Cancer risk from radon exposures in mines: new research on an old problem

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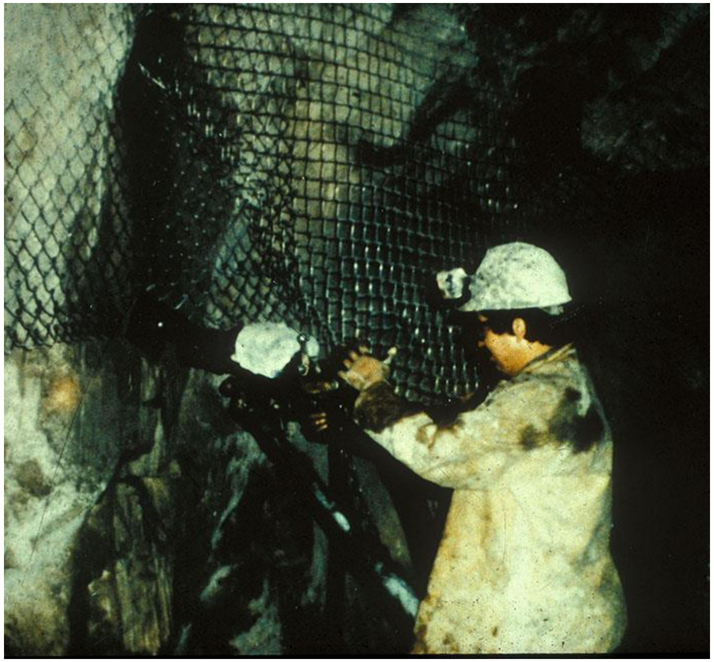
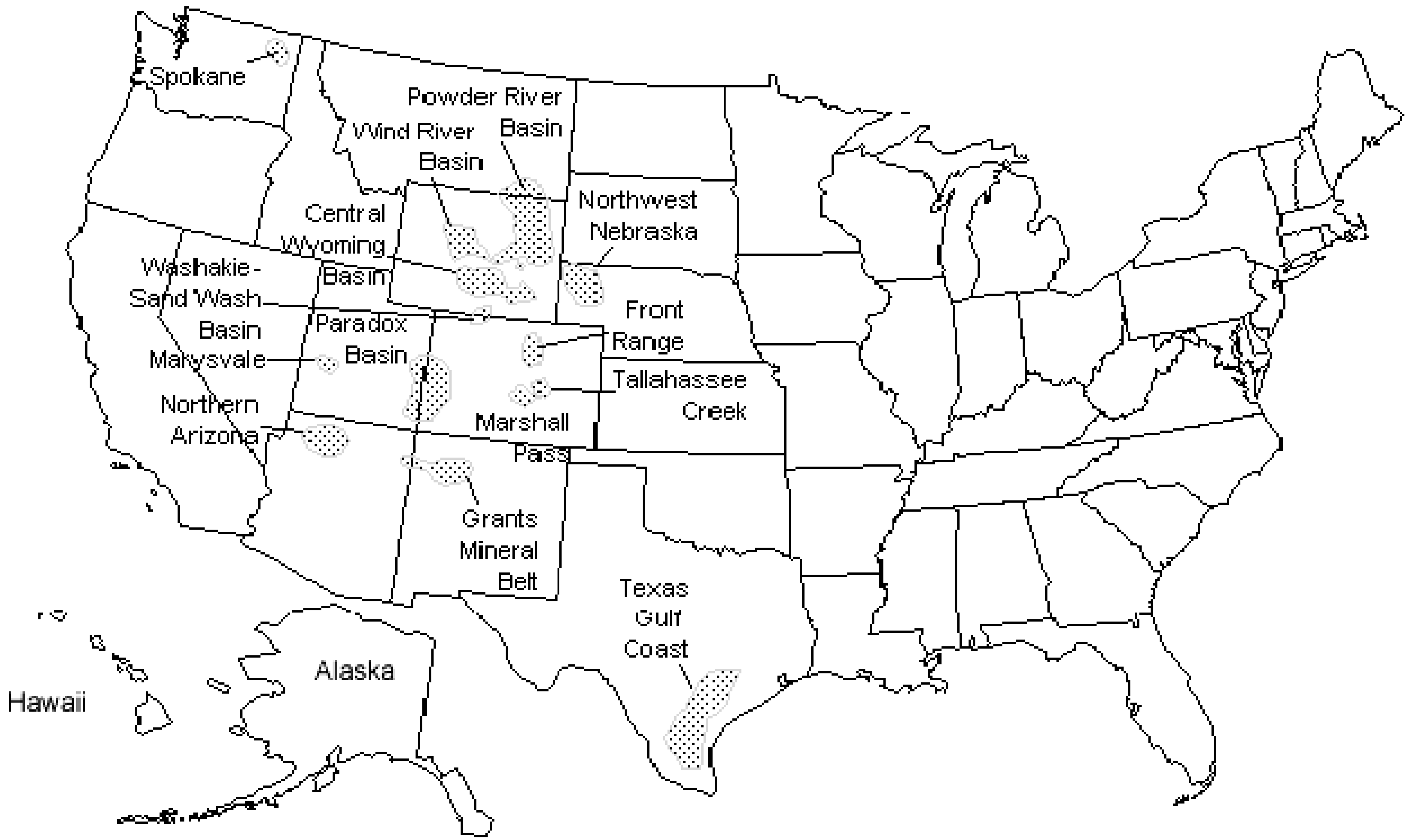
What is radon?

- An odorless, colorless radioactive gas, which occurs naturally throughout the earth's crust
  - Ultimate source is uranium, which is usually at very low levels (e.g., 1-3 parts per million) in most rocks and soils
- Elevated in some geological formations with greater uranium
  - Vanadium
  - Some granites and karst limestone
  - Hard-rock mines
- Radioactive decay→ radon progeny



Major U.S. Uranium Reserves



Sources: Based on U.S. Department of Energy, Grand Junction Project Office (GJPO), National Uranium Resources Evaluation, Interim Report (June 1979) Figure 3.2; and GJPO data files.

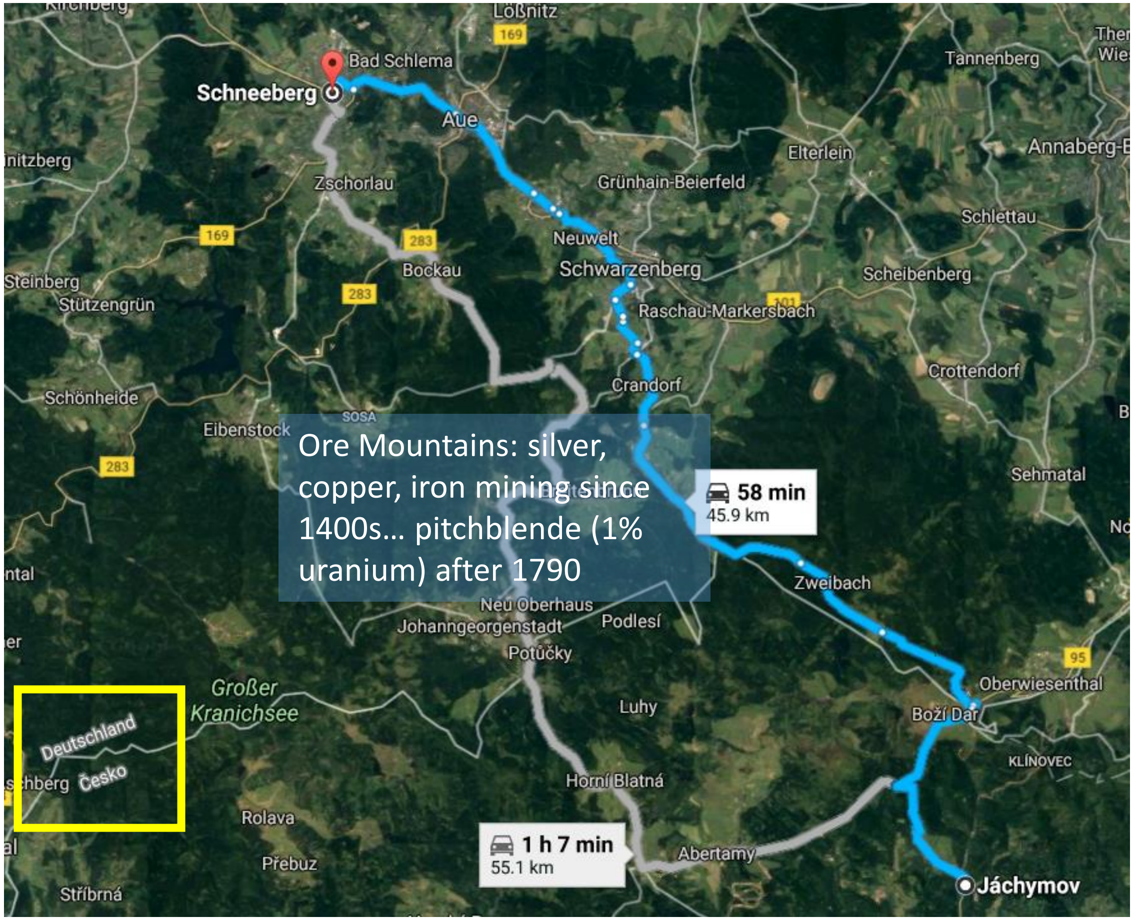
Uranium mines and mills in Canada

- Out of 18 facilities, 10 are closed or decommissioned
- All active mines (n=3) and mills (n=3) are in northern Saskatchewan

Source: Canadian Nuclear Safety Commission

http://nuclearsafety.gc.ca/eng/uranium/mines-and-mills/index.cfm#OperatingUraniumMinesandMills

Earliest mining in high-radon area



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CANCER OF THE LUNG IN THE MINERS OF JÁCHYMOV (JOACHIMSTAL)

REPORT OF CASES OBSERVED IN 1929–1930

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INTRODUCTION

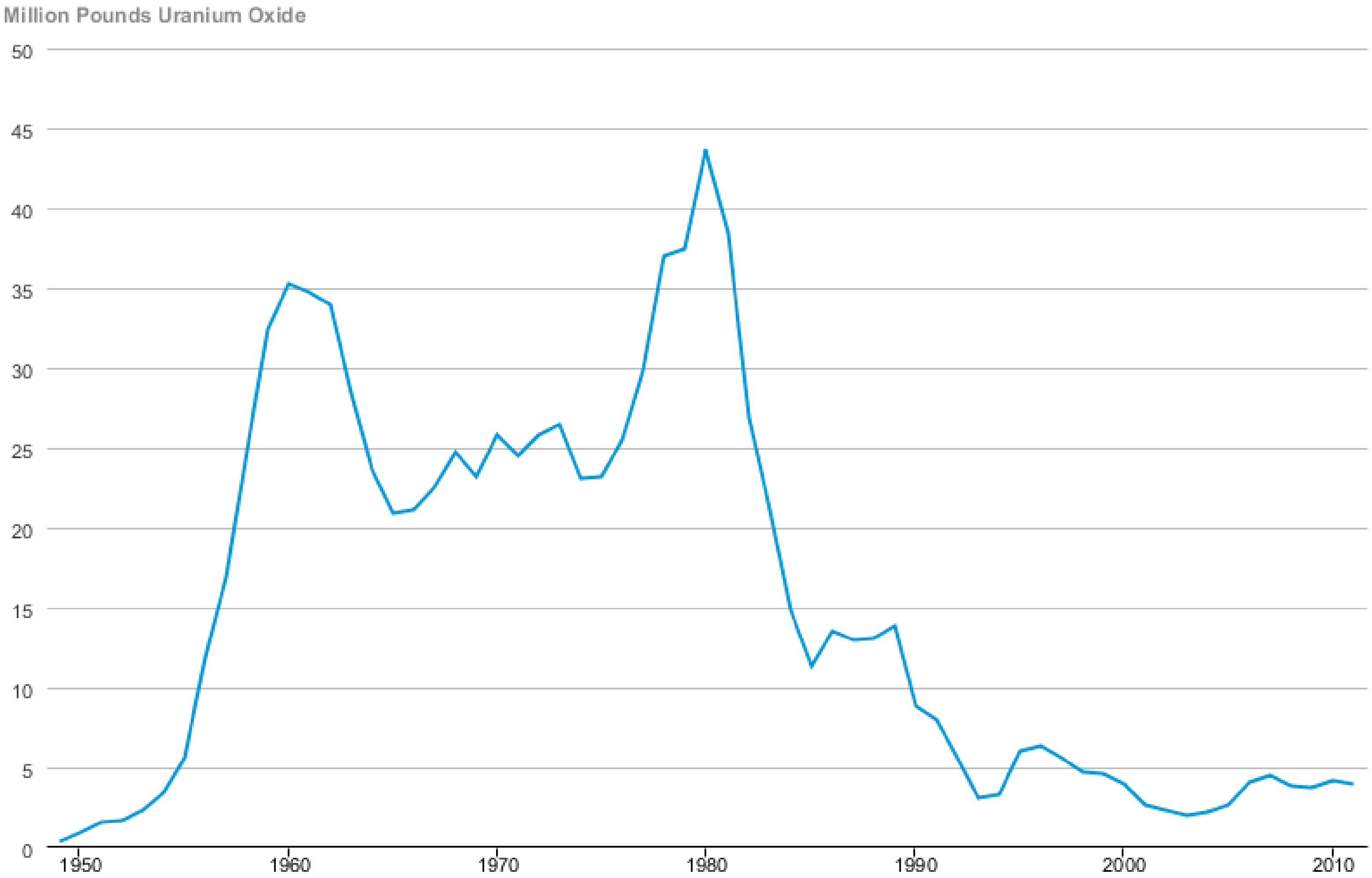
A miner's life has always been fraught with danger. Besides various traumatic accidents, to which the miner is exposed, his health and life are endangered by the poisonous atmosphere of his environment.

In the mines of the Erz Mountains, on both the Bohemian and Saxon sides, it has been known for some centuries that the miners die in the prime of life with symptoms of damaged lungs and rapidly progressing cachexia. These conditions, especially well known at the Schneeberg mines in Saxony, have been mentioned or described by many writers, *viz.* Agricola in 1500, Matthesius in 1559, Pansa in 1814, Scheffler (1) in 1770, and others. The real nature of the affection was not discovered, however, until 1879, when Härting and Hesse (2), by clinical and anatomical research, proved it to be a malignant tumor of the lungs. Latterly, the matter has been

US uranium mining: historical context

- In the 1940s, a “uranium rush” began in southwest US, to supply feed material for nuclear weapons production
- Hundreds of mines were dug during the 1950s-60s, many were small operations
- The largest and most productive area of uranium mining in the U.S. was the Colorado Plateau of the four corners region (Arizona, Colorado, New Mexico, Utah)

Table 9.3 Uranium Overview, 1949-2011, Domestic Concentrate Production



Source: U.S. Energy Information Administration

U.S. Public Health Service (PHS) Study

In 1950, U.S. PHS began studies of conditions in mines

- Duncan Holaday initially measured radon in U.S. mines and reported it was much too high (37 - 22,000 pCi/L), but his alerts went mostly unheeded
- Prospective cohort study of a subset of white and American Indian miners began in July 1950, including medical exams and questionnaires, continuing to 1964
- 12,000 mine measurements made for radon progeny from 1950-63
- Doses were expressed in the unit "working level months" (WLM)
  - A WL is a unit of measure of the potential alpha energy concentration in air from a mixture of short-lived radon radioactive decay progeny
  - A WLM is working for 170 hours at that concentration

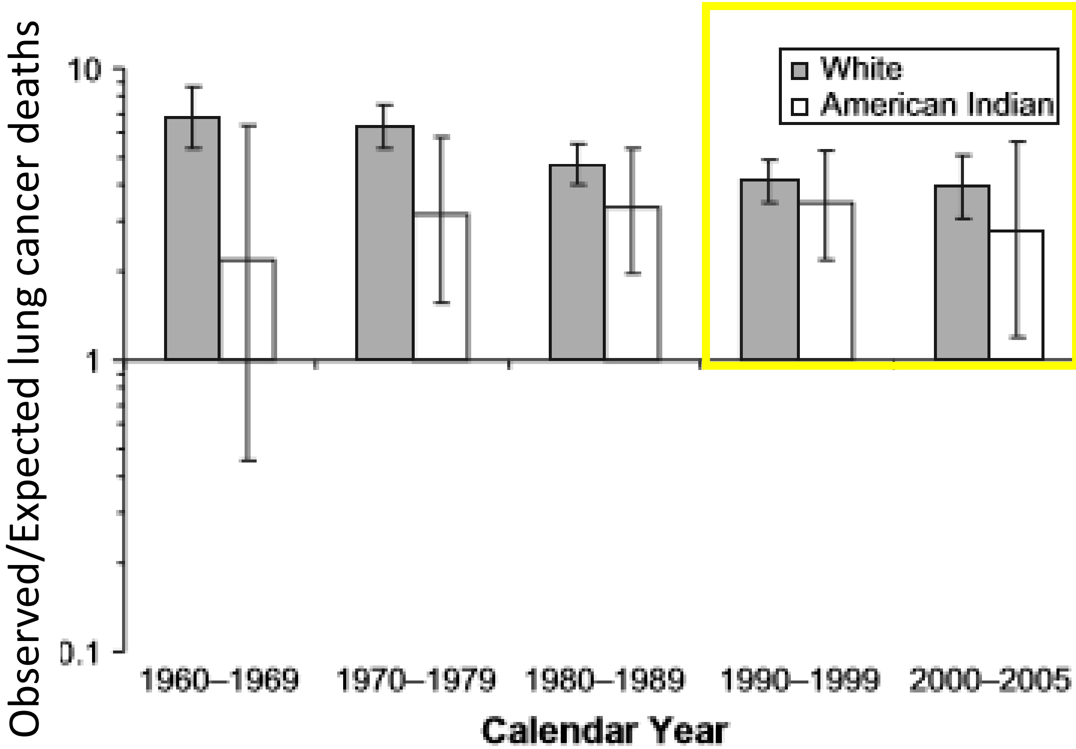
U.S. Public Health Service (PHS) Study

Early findings

- In 1960, 5-fold higher lung cancer rates began to be reported (Time Magazine, 12/26/1960)
- Comprehensive dose-response evaluation in 1969 (Lundin et al. Health Phys 16:571-8)
  - 6-fold elevated lung cancer rate in white miners (15% of all deaths), plus dose-response trend
  - No excess (n=2) in American Indian miners; differences attributed to lower smoking rate
  - Smoking somehow modified the effect of radon: excess number of lung cancers was 1.7 (per unit of person-time-dose) for non-smokers and 17 for smokers
  - Risks varied by years since first exposure: no risk <5 years, and increasing risk to beyond 10 years

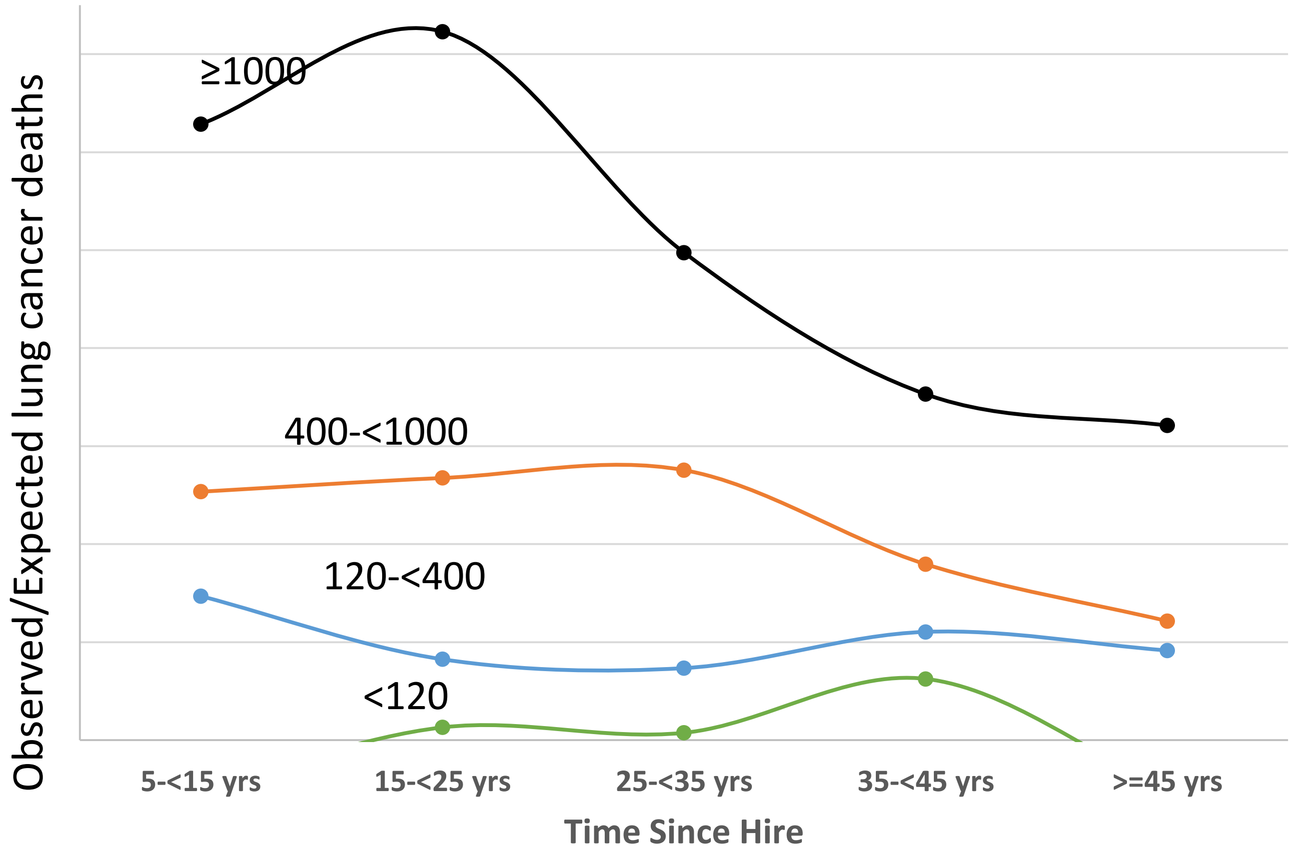
New follow-up of cohort shows lung cancer risks remain high

- 4022 miners (19% Navajo) followed through 2005
- Average dose: 808 WLM
- 209 new lung cancer deaths occurred, 1990-2005
  - White miners had 4x expected number
  - Navajo miners had 3.3x expected number

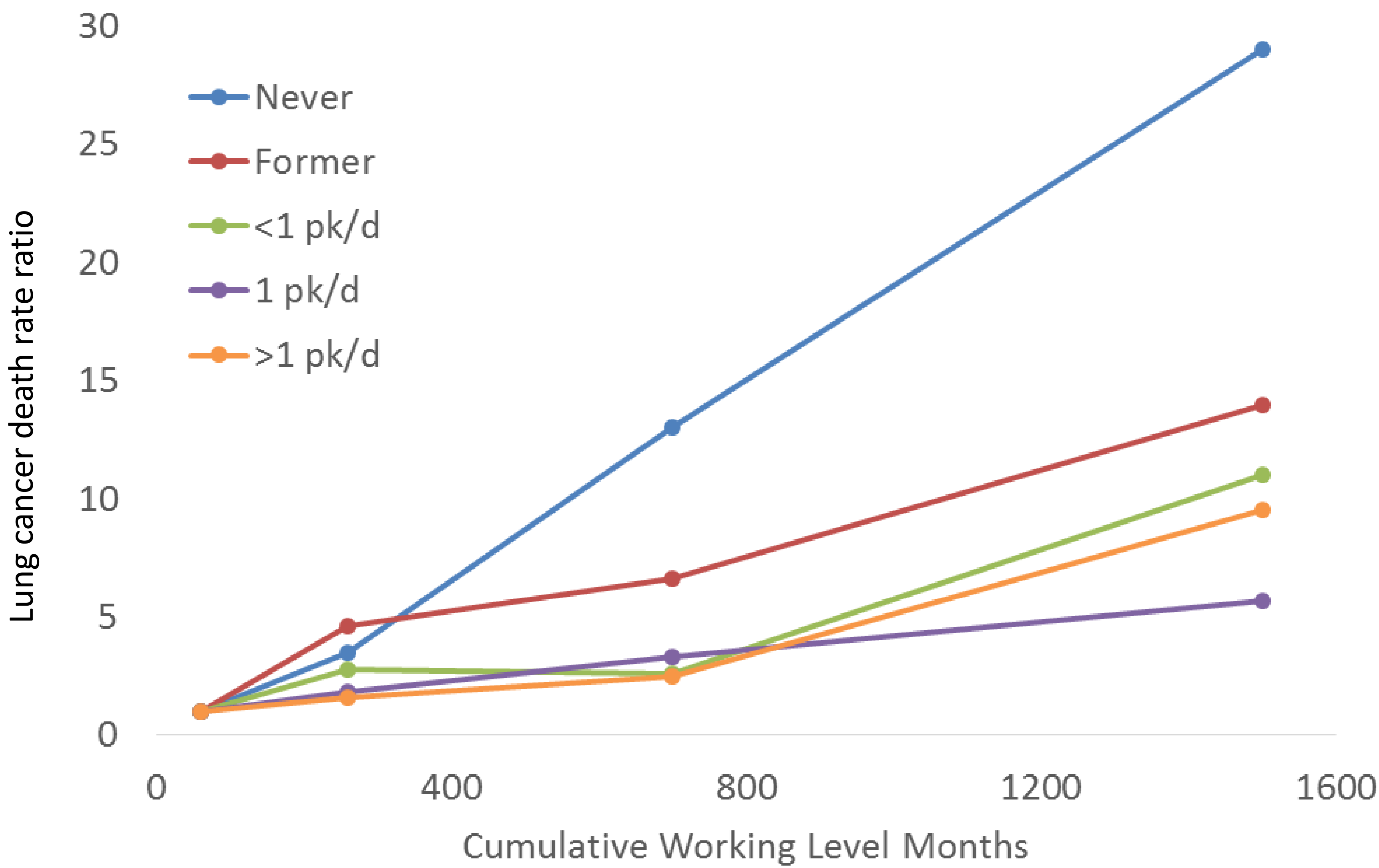


(Schubauer-Berigan et al. Am J Epidemiol 2009; 169:718–730)

Lung cancer excess peaked earlier for higher than for lower doses

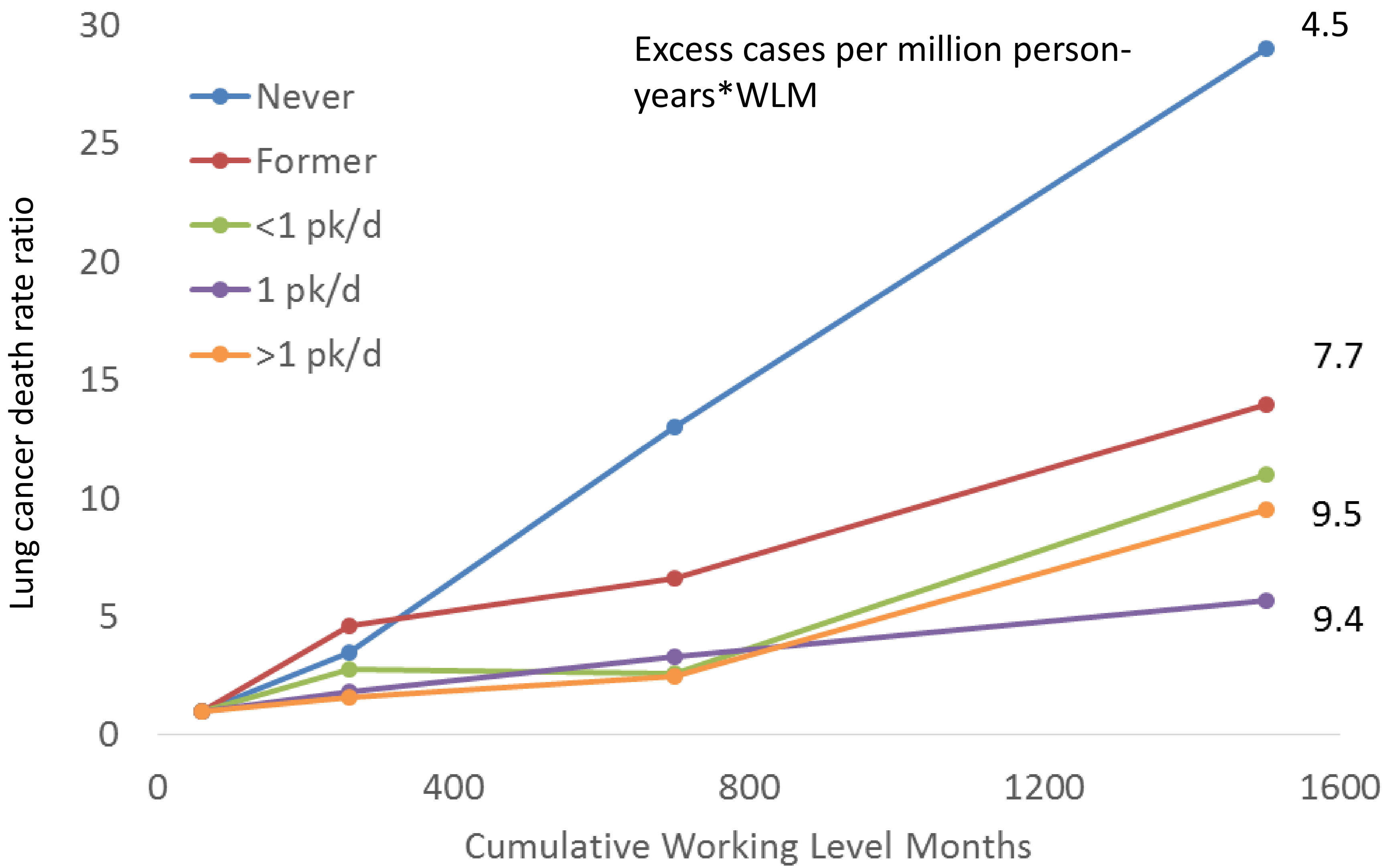


Lung cancer <u>relative</u> risk by dose group is much higher for never-smokers than for smokers…



U.S. Colorado Plateau Cohort Study

…but the excess number of lung cancer cases (per WLM) is much higher for heavy smokers than never-smokers



U.S. Colorado Plateau Cohort Study

The estimated radon-attributable risk of lung cancer varies by smoking group

Never-smokers		Radon-attributable
Total observed lung cancers	76	
Est. # lung cancers caused by radon	68.3	90%
Former smokers		
Total observed lung cancers	234	
Est. # lung cancers caused by radon	199	85%
Current smokers <1 pack/day		
Total observed lung cancers	52	
Est. # lung cancers caused by radon	36.9	71%
Current smokers 1 pack/day		
Total observed lung cancers	150	
Est. # lung cancers caused by radon	95.1	63%
Current smokers >1 pack/day		
Total observed lung cancers	100	
Est. # lung cancers caused by radon	60.7	61%

Data through 2005 (Schubauer-Berigan et al. 2009)

The estimated radon-attributable risk for lung cancer is higher for American Indian miners (lower smoking rates)

American Indian		Radon-attributable
Total observed lung cancers	63	
Est. # lung cancers caused by radon	52.5	83%
White		
Total observed lung cancers	549	
Est. # lung cancers caused by radon	360	66%

Data through 2005 (Schubauer-Berigan et al. 2009)

Studies of Canadian uranium miners

- Three major cohort studies of Canadian uranium miners
  - Ontario: 28,500 miners with average dose of 21 WLM (Howe et al. 1986; Navaranjan et al. 2016)
  - Beaverlodge (Saskatchewan): ~6900 exposed miners with average dose of 17 WLM (Kusiak et al. 1991; Lane et al. 2010; Zablotska et al. 2014)
  - Port Radium (Northwest Territories): 1420 exposed miners with average dose of 243 WLM (Howe et al. 1987 ; Lane et al. 2010; Zablotska et al. 2014)
- All three studies showed significant dose-response
  - Higher doses were associated with higher lung cancer risk within each cohort
  - New follow-up of cohorts has confirmed these findings

Pooled international study of radon-exposed miners
(Lubin et al. 1994)

Cohort	Type of mine	No. exposed miners	Mean dose (WLM)
Radium Hill (AUS)	Uranium	1457	7.6
Beaverlodge	Uranium	6895	17.2
Ontario	Uranium	21,346	30.8
France	Uranium	1769	68.7
Sweden	Iron	1294	80.6
New Mexico	Uranium	3457	110
Czech Republic	Uranium	4284	198
Port Radium	Uranium	1420	243
China	Tin	13,649	277
Newfoundland	Fluorspar	1751	367
Colorado Plateau	Uranium	3347	807

How have radon-exposed miner study findings been used?

- Establishing protective exposure limits for workers and the general public

Table 1. Applicable protection standards and guidance for occupational exposure to radon progeny.

Standard type	Agency	Reference	Covered population	Annual level (WLM)
Guidance	ICRP	Publication No. 126	All	1
	NCRP	Report No. 77	Public	2
	ACGIH	2011 TLVs® and BEIs®	Workers	4
	NIOSH	Publication No. 88-101	Underground miners	1
Regulation	DOE	10 CFR 835, Appendix A	DOE workers	10
	MSHA	30 CFR Part 57	Underground miners	4
	USNRC	10 CFR 20, Appendix B, Table 1	Licensee workers	4
	OSHA	29 CFR 1910.1096, 29 CFR 1926.53	Workers not regulated by DOE, MSHA or NRC	12

BEI, biological exposure index; CFRs, Code of Federal Regulations; TLV, threshold limit value.

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How have radon-exposed miner study findings been used?

- Estimating lung cancer risk from a working lifetime of radon exposure, in areas with elevated radon dose

Agency	Annual occupational dose level	Working lifetime	Estimated lifetime chance of getting radon-induced lung cancer	Reference
NIOSH	1 WLM	30 years	10 in 1000	NIOSH 88-101 (1987)
NCRP	2 WLM*	30 years	12 in 1000	NCRP 116 (1993)
ICRP	1 WLM	30 years	15 in 1000	ICRP 115 (2010)

*Remedial action level for annual exposures to the public

What about current radon levels in non-uranium mines?

- Ventilation is the main approach to reduce exposure levels in underground mines

Table 2. Results from radon progeny area monitoring in US underground mines from 2000 to 2015.[a]

Mine type	Mines (*n*)	Mine operations (person-years)	Samples (*n*)	PAEC (WL)		
				Mean	Median	Interquartile range
All	328	25 183	3538	0.79	0.01	0.05
Metals	138	10 771	1317	0.20	0.03	0.19
Uranium/vanadium	20	112	461	0.50	0.28	0.46
Gold	74	3017	378	0.04	0.00	0.03
Lead–zinc	17	3982	232	0.03	0.02	0.03
Silver	10	1313	118	0.04	0.01	0.02
Other metals	17	2347	128	0.08	0.03	0.11
Nonmetals	48	8593	557	0.06	0.00	0.02
Salt	14	1907	312	0.08	0.00	0.02
Trona	4	4705	66	0.01	0.00	0.01
Gemstone	4	12	55	0.08	0.04	0.08
Other nonmetals	26	1969	124	0.03	0.00	0.02
Stone and sand	142	5819	1664	1.49	0.01	0.02

[a]Compiled from the MSHA database accessed mid-October 2015.

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Current questions motivating new Pooled Uranium Miner Analysis (PUMA)

- How does dose-response for lung cancer at low occupational doses compare to high doses?
  - A huge new cohort (Wismut) from former East Germany has a wide range of dose levels
  - Important for hard-rock mines, which have lower radon levels
- How does lung cancer risk from workplace radon change over miners' lifetime?
- More lung cancers among the never-smokers permits better estimation of smoking-age-dose interaction
  - Useful to predict risks in increasingly non-smoking workers
- Are any other diseases caused by uranium mining?
  - Other cancers, idiopathic pulmonary fibrosis, renal disease

PUMA cohort study – 126,739 miners and 7495 lung cancer deaths

Cohort	Follow-up period	No. miners	Deceased by end of follow-up	No. lung cancer deaths	Principal investigator
Ontario	1954-2007	28,546	18%	1230	M. Do
Beaverlodge	1950-1999	9,498	30%	279	L. Zablotska
Port Radium	1950-1999	3,047	30%	230	L. Zablotska
Czech Republic	1952-2010	9,978	53%	1141	L. Tomasek
France	1946-2007	5,086	38%	211	E. Rage
Germany	1946-2008	62,978	44%	3542	M. Kreuzer
Colorado Plateau	1960-2005	4,137	72%	612	M. Schubauer-Berigan
New Mexico	1943-2012	3,469	not reported	250	J. Samet

Conclusions

- Epidemiology studies of miners have clearly established that radon causes lung cancer, even at relatively low levels
- Emerging studies on lifetime risks of lung cancer and other diseases will help inform risk assessment to protect miners and other workers—as well as the general public—from the harmful effects of radon exposure
- A lot is already known and put into practice to reduce radon exposure levels in mines
  - This relies on use of good exposure monitoring practices in mines that may have elevated levels of radon progeny
- Much of what we understand about the health risks of radon exposure comes from studies of underground miners…we owe these workers a huge debt of gratitude

Questions?

For more information

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