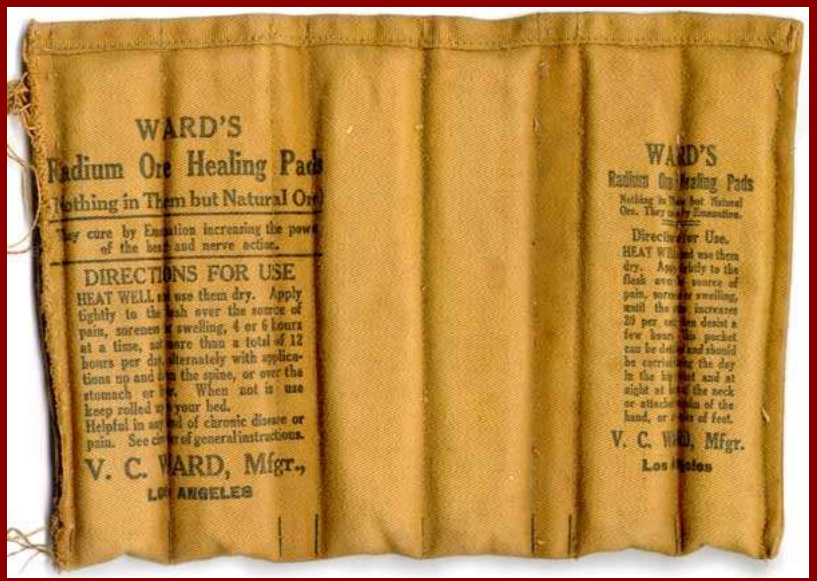
“Radium cures” (c. 1928)

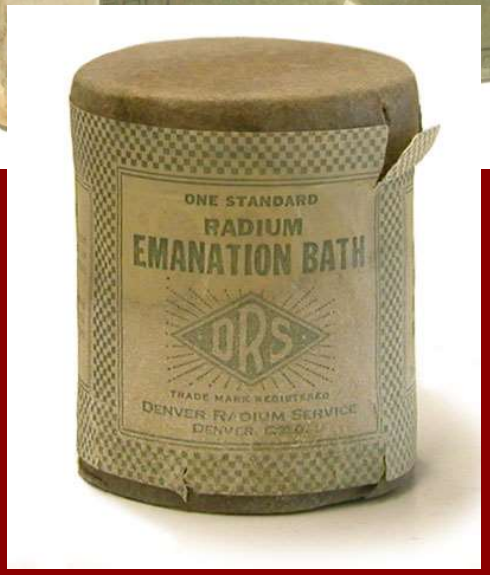


“Radium cures (c. 1928)”

Contained 1 mCi of ^{226}Ra and ^{228}Ra per 0.5 ounce.
Consumed by Eben Byers, owner of a steel company.
He consumed 3 bottles a day for three years.
Teeth fell out. His upper jaw and most of his lower jaw had to be removed. He died at the age of 51 in 1932.

Other radium cures (c. 1915 to 1935)





The story of the “Radium Girls”

The Radium Girls were a group of female factory workers who ingested radium from painting watch dials with glow-in-the-dark paint.

Two examples:

The United States Radium factory in New Jersey from 1917 to 1926.

The Radium Dial Company in Ottawa, Illinois.

The story of the “Radium Girls”

Early 1920s: dentists observed increased occurrences of jaw necrosis; bone decay.

1922-1924: Four dial painters died of jaw necrosis.

1925: Possibly first suggestion that jaw decay linked to dial painting.

U.S. Radium Corporation hired a fake doctor.

The story of the "Radium Girls"

Five of the women challenged the system in a court case that established the right of individual workers who contract occupational diseases to sue their employers. All died by the 1930s

Body content measurements from 27 dial painters were made. This information was used in 1941 by the National Bureau of Standards to establish a tolerance level for radium as 0.1 μCi (3.7 kBq).

PAGE 1 HERALD EXAMINER

Woman Tells How Radium Dooms Her

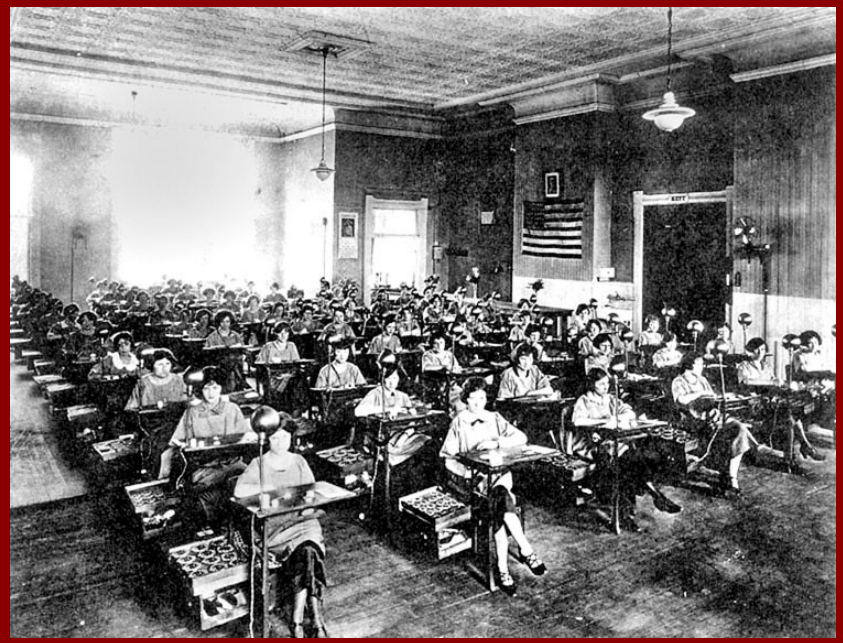
Collapses as Doctor Prepares to Predict Fatality

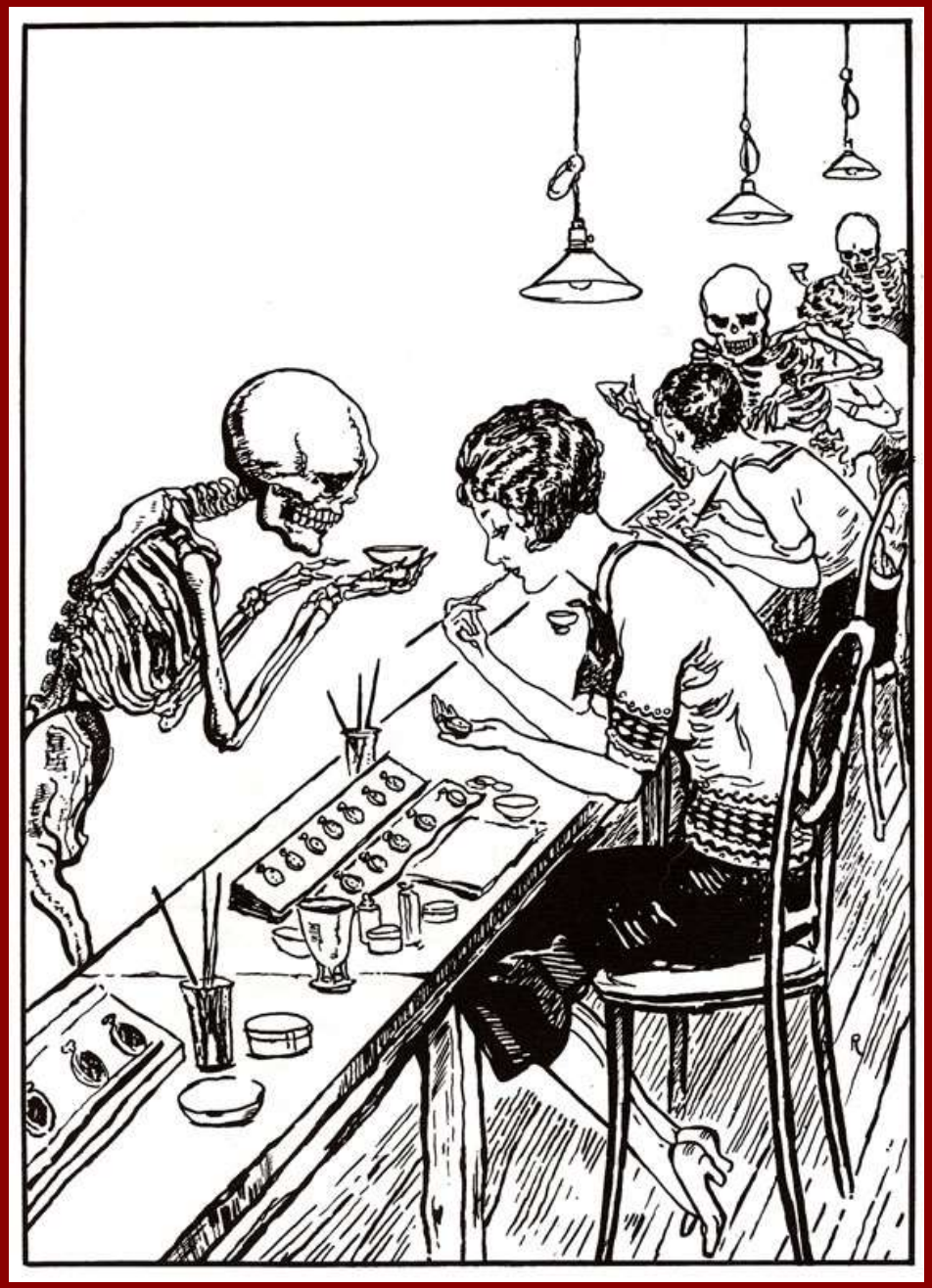
To Finish Recital if—'She Is Alive'

MRS. CATHERINE DONOHUE, RADIUM POISON VICTIM, JUST AFTER SHE COLLAPSED. Her husband, Thomas Donohue, comes to her aid during hearing on compensation for injuries.

Radium girls in Ottawa Illinois

Radium Dial, Inc. began operation in 1916. Moved to a second building in 1930 and changed their name to Luminous Processes, Inc. During World War II, the company prepared luminous dials for the military. Again, the workers were not told about potential health affects (suspected by 1925).





367,797

DAILY TIMES

CHICAGO'S PICTURE NEWSPAPER

LATE PICTU

Vol. 8. No. 258 WEDNESDAY, JULY 7, 1937 TWO CENTS

RADIUM DEAT
ON RAMPAGE!

(Story

DOOMED TO TORTURED, HORRIBLE DEATH!—Marked for death from "radium poisoning" contracted while an emplo
Radium Dial Co. of Ottawa, Ill., Mrs. Charlotte Purcell, 31, 6749 S. Halsted st., lives in daily fear of end that is inevitable. Y
lawyer hence of collecting damages along with 14 other doomed women workers—at hearing before Illinois industrial comm
July 25 at Ottawa—may bring only $667. (Story on page 3)

The end of the Ottawa Radium girls

By 1934, seven women were called the "Ottawa Society of the Living Dead." More joined with time.

The radium-contaminated buildings in Ottawa were demolished in 1969 and 1984, but radium contamination was detected at 16 locations in Ottawa. 13 have been remediated.

See https://www.atsdr.cdc.gov/hac/pha/ottawaradiationareas/ottawaradiationareaspha072506.pdf

The Radium Girl in Ottawa, Illinois

Plutonium and Health Issues

Radiotoxicity of Plutonium

^{241}Pu yields 104 Ci per gram of metal

^{238}Pu yields 17.3 Ci per gram of metal

Most plutonium isotopes generally release > 5 MeV alpha particles and < 20 keV gamma and x-rays as they transform into uranium.

Plutonium and Health Issues

If ingested, very little Pu (~ 0.05%) is absorbed from the gastrointestinal tract.

Very little Pu enters the body by dermal contact (unbroken skin).

Breathing Pu-contaminated air is the greatest threat to human health.

$^{239}PuO_2$, is only moderately soluble in water, which results in long-term retention in the lung following inhalation exposure.

Plutonium and Health Issues

Some Pu will remain in the lungs and will eventually migrate to bones and the liver.

Pu leaves the body slowly via urine and feces. If Pu enters your lungs today, a portion of it will still be present in the body 30 to 50 years later.

Plutonium and Health Issues

Plutonium is carcinogenic:

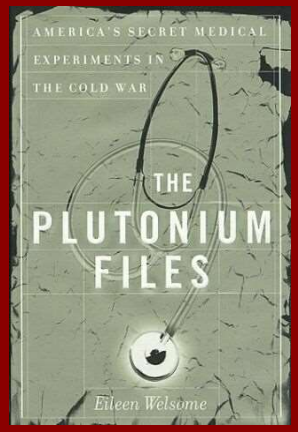
Cancers of the lungs, bone and liver

Pu impairs the immune system.

Birth defects? No clear evidence.

"In the 1957, Queen Elizabeth II was visiting the Harwell [Laboratory], and was handed a lump of plutonium in a plastic bag and invited to feel how warm it was"

"The Plutonium Files"



Human experiments with Pu on humans during 1940s to the 1960s. Crude experiments to use Pu as a "magic bullet" to cure cancer and other diseases. Sponsored by the Atomic Energy Commission and the Department of Defense.

Often conducted in secret.

Patients were not always informed as to what was being given to them or why.

Plutonium and Health Issues

The National Academy of Sciences recommended a model in which there is a 15-year latent period following inhalation exposure to Pu in which there are no effects, followed by a 30-year period in which there is a constant risk of:

1.3 chance per million per year per rem for lung cancer.

1.0 chance per million per year per rem for bone cancer.

Plutonium and Health Issues

0.3 chance per million per year per rem for GI and liver cancer from Pu.

If one inhales 10 μg of Pu-239, you may have a 1 in 130 chance of developing cancer as a result.

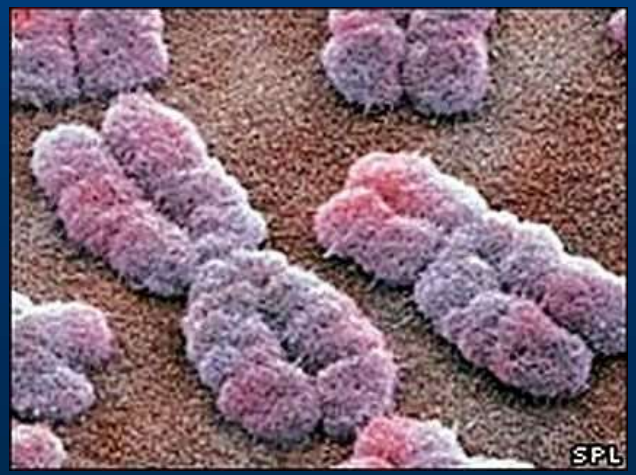
No studies are known regarding death or lifespan shortening in humans after oral exposure to plutonium.

Occupational Exposure

No conclusive evidence that plutonium produces genetic damage in humans (alteration or mutation of reproductive cells).

Some studies suggest evidence of dose-related increases in chromosomal damage in plutonium workers who have with measurable levels of Pu

in their bodies.



Cesium and Health

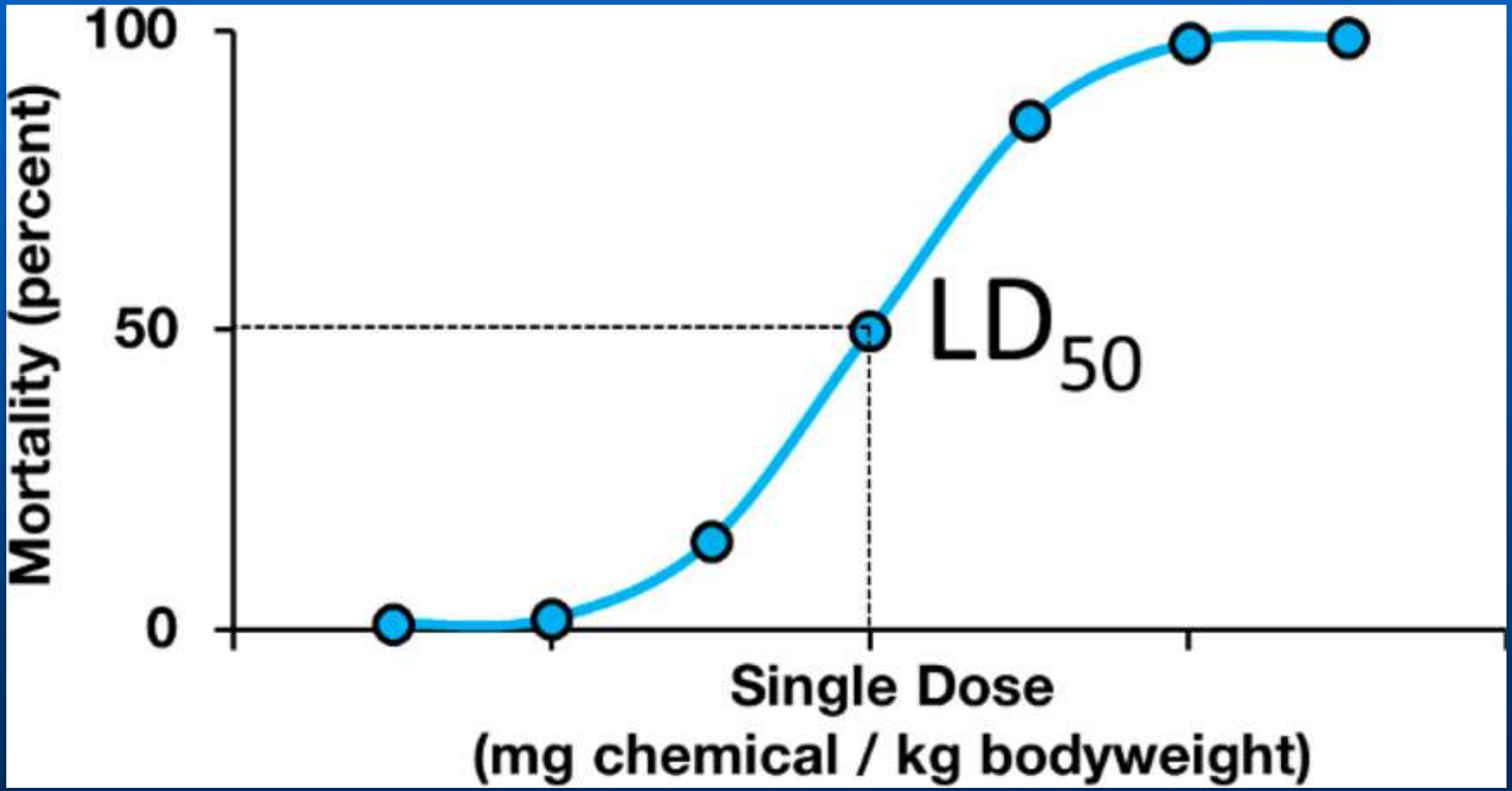
^{137}Cs decays to ^{137}Ba with a half-life of 30.23 ± 0.16 years.

$$^{137}Cs \rightarrow {}^{137m}Ba + \beta^-$$

$$^{137m}Ba \rightarrow {}^{137}Ba + \gamma$$

Low toxicity to animals: acute oral LD_{50} for mice and rats range from 800 to 2,000 mg Cs/kg of the animal.

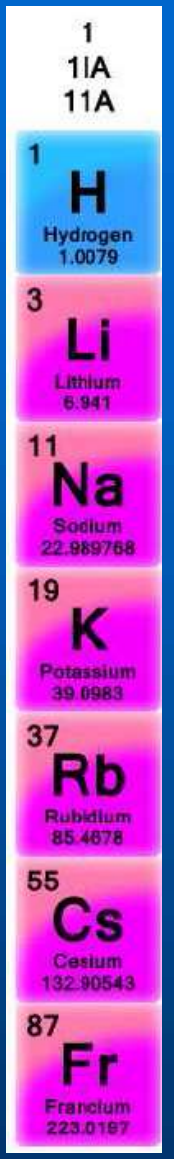
Lethal Dose$_{50}$ defined



Cesium and Health

Soluble forms of cesium are absorbed by the GI tract. Absorbed cesium behaves like potassium.

^{137}Cs is absorbed by dermal contact. If inhaled, ^{137}Cs will become rapidly distributed throughout the body via blood circulation.



Cesium and Health

In a study in which 10 healthy volunteers were fed ^{134}Cs- and ^{137}Cs-contaminated food: 6% eliminated with a half-life of 0.3 day, 95% eliminated with a half-life of 90 days.

Once cesium enters the body, kidneys begin to remove it from the blood; some cesium is quickly released in the urine. A small portion is also released in the feces.

Cesium in the environment

The maximum concentration of ^{137}Cs in pasteurized milk from 65 cities in the United States was 14 pCi/L in May 1989

(*Chernobyl was in 1986*)

NRC effluent concentrations (limits) for ^{137}Cs is 1,000 pCi/L in water and 0.2 pCi/L of air

Tritium and Health

Toxicity of Tritium (^3H)

One proton and two neutrons

Decays as $^3H \rightarrow {}^3He + \beta^- + \text{anti-}\eta$

Half-life of 12.26 years

By-product of neutron absorption by boron.

Occurs naturally in surface water; 10 to 30 pCi/L

Tritium and Health

^3H_2O is indistinguishable from ordinary water, and it moves like water in the environment. It is mobile like water.

^3H can enter the body by drinking water or breathing air containing ^3H gas or as ^3H_2O vapor.

Will be completely absorbed into the bloodstream.

Tritium and Health

Become uniformly distributed throughout all biological fluids within one to two hours

Has a biological half-life of about 10 days (can be shortened to 4 to 8 hours using dialysis machines).

As with all beta sources, the major health concern is cell damage caused by ionizing radiation with a potential for future cancer growth.

Tritium and Health

The U.S. EPA decided that the Maximum Contaminant Level (MCL) of ^{3}H in drinking water is 20,000 pCi/L.

The life-time cancer mortality risk factor for ingesting ^{3}H is 4.4×10^{-14}/pCi.

What does this mean?

Suppose that you drank well water containing the MCL of ^{3}H during your entire life. Would this harm you?

If you consumed water with tritium . . .

20,000 pCi/L x 2L/day x 365 days/year x 78.2 years/life time = 1.1417×10^{9} pCi

1.1417×10^{9} pCi x 4.4×10^{-14}/pCi = 5.0236×10^{-5} or 1 chance in 19,906 of death by cancer because of consuming this much tritium. Is this risk acceptable?

If you consumed water with tritium . . .

Another example,

If a residential drinking water well contained 1,600 pCi/L of $^{3}H_2O$, the radiation dose would be about 0.3 mrem per year. This dose is about 1,000 times less than background levels.

Nuclear power plants routinely release tritiated water. The U.S. NRC release limit of $^{3}H_2O$ is 3 mrem per year.

Lifetime risk of death by cancer from ingesting contaminated water

Estimated mortality = concentration in water (pCi/L) x 2L/day x 365.4 days/year x 78.2 years x risk coefficient x the number of people.

Risk Coefficients. "The U.S. EPA has developed mortality risk coefficients for nearly all radionuclides to estimate the lifetime risk of incurring by a fatal cancer from environmental exposures ."

U.S. EPA Risk coefficients

"These coefficients have been calculated by state-of-the-art methods and computer models that averaged over age, gender dependence of intake, metabolism, and radiogenic risk, as well as competing causes of death, to estimate health risks from internal and external exposures."

Example: $^{241}Am = 9.5 \times 10^{-11}/pCi$

Lifetime risk of death by cancer from ingesting contaminated water

Let the concentration = 1 pCi/L. A person drinks 2L per day for his or her entire life.

^{241}Am = 5 deaths in 1,000,000 more than background.

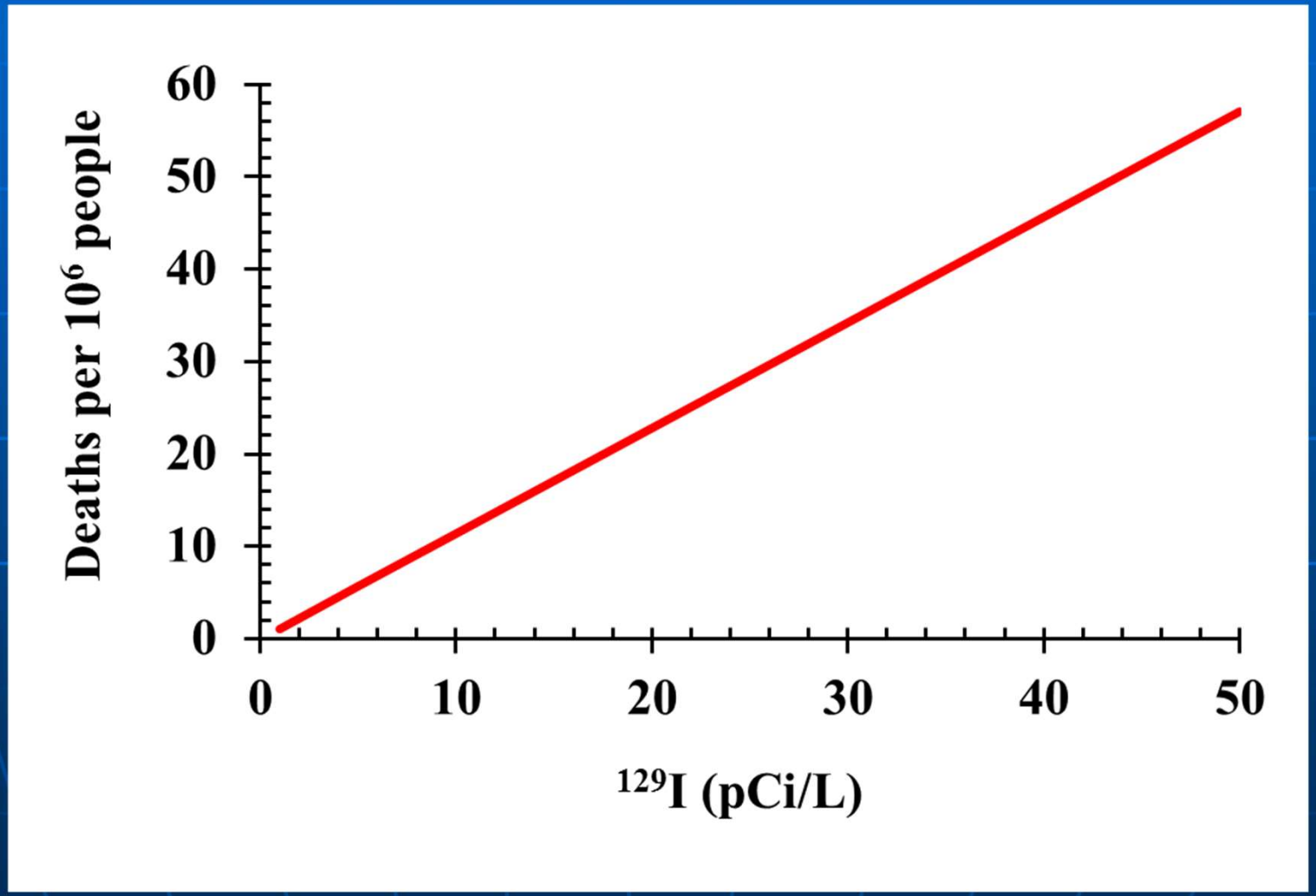
^{36}Cl = 2 deaths in 10,000,000

^{99}Tc, ^{129}I = 1 death in 1,000,000

^{242}Pu = 7 deaths in 1,000,000

^{226}Ra = 166 deaths in 1,000,000

Linear relationship between predicted mortality and concentration



Lifetime risk of death by cancer from inhaling contaminated air

Estimated mortality = concentration in air (pCi/m^3) x 20 m^3/day x 365.4 days/year x 78.2 years x risk coefficient x the number of people.

Inhalation risk coefficients

Example: $^{242}Pu = 2.8 \times 10^{-8}$/pCi

Inhaling Plutonium dust

Let the concentration of particulate matter = 0.01 ηgPu/m^3

10^{-11}g x 0.004 Ci/g (specific activity) = 0.04 pCi/m^3

(0.04 pCiPu/m^3) x (20 m^3/day) x 365.4 days/year x 78.2 years x 2.8 x 10^{-8}/pCi x 10^6 people = 640 cases of fatal cancer greater than background.

Occupational exposure to Pu

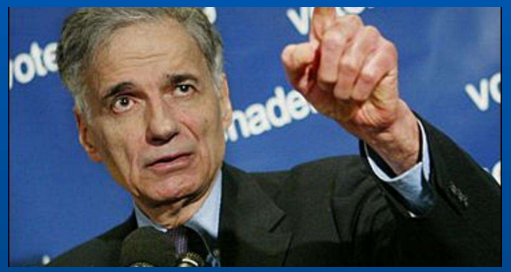
(0.04 pCi/m^3) x (60 m^3/work day) x 300 days x 20 years x 2.8 x 10^{-8}/pCi x . . . .

1,000 people at a plant: < 1 person

10,000 people at a plant: 1 person

How toxic is Pu?

Plutonium is constantly referred to by the news media as “the most toxic substance known to mankind." (Ralph Nader, activist and lawyer)



Is this true?

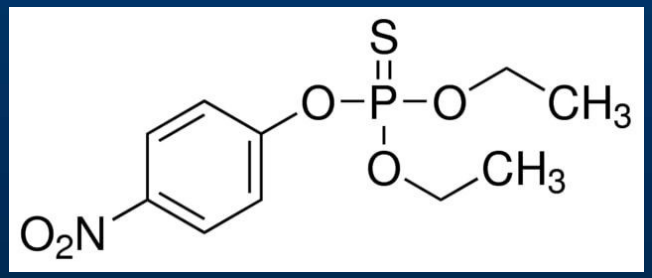
Radiological toxicity versus chemical toxicity

Long-term carcinogen because of its radiotoxicity but ^{226}Ra is about 200 times more radiotoxic than plutonium.

How toxic is plutonium?

No evidence that plutonium is acutely toxic in short-term, oral exposures.

The "poison is in the dose", but arsenic, parathion (a banned insecticide), HCN, sarin (a banned nerve gas) and botulinum (baht-chu-line-um) toxin are more acutely toxic than plutonium.



How toxic is plutonium?

Botulinum toxin is protein produced by bacteria (Clostridium botulinum), and

is thought to be the most toxic substance known with a human LD_{50} of roughly 0.005 to 0.05 µg/kg.

How toxic is plutonium?

If we gave 100 people who weighed 60 kg, a dose of about 1.7 ug of botulinum toxin to each person, it would kill 50 people in a matter of days (nerve paralysis).

Needless to say, the claims about plutonium toxicity have been exaggerated.

Plutonium, often called "the most toxic substance known to man," is actually 1000x LESS toxic than Botox, the chemical that people inject under their skin to reduce wrinkles.

Class Assignment 2

Read Chapter 1.

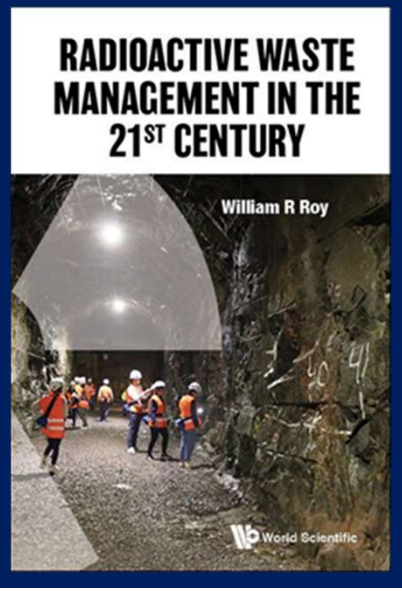
Answer Review Questions 5, 6, 7, 8, and 13.

Rubric:

This assignment is worth 20 points.

Each question is worth 4 points.

Typed or handwritten. Do not send by email as an attachment.



Questions?