Overview of Occupational Radon Exposure - Past, Present and Future

Presented To:

IAEA ORP 2014

2nd International Conference on Occupational Radiological Protection

Vienna, Austria - December 1- 5, 2014

Session 8: Occupational Radiation Protection in the Workplaces Involving Exposure to Radon

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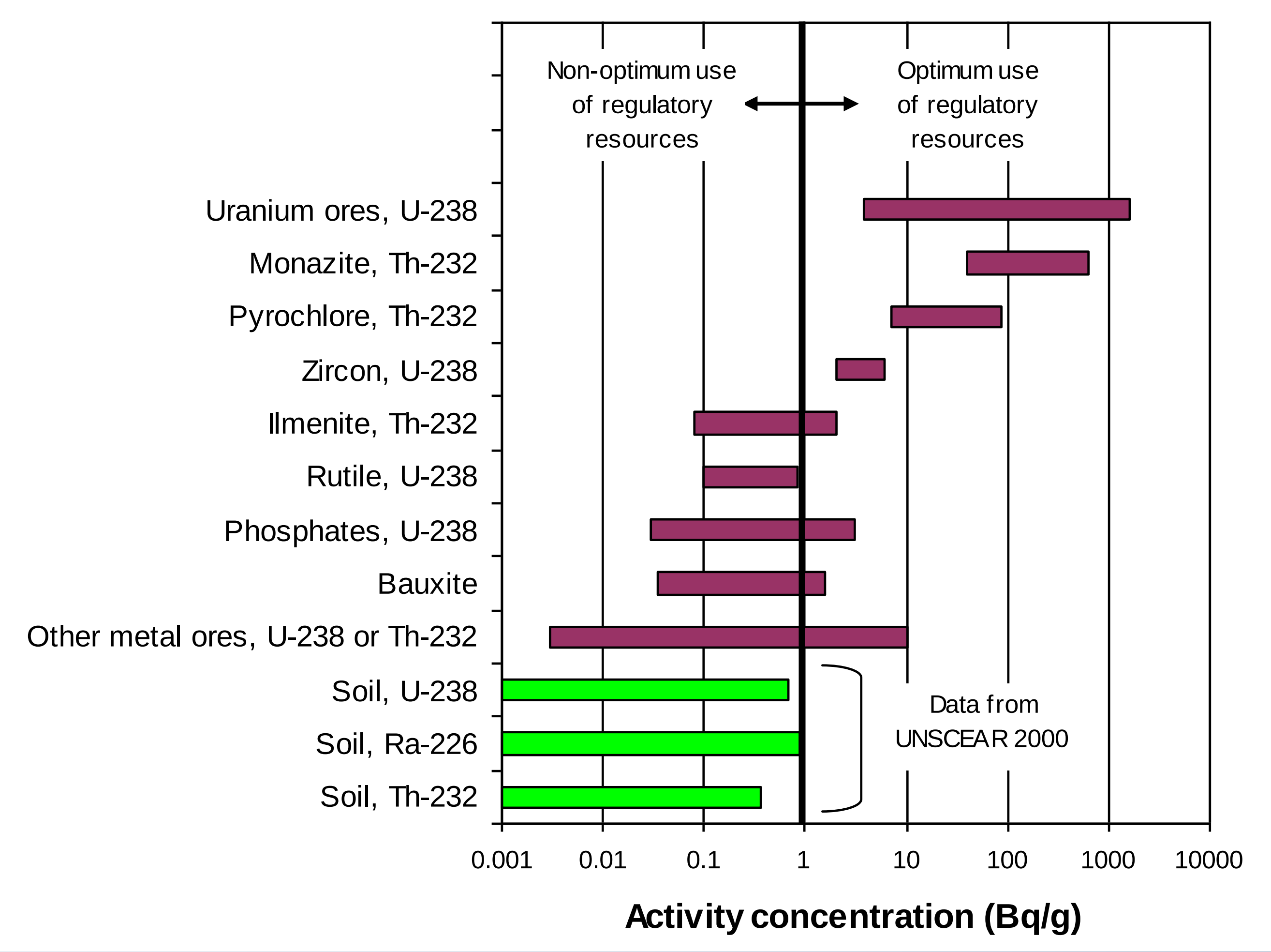
Every thing is naturally radioactive

Uranium-238, radium-226 and radon-222 are ubiquitous

Concentration Ranges of Uranium and Thorium Series Radionuclides



After Wymer, 2008

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Recognition of lung cancer as a risk to miners

- **Mining of metals and minerals has been taking place for thousands of years**
- **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***
- **as early as Agricola, there was a recognition of an unusually high incidence of a fatal lung disease in miners**
  - the unusual, lung disease was eventually (500 years later) recognized as lung cancer
  - which 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

- 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 which resulted in substantial improvements in radon levels in uranium mines
- Evolution of regulation is illustrated by the US experience

Evolution of Radon Standard in the USA -1

- The United States uranium industry began after World War II when the government began to buy uranium.
- Early mine operators knew nothing of the hazard of exposure to radon and no government agency had the authority to regulate the health and safety of miners.
- In 1949, the U.S. Public Health Service became concerned about the potential hazard based on the experience of the Joachimsthal/Schneeberg mines.
- Measurements in about 40 mines in Utah and Colorado and confirmed high concentrations averaging over 92,000 Bq/m^3 (2,500 pCi/L).

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

Area	Number 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

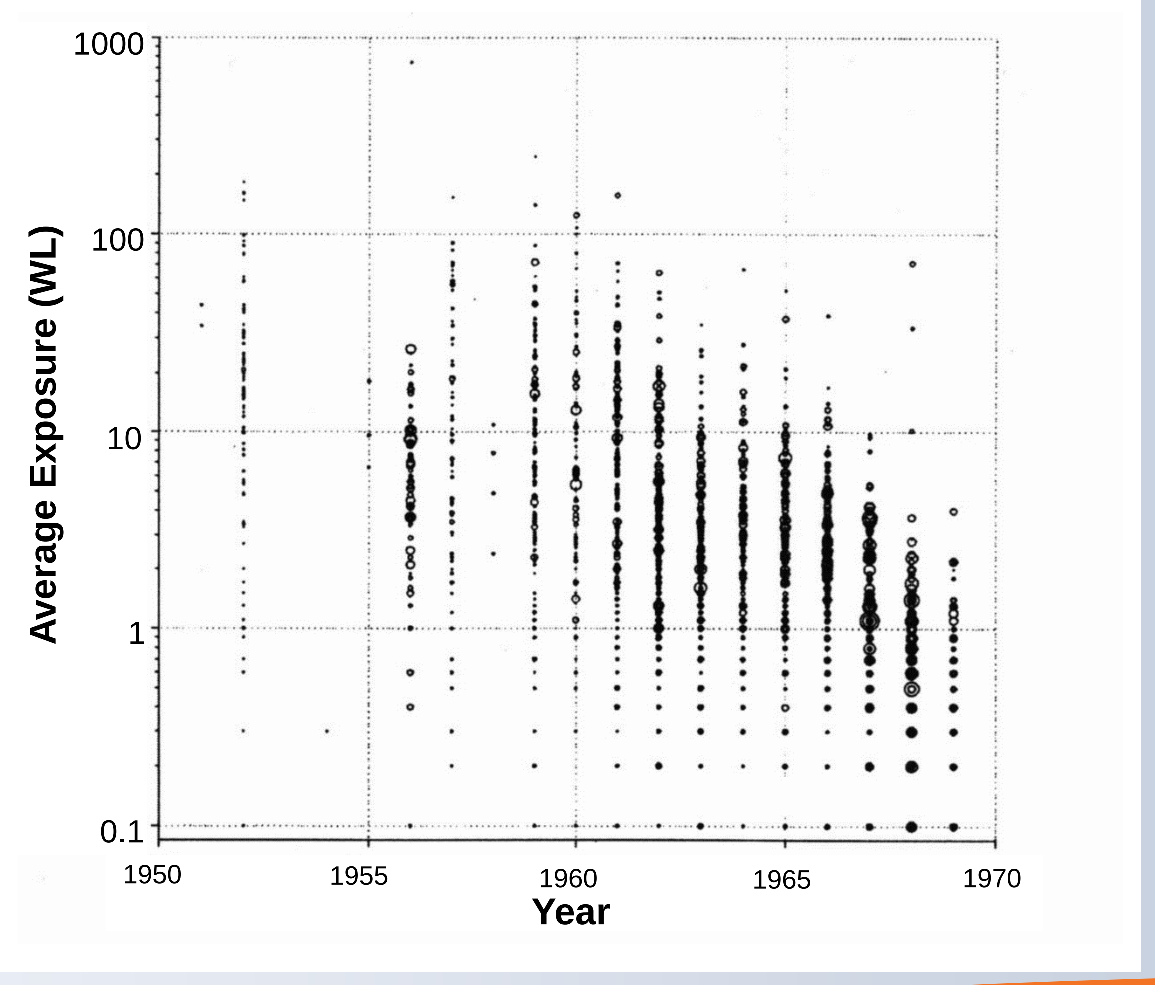
Evolution of Radon Standard in the USA - 2

- **Beginning in 1954, the U.S. Atomic Energy Commission had regulatory authority over the uranium industry**
  - after the material was mined but had no authority to regulate the mining industry.
  - There were no mining industry standards and no personnel experienced in assessing the hazard within the mining community.
- **In 1955, the Public Health Service developed the concept of expressing a tolerance level in terms of the potential alpha energy of radon decay products in air**
- **In 1958, the Nuclear Standards Board of the American National Standards Association (later Institute), established a committee to develop a standard for uranium mines and mills.**

Evolution of Radon Standard in the USA - 3

- The adoption of 1 WL standard was adopted in 1960 (12 working level months per year)
- Its utility was in that 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.
- The standard was reduced to 4 WLM per year in 1971 as the emerging picture of lung cancer developed.
- This standard is still in effect in mines in the United States.

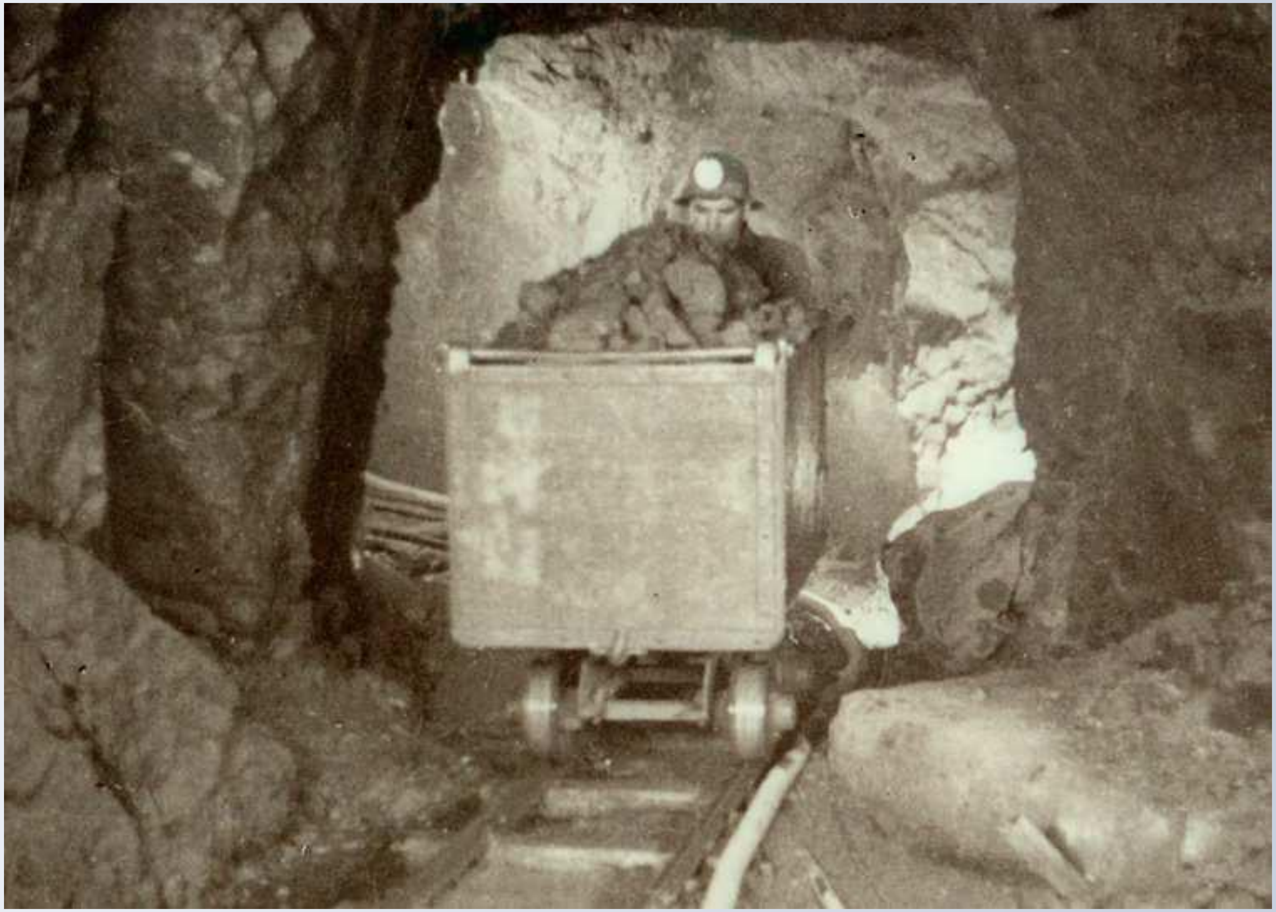
Measured Exposures for Underground Uranium Mines in Colorado



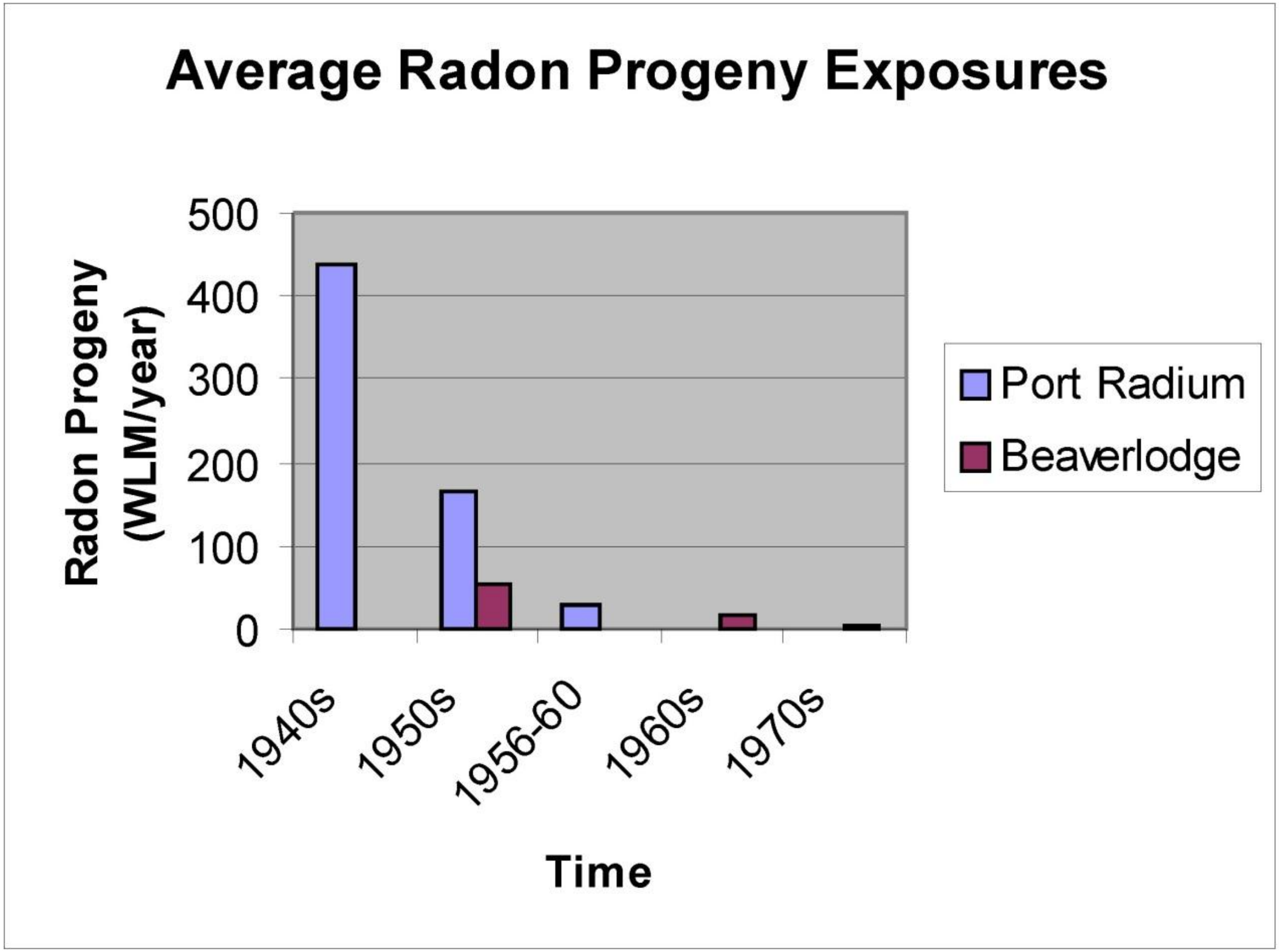
Epidemiological Studies of Miners Considered in UNSCEAR 2006 – Annex E

- Colorado Plateau
- Ontario
- Czech
- Swedish Iron
- Beaverlodge
- Wismut
- Port Radium
- French Uranium
- Chinese (uranium and tin)
- Newfoundland (fluorspar)

Port Radium, 1940



Port Radium Hand Sorting



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Drilling

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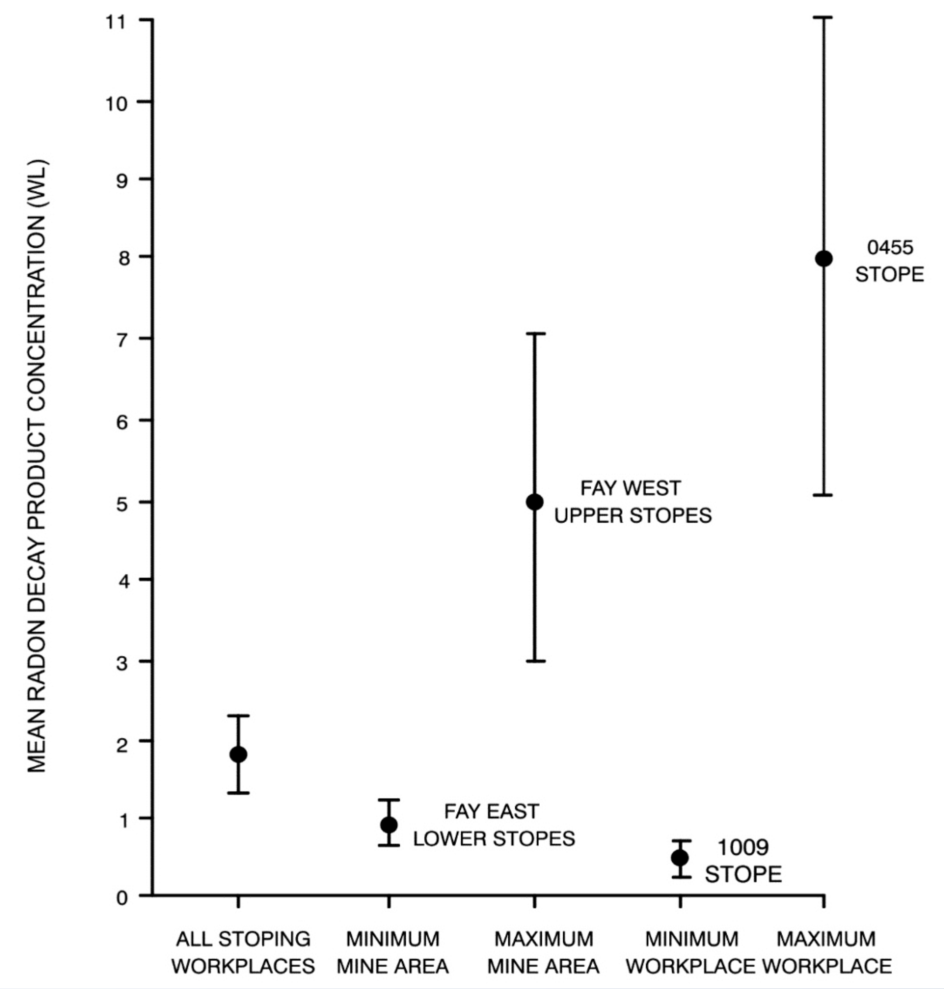
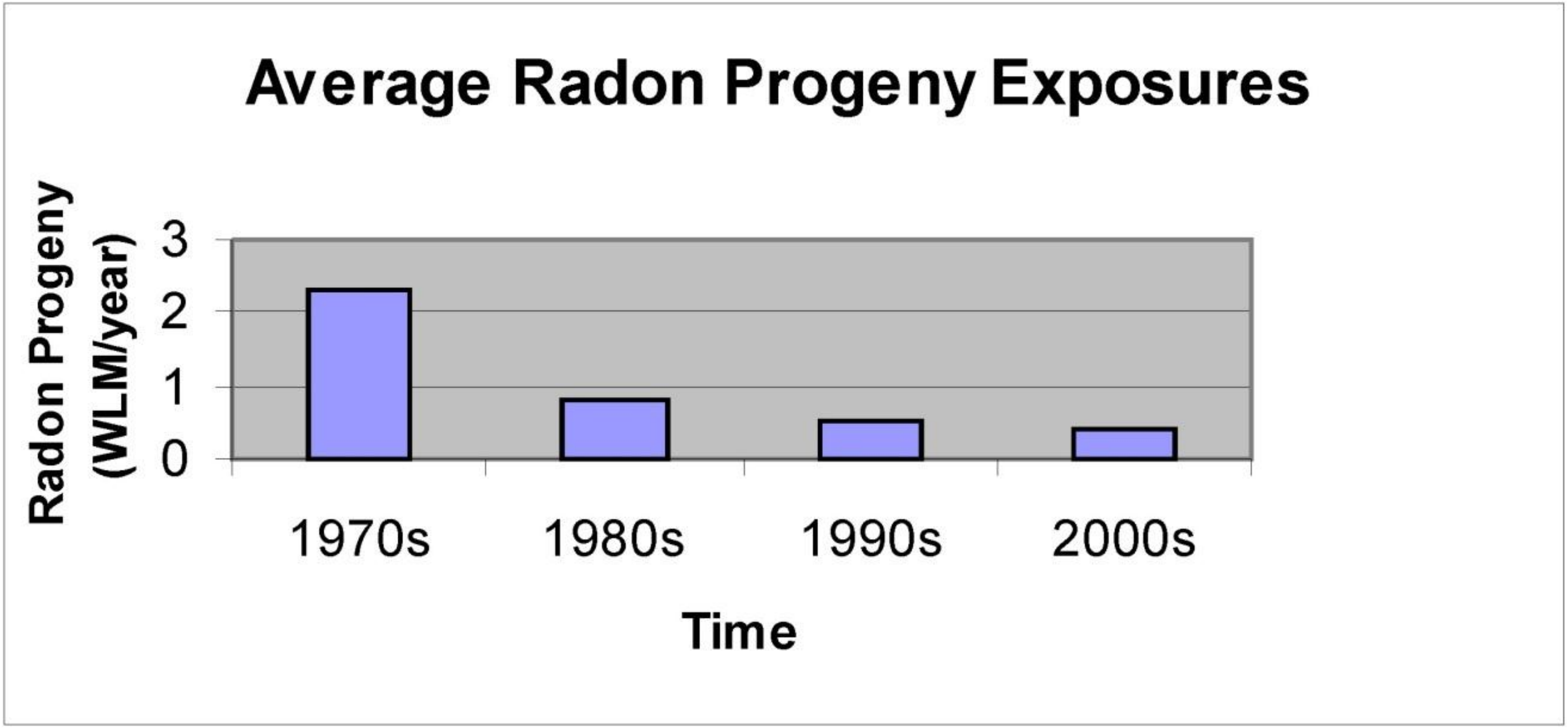
"Concentrations of radon/radon daughters vary considerably in uranium mines and are difficult to forecast. Airborne radiation levels do not conform to grade of ore; some of the highest levels encountered are in waste headings. Small flows of radon-laden groundwater can be the source of very high concentrations when least expected. Concentrations of radon and its daughters change rapidly with ventilation, and even minor airflows produced by the pneumatic equipment have an appreciable effect."

Smith, 1972 Re: Beaverlodge

Estimates of 1963 Mean Radon Decay Product Concentration (WL) By Level of Aggregation of Stoping Workplaces at Beaverlodge





Average Radon Progeny Exposures
Radon Progeny (WLM/year)
3
2
1
0
1970s
1980s
1990s
2000s
Time

Elliot Lake Mines 1980’s

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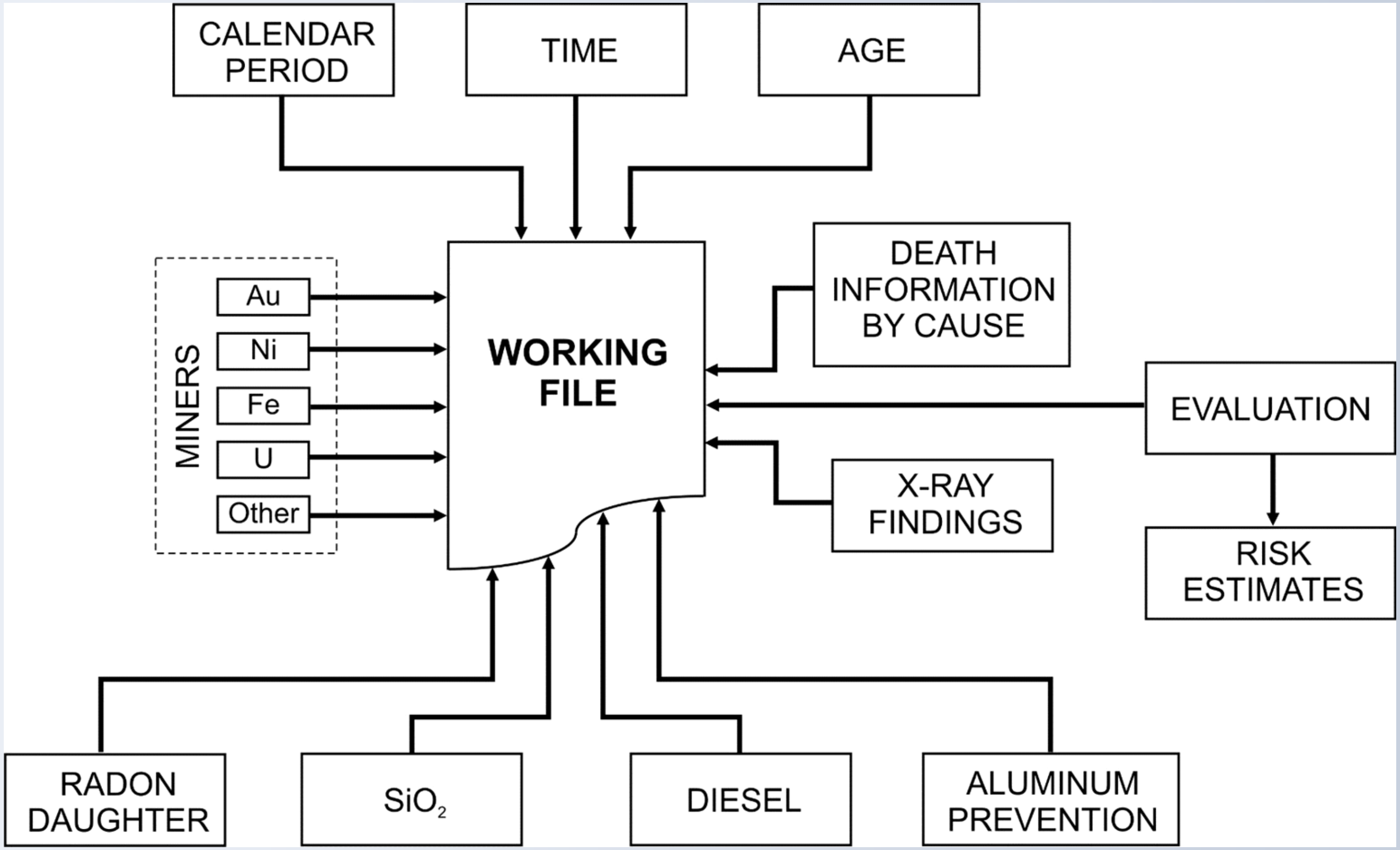
Uranium Mine Environments are Complex

Design of Muller et. al. Study (1983)



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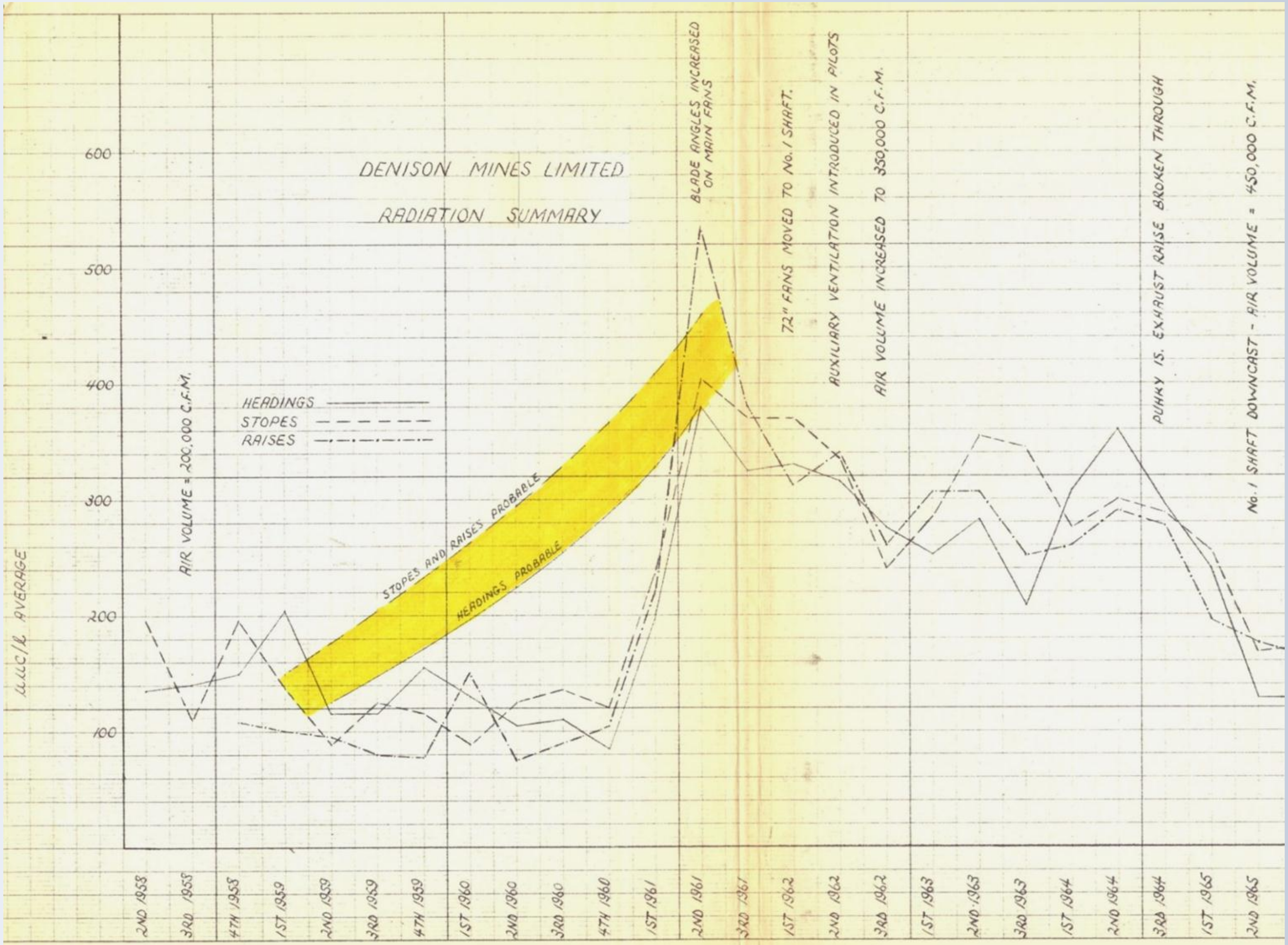
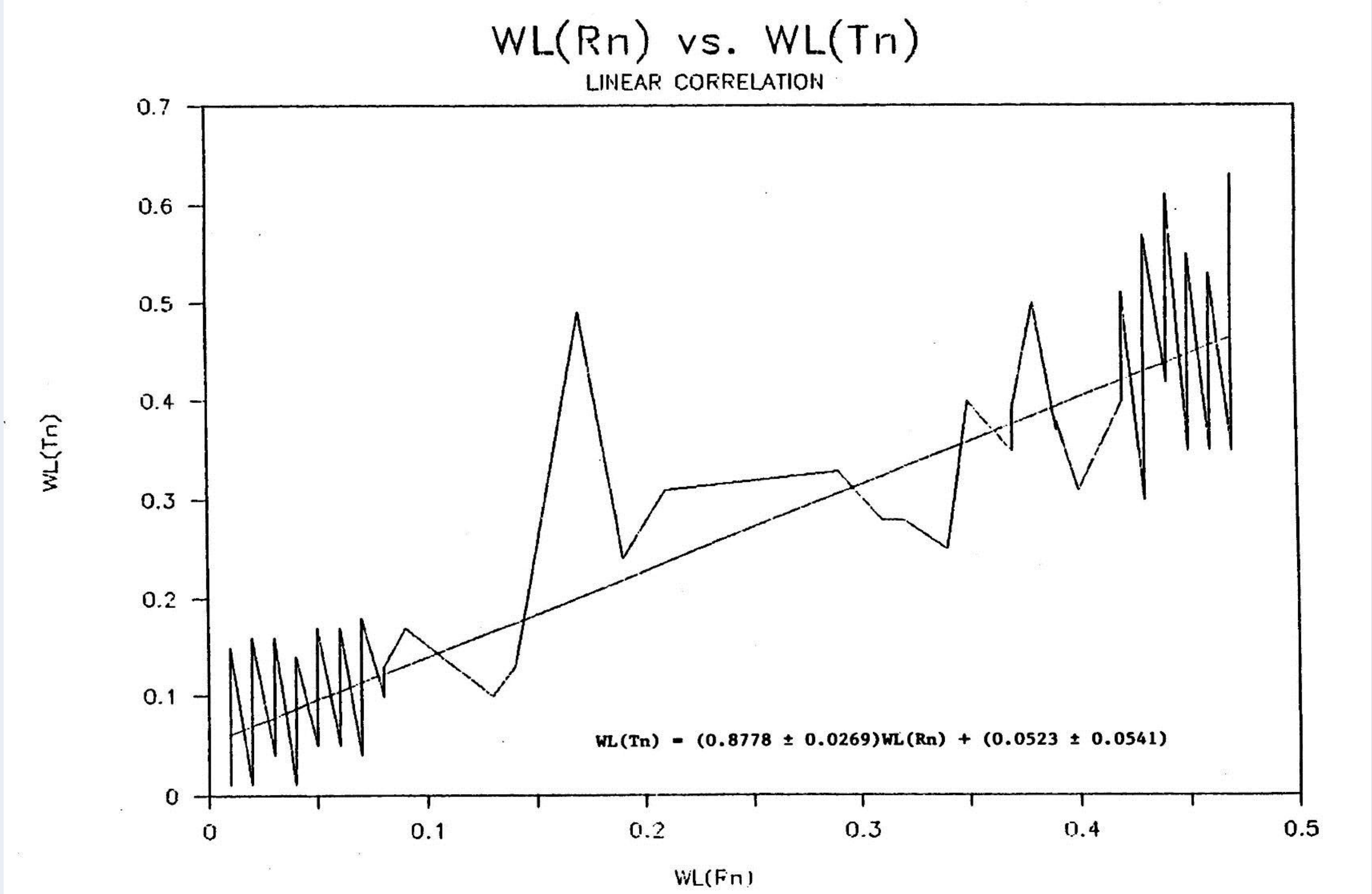

DENISON MINES LIMITED
RADIATION SUMMARY
μμc/L AVERAGE
600
500
400
300
200
100
HEADINGS
STOPES
RAISES
AIR VOLUME = 200,000 C.F.M.
STOPES AND RAISES PROBABLE
HEADINGS PROBABLE
BLADE ANGLES INCREASED ON MAIN FANS
72" FANS MOVED TO No. 1 SHAFT.
AUXILIARY VENTILATION INTRODUCED IN PILOTS
AIR VOLUME INCREASED TO 350,000 C.F.M.
PUHKY IS. EXHAUST RAISE BROKEN THROUGH
No. 1 SHAFT DOWNCAST - AIR VOLUME = 450,000 C.F.M.
2ND 1958
3RD 1958
4TH 1958
1ST 1959
2ND 1959
3RD 1959
4TH 1959
1ST 1960
2ND 1960
3RD 1960
4TH 1960
1ST 1961
2ND 1961
3RD 1961
1ST 1962
2ND 1962
3RD 1962
1ST 1963
2ND 1963
3RD 1963
1ST 1964
2ND 1964
3RD 1964
1ST 1965
2ND 1965



WL(Rn) vs. WL(Tn)
LINEAR CORRELATION
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
WL(Tn)
WL(Tn) = (0.8778 ± 0.0269)WL(Rn) + (0.0523 ± 0.0541)
0
0.1
0.2
0.3
0.4
0.5
WL(Rn)

WLM

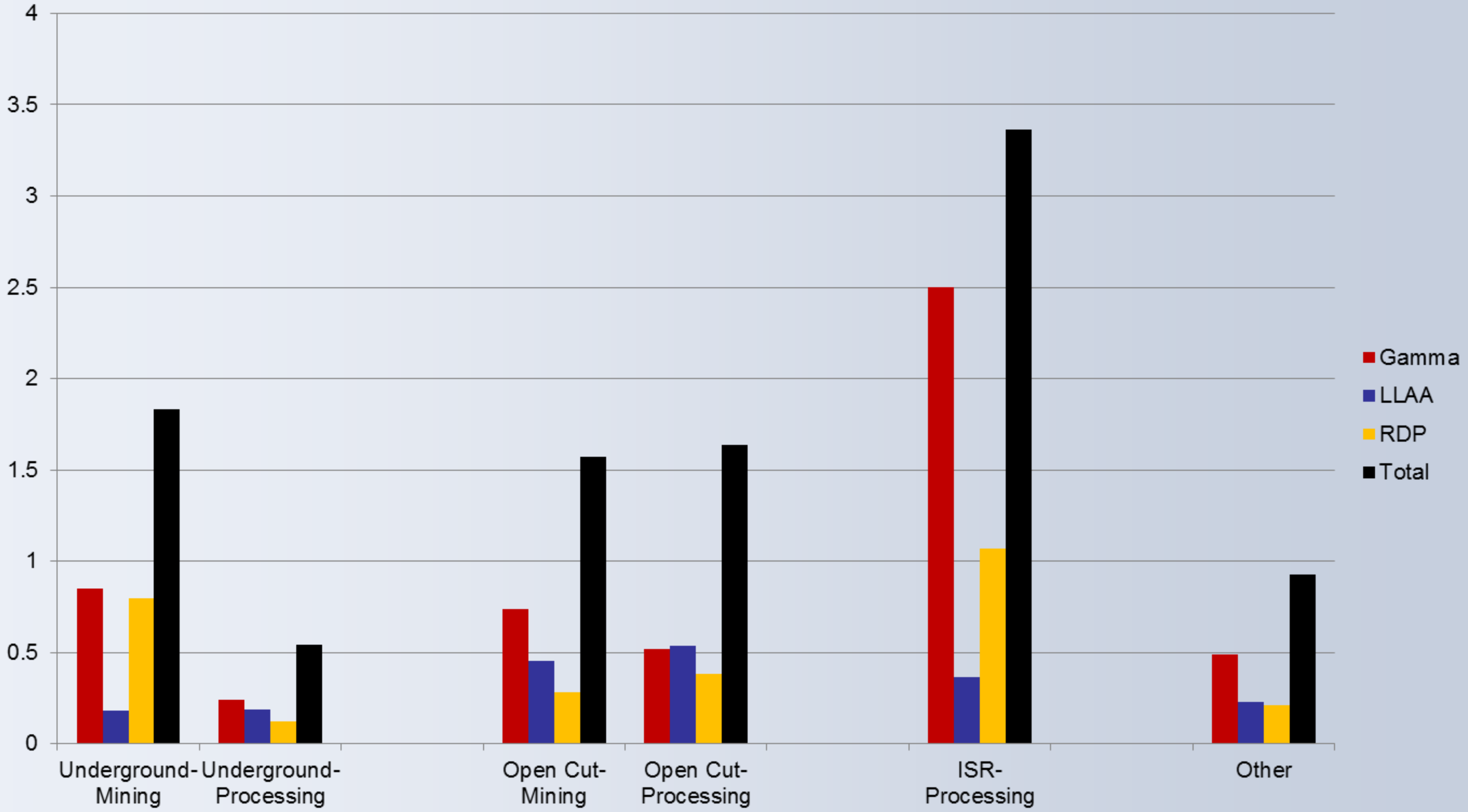
- **WLM estimates based on area monitoring**
  - Standard WLM (best estimate)
  - Special WLM (reasonable upper based)
- **WL (mine) = (0.8 x stopes/raise) + (0.2 x travelway)**
- **WHF correct for non-standard work hours**
- **Mean WLM 53.5**

  = [½ x 33 STD WLM] + [½ x 74 WLM Special WLM]

* Muller et al. 1983 (Part I)


Modern Mine

Exposures in Modern Uranium Mines



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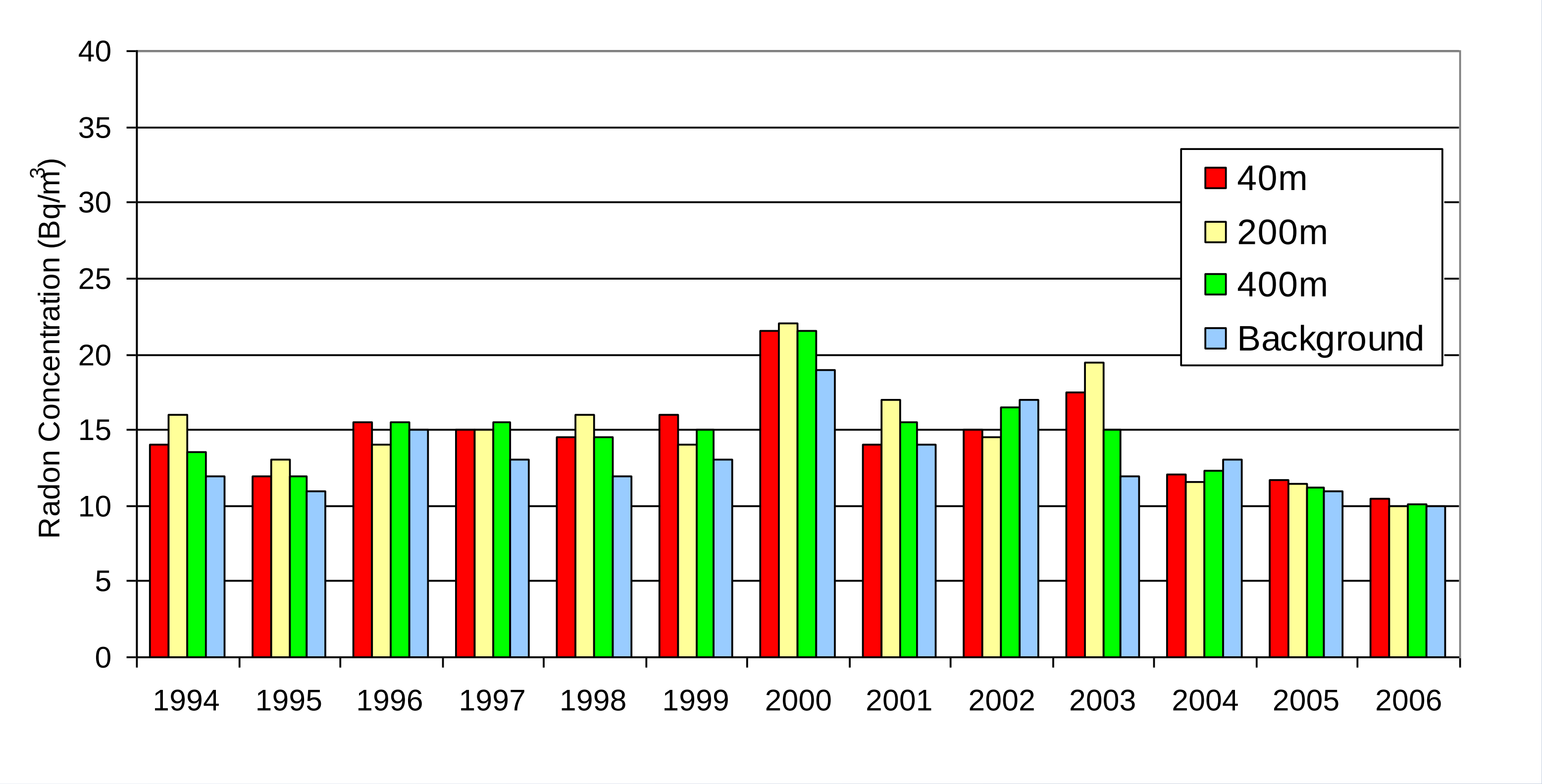
Examples of NORM Sources

- Soils
- Uranium mining and waste management
- Coal ash
- Phosphate fertilizer production
- Tantalum raw materials
- copper mining wastes
- Rare earth minerals production
- Radon in groundwater
- Radon from unconventional resource development ("fracking")
- Etc.…

Annual Average Radon Concentration Around PG Stacks



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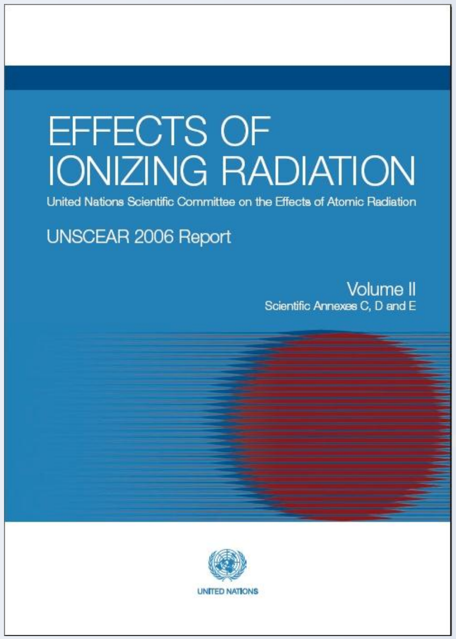
Examples of radon other than uranium

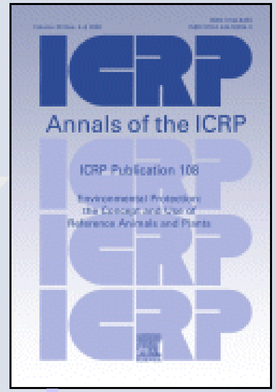
- Tourist Caves and Mines Open to Visitors - in some caves as high as 20,000 Bq/m^3.
- Graphite mines - radon concentrations vary winter and summer but levels up to 6000 Bq/m^3
- Fluorspar - radon concentration in Newfoundland mine averaged around 3500 Bq/m^3
- Oil shale mines - average radon concentrations o around 430 Bq/m^3.
- Chinese Coal mines – up to 1200Bq/m^3
- Groundwater - typical levels reported by the EPA from a few to perhaps 1000 to 30 000 Bq/m^3 but can be very high up to 10^6 Bq/m^3 or more

International Radiation Safety Regime



UNSCEAR
Scientific basis

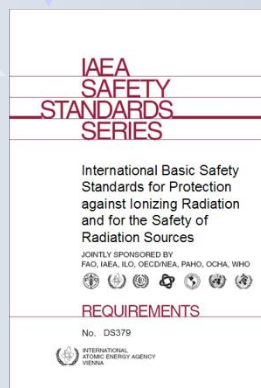
issues effects risks



ICRP
Protection philosophy, principles and units

recommendations

issues levels trends



IAEA, WHO, ILO, FAO etc.
-Safety standards
-Protection programmes

ILO convention 115: occupational radiation protection

FAO/WHO Codex Alimentarius Commission (food contamination guides)

UN transport regulations for radioactive material

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ICRP's New Approach

- Currently ICRP uses a dose conversion convention (DCC) to calculate effective dose per unit exposure to radon progeny based on epidemiology;
- The detriment adjusted risk coefficient for radon is likely to double;
- ICRP intends that in the future, doses from radon and its progeny would be calculated using ICRP biokinetic and dosimetric models;
- Current dose conversion values may continue to be used until dose coefficients are available.

Past Measurements

- The major factor controlling the bronchial dose from inhalation of ^{222}Rn decay products is their associated particle size (activity size distribution – especially in range of 1 to< 10 nm)
- The decay products attach mainly to the ambient particle distribution but a small fraction, mainly ^{218}Po, remain as small nuclei called the unattached fraction.
- Activity size distributions in mines have not been well measured, mainly because it is a difficult research area and current instruments are mainly for laboratory use.

Overview

- **Radon levels vary widely by region, mineralogy and work practice**
- **Radiation protection guidance for radon has been developed by international authorities, notably the ICRP and the IAEA**
- **Radon levels in modern uranium mines are very low, typically well below the current limit of 4 WLM per year**
  - the continued application of ALARA and good work practice will continue to ensure safe levels of workplace radon in uranium mine
  - it will be important in the future to ensure that the same radiation protection principles are applied to none-uranium mines and workplaces.