Perspectives on Radiation Risk at Regulatory Levels

Presented To:

NMA-NRC
DENVER, COLORADO
12 JUNE 2023

Presented By:

Douglas Chambers, Ph.D.
Arcadis

Todays Topics

- Everything is Radioactive
- Radiation Risk
- Examples of Radiation dose criteria
- Perspective on radiation risk at regulatory levels

We Live in a Naturally Radioactive World

- Radiation is all around us, all the time, not just from the nuclear fuel cycle
- Every person, plant and animal is exposed to natural radioactivity
- Most people also are also exposed at times in their lives to medical radiation

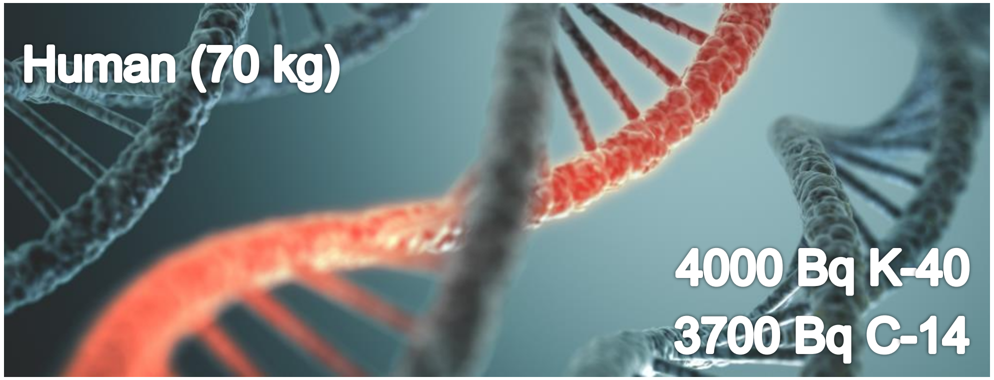
ARCADIS Design & Consultancy for natural and built assets

Sources of Natural Radiation

Cosmic Rays: Radiation that reaches the Earth from space

Rocks and Soil: Some rocks are radioactive and emit gamma radiation and also are the source of radioactive radon gas (from U-238 and Th-232 natural decay series)

Living Things: Plants absorb radioactive materials from the soil and pass these up the food chain



Terrestrial NORM ~ 1mSv/yr

Ra-226 (U-238 Decay Series)

Th-232 (Th-232 Decay Series)

K-40

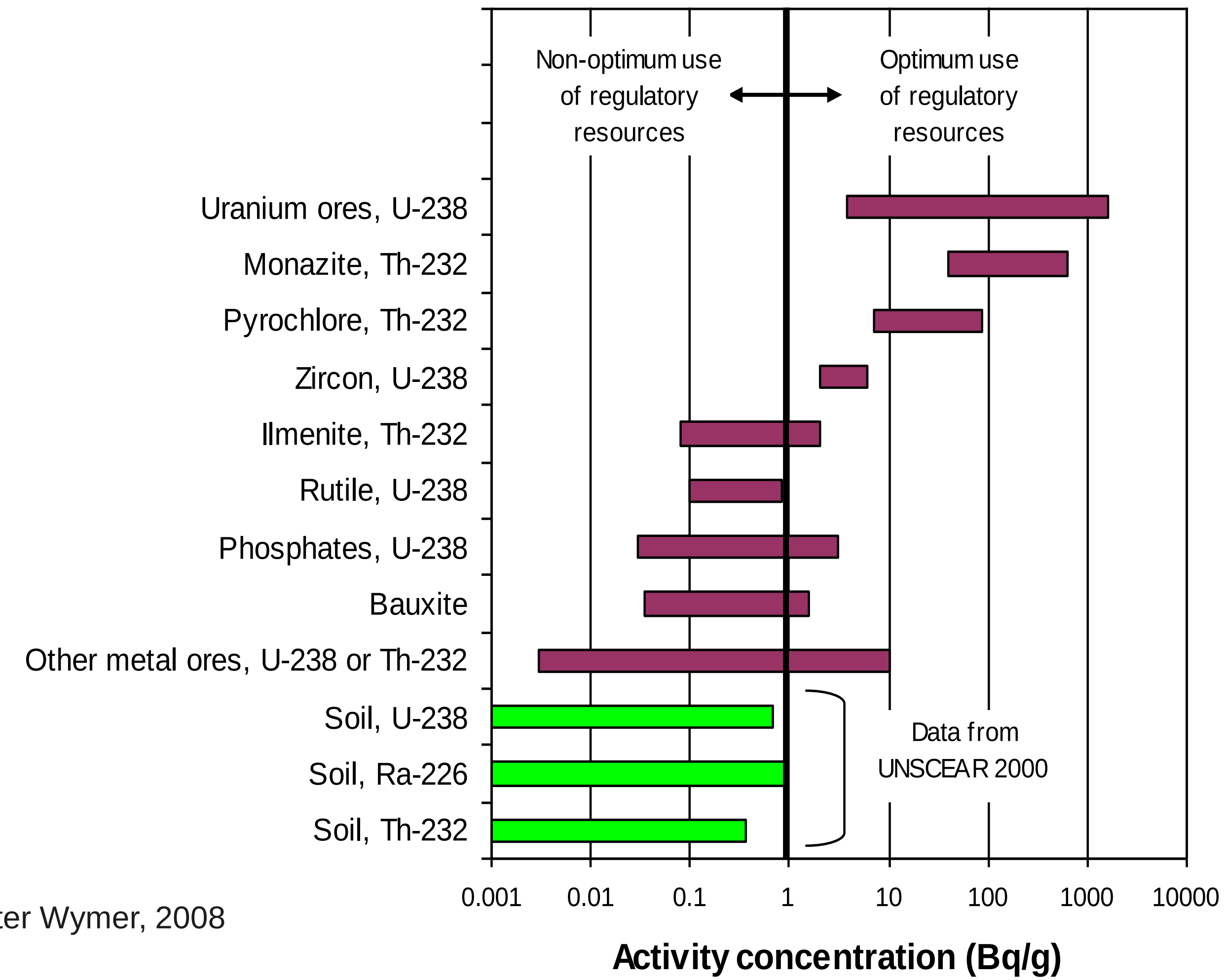
Cosmogenic NORM ~30uSv/yr

C-14	H-3
Na-22	Be-7

Key Radionuclides for Front end of uranium fuel cycle – minng and milling

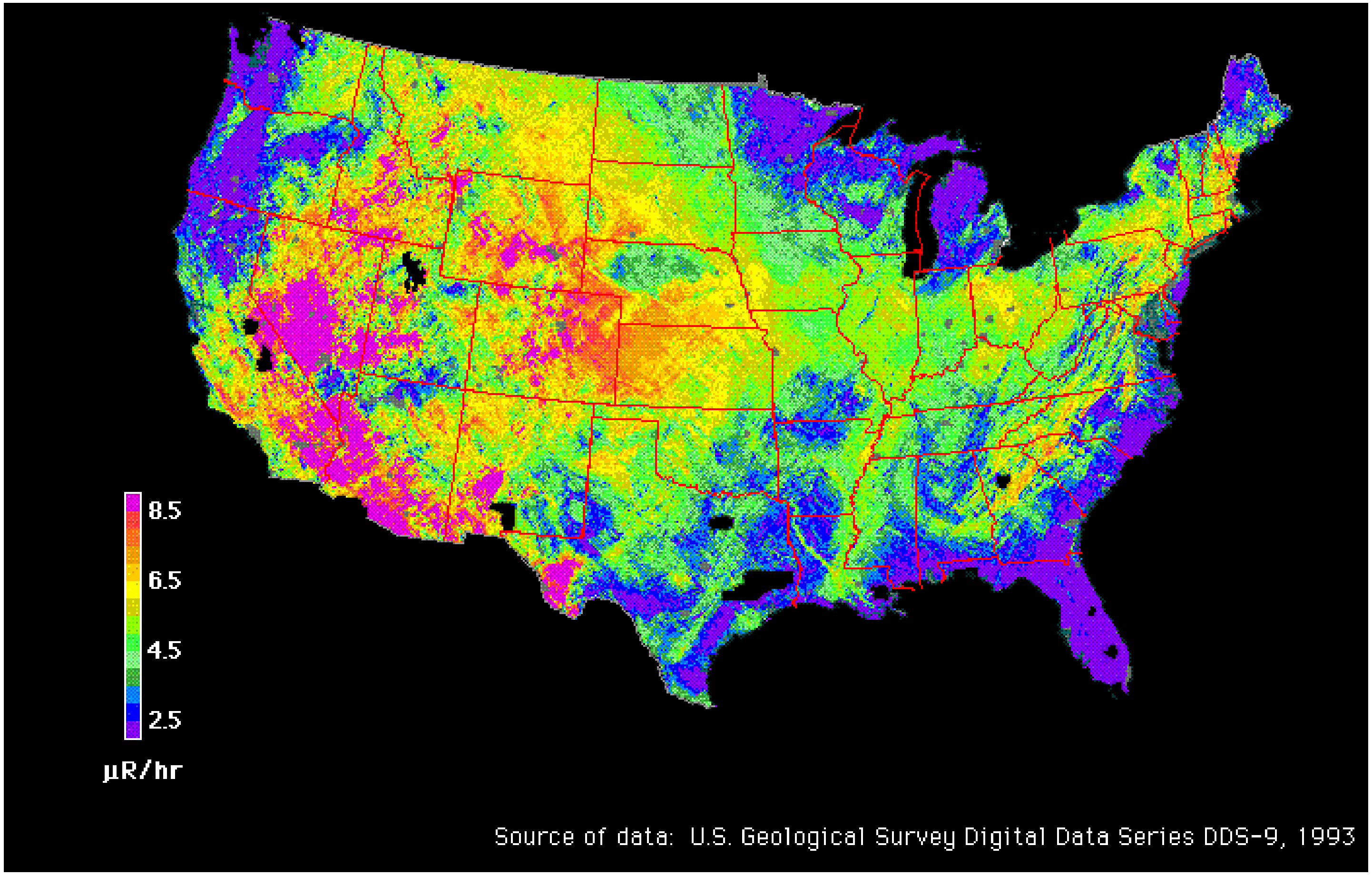
- Uranium (and thorium) decay chain radionuclides, notably
  - Radium (Ra-226
  - Rn-222

Uranium and Thorium Series Radionuclides are ubiquitous



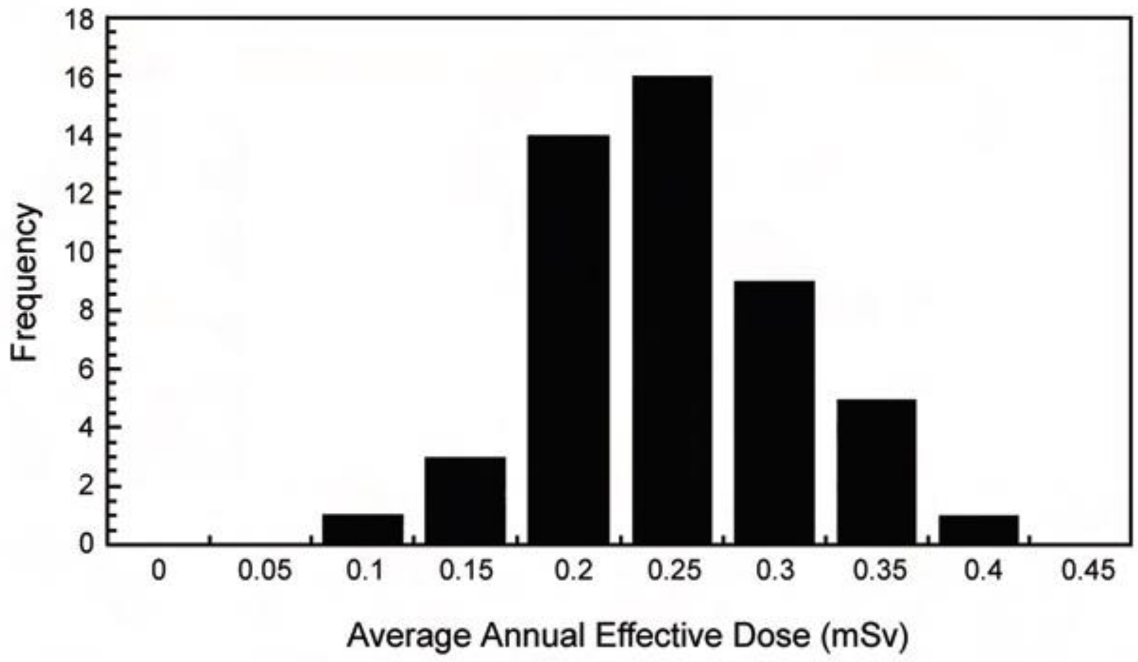
After Wymer, 2008

Terrestrial Gamma-Ray Exposure at 1m Above Ground



Variability of Terrestrial Annual Effective Dose

NCRP 160



Radon

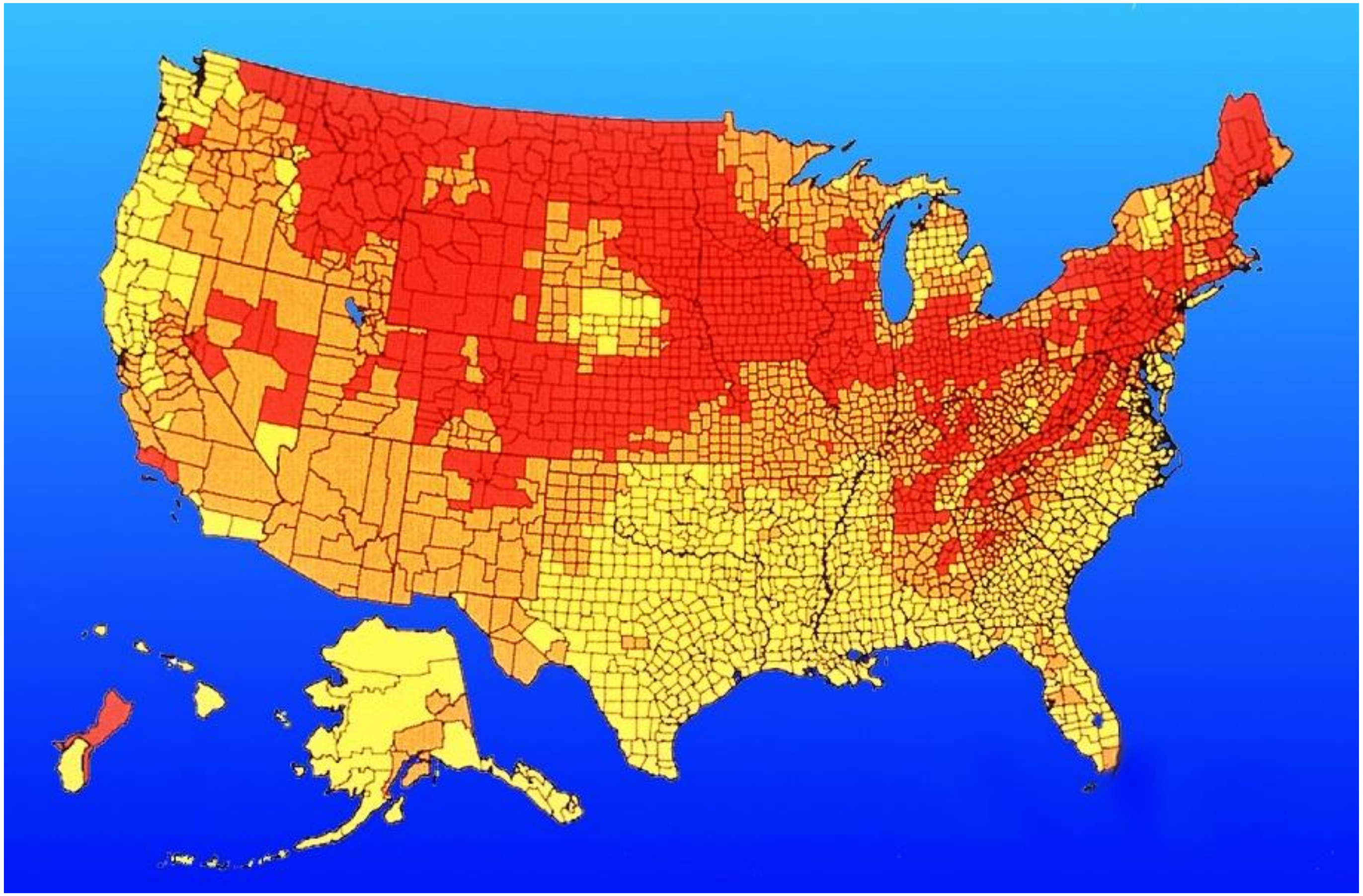
A natural radioactive noble gas found everywhere

Radon levels are higher indoors than outdoors):

- Average indoor level in US is about 1.3 pCi/L;
- Average outdoor level in the US is about 0.4 pCi/L.

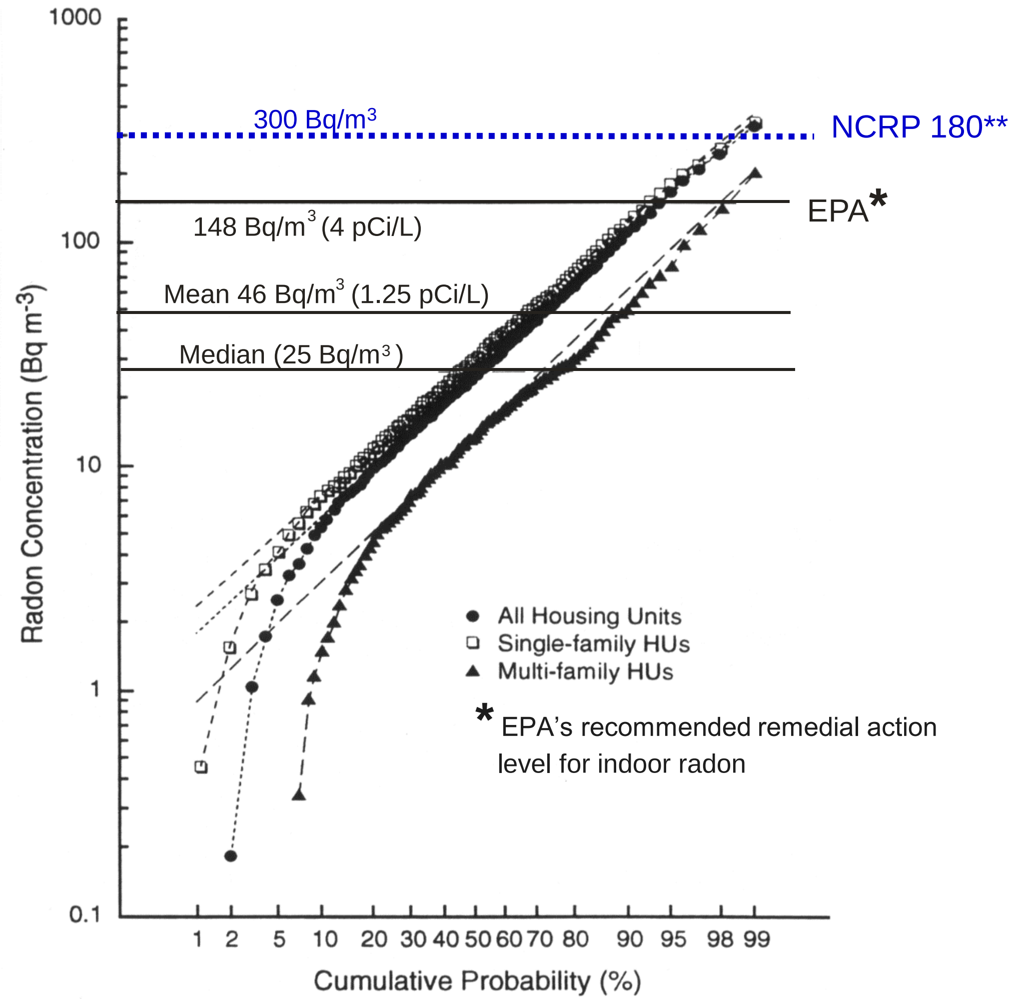
Ambient radon levels vary widely.

EPA Map of Radon Zones



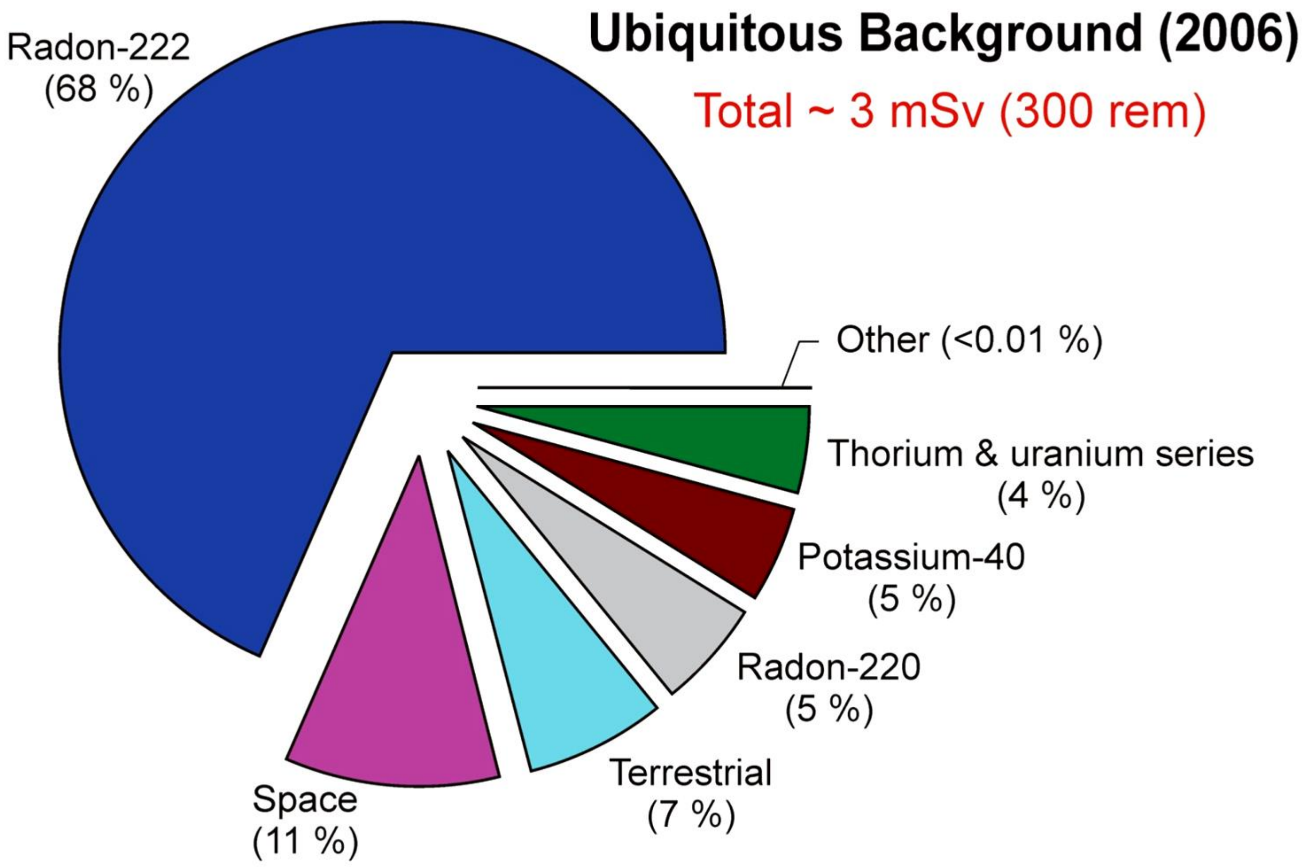
Z1 - Predicted average indoor screening level > than 4 pCi/L
Z2 - Predicted average indoor screening level between 2 and 4 pCi/L
Z3 - Predicted average indoor screening level less than 2 pCi/L

Distribution of Indoor Radon Levels in U.S. Homes*



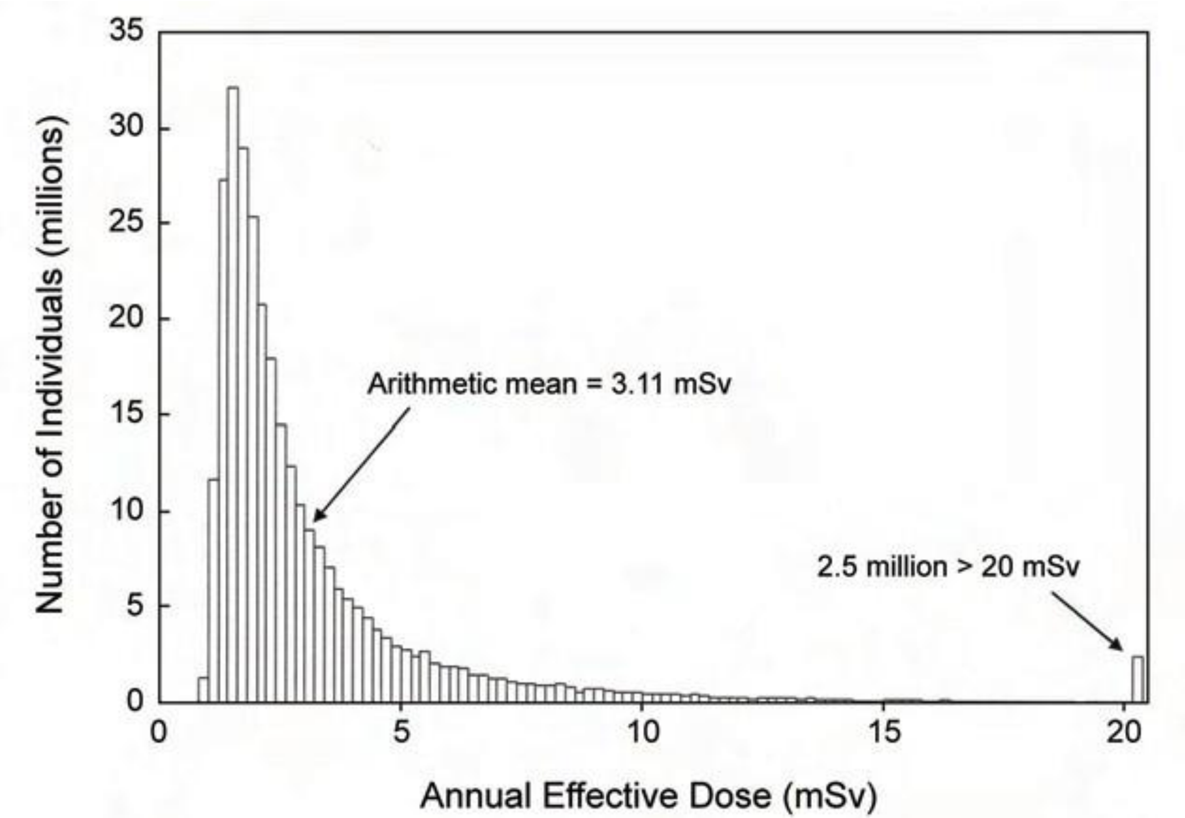
*Marcinowski (1994)
**Above 300 Bq/m^3, remedial action should be considered

Sources of Radiation Exposure to the U.S. Population



Source: NCRP Report No. 160, 2009

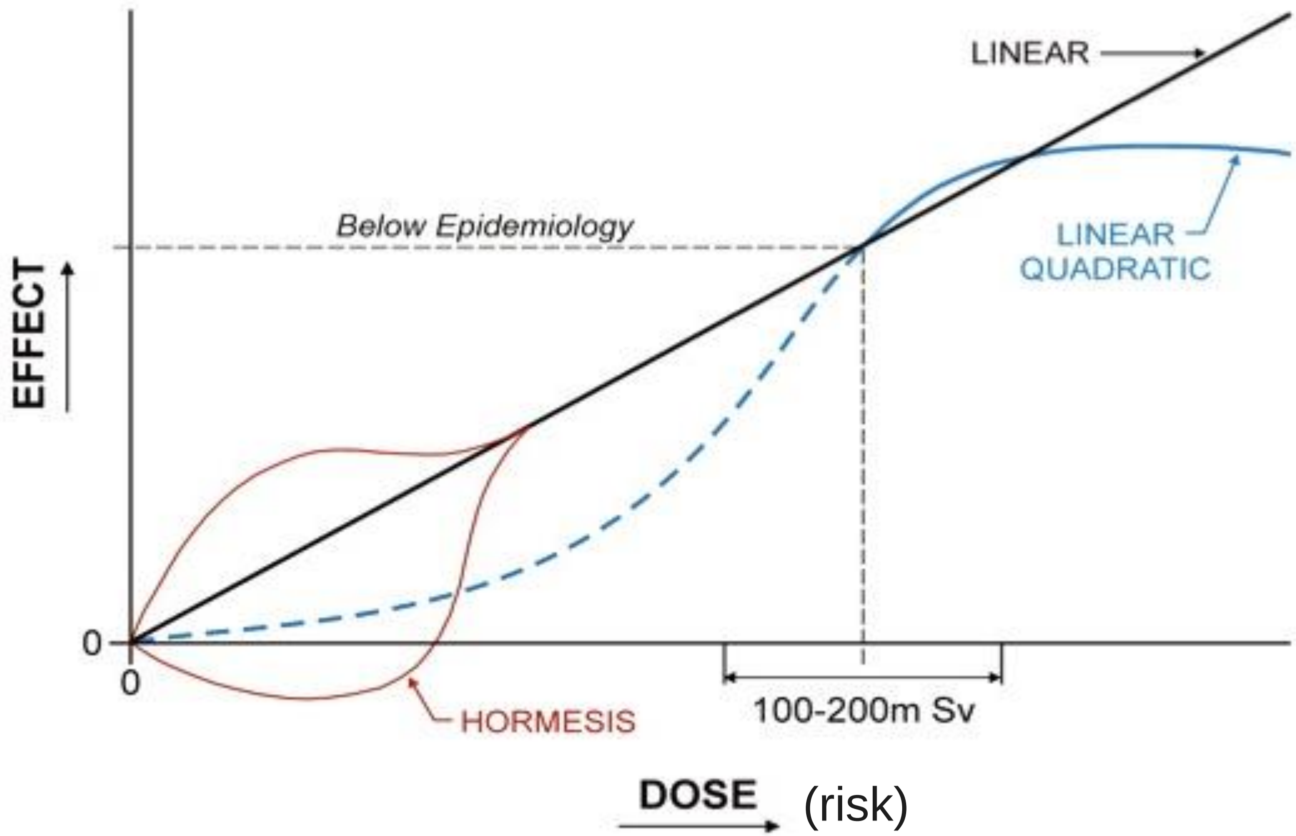
Annual Effective Dose NCRP 160



Todays Topics

- Everything is Radioactive
- Radiation Risk
- Examples of Radiation dose criteria
- Perspective on radiation risk at regulatory levels

Dose Response Models



LNT

- Current science suggests there is some risk from any exposure to radiation. However,
  - *it is very hard to tell whether a particular cancer was caused by very low doses of radiation* [natural or man-made] *or by something else*.

NCRP 180 (2018)

- *For stochastic effects, the linear non threshold (LNT) model for dose response is used for implementation of the system of radiation protection as a prudent and practical tool for managing radiation exposure in order to reduce the possibility of such effects at or below an effective dose of 100 mSv.*

- *For purposes of implementing the system of radiation protection, the NCRP applies the same nominal radiation detriment adjusted risk coefficients for cancer and heritable effects as ICRP (2007) i.e. for stochastic effects, a lifetime risk of*
  - *5 E-02 per Sv*
  - *5E-05 per mSv*
  - *5E-07 per mrem*

RADON

Radon Risks need some extra discussion

Lung Disease in the Middle Ages

In the 15th century, a large silver deposit was discovered at Joachimsthal in Bohemia which was the basis for Agricola’s treatise on mining *De Re Metallica.*

Lung Disease and Radon in Miners

This unusual lung disease was eventually, some 500 years later, recognized as lung cancer.

This lung disease was reported to have caused up to 70% of the miners' deaths.

Radon levels in these medieval mines were thought to have had radon progeny levels ranging from 30 to 150 WL.

Motivation for Occupational Radon Guidance

Around 1950, Radon in US uranium mines was found to be of the same order as for mines in the Erz Mountains.

In 1949, the U.S. Public Health Service became concerned about the potential hazard based on the experience of the Joachimsthal/Schneeberg mines.

Radon Concentrations Found in US Uranium Mines in 1949 to 1950*

Area	# of Mines	Range of Radon Concentrations (pCi L^{-1})	Median Value (pCi L^{-1})
Navajo reservation	4	37 – 7,500	345
Utah	10	100 – 50,000	5,000
Colorado	24	135 – 22,300	2,540

* Holaday and Doyle, 1964

MOTIVATION FOR OCCUPATIONAL RADON GUIDANCE

By the mid 1950's, there was a global awareness of the risk of lung cancer in miners.

This drove the development of radiation protection guidelines for radon and consequent parallel changes to mining methods and ventilation practices.

The radon guidelines and standards evolved over time as our understanding of the radon hazard evolved through measurement and epidemiology studies of miners.

These actions resulted in substantial improvements in radon levels in uranium mines in th United States, Canada, and elsewhere.

Evolution of Radon Standard in the USA - 3

A 1 WL standard was adopted in 1960 (12 working level months per year)

- It was thought to be directly related to lung dose.
- The standard was the impetus for a significant decrease in miner exposures beginning in 1960, as states and mining companies began implementing control through mine planning and increased ventilation.

1967 Joint Committee on Atomic Energy

The 4 WLM per year was adopted in 1971 and is still in effect in mines in the United States.

- ANSI is working on an update to N13.8-1973

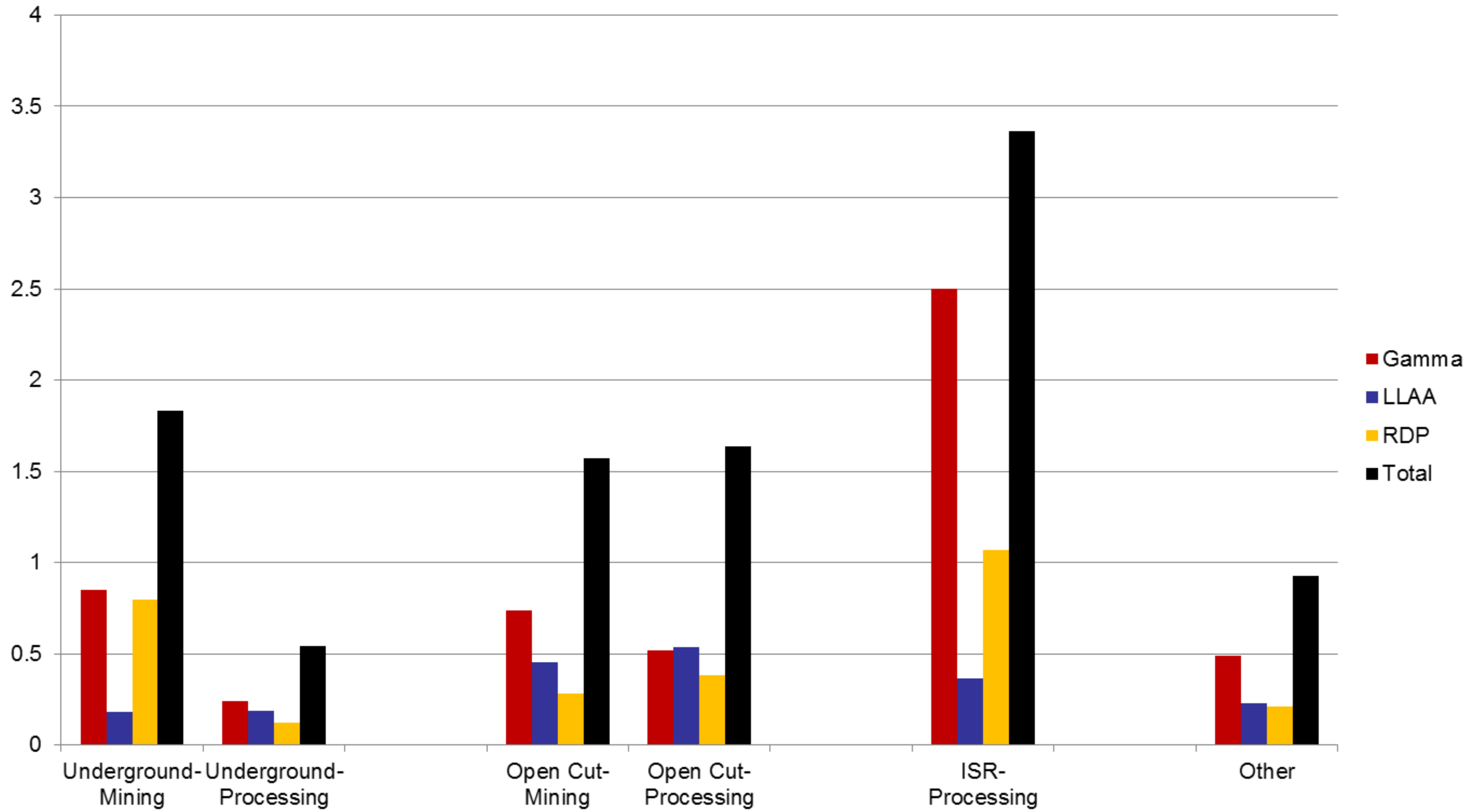
UMEX – The Idea

For nuclear industry workers there are a number of databases of occupational doses at both international and national level (IAEA Information System on Occupational Exposure {ISOE}, Canada's national dose registry…)

Similar systems are in place or being developed for medical exposures and industrial workers

The Information System for Uranium Mining Exposures (UMEX) was designed by the IAEA to examine global occupational exposures in uranium mining and processing

Exposures in Modern Uranium Mines (mSV/yr)



Epidemiological Dose Conversion Convention (DCC)

Obtain DCC by dividing the risk (LEAR) per WLM by the risk coefficient per mSv

$$DCC\ (mSv/WLM) = \frac{risk\ (LEAR)\ /\ WLM}{risk\ /\ mSv}$$

- risk per Sv has been reduced from 5.6% (ICRP 60) to 4.2% (2007) for occupational (adults) and 7.3% (ICRP 60) to 5.7% (2007) for the general population (whole)
- if risk per mSv is increased then it follows that the allowable mSv dose would decrease if the same degree of protection was required

Life Table Modelling

Required to estimate lifetime excess absolute risk (LEAR) from exposure

Application of risk projection models to various populations

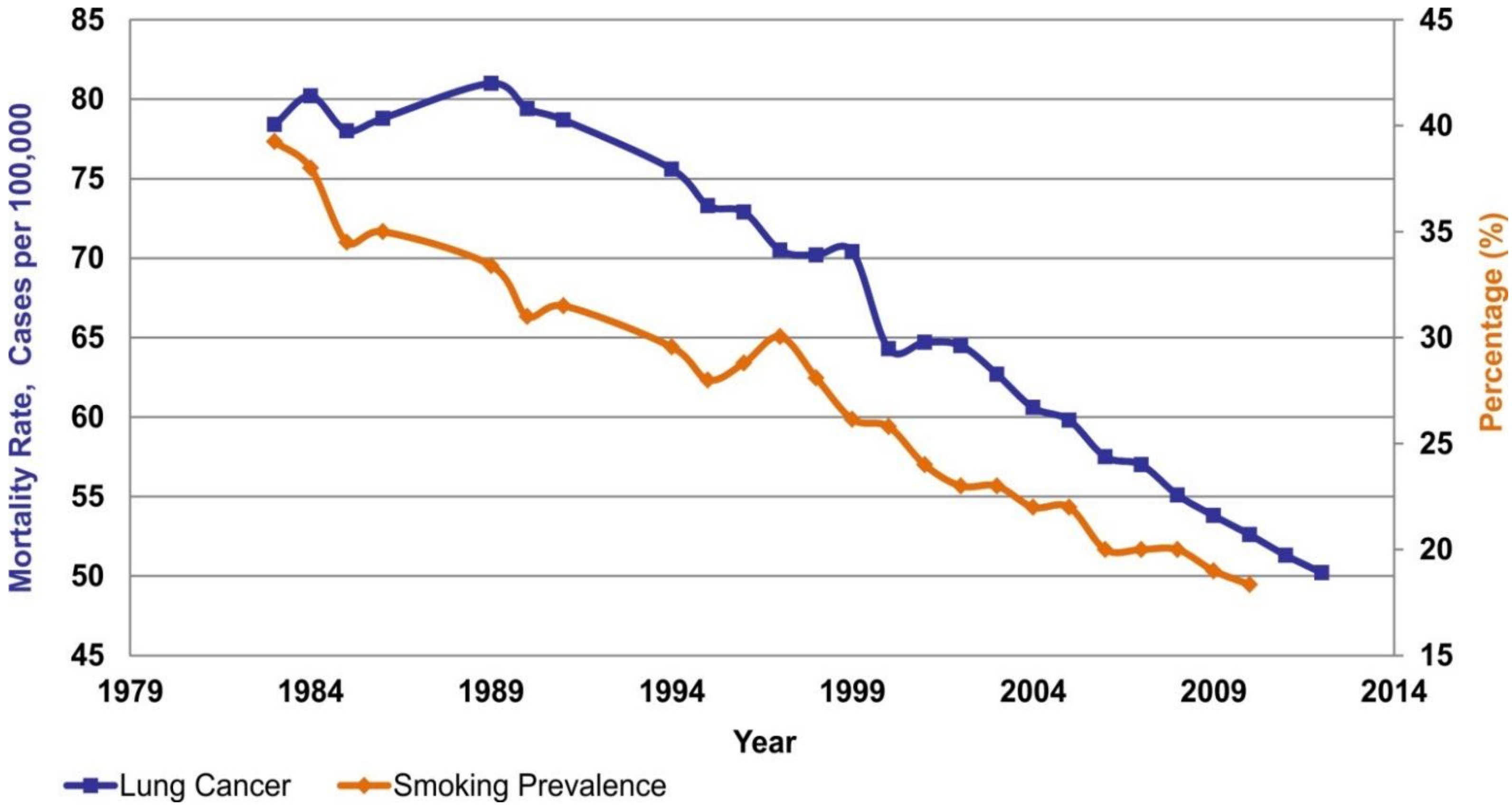
- ICRP 103 Populations (4)
- Canada by smoking status

Risk / WLM (and DCC) depends on

- relative projection risk model
- **baseline lung cancer mortality (dominated by smoking)**

Implications of smoking prevalence needs to be considered

AGE STANDARDIZED MORTALITY AND SMOKING PREVALENCE



Lung Cancer and Radon: Pooled Analysis of Uranium Miners Hired in 1960 or Later [EHS May 2022]

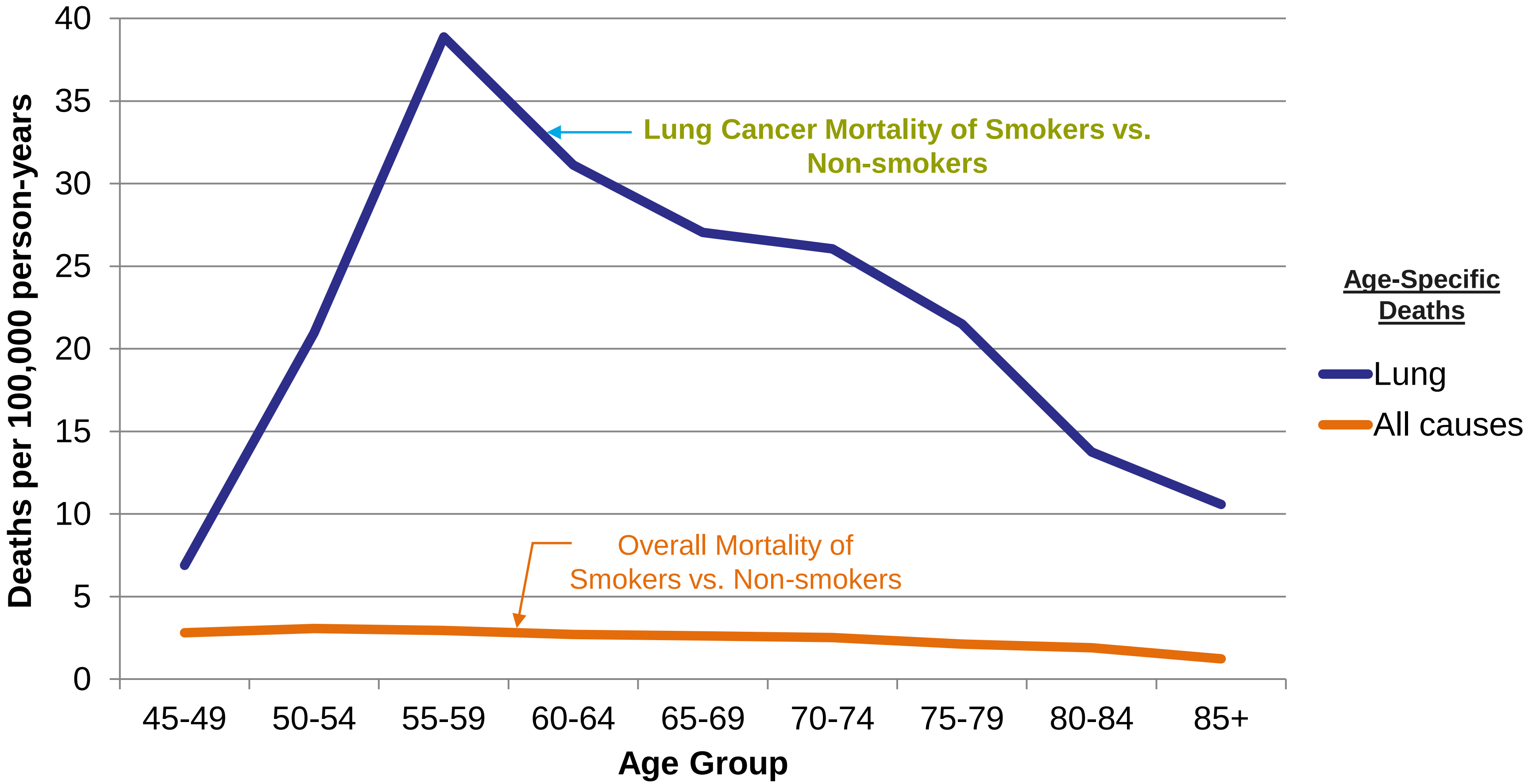
- analyses of European uranium miners suggested that the ERR*/100 WLM was larger for nonsmokers than smokers

- Unable to assess effect of modification tobacco smoking thus the observation:

- "*reflect a weighted average of associations for smokers and non-smokers, and given the high prevalence of smokers in the PUMAproject,19will tend to be weighted toward the radon–lung cancer association among smokers.* ***We therefore suggest caution when transporting estimates between populations with differing smoking distributions"***

**** ERR -> relative (to baseline risk)***

RATIO OF RISKS OF AGE-SPECIFIC DEATHS IN MALE SMOKERS/NON-SMOKERS



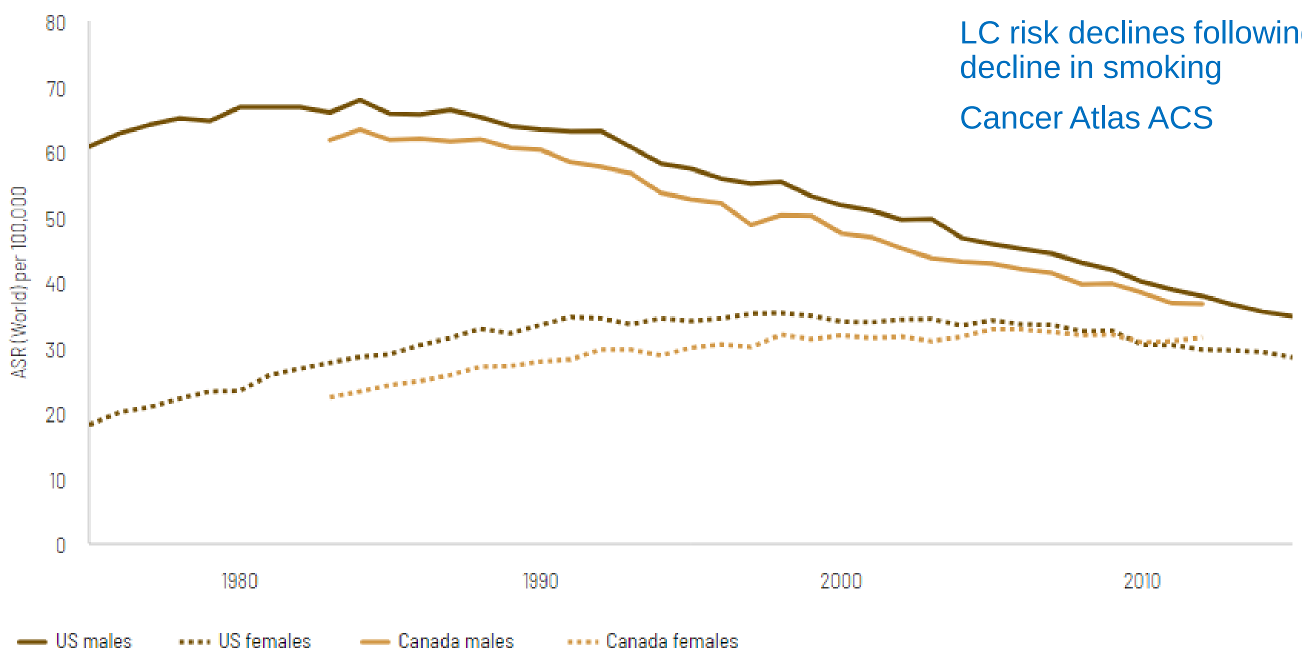
DCC ($mSvWLM^{-1}$) for Males with Smoking Prevalence of 20% and 30% by Risk Projection Model (values rounded).

Smoking Prevalence	GSF (ICRP 65) [5]	BEIR VI [17]	French/Czech [22]	Ontario [18]	Wismut [21]	Eldorado [20]	Darby [3]
30%	6	11	10	5	6	14	5
20%	4	8	8	4	4	10	4

SHARE

Figure 3

Lung cancer incidence trends by sex in the United States and Canada, 1975–2015



canceratlas.cancer.org

LC risk declines following decline in smoking

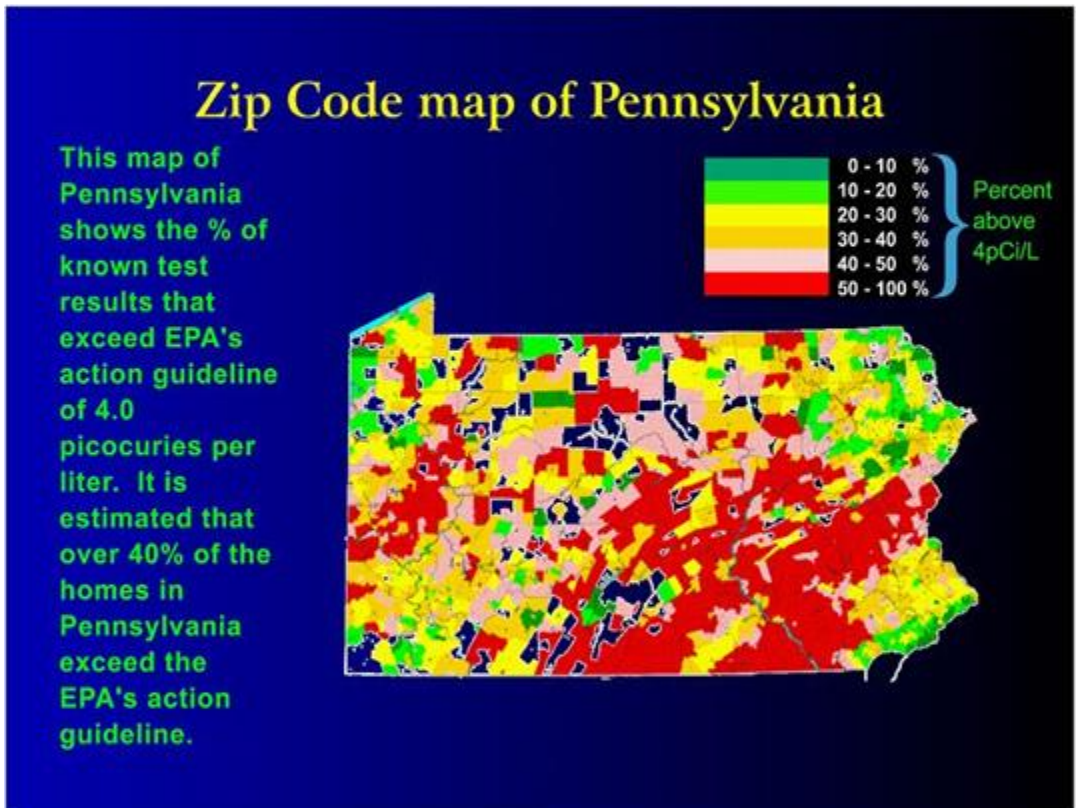
Cancer Atlas ACS

December 1984 – "Radon Hits the Fan"

Radon
Rn
Atomic Number: 86
Atomic Mass: (222)

Watras House, Boyertown PA

~2,600 pCi/L



Risk from radon - smokers

RADON RISK IF YOU SMOKE

Radon Level	If 1,000 people who smoked were exposed to this level over a lifetime*...	The risk of cancer from radon exposure compares to**...	WHAT TO DO: Stop Smoking and...
20 pCi/L	About 260 people could get lung cancer	◂ 250 times the risk of drowning	Fix your home
10 pCi/L	About 150 people could get lung cancer	◂ 200 times the risk of dying in a home fire	Fix your home
8 pCi/L	About 120 people could get lung cancer	◂ 30 times the risk of dying in a fall	Fix your home
4 pCi/L	About 62 people could get lung cancer	◂ 5 times the risk of dying in a car crash	Fix your home
2 pCi/L	About 32 people could get lung cancer	◂ 6 times the risk of dying from poison	Consider fixing between 2 and 4 pCi/L
1.3 pCi/L	About 20 people could get lung cancer	(Average indoor radon level)	(Reducing radon levels below 2 pCi/L is difficult)
0.4 pCi/L		(Average outdoor radon level)	

Note: If you are a former smoker, your risk may be lower.

Risk from radon – never smokers

RADON RISK IF YOU'VE NEVER SMOKED

Radon Level	*If 1,000 people who never smoked were exposed to this level over a lifetime*...*	*The risk of cancer from radon exposure compares to**...*	*WHAT TO DO:*
20 pCi/L	*About 36 people could get lung cancer*	*◀ 35 times the risk of drowning*	*Fix your home*
10 pCi/L	*About 18 people could get lung cancer*	*◀ 20 times the risk of dying in a home fire*	*Fix your home*
8 pCi/L	*About 15 people could get lung cancer*	*◀ 4 times the risk of dying in a fall*	*Fix your home*
4 pCi/L	*About 7 people could get lung cancer*	*◀ The risk of dying in a car crash*	*Fix your home*
2 pCi/L	*About 4 people could get lung cancer*	*◀ The risk of dying from poison*	*Consider fixing between 2 and 4 pCi/L*
1.3 pCi/L	*About 2 people could get lung cancer*	*(Average indoor radon level)*	*(Reducing radon levels below 2 pCi/L is difficult)*
0.4 pCi/L		*(Average outdoor radon level)*	

Note: If you are a former smoker, your risk may be higher.
*Lifetime risk of lung cancer deaths from *EPA Assessment of Risks from Radon in Homes* (EPA 402-R-03-003).
**Comparison data calculated using the Centers for Disease Control and Prevention's 1999-2001 National Center for Injury Prevention and Control Reports.

Smoking to non smoking about 8 times the risk

CancerFacts and Figures (ACS, 2023)

- Smoking accounts for 80% of the risk of LungCancer
- Smoking increases the risk of Lung Cancer (compared to non-smokers) by a factor of 25

Todays Topics

- Everything is Radioactive
- Radiation Risk
- Examples of Radiation dose criteria
- Perspective on radiation risk at regulatory levels

Exemplar Radiation Criteria

- 100 mrem/yr (1 mSv/yr) – 10 CFR Part 20.1301
- 0.1 pCi/L radon(with dtrs) – 10 pCi/L radon(without dtrs) - 10 CFR Part 20 App B Table 2 Effluent Concentrations
- 10 mrem/year – NESHAPs radon from mine vents 40CFR Part 61 Sub B
- Target Risk range 10^{-6} to 10^{-4} (lifetime*) - CERCLA 10 CFR Part 20 App B i.e., corresponding to a dose range of
  - 2 mrem to 200 mrem.

* Note that the annual risk is about 80 times smaller

Radon Measurements

10CFR 20.1302 allows either measurement or models to determine compliance to the annual dose limit in 20.1301;

Concentration limits related to the public dose limit are

- 0.1 pCi/L - with progeny
- 10 pCi/L without progeny

At low concentrations the incremental levels are uncertain;

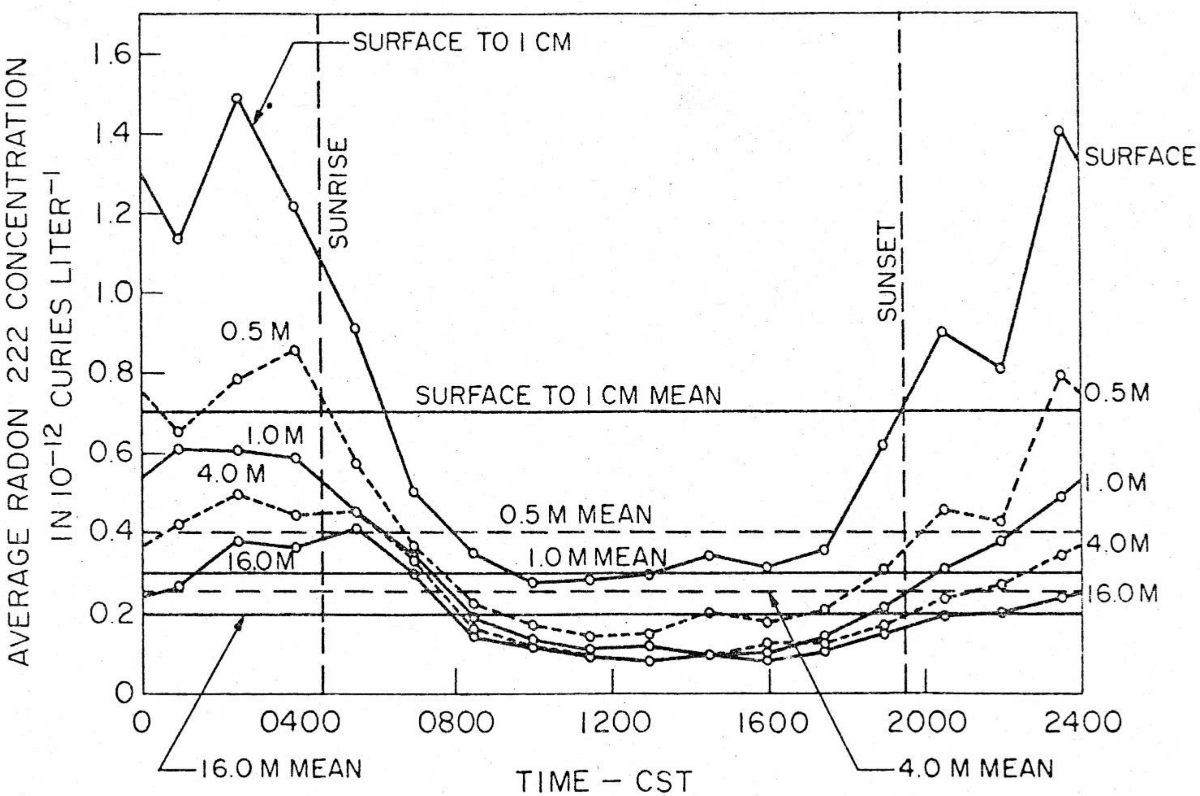
Todays Topics

- Everything is Radioactive
- Radiation Risk
- Examples of Radiation dose criteria
- Perspective on radiation risk at regulatory levels

Outdoor Radon

- Radon levels in outdoor air are affected by the regional geology, meteorology, local topography…
- The NAS (1999) report many areas with outdoor radon levels ranging from 0.12 to 0.3 pCi/L
- Also according to NAS (1999), the highest concentrations in continental US are found <u>in the Colorado Plateau where measurements ranged from 0.5 to 0.75 pCi/L of air (18.5–30 Bq/m^3)</u>

Radon Levels Change Diurnally and by Season



SOURCE: After Pearson, U.S. Department of Health & Welfare, 1967

Radon concentrations typically reach their maximum in the summer to early winter, whereas from late winter to spring, concentrations are usually at a minimum as a result of meteorological changes and soil moisture (and snow) conditions (NAS 1999).

Measuring outdoor radon

- Unlikely to be able to detect low concentrations of (< say 0.5 pCi/L) incremental radon in presence of variable natural background

44

Exposure to Gamma radiation

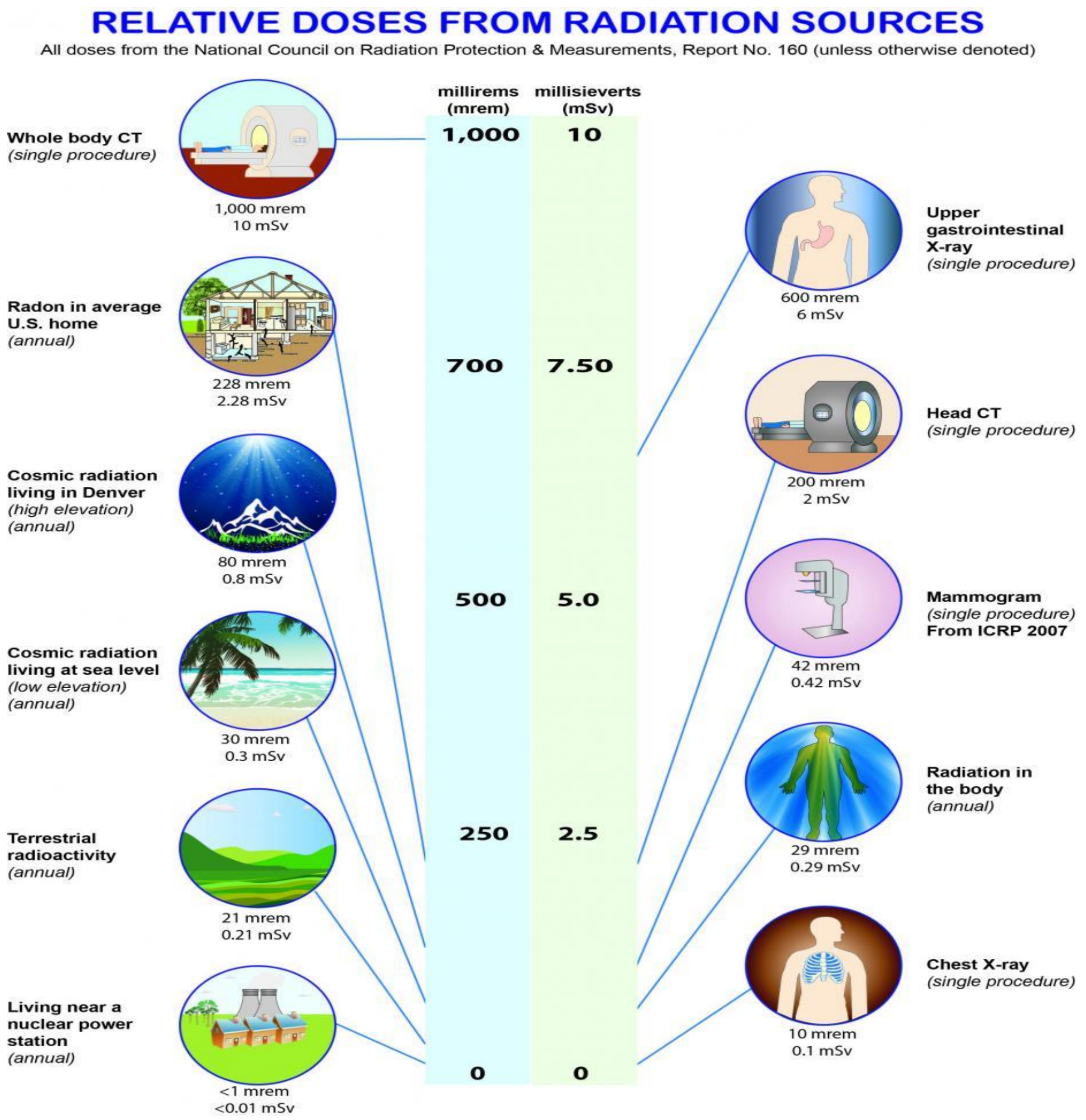
- Average external gamma radiation doses dueto terrestrial gamma quite variable across the USA with a notional average of about 0.3 mSv/yr
- Systematic MARSSIM style measurements needed to determine incremental gamma dose from natural background

Annual Effective Dose

- Dose from natural background is of the order of 300 mrem/yr and variable
  - The annual dose limit (above natural background) of 100mrem/yr for licenced facilities is about 1/3 of average annual dose and within the variability of annual dose from natural background
  - The annual dose of 10 mrem/yr for radon from mine vents is about 1/30th of that from natural background and indeed, small compared to the variability in natural background dose across the USA

Doses from Common Radiation Sources

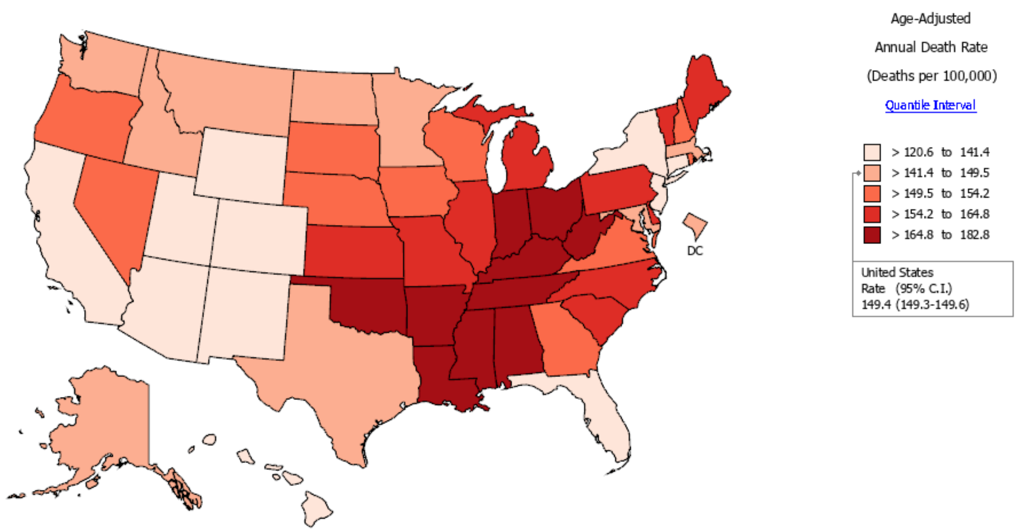
https://www.epa.gov/radiation/radiation-sources-and-doses



Cancer Deaths by State (annual rates of death)

Cancer Death Rates by State

All Races (includes Hispanic/Latino), Both Sexes, All Ages, 2016-2020



Suggested Citation:
HD*Pulse*: An Ecosystem of Minority Health and Health Disparities Resources. National Institute on Minority Health and Health Disparities. Created 6/11/2023. Available from https://hdpulse.nimhd.nih.gov.

Notes:
State Health Departments may provide more current or more local data.
Data presented on the HDPulse Web Site may differ from statistics reported by the State Health Departments.
For more information about which causes of death are included in Cancer please refer to the definitions.
Source: Death data provided by the National Vital Statistics System public use data file. Death rates calculated by the National Institutes of Health using SEER*Stat. Death rates (deaths per 100,000 population per year) are age-adjusted to the 2000 US standard population (19 age groups: <1, 1-4, 5-9, ... , 80-84, 85+). Population counts for denominators are based on the Census US Population Data File as modified by NCI.

Rural-Urban Continuum Codes (developed by the United States Department of Agriculture (USDA) are used on this website to distinguish which counties are rural and urban; additionally, how much of a state's population is classified as rural or urban. For more information about using Rural-Urban Continuum Codes, go to the rural urban page.

Deaths per million are 10 times larger

Note that the death rates on the Colorado Plateau are in the lowest category

Lifetime risk of Cancer(%)

Site	Sex	Lifetime	“risk”
All	Male	40.9	1 in 2
	Female	39.1	1 in 3
Lung Cancer	Male	6.2	1 in 16
	Female	5.8	1 in 17
From Cancer Facts and Figures ACS 2023			

Smoking Prevalence*

- 1965
  - Male ≈ 50%
  - Female ≈ 35%
- 2021
  - Male ≈ 15%
  - Female ≈ 10%

At a lifetime risk of 1E-04, we have a risk of 0.01%

***Cancer Facts and Figures ACS (2023)**

Risks from radiation at regulatory levels are small and well within the range of natural variation