

# Radon: Fact or Fiction

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# Overview

- Bradford Hill Criteria for Causality
- Lung Cancer Mortality
- Radon Occurrence
- Radon Health Effects
- Radon Epidemiology
- National and International Guidance
- Radon Resources

# Bradford-Hill Criteria for Causality

1. Strength of the association
2. Consistency of findings
3. Specificity of the association
4. Temporal sequence of association
5. Biological gradient (Dose-Response)
6. Biological plausibility
7. Coherence
8. Experiment
9. Analogy



# Bradford-Hill Criteria for Causality

## Strength of the Association

- Criterion suggests that a larger association increases the likelihood of causality.

## Consistency of Findings

- The credibility of findings increases with repetition of findings, including consistency of study findings across different populations and geographical locations.

## Biological Gradient (Dose Response)

- The argument for causality is stronger in the presence of a dose–response relationship, where higher or longer exposure leads to an increased risk of disease.



# Bradford-Hill Criteria for Causality

## Biological Plausibility

- A conceivable mechanism for causation between exposure and disease exists.

## Specificity of the Association

- Causality is more likely if the exposure causes only one specific disease or syndrome, or if a specific location or population are being affected.

## Temporal Sequence of Association

- Exposure must occur before the disease, and not after a latency period that is too long. This criterion must always be fulfilled for causality to be concluded.

# Bradford-Hill Criteria for Causality

## Coherence

- The association agrees with previous knowledge available about the disease and/or exposure.

## Experiment

- “Experiment” relates to the decrease in disease risk when the exposure is removed and often involves animal models.

## Analogy

- Previous evidence of an association between a similar exposure and disease outcome to strengthen the current argument for causation.

# Bradford-Hill Criteria for Causality - Radon

## Strength of the Association

- Lung cancer rates higher for individuals with higher cumulative radon decay product exposure

## Consistency of Findings

- Different “types” (case-control, cohort, and experimental) studies produce similar findings

## Biological Gradient (Dose-Response)

- Increased lung cancer risk is observed with increasing protracted radon decay product exposure



# Bradford-Hill Criteria for Causality - Radon

## Biological Plausibility

- It is very plausible that protracted radon decay product exposure causes DNA damage to the lung (resulting in cancer).

## Specificity of the Association

- Lung cancer rates are observed in miners with high radon exposures

## Temporal Sequence of Association

- Radon exposure precedes onset of disease

# Bradford-Hill Criteria for Causality - Radon

## Coherence

- Theory 'makes sense' given existing evidence about the carcinogenicity of alpha particles

## Experiment

- Animal exposed to high radon concentrations develop lung tumors



## Analogy

- Other alpha particle emitting radionuclides are known human carcinogens



# United States Cancer Mortality 2020

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## Estimated New Cases

			Males	Females			
Prostate	191,930	21%			Breast	276,480	30%
Lung & bronchus	116,300	13%			Lung & bronchus	112,520	12%
Colon & rectum	78,300	9%			Colon & rectum	69,650	8%
Urinary bladder	62,100	7%			Uterine corpus	65,620	7%
Melanoma of the skin	60,190	7%			Thyroid	40,170	4%
Kidney & renal pelvis	45,520	5%			Melanoma of the skin	40,160	4%
Non-Hodgkin lymphoma	42,380	5%			Non-Hodgkin lymphoma	34,860	4%
Oral cavity & pharynx	38,380	4%			Kidney & renal pelvis	28,230	3%
Leukemia	35,470	4%			Pancreas	27,200	3%
Pancreas	30,400	3%			Leukemia	25,060	3%
<b>All Sites</b>	<b>893,660</b>	<b>100%</b>			<b>All Sites</b>	<b>912,930</b>	<b>100%</b>

## Estimated Deaths

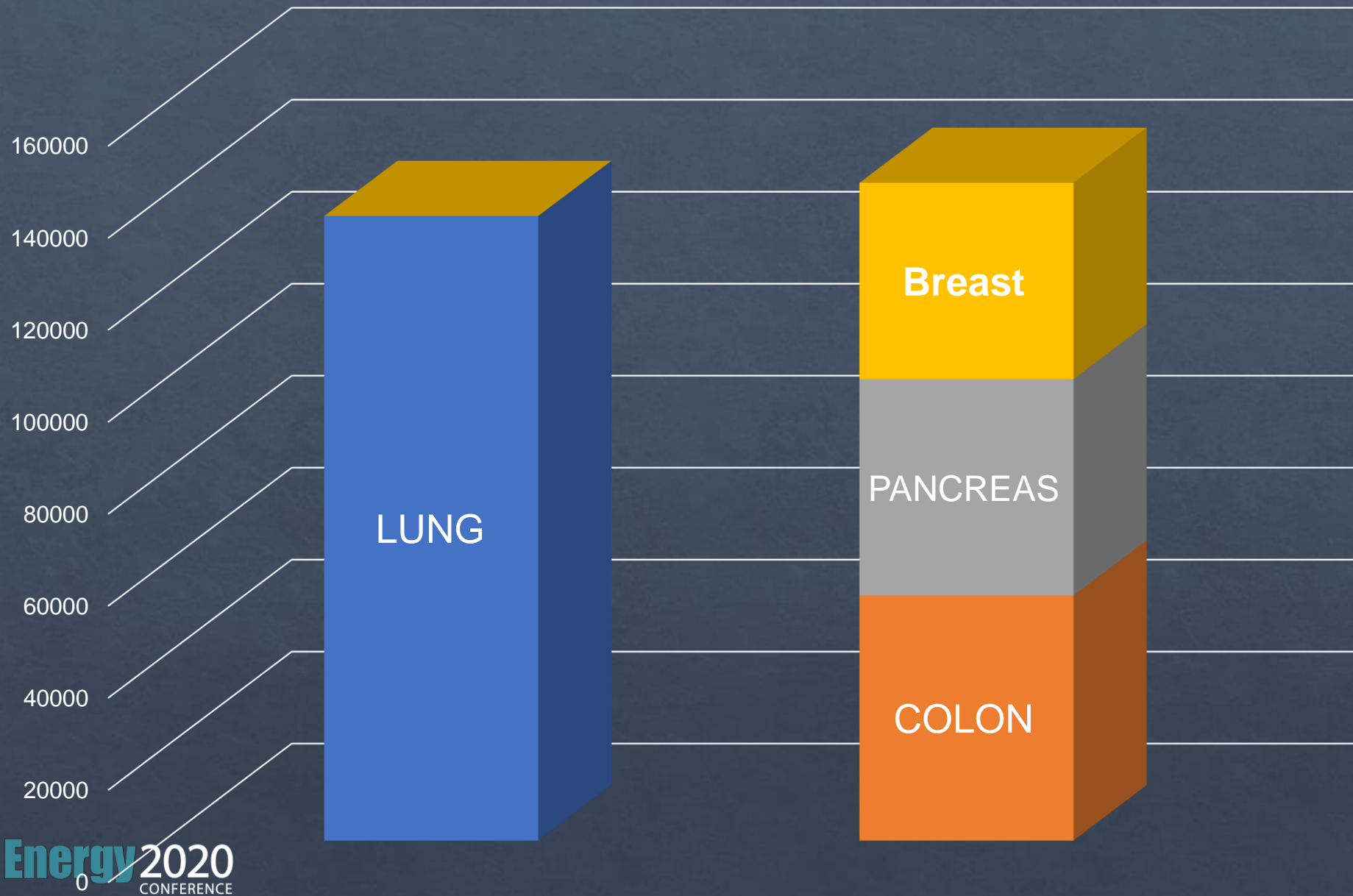
			Males	Females			
Lung & bronchus	72,500	23%			Lung & bronchus	63,220	22%
Prostate	33,330	10%			Breast	42,170	15%
Colon & rectum	28,630	9%			Colon & rectum	24,570	9%
Pancreas	24,640	8%			Pancreas	22,410	8%
Liver & intrahepatic bile duct	20,020	6%			Ovary	13,940	5%
Leukemia	13,420	4%			Uterine corpus	12,590	4%
Esophagus	13,100	4%			Liver & intrahepatic bile duct	10,140	4%
Urinary bladder	13,050	4%			Leukemia	9,680	3%
Non-Hodgkin lymphoma	11,460	4%			Non-Hodgkin lymphoma	8,480	3%
Brain & other nervous system	10,190	3%			Brain & other nervous system	7,830	3%
<b>All Sites</b>	<b>321,160</b>	<b>100%</b>			<b>All Sites</b>	<b>285,360</b>	<b>100%</b>



# United States Cancer Mortality 2020

Cancer Mortality 2020	
Cancer Type	Estimated U.S. Deaths in 2020
1. Lung and Bronchus	135,720
2. Colon and Rectum	53,200
3. Pancreas	47,050
4. Breast	42,690
5. Prostate	33,330
6. Liver and Intrahepatic Bile Duct	30,160
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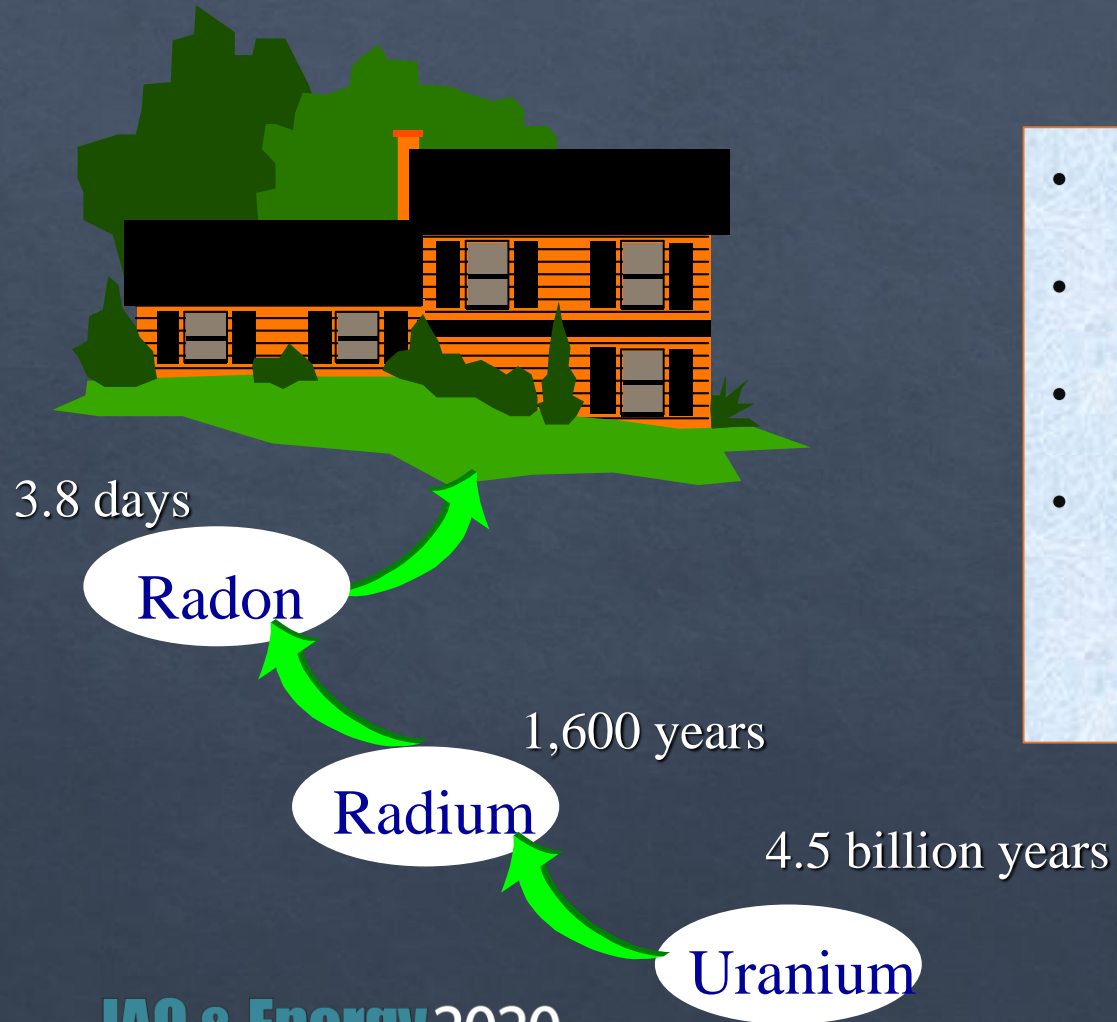
## ESTIMATED CANCER DEATHS IN THE U.S. 2020



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# Radon from Geologic Sources

- Radon is a radioactive noble gas
- It is naturally occurring outdoors
- You can not see or smell it
- It enters buildings primarily from the soil

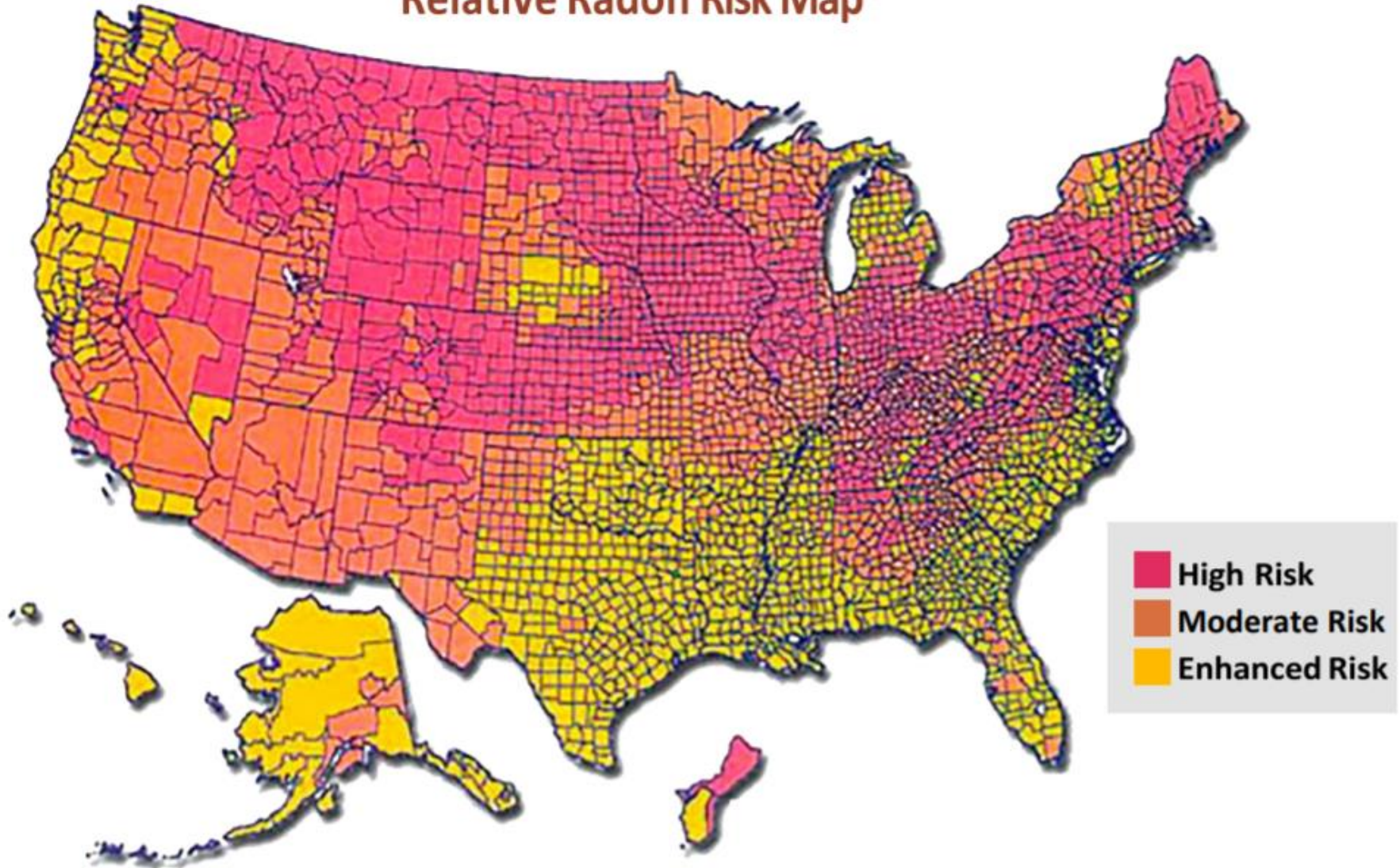




# Radon Measurement

- picoCurie/Liter = pCi/L    1 pCi = 2.2 dpm
- EPA Radon Action Level    = 4 pCi/L
- World Health Organization Reference Level    = 2.7 pCi/L
- National Median Indoor Radon concentration    = 1.3 pCi/L
- National Average Outdoor Radon Concentration    = 0.4 pCi/L

## Relative Radon Risk Map\*



# RADON - RISK PERCEPTION

- Invisible, odorless, colorless
- Naturally occurring **outdoors**
- Can not link an individual death to radon exposure
- Long latency period
- Not a dread hazard
- Cancers occur one at a time
- Lung cancer does not occur in children
- Voluntary risk
- Lack of press – no sensational story
- No sensory reminders to repetitively stimulate us to think about it



# Radon Epidemiology

- 1556 Agricola - Miners in Europe
- 1770 Carl Lebrecht Schefflers – Morbidity of Miners
- 1879 Harting & Hesse - Lung Cancer in Miners
- 1921 Uhlig - Radium Emanations & Lung Cancer
- 1950s Peller - First Review of Mining Related Cancers
- 1950s Studies of Underground Miners (ongoing)
- 1980s Residential Radon Studies
- 1994 NCI Pooled Analyses of Miners
- 1998 NAS BEIR VI Report
- 2005 North American and European Pooled Residential Radon Studies
- 2007 Global Pooling of Residential Radon Studies
- 2018 New pooling effort for studies of U miners



**1985 ??**



WASHINGTON POST FEB 6, 1986

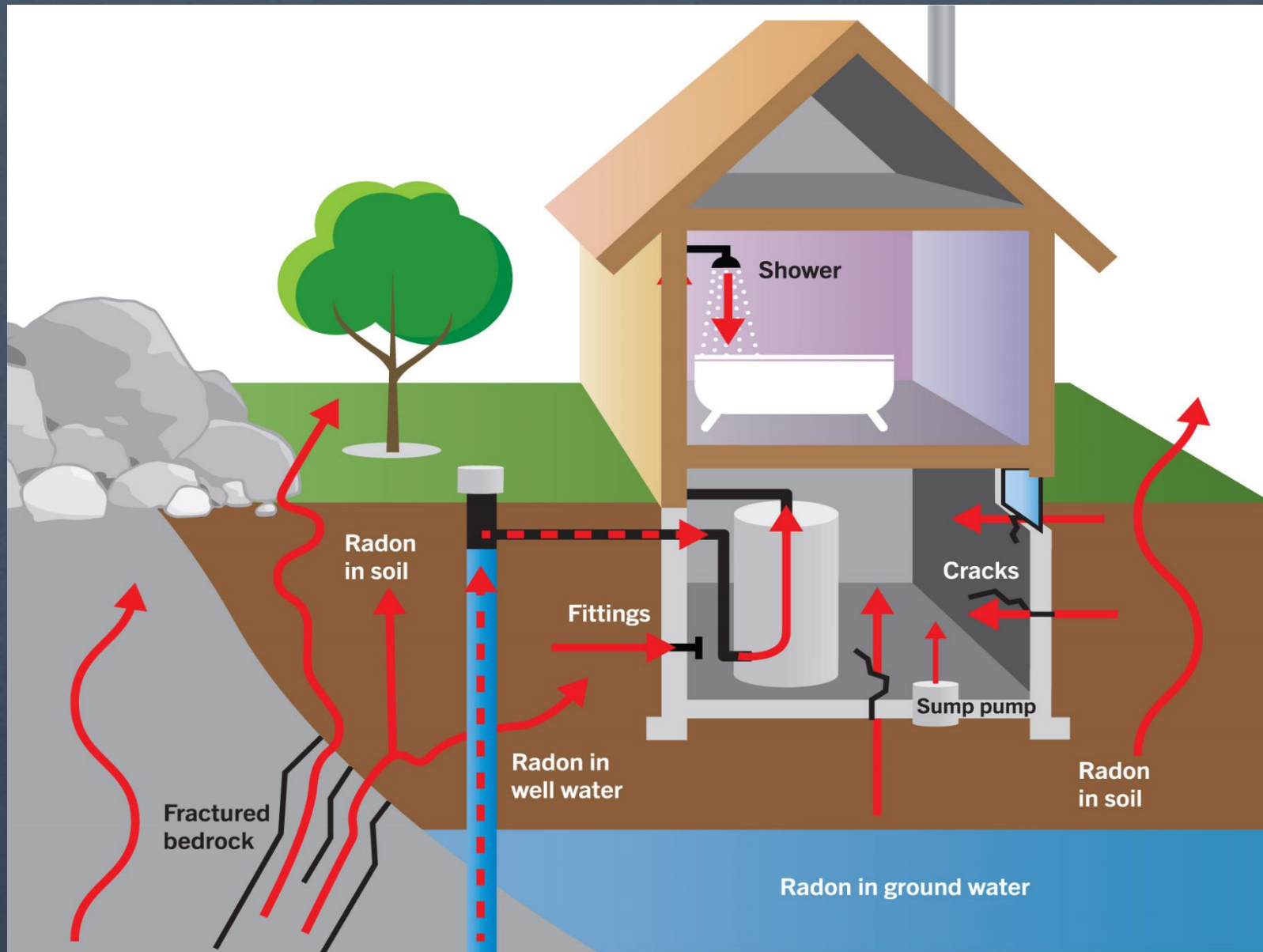




## Stanley Watras at the Limerick Nuclear Power Plant, Christmas 1984

"I just thank God that if it was going to be anybody living in that house, it would be me, somebody who could, through their work activities, discover the situation,"

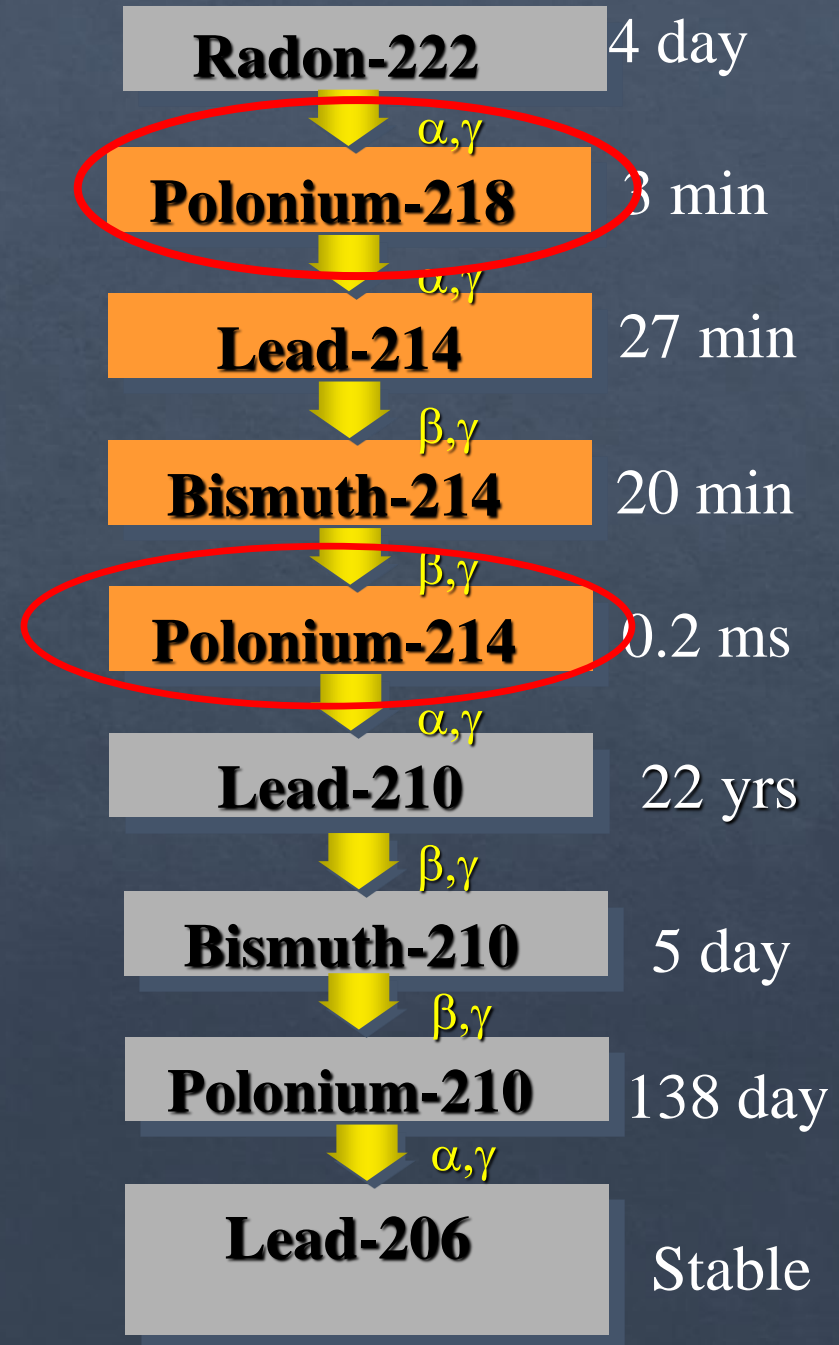
*Philadelphia Inquirer March 20, 1985*



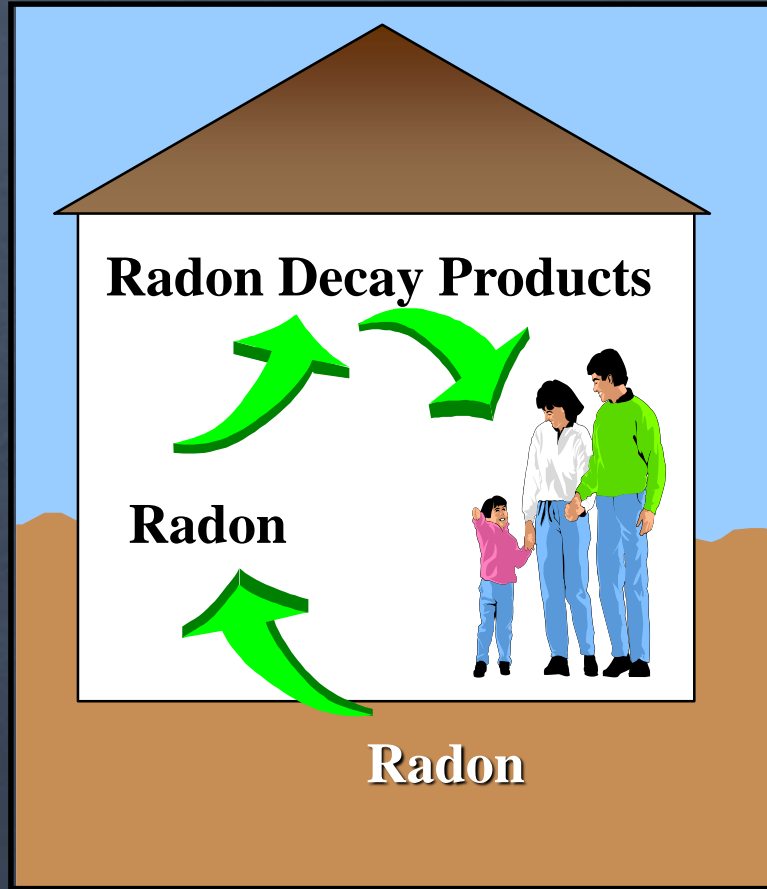


# Radon Decay Products

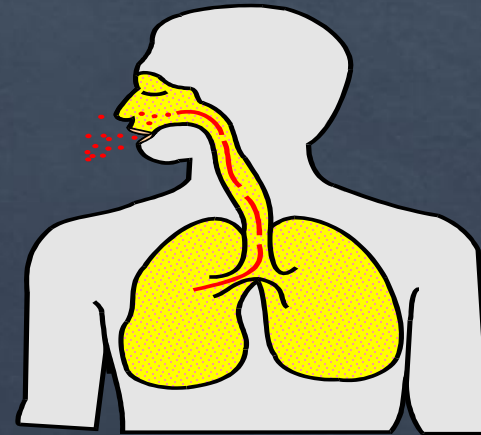
Po-218 and Po-214 deliver the majority of radiation dose to the lung.



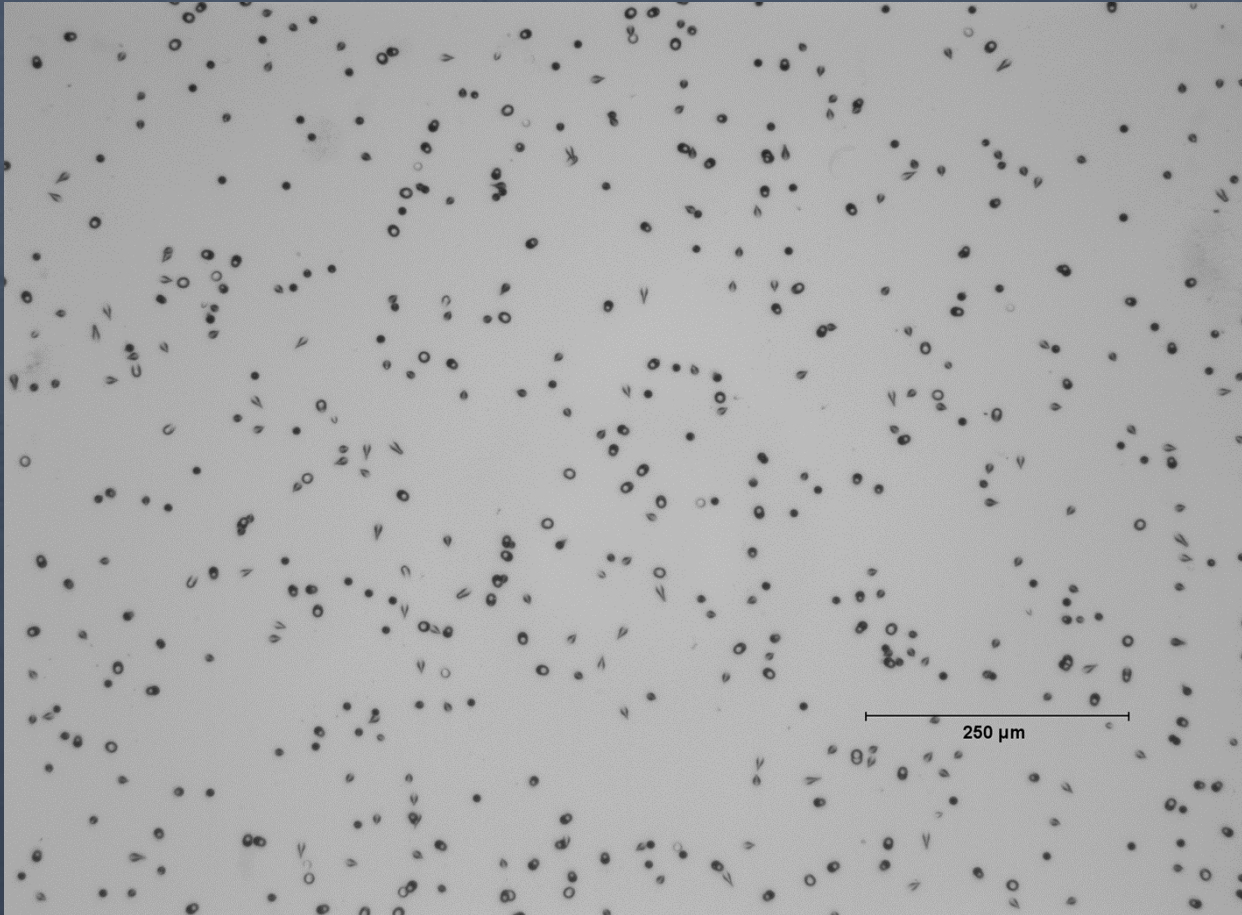
# Why are radon decay products a health concern?



These particles are easily inhaled and deposited in the lungs where they can damage sensitive lung tissue.



# Alpha Tracks





# What Happens When Radon Decay Products Are Inhaled ?



*Double Strand DNA Breaks*

- Highly radioactive particles adhere to lung tissue, where they can irradiate sensitive cells.
- Radiation can alter the cells, increasing the potential for cancer.



# Ionizing radiation can directly and indirectly damage DNA

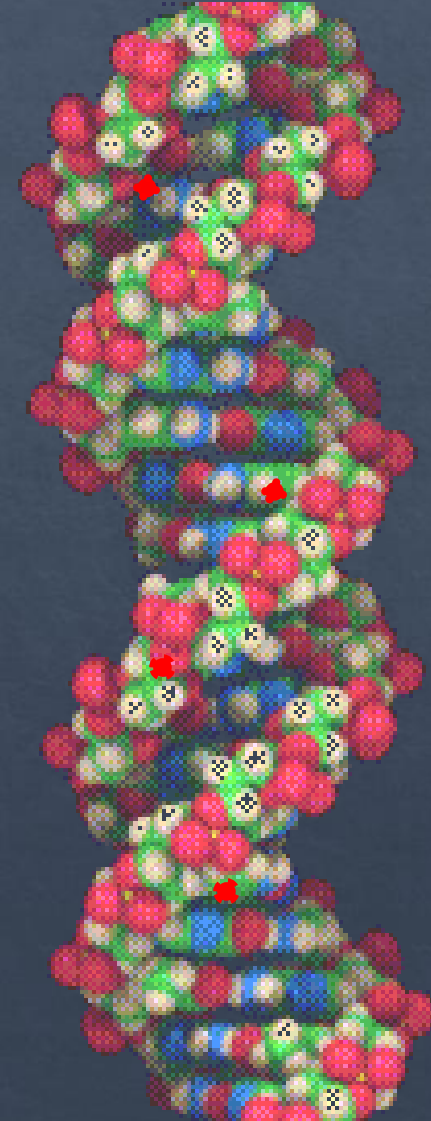
## *Alpha Particle*

Defects in tumor suppressor genes – p53

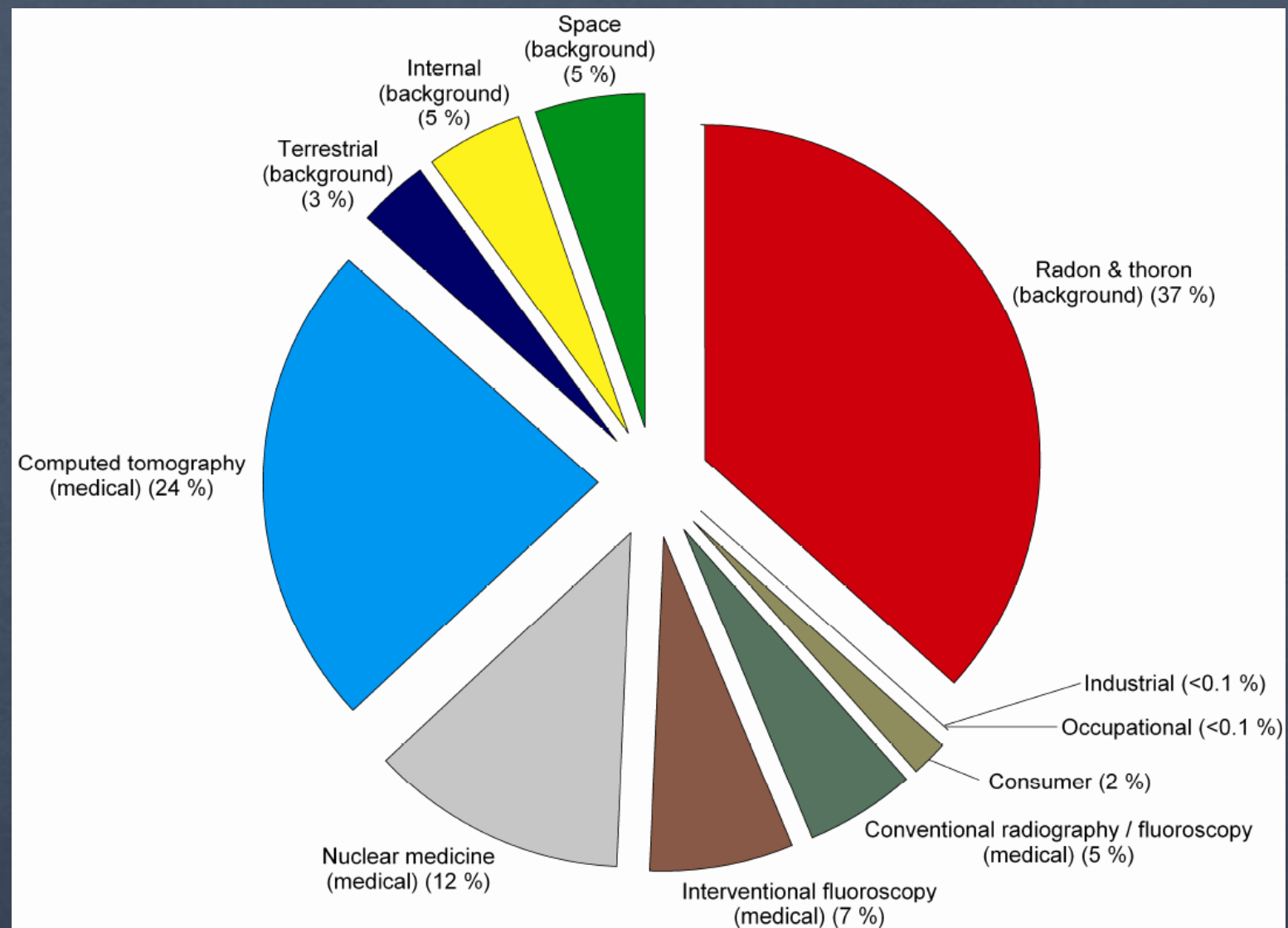
At risk individuals—GSTM<sub>1</sub>  
(glutathione S-transferase M1)

Free radical  
formation

Double-strand  
DNA breaks



## Biological Plausibility

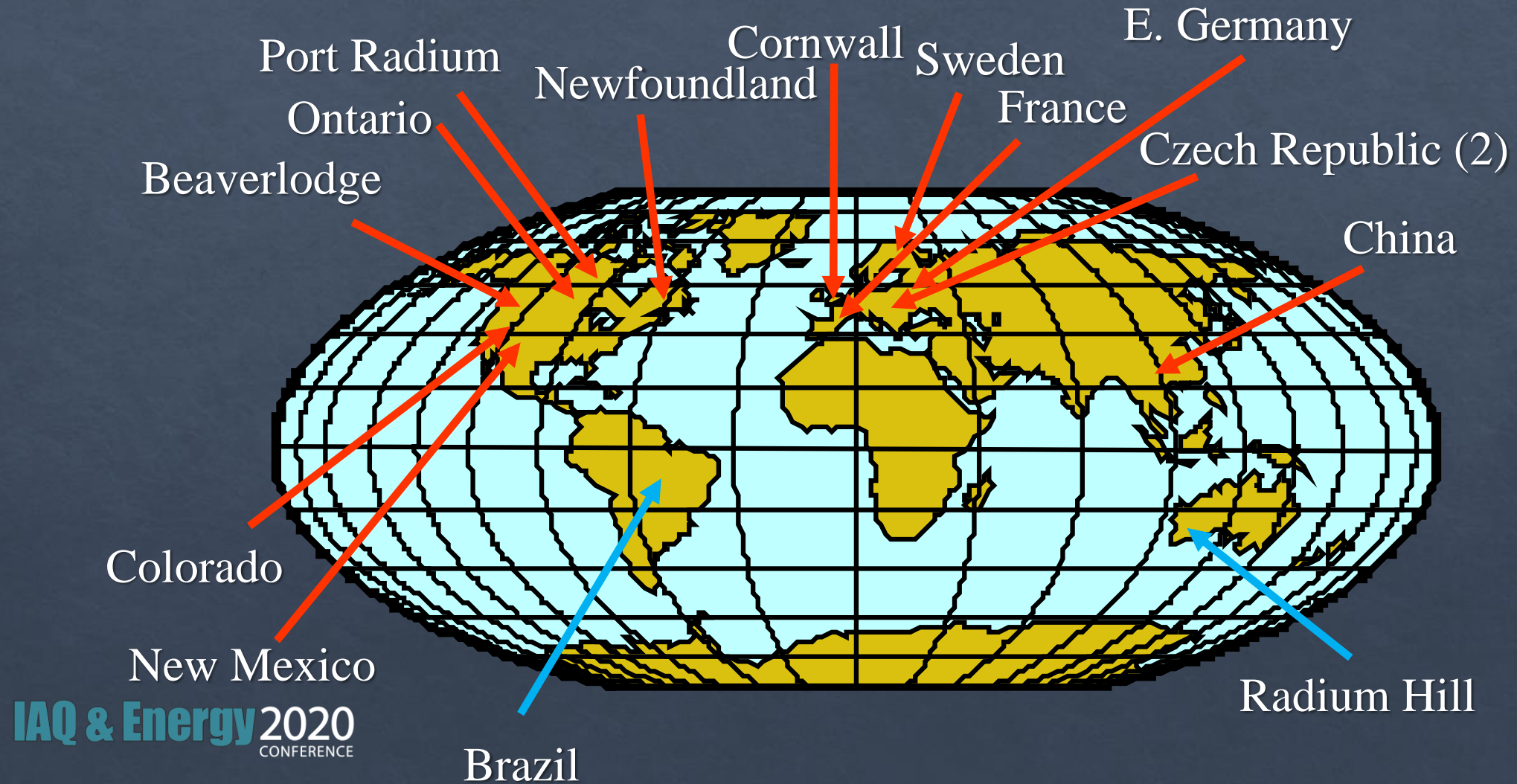


From NCRP Report No. 160, “Ionizing  
Radiation Exposure of the Population of the  
United States” (2009)

# Radon Epidemiology Study Designs

- Ecological Study
  - Compares level of disease & exposure in groups
  - Cannot correlate exposure to sick individuals
  - Cannot control for confounders
- Retrospective Cohort Study (e.g., underground miner studies)
  - Identify populations based on exposure
  - Follow for disease occurrence
- Case-Control Study (Residential Studies)
  - Identify Individuals with disease & individuals without disease
  - Look at and compare exposures

# Cohort Studies (15) of Radon-Exposed Miners



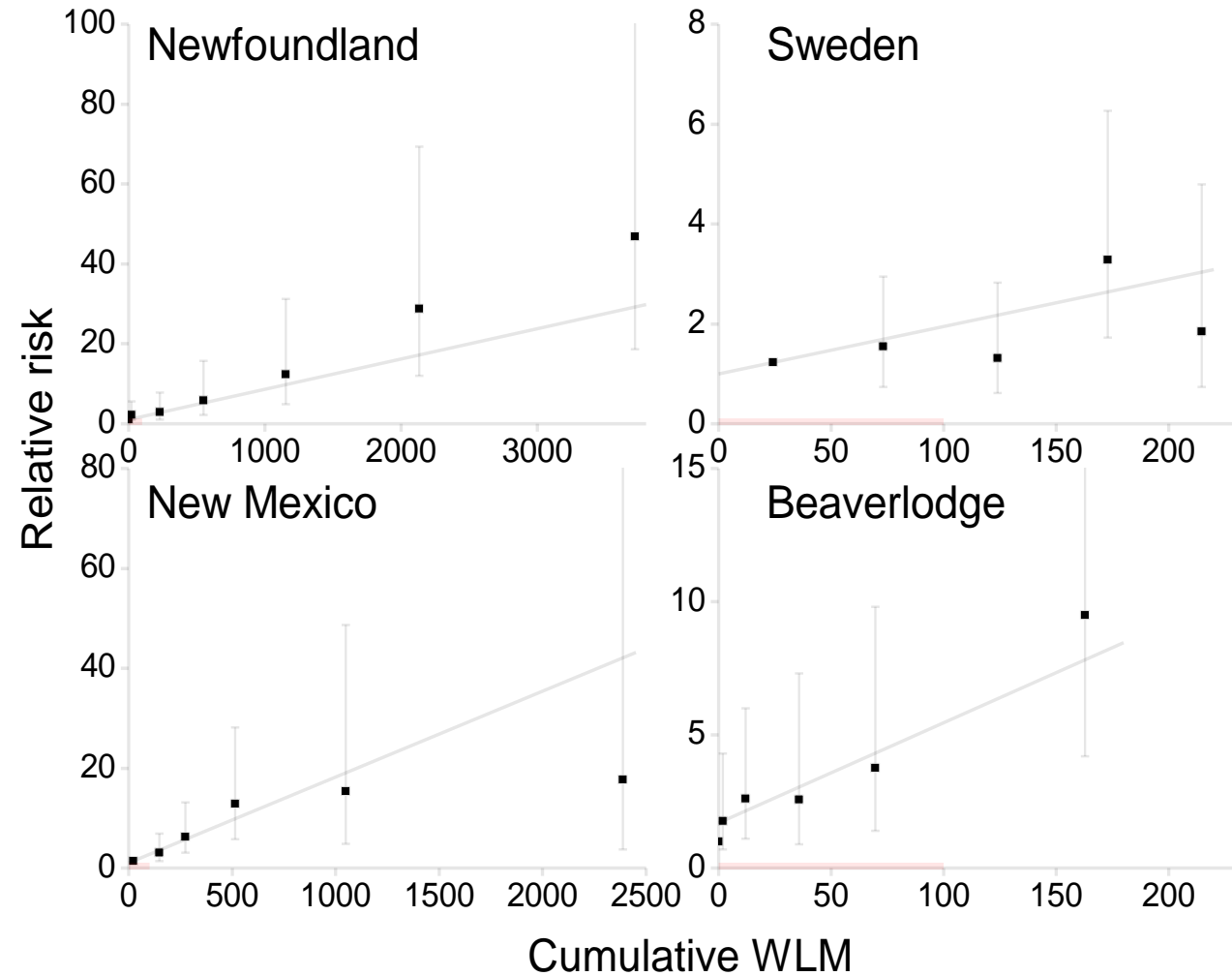


# Dose-Response in Miner Studies

Strength of the  
Association

Consistency of  
Findings

Biological Gradient  
(Dose Response)

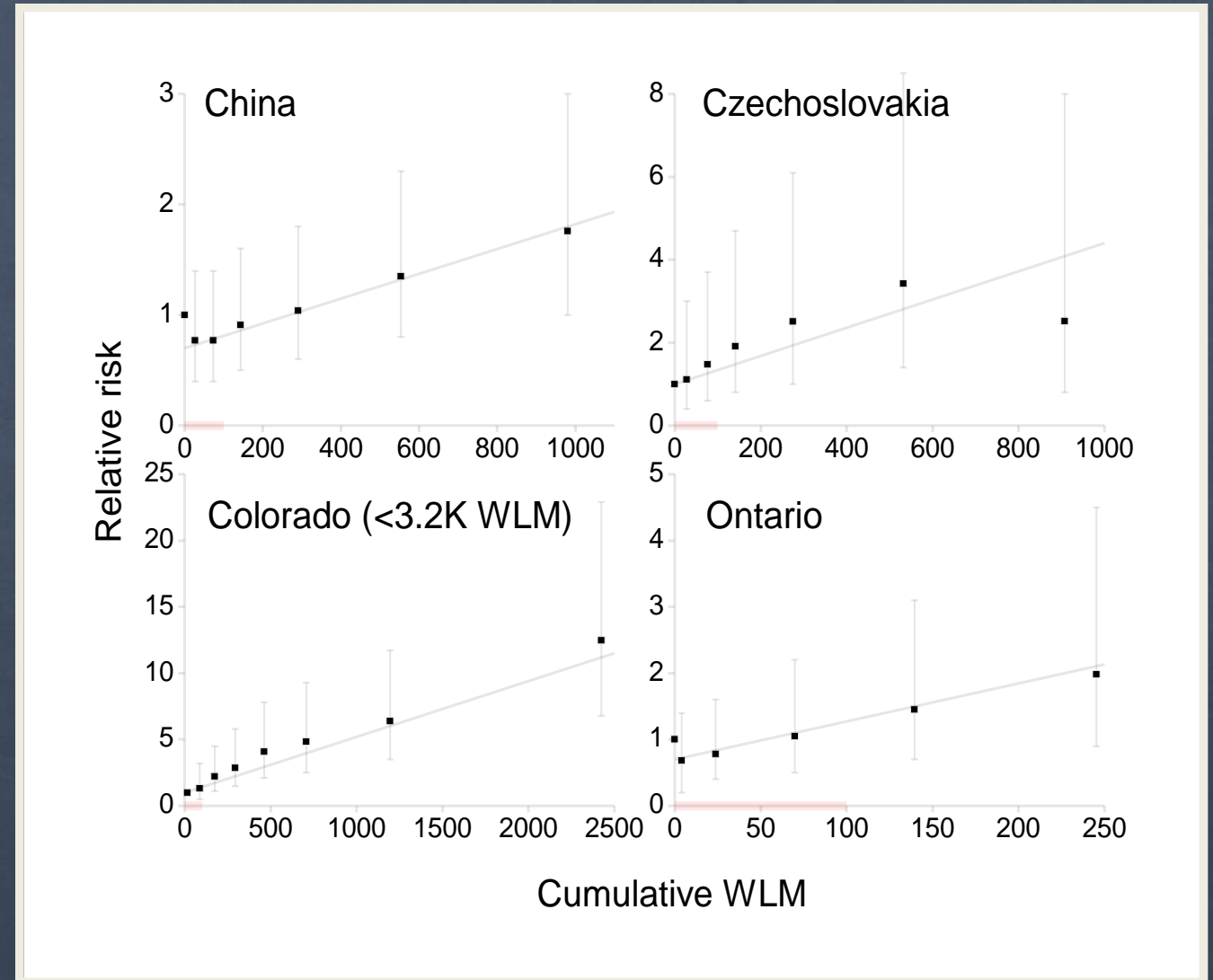


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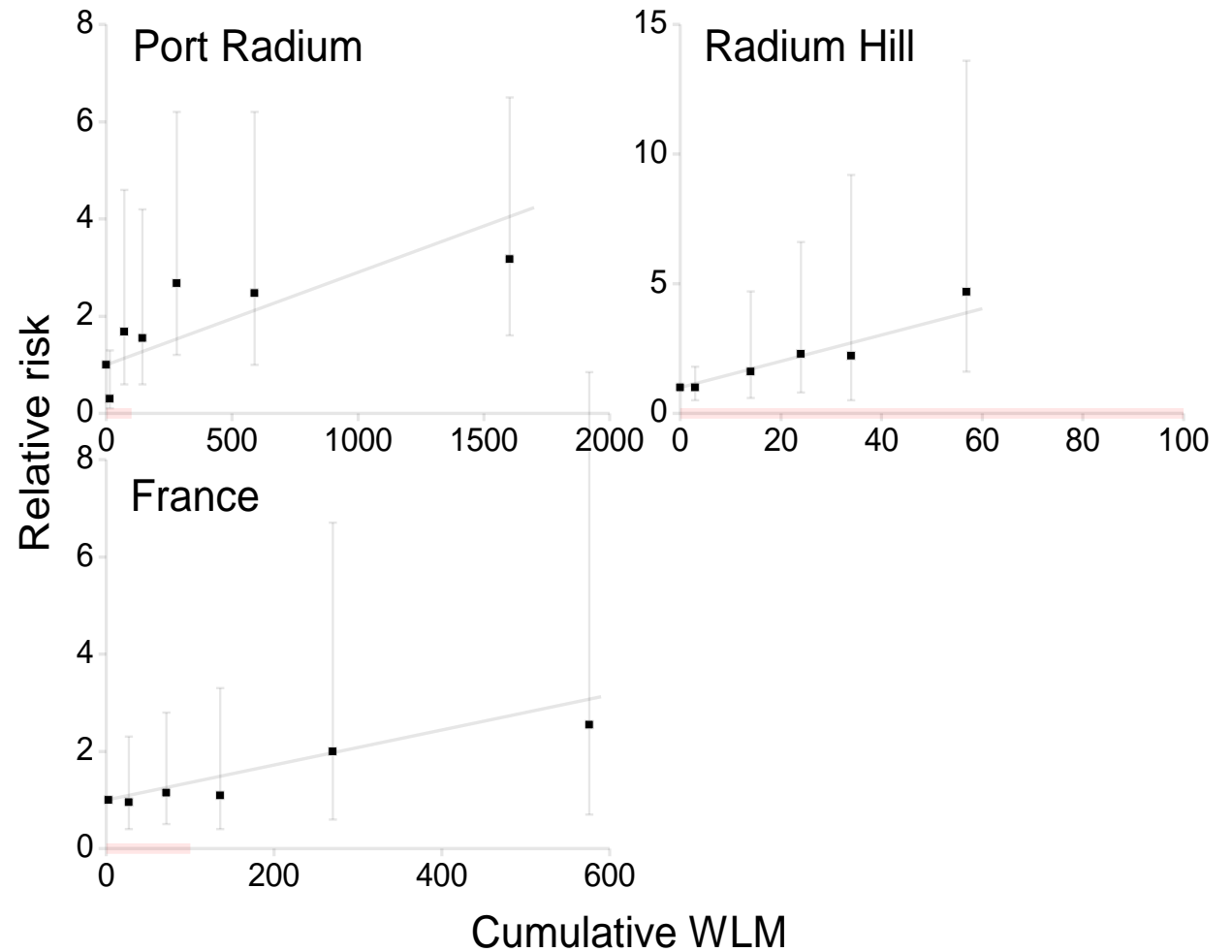
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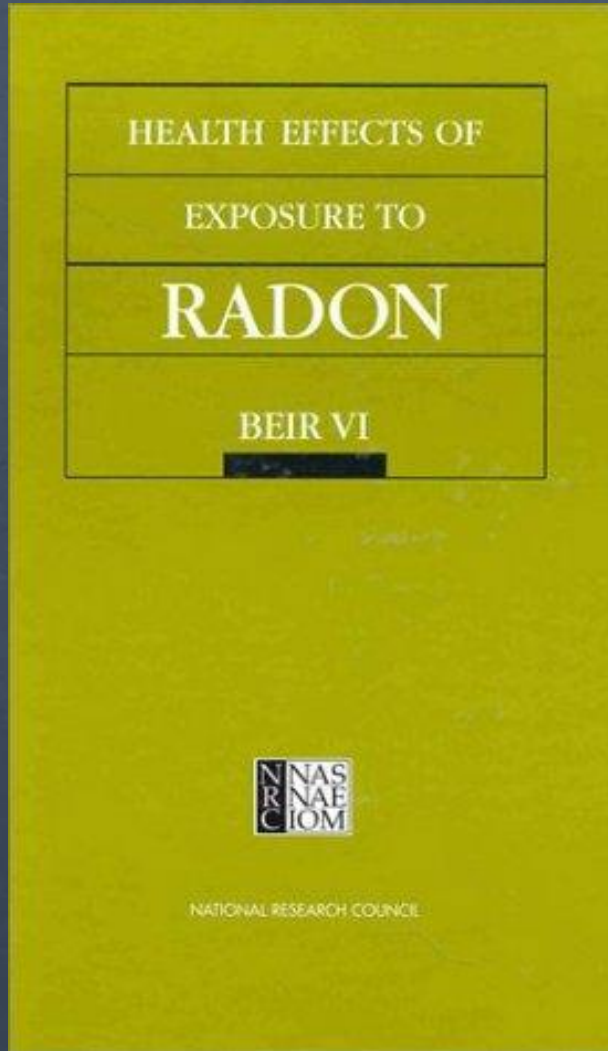
Biological Gradient  
(Dose Response)

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Lubin et al. 1995, NRC BEIR VI, 1999

# National Academy of Sciences BEIR VI 1999



- Risk estimates based primarily on radon-exposed miners
- Estimated 18,600 lung cancer deaths each year in the U.S. from residential radon exposure

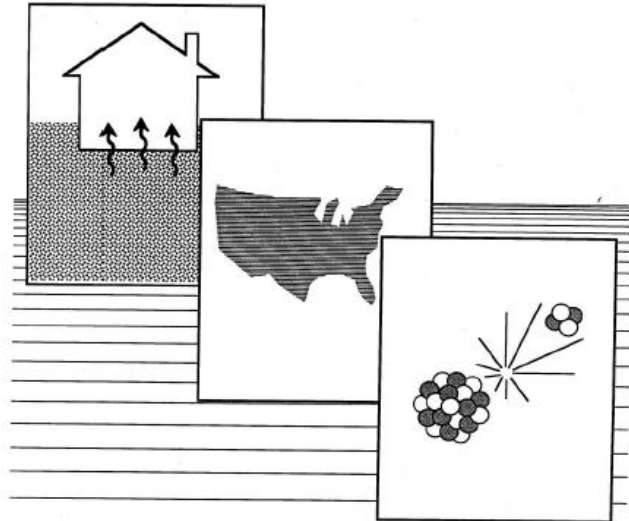


# National Research Council Conclusions

- Serious public health problem
- Second-leading cause of lung cancer
- No evidence of a threshold
- Effects of Radon & Smoking more powerful (i.e., submultiplicative) in combination
- Reduction of residential radon levels above 4 pCi/L could prevent approx. 1/3 of the annual deaths



## EPA Assessment of Risks from Radon in Homes



In 2003, the EPA updated the BEIR VI risk estimates to 21,000 radon-related lung cancer deaths each year in the United States.

[http://www.epa.gov/radon/risk\\_assessment.html](http://www.epa.gov/radon/risk_assessment.html)

Based on its analysis, EPA estimates that out of a total of 157,400 lung cancer deaths nationally in 1995, **21,100 (13.4%)** were radon related.

## Lifetime Risk of Lung Cancer Death from Radon Exposure in Homes

Risk Is Shown per 100,000 Individuals

RADON LEVEL (pCi/L)	NEVER SMOKERS	CURRENT SMOKERS	GENERAL POPULATION
20	3,600	26,000	11,000
10	1,800	15,000	5,600
8	1,500	12,000	4,500
4	730	6,200	2,300
2	370	3,200	1,200
1.25	230	2,000	730
0.4	73	640	230
Estimated Risks <u>at</u> the EPA Action Level (4 pCi/L)			
Never Smokers 7/1000   Smokers 62/1000			



## Cancer Mortality 2020

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<b>Radon-Induced Lung Cancer</b>	<b>21,100</b>
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# Residential Radon Case-Control Studies Around the World

## European Studies

### 13 Studies from 9 Countries

- Austria
- Czech Republic
- Finland [nationwide]
- Finland [south]
- France
- Germany [eastern]
- Germany [western]
- Italy
- Spain
- Sweden [nationwide]
- Sweden [never smokers]
- Sweden [Stockholm]
- United Kingdom

- Total 7,148 cases and 14,208 controls

## North American Studies

### 7 Studies from 2 countries:

- New Jersey
- Winnipeg
- Missouri I [non-smoking women]
- Missouri II [women]
- Iowa
- Connecticut
- Utah-South Idaho

- Total 3,622 cases and 4,966 controls





## Residential Radon Gas Exposure and Lung Cancer

### The Iowa Radon Lung Cancer Study

R. William Field,<sup>1</sup> Daniel J. Steck,<sup>2</sup> Brian J. Smith,<sup>3</sup> Christine P. Brus,<sup>1</sup> Eileen L. Fisher,<sup>1</sup> John S. Neuberger,<sup>4</sup>  
Charles E. Platz,<sup>5</sup> Robert A. Robinson,<sup>5</sup> Robert F. Woolson,<sup>3</sup> and Charles F. Lynch<sup>1</sup>

Exposure to high concentrations of radon progeny (radon) produces lung cancer in both underground miners and experimentally exposed laboratory animals. To determine the risk posed by residential radon exposure, the authors performed a population-based, case-control epidemiologic study in Iowa from 1993 to 1997. Subjects were female Iowa residents who had occupied their current home for at least 20 years. A total of 413 lung cancer cases and 614 age-frequency-matched controls were included in the final analysis. Excess odds were calculated per 11 working-level months for exposures that occurred 5–19 years ( $WLM_{5-19}$ ) prior to diagnosis for cases or prior to time of interview for controls. Eleven  $WLM_{5-19}$  is approximately equal to an average residential radon exposure of 4 pCi/liter (148 Bq/m<sup>3</sup>) during this period. After adjustment for age, smoking, and education, the authors found excess odds of 0.50 (95% confidence interval: 0.004, 1.81) and 0.83 (95% percent confidence interval: 0.11, 3.34) using categorical radon exposure estimates for all cases and for live cases, respectively. Slightly lower excess odds of 0.24 (95 percent confidence interval: –0.05, 0.92) and 0.49 (95 percent confidence interval: 0.03, 1.84) per 11  $WLM_{5-19}$  were noted for continuous radon exposure estimates for all subjects and live subjects only. The observed risk estimates suggest that cumulative ambient radon exposure presents an important environmental health hazard. *Am J Epidemiol* 2000;151:1091–1102.

# Residential Radon Studies

Odds Ratios  
at 4.0 pCi/L  
(150 Bq/m<sup>3</sup>)

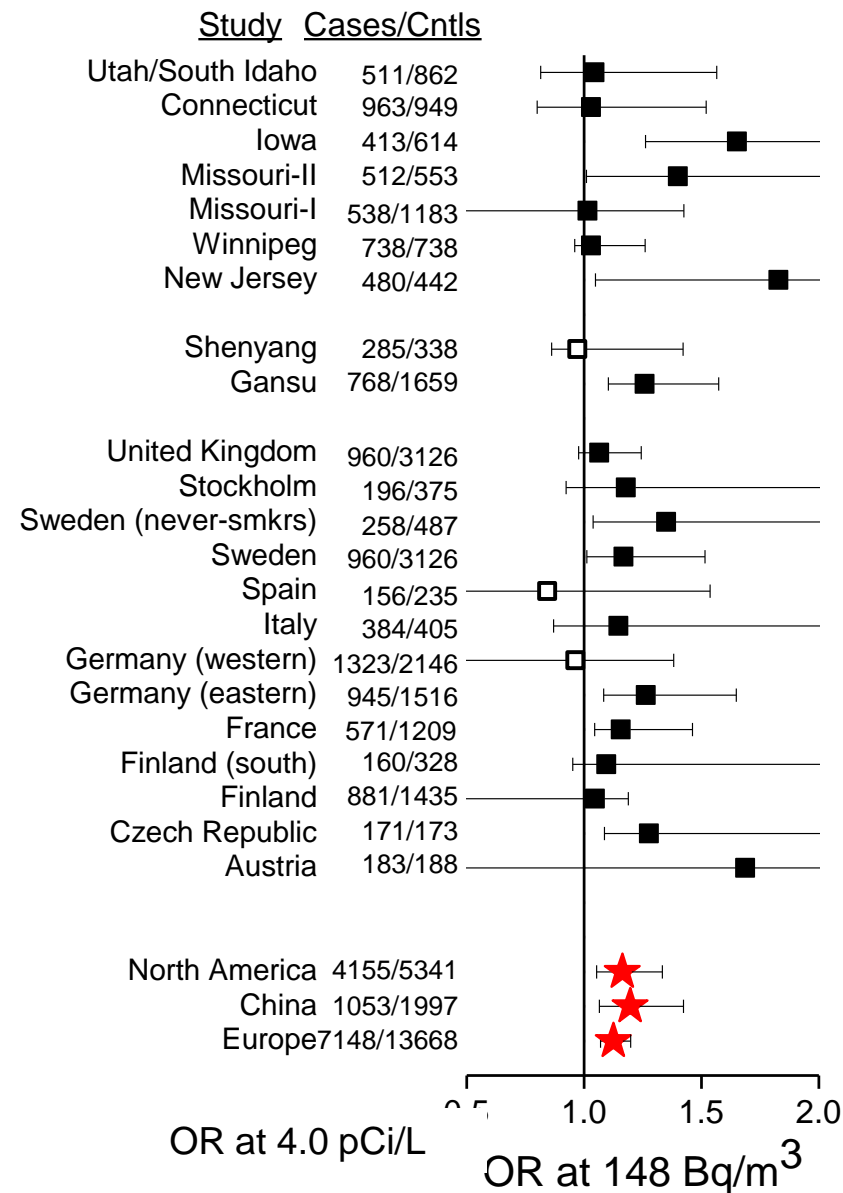
Consistency of  
Findings

NA: Krewski et al. 2005, 2006

China: Lubin 2004

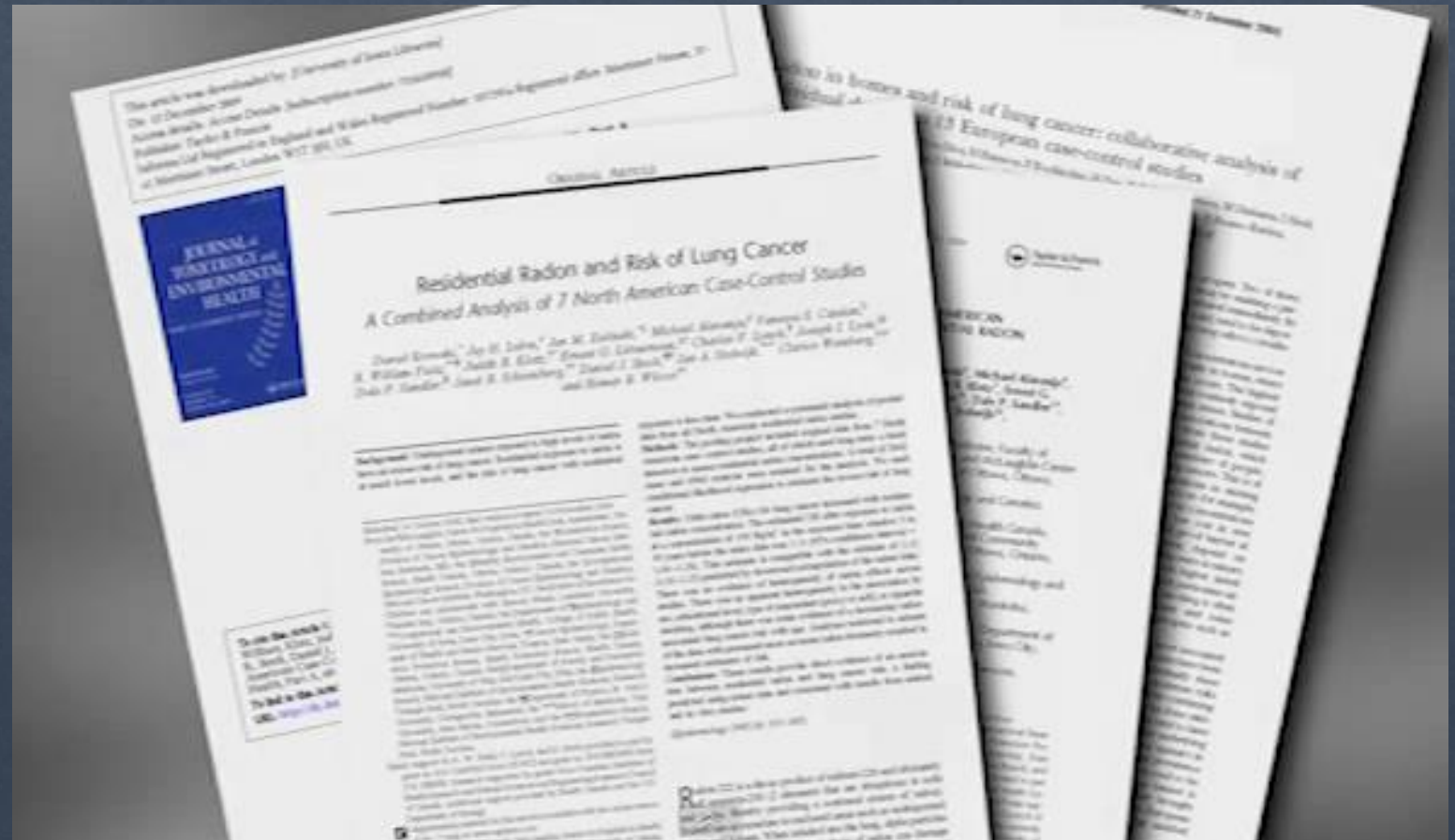
Eur: Darby et al. 2004, 2006

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# Pooled Residential Radon Studies

- Pooling results published 2004-2006
  - North America (7)
  - Europe (13)
  - China (2)





## Pooled Analyses Agreement at 3 pCi/L ??

New Jersey, Missouri I, Canada, Iowa, Missouri II, a combined study from Connecticut, Utah and S. Idaho

10% – 18%

Shenyang, China, Stockholm, Sweden, Swedish nationwide, Winnipeg, Canada, S. Finland, Finnish nationwide, SW England, W. Germany, Sweden, Czech Republic, Italy-Trento, Spain, Austria, France, China - Gansu Province, E. Germany

# Results of Major Radon Epidemiological Studies

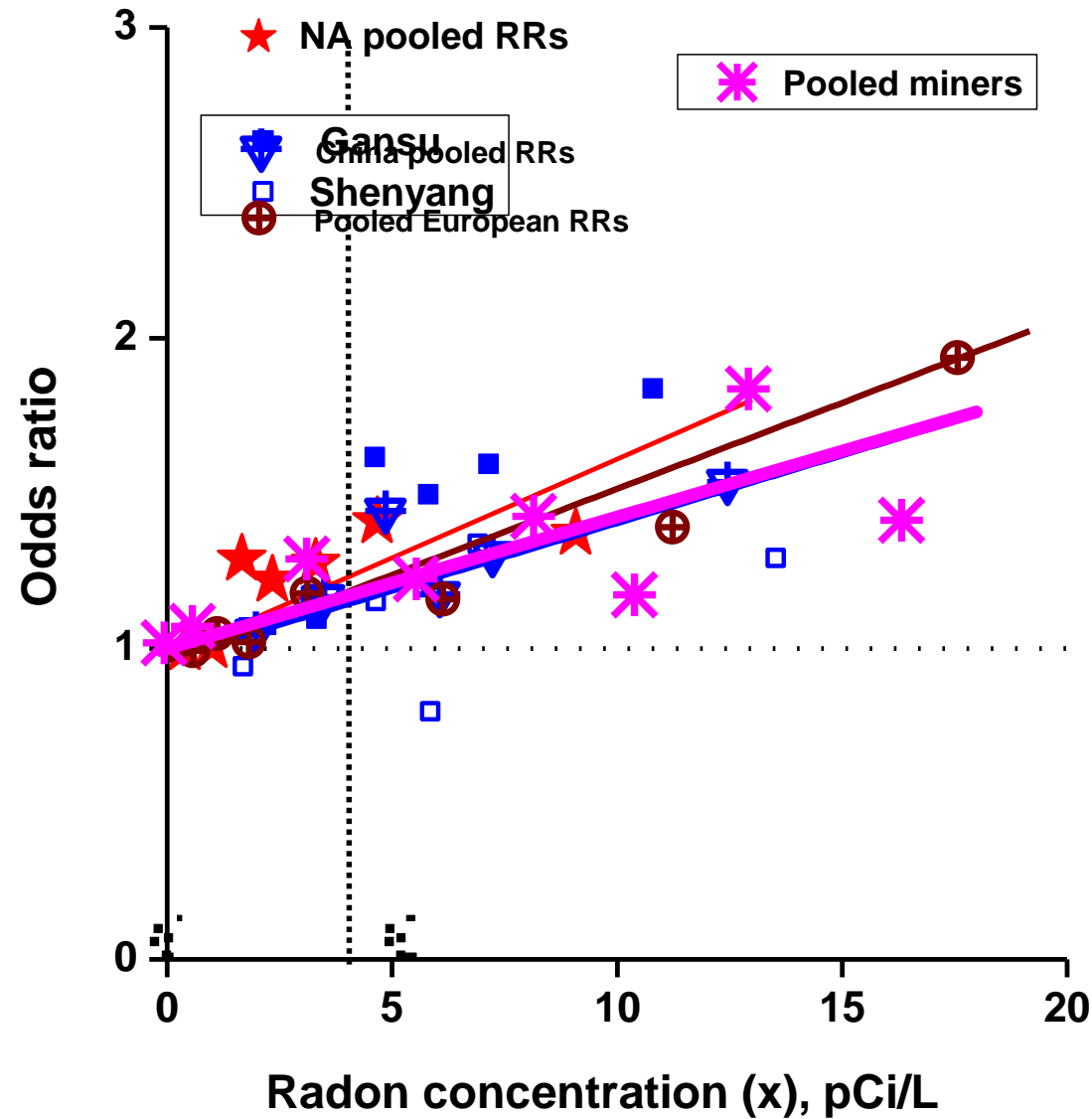
Coherence

Strength of the  
Association

Consistency of  
Findings

Biological Gradient  
(Dose Response)

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# National and International Guidance on Radon



# The International Radon Project

## WHO - IRP Website 2005

"Recent findings from case-control studies on lung cancer and exposure to radon in homes completed in many countries allow for substantial improvement in risk estimates and for further consolidation of knowledge by pooling data from these studies."

**" The consistency of the findings from the latest pooled analyses of case-control studies from Europe and North America as well as China provides a strong argument for an international initiative to reduce indoor radon risks."**

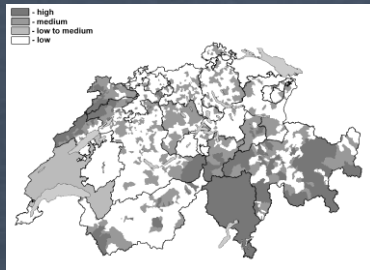
# WHO-IRP National Partners



- Albania
- Argentina
- Austria
- Belgium
- Brasil
- Bulgaria
- Canada
- China
- Czech Republic
- Finland
- France
- Georgia
- Germany
- Greece
- Hungary
- India
- Ireland
- Italy
- Japan
- Lithuania
- Luxembourg
- Norway
- Poland
- Romania
- Russian Federation
- Serbia
- Slovenia
- South Korea
- Spain
- Sweden
- Switzerland
- Turkey
- USA
- Ukraine
- United Kingdom

## 6. National radon programmes

### KEY MESSAGES



- National radon programmes should aim to reduce the overall population risk and the individual risk for people living with high radon concentrations.
- To limit the risk to individuals, a national reference level of  $100 \text{ Bq/m}^3$  is recommended. Wherever this is not possible, the chosen level should not exceed  $300 \text{ Bq/m}^3$ .
- To reduce the risk to the overall population, building codes should be implemented that require radon prevention measures in homes under construction. Radon measurements are needed because building codes alone cannot guarantee that radon concentrations will be below the reference level.
- Detailed national guidance on radon measurement protocols is essential to ensure quality and consistency in radon testing. A national radon database that monitors the measurement results over time can be used to evaluate the effectiveness of a national radon programme.
- An effective national radon programme requires input from several agencies within a country. One agency should lead the implementation and coordination and ensure linkage with tobacco control and other health promotion programmes.





# WHO HANDBOOK ON INDOOR RADON

## A PUBLIC HEALTH PERSPECTIVE



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**How does the project work?**  
IRP working groups:  
■ Risk Assessment  
■ WHO Exposure Guidelines  
■ Cost Effectiveness  
■ Measurement and Mitigation  
■ Risk Communication  
■ Coordination and Evaluation  
Network and working group meetings  
Production of Radon-related databases, reports and recommendations  
Project coordination through WHO

**Time to act**  
The largest contribution to environmental radiation in many countries comes from radon  
■ The science is clear: the dangers of radon exposure are well established  
■ Effective ways to reduce radon levels are available

**The challenge**  
Translating scientific knowledge into public health action to minimize the health risks for the population.  
■ The WHO IRP project will contribute to this through a concerted effort of partners from all over the world.

Membership is open to any WHO member state government, i. e. department of health, or representatives of other national institutions concerned with radiation research and protection.

A global project to increase awareness on **radon** and health support action to decrease **radon** levels in homes

Radiation and Environmental Health Unit  
Protection of the Human Environment  
World Health Organization  
1211 Geneva 27, Switzerland  
Tel.: +41 22 791 2864  
Fax: +41 22 791 4122  
e-mail: radon@who.int

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Radon

INTERNATIONAL RADON PROJECT

**The International Radon Project (IRP)**

WHO INITIATIVE TO REDUCE LUNG CANCER RISK AROUND THE WORLD

Exposure to radon in the home and workplace is one of the main risks of ionizing radiation causing tens of thousands of deaths from lung cancer each year globally. In order to reduce this burden it is important that national authorities have methods and tools based on solid scientific evidence and sound public health policy. The public needs to be aware of radon risks and the means to reduce and prevent these.

In 1996 WHO published a [report](#) containing several conclusions and recommendations covering the scientific understanding of radon risk and the need for countries to take action in the areas of risk management and risk communication.

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1. The International Radon Project (IRP)
2. [The International Radon Project \(IRP\) cont.](#)
3. [Additional Information on Radon](#)
4. [Radon in drinking water](#)

# REDUCING ENVIRONMENTAL CANCER RISK

What We Can Do Now

6. The cancer risk attributable to residential radon exposure has been clearly demonstrated and must be better addressed. The following are needed:
  - The Environmental Protection Agency (EPA) should consider lowering its current action level (4 pCi/L) for radon exposure, taking into account data on radon-related cancer risk developed since the existing action level was established.
  - Public and health care provider education should be developed and broadly disseminated to raise awareness of radon-related cancer risk.



# Breathing Easier



## Do you ask your patients if they've tested their homes for radon?

*"Educating patients about the risk, and promoting the use of radon test kits, is something everyone can do and should do."*

- Charles Lynch, M.D., Ph.D.

*"I remember him putting his face in his hands. He was sitting next to me out in his waiting room, and he just said, 'Why don't physicians know about this?'"*

- Gail Orcutt, Pleasant Hill

*"I want physicians personally to test their homes. We can really have an influence if we can get people to test. As physicians, we can model the behavior that we'd like our patients to follow."*

- Timothy Vermillion, D.O.

Watch a video to learn how asking this important question could save lives:



(12-minute version)



Download educational fliers to hang in clinic or exam rooms:

Iowa-Specific Fliers (click images below to view and print)



National Fliers (click images below to view and print)



CRCPD Publication E-15-2

## Reducing the Risk from Radon: Information and Interventions

*A Guide for Health Care Providers*

RadonLeaders.org





# Availability of Guide and Reference Material

## Radon Leaders -

<http://www.radonleaders.org/resources/reducingtheriskfromradon>

The following videos explain how asking this important question could save lives:



# Medical Organizations



**American Academy of  
Family Physicians**

American Family Physician®

Editorial on radon risk for their journal that includes “180,000 loyal readers”.

&lt;&lt; Previous article

Sep 1, 2018 Issue

Next article &gt;&gt;

**Editorials**

# Radon: A Leading Environmental Cause of Lung Cancer

 PDF  PRINT  COMMENTSSHARE   

R. WILLIAM FIELD, PhD, MS, University of Iowa College of Public Health, Iowa City, Iowa

*Am Fam Physician.* 2018 Sep 1;98(5):280-282.

Protracted exposure to radon decay products is the leading environmental cause of cancer mortality in the United States.<sup>1,2</sup> Family physicians play a key role in informing their patients about the health risks posed by radon exposure and in recommending proactive actions to reduce radon exposure.



# Summary

- Radon is a global public health concern.
- The residential radon studies have provided direct evidence that prolonged residential radon is one of our leading public health risks and major cause of cancer mortality.
- Radon is our leading environmental cause of cancer mortality in the United States and seventh leading cause of cancer mortality overall.

# Radon: Fact or Fiction

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