Radiation Protection in Mining with a Focus on Radon

Presented To:

THE NINTH INTERNATIONAL SYMPOSIUM ON NATURALLY OCCURRING RADIOACTIVE MATERIAL
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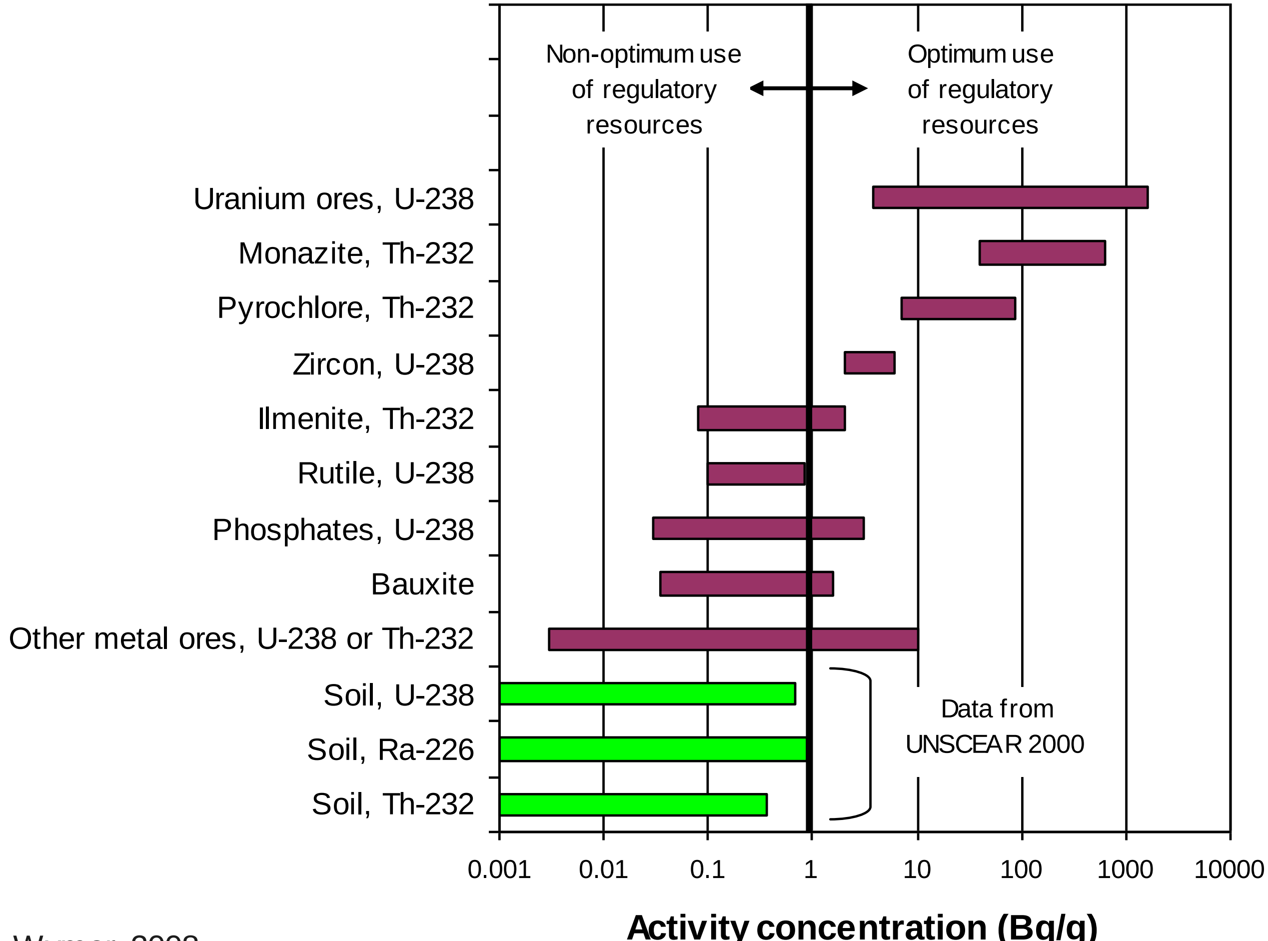
Everything is Naturally Radioactive

Uranium-238, **Radium-226** and Radon-222 are ubiquitous

Concentration Ranges of Uranium and Thorium Series Radionuclides



After Wymer, 2008

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
- This 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

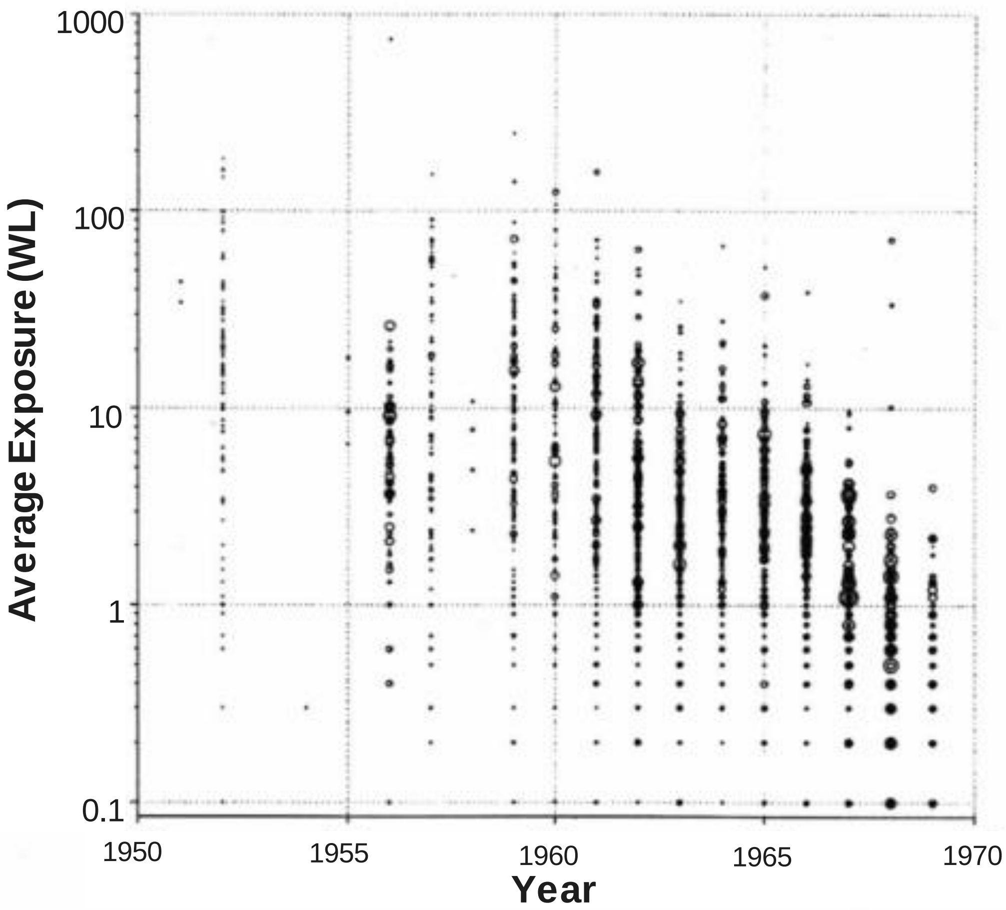
By the mid 1950's, there was a global awareness of the risk of lung cancer in miners.

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

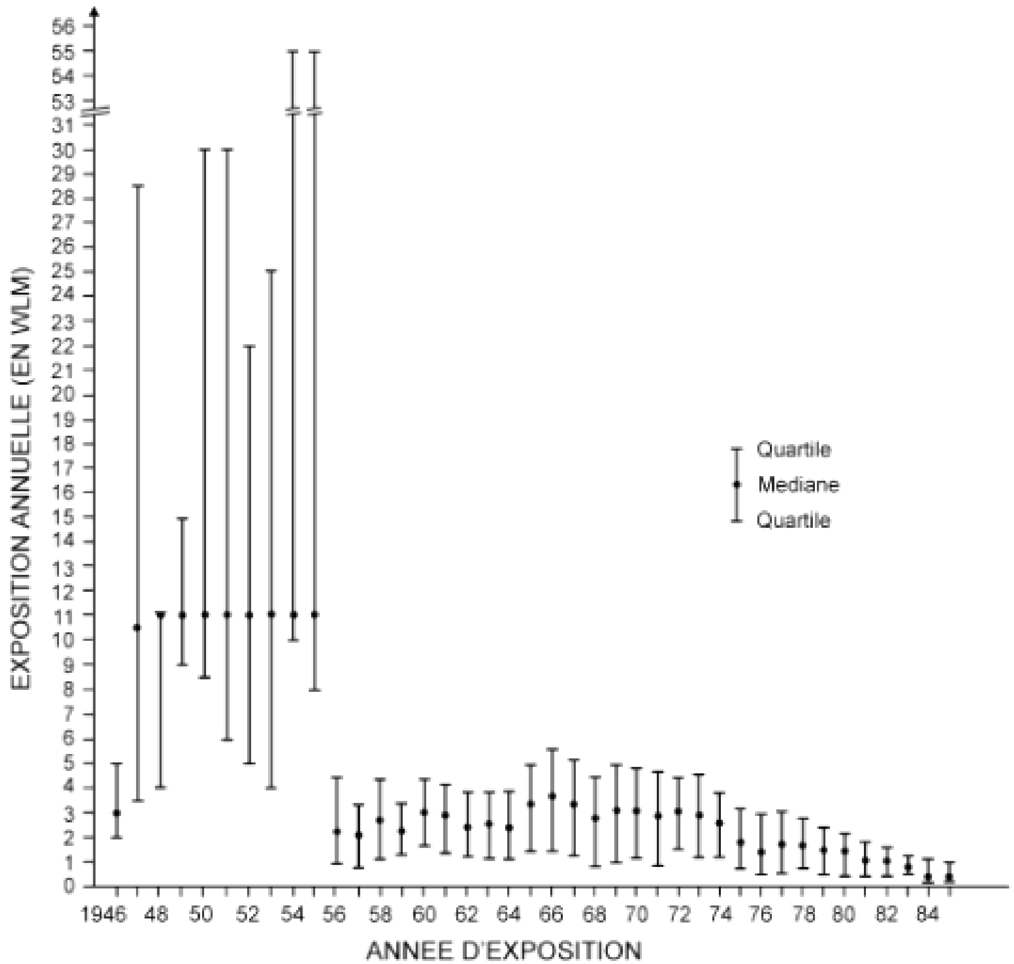
The radon guidelines and standards evolved over time as our understanding of the radon hazard evolved through measurement and epidemiology studies of miners.

These actions resulted in substantial improvements in radon levels in uranium mines in Canada and elsewhere.

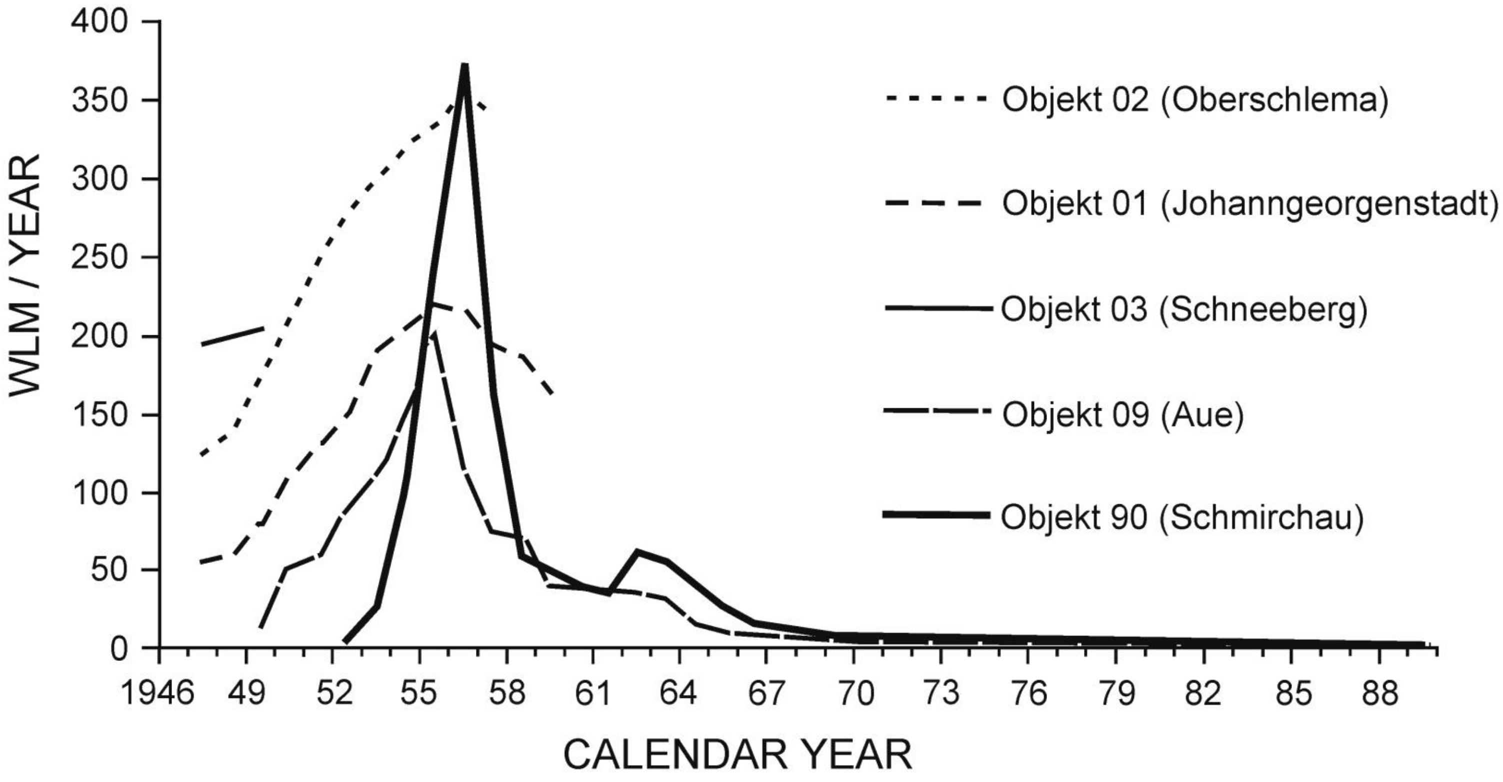
MEASURED EXPOSURES FOR UNDERGROUND URANIUM MINES IN COLORADO



Annual Exposure (WLM) in French Uranium Mines



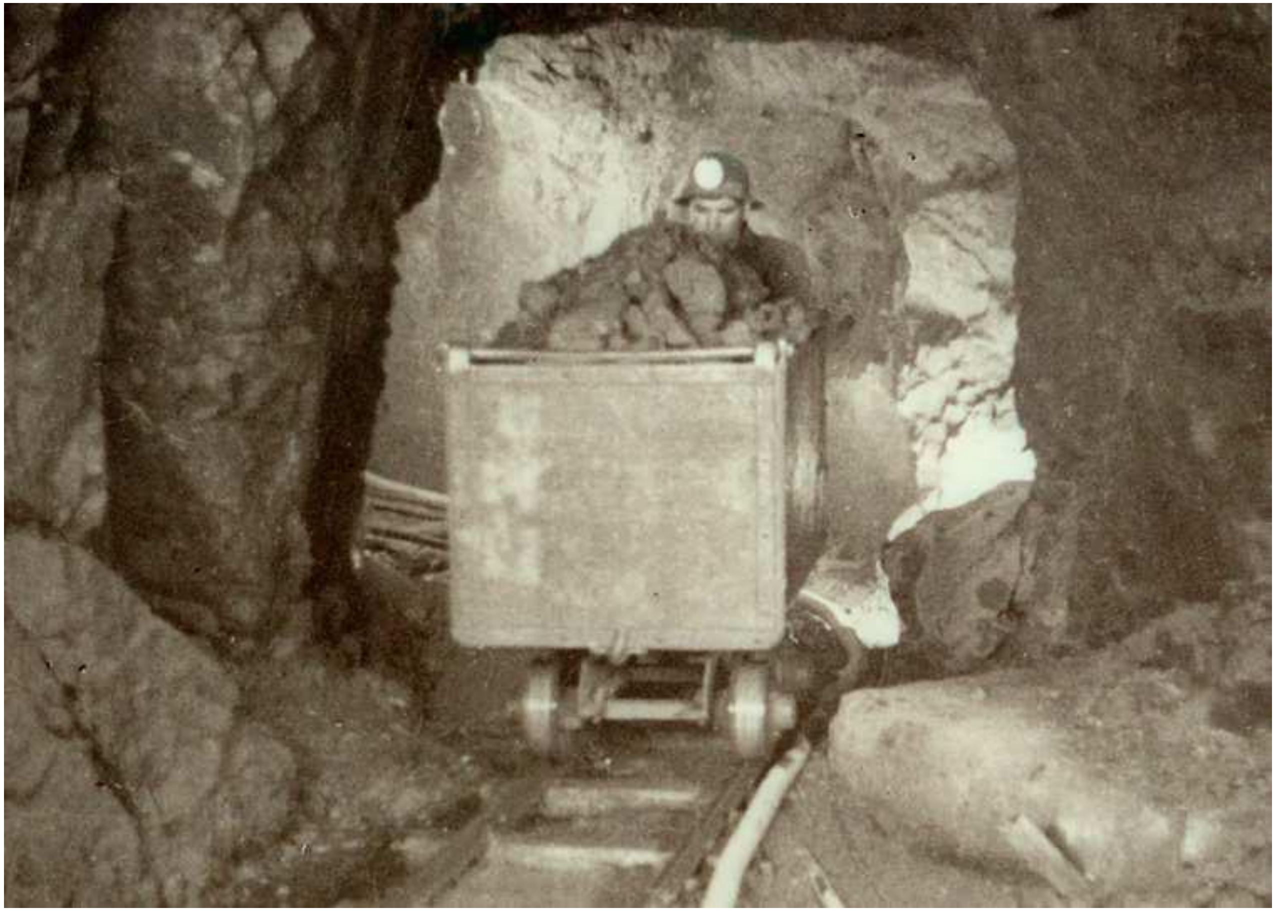
Estimates of Exposure to Wismut Miners



URANIUM MINING IN CANADA

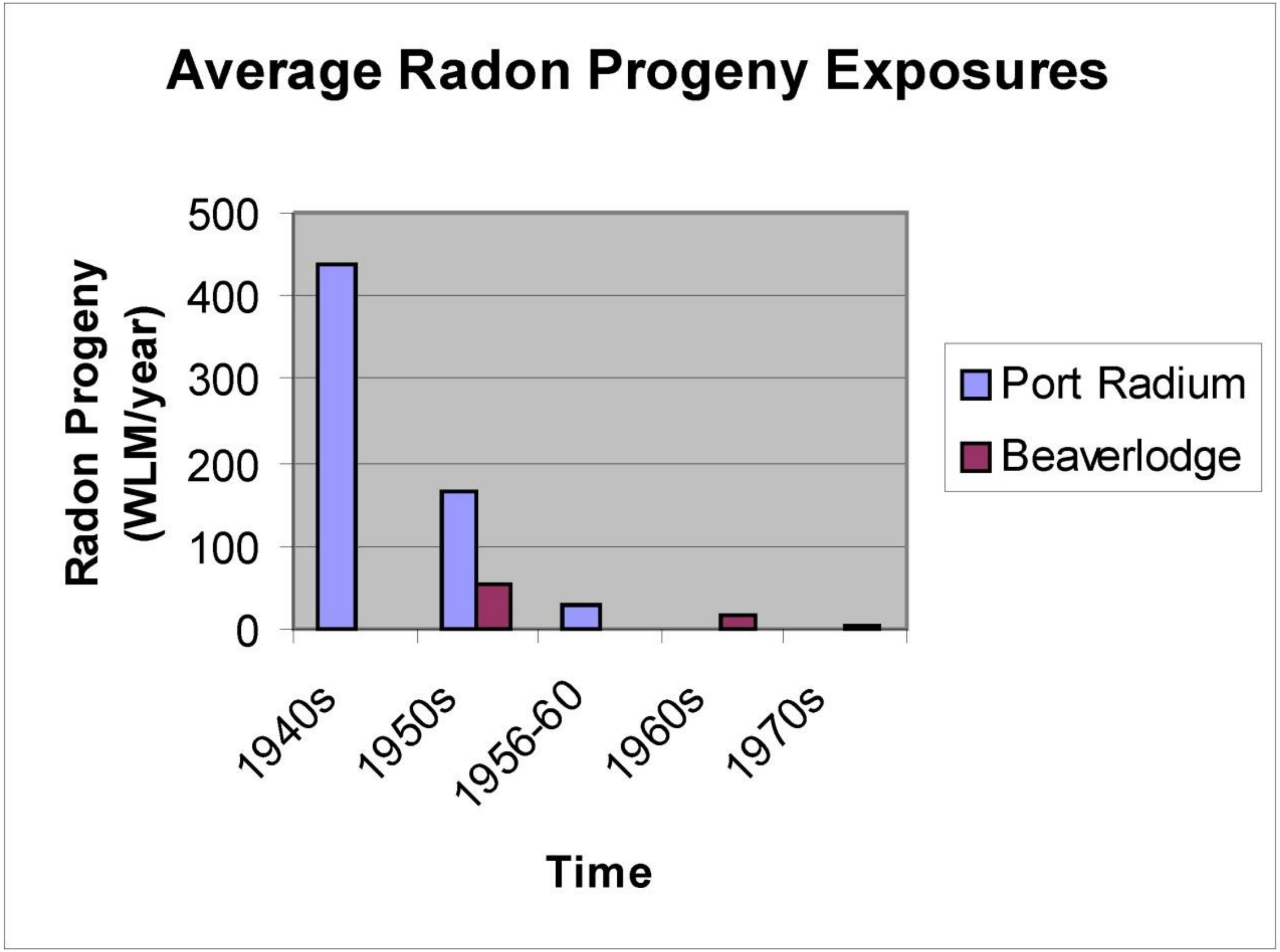
- Underground mining, initially for radium, later for uranium started in 1932 at Port Radium in the Northwest Territory
- By 1951 Beaverlodge mine in northern Saskatchewan was in operation (later many satellite mines)
- By the early 1950's uranium was mined in Ontario at Elliot Lake (some 23 companies), Agnew lake and Bancroft
- Since the mid 1970's uranium mining has focussed in northern Saskatchewan
- Several new developments planned for Saskatchewan and elsewhere in Canada

PORT RADIUM, 1940



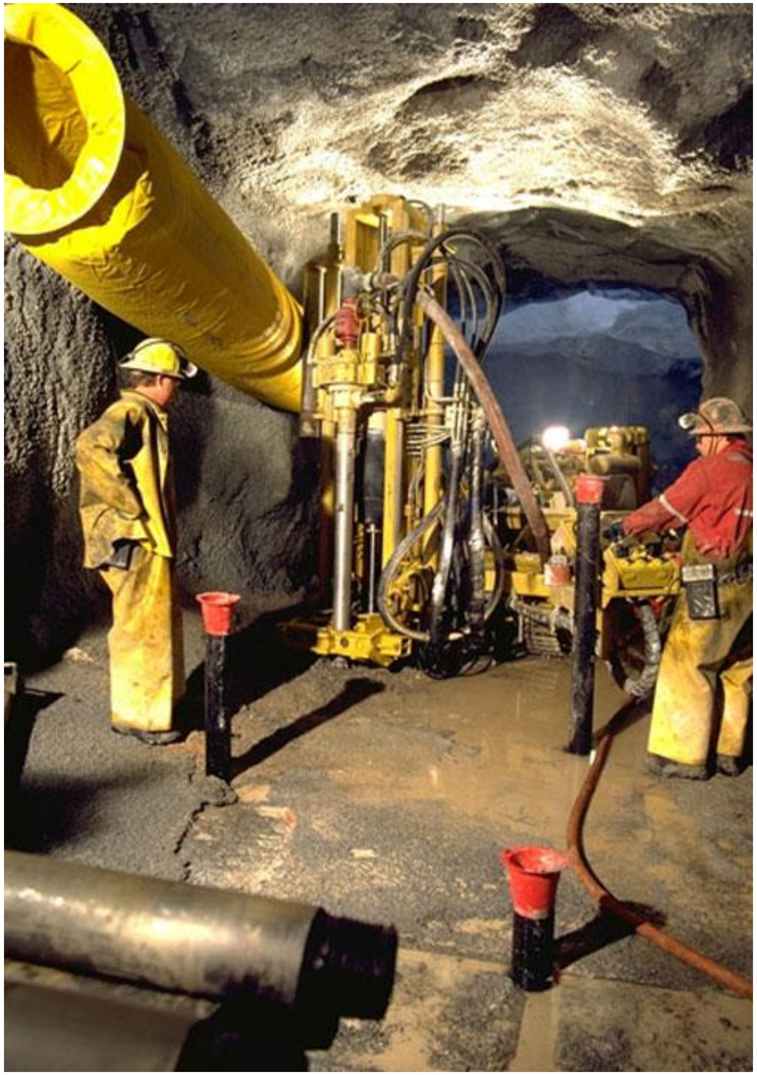
PORT RADIUM HAND SORTING

RADON 1940 TO 1970



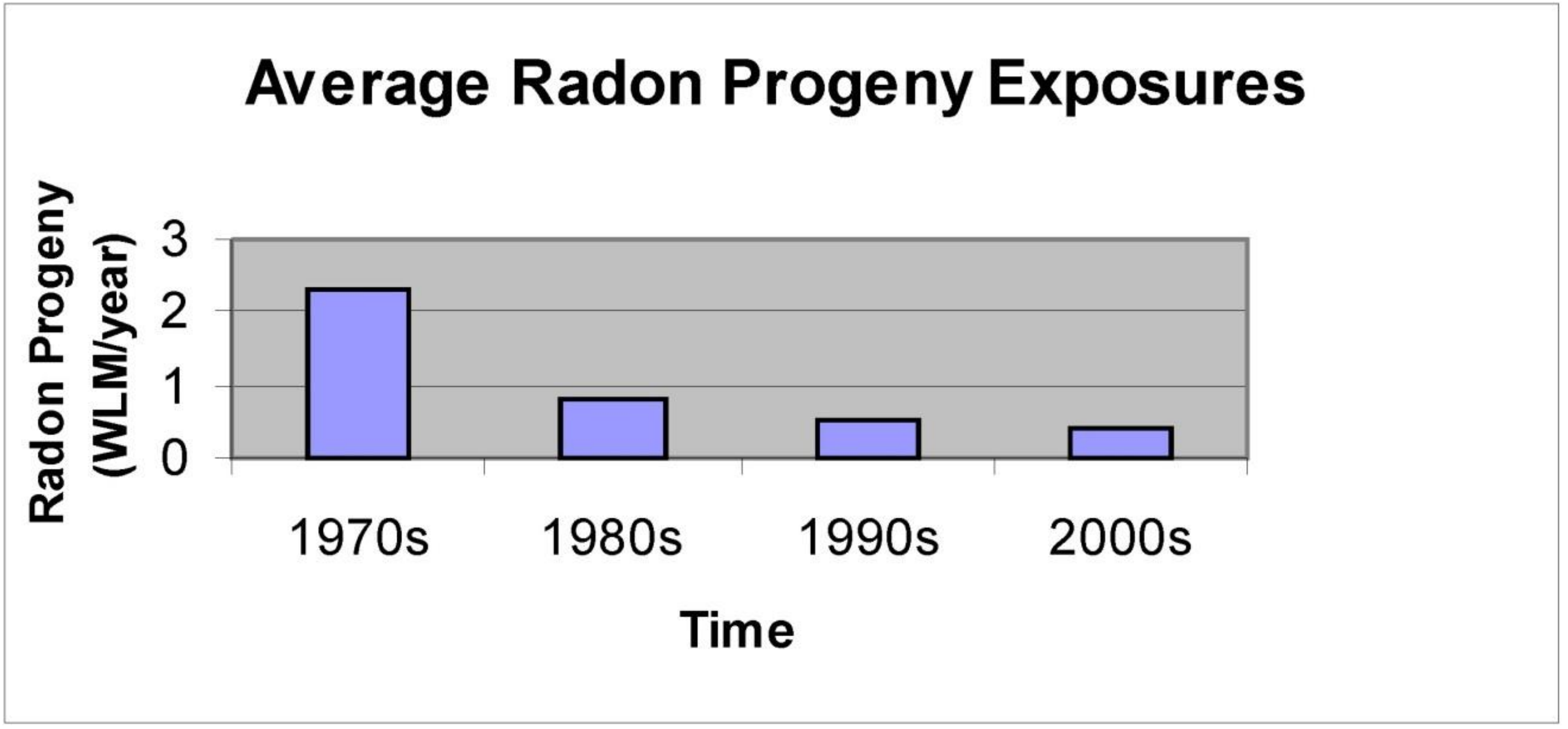
ELLIOT LAKE MINES 1980s

RABBIT LAKE 2000's

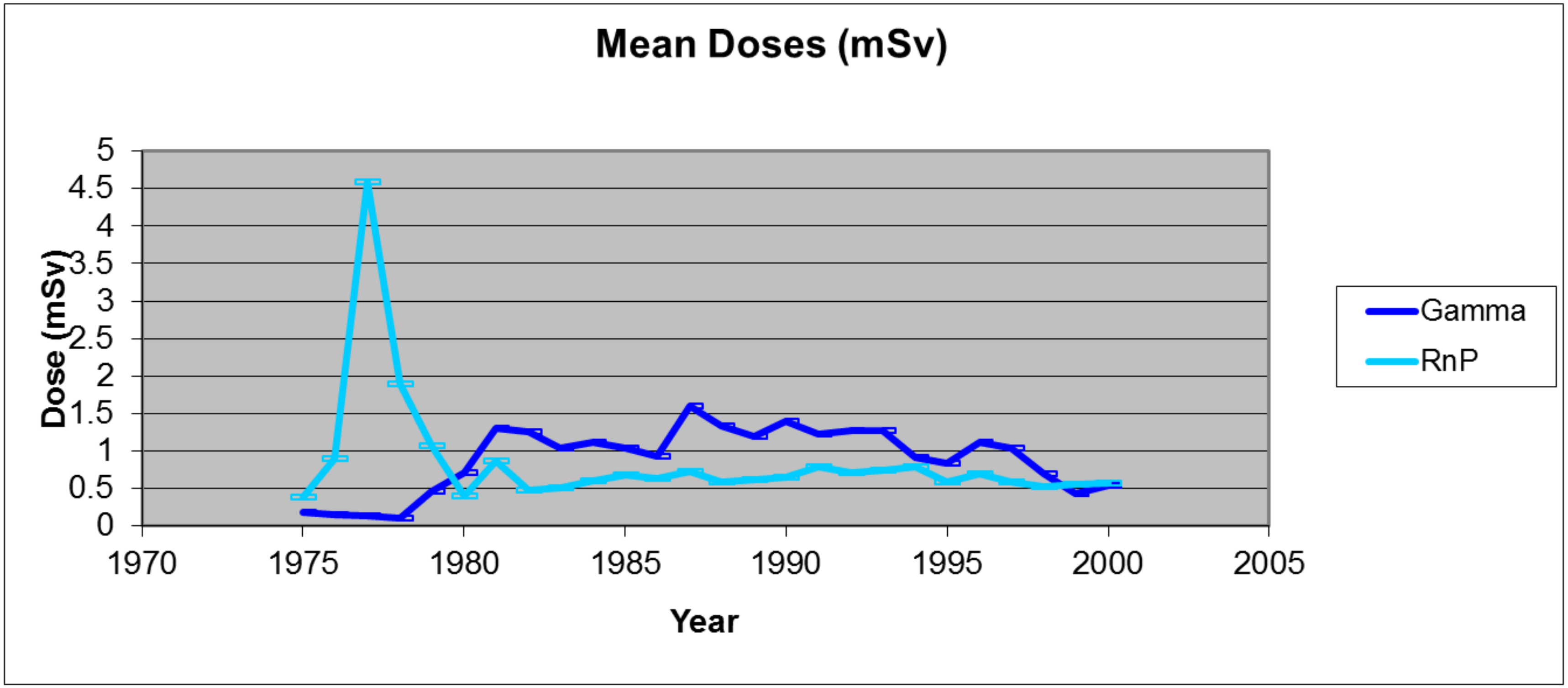


MODERN URANIUM MINE

RADON 1970 TO PRESENT



MEAN DOSES FOR CURRENT MINING



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

UMEX – Objectives

To develop an information system for occupational exposure in uranium mining and milling

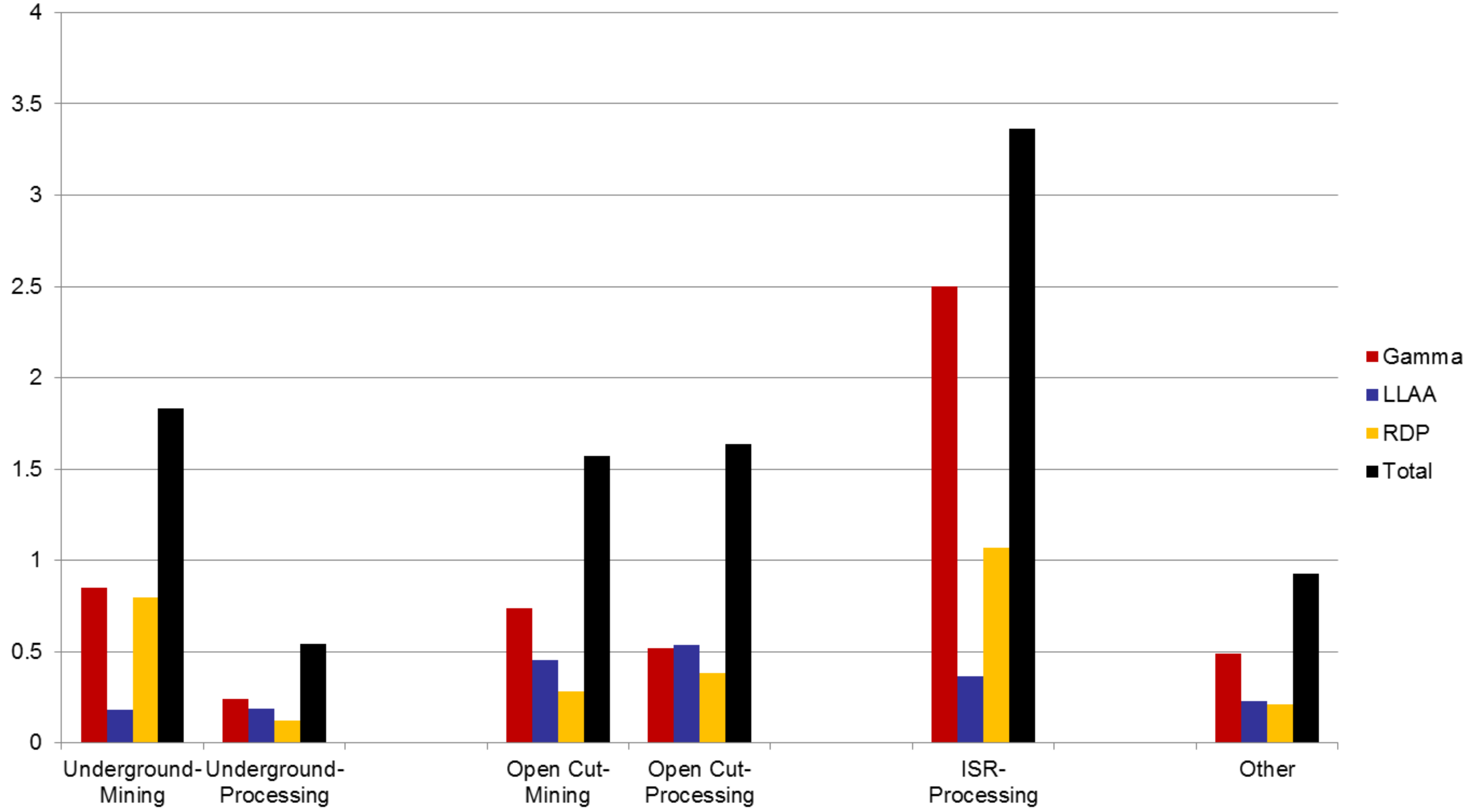
To obtain a global picture of the occupational radiation protection experiences in uranium mining and processing industry worldwide

To identify leading practices and opportunities and to derive actions to be implemented for assisting in optimising radiation protection

The UMEX project commenced in 2012

There is a separate paper in this conference which will discuss UMEX in more detail

Exposures in Modern Uranium Mines



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.…

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 1200 Bq/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

Examples of doses* from radon (other than uranium mines)

- Coal Mines
  - Pakistan ~ 2.1 to 7 mSv/a
  - China ~ 2.4 to 10) mSv/a
- South Africa Gold ~ 5 to 7 mSv/a
- Australia non U ~ 1.4 (range of 0.4 for nickel to 4.2 for coal)

*Data for UG mines from UNSCEAR 2008 Annex B, based on 5 mSv/WLM.

Radiation Safety Issues in South Africa Gold

The radiation issues in underground gold mines in South Africa producing uranium were investigated in the late 1950’s/early 1960’s by the mining industry

Radiation exposures occurred underground from radon daughters

In certain gold mines and areas of mines, exposures could be multiples of the annual dose limit

There was little regulation or control

Assessing Underground Exposures

Most underground workers in South Africa receive doses well below 6 mSv per annum,

These doses will double with the new ICRP dose convention,

In some work areas there are problems with compliance with dose limits (in older, shallower mines),

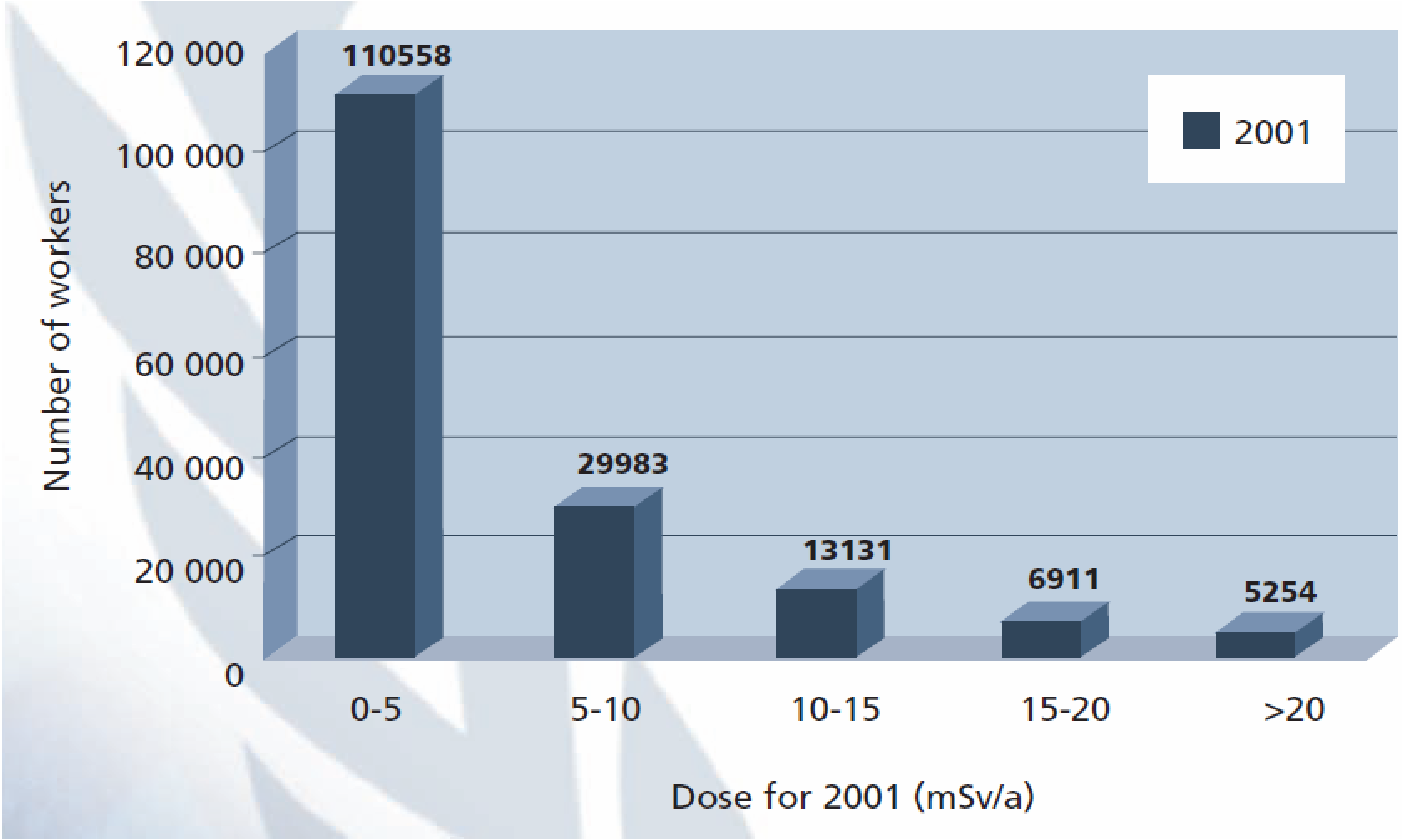
If ventilation improvements are not possible, workers can be rotated from underground work to surface when annual exposures exceed 15 mSv over 12 month period, or

Classify as a special case mine, with a 50 mSv annual limit and 100 mSv over 5 years,

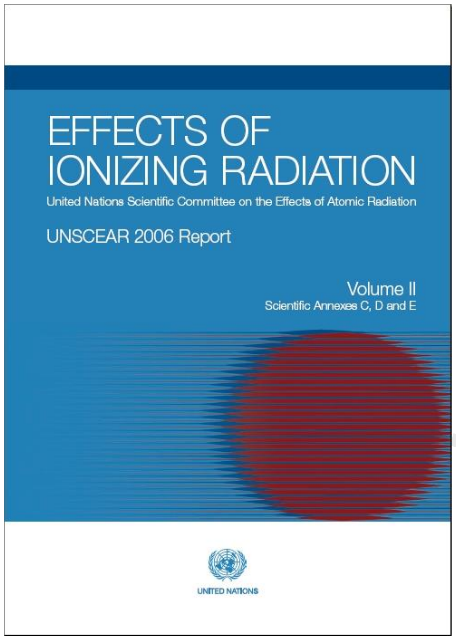
Monthly individual dose reports are required,

Dose limitation approach must be agreed with unions, regulator and operator.

South Africa Underground Miners: Annual Exposures: 2001

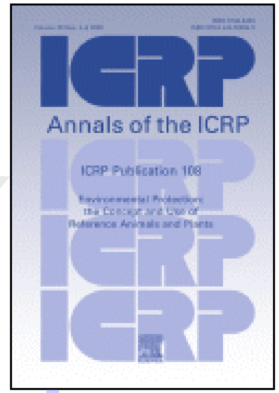


International Radiation Safety Regime



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)

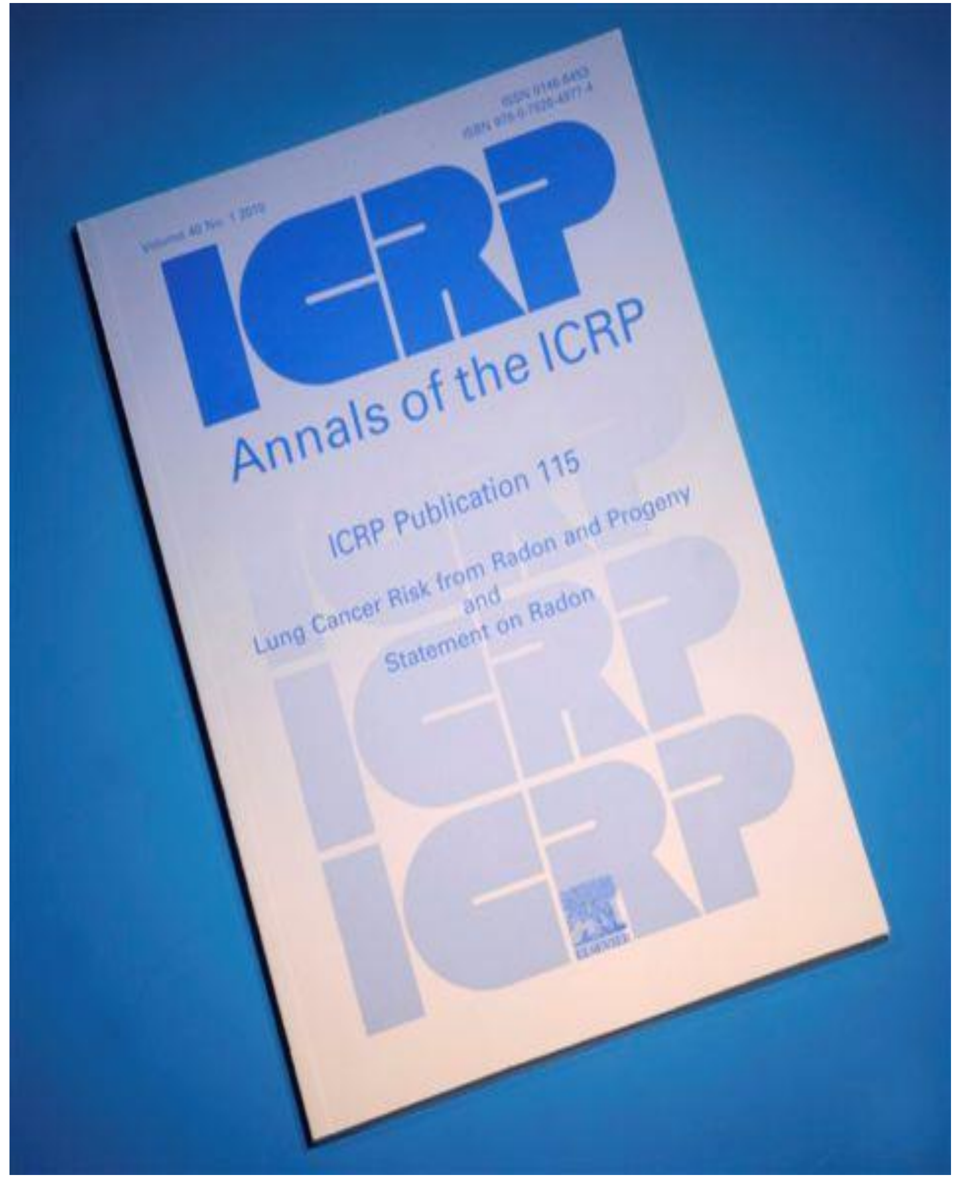
UN transport regulations for radioactive material

27

Publication 115

Lung cancer risk from radon and progeny and Statement on Radon.

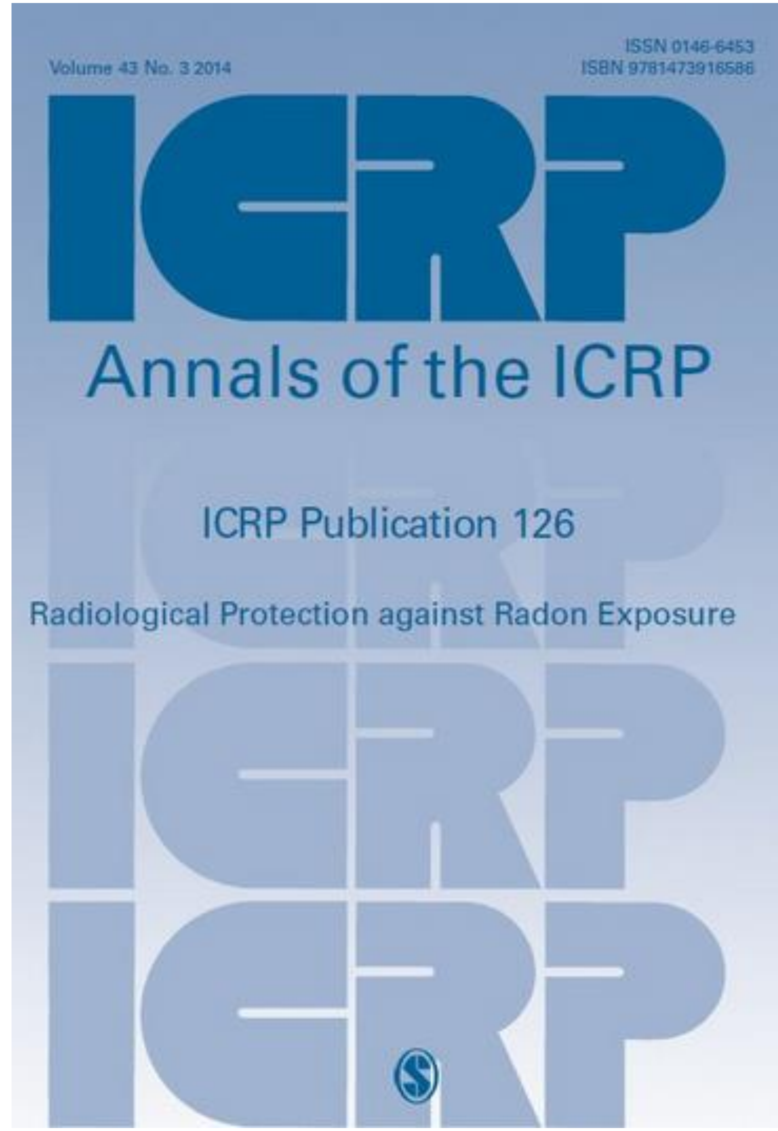
(2010)

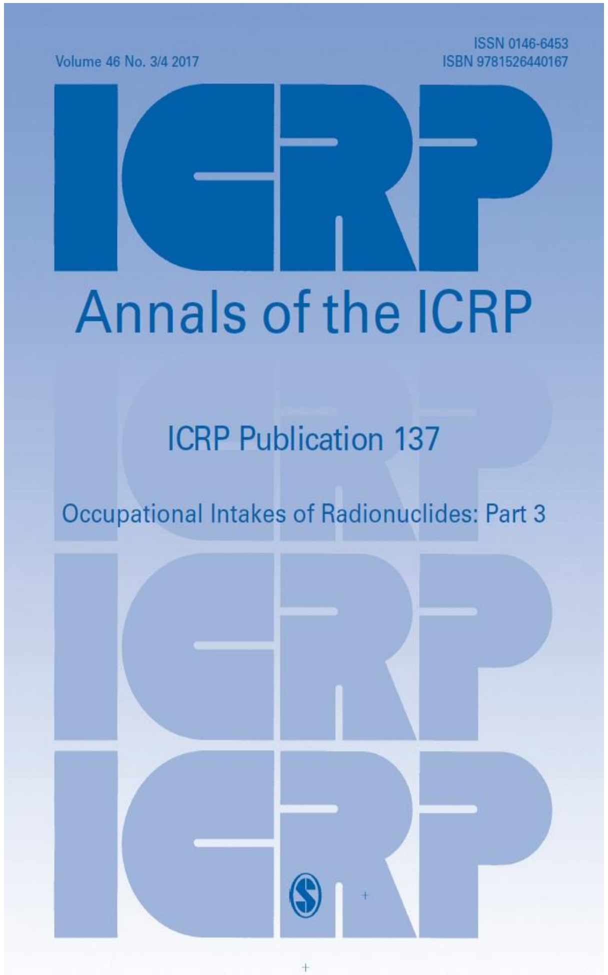


Publication 126

Radiological Protection against Radon Exposure.

(2014)





- Publication 65 (ICRP, 1993)

  Provided an epidemiologically based dose conversion convention, with a value of 1.4 mSv per mJ h m^3 , or

  ~ 5 mSv per WLM

- Publication 137 (ICRP, 2017)

  Recommends that for the calculation of doses following inhalation of radon and radon progeny in underground mines and in buildings, in most circumstances, the Commission recommends a dose coefficient of 3 mSv per mJ h m^3 , or

  ~ **10 mSv per WLM**.

How are Doses and Risks from Exposure to Radon and RDP Estimated?

- Historically, miners exposure to radon and progeny were estimated using working level months
  - Exposures were converted to “dose” using a dose conversion convention (DCC) based on **epidemiology** of miners (and more recently, for people exposed to radon in their homes)
  - miner studies are subject to uncertainty from dose estimation, other workplace exposures and smoking prevalence.
- A system of radon dosimetry using lung **dosimetry** models has developed to a high level of sophistication
  - No models are perfect and many assumptions are needed
  - Epidemiology is needed to convert from dose to risk.

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

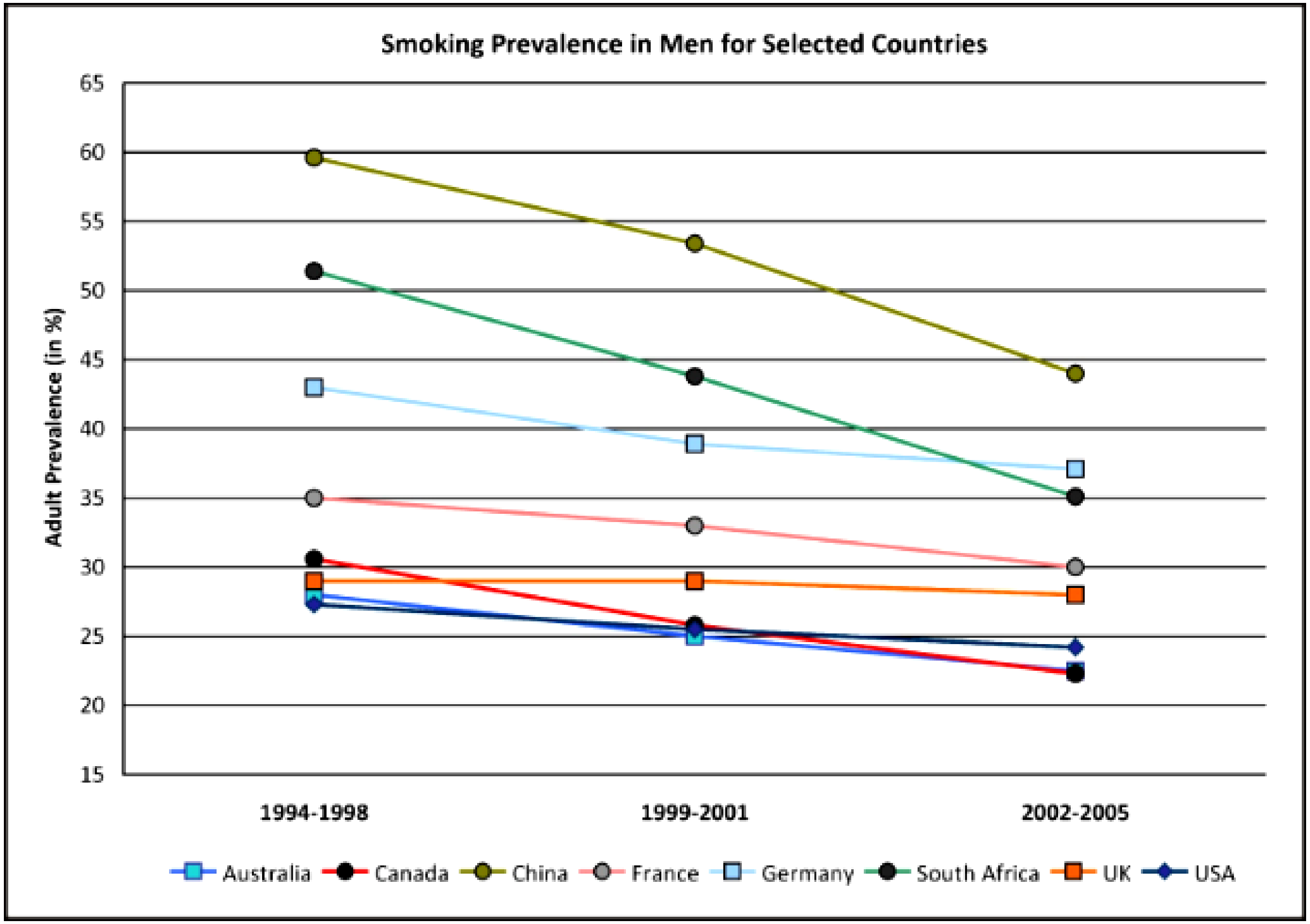
- ICRP 103 Populations (4)
- Canada by smoking status

Risk / WLM (and DCC) depends on

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

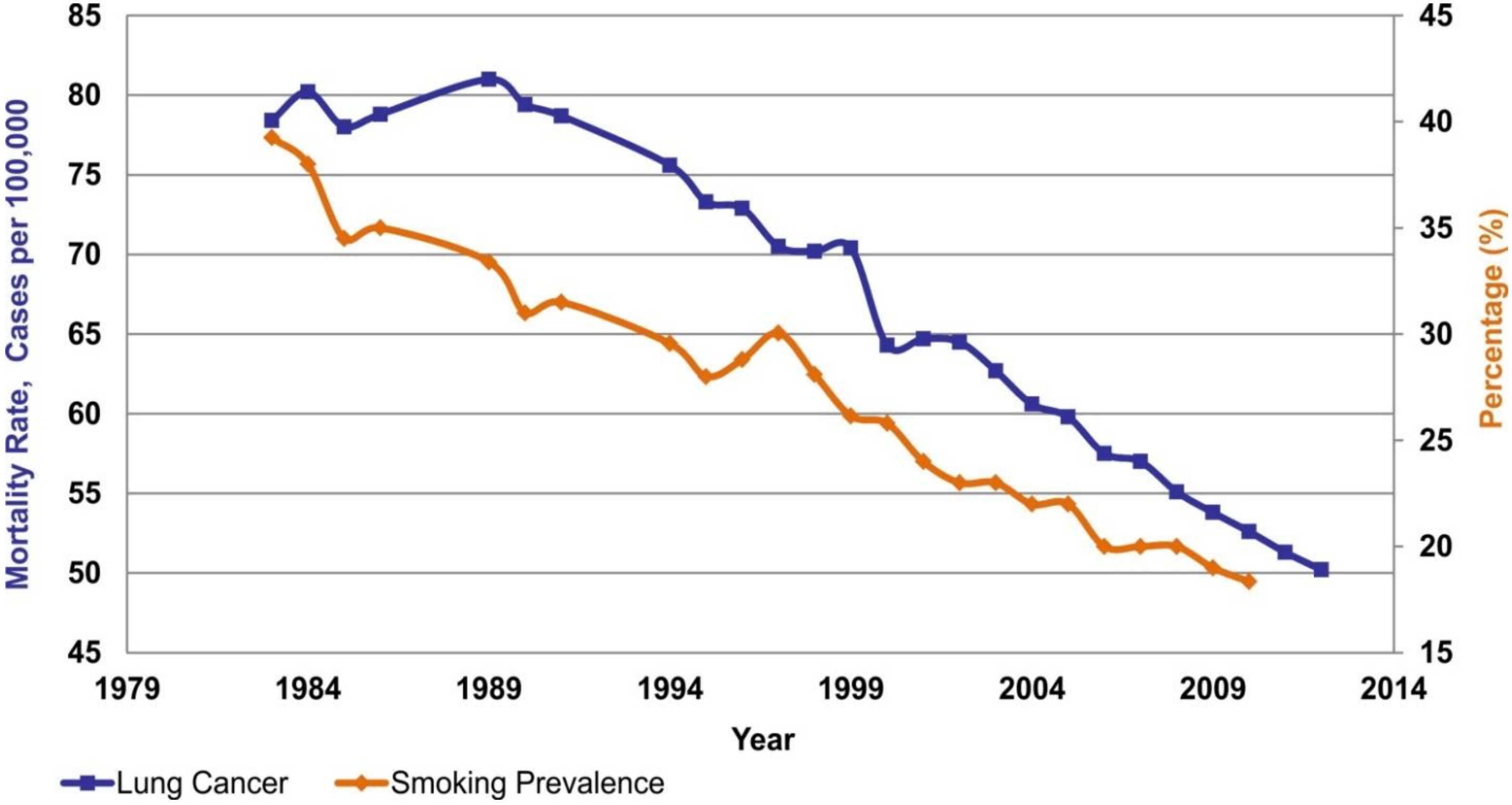
Implications of smoking prevalence needs to be considered

SMOKING PREVALENCE (MALE)



Canada male is about 16 % in 2017

AGE STANDARDIZED MORTALITY AND SMOKING PREVALENCE



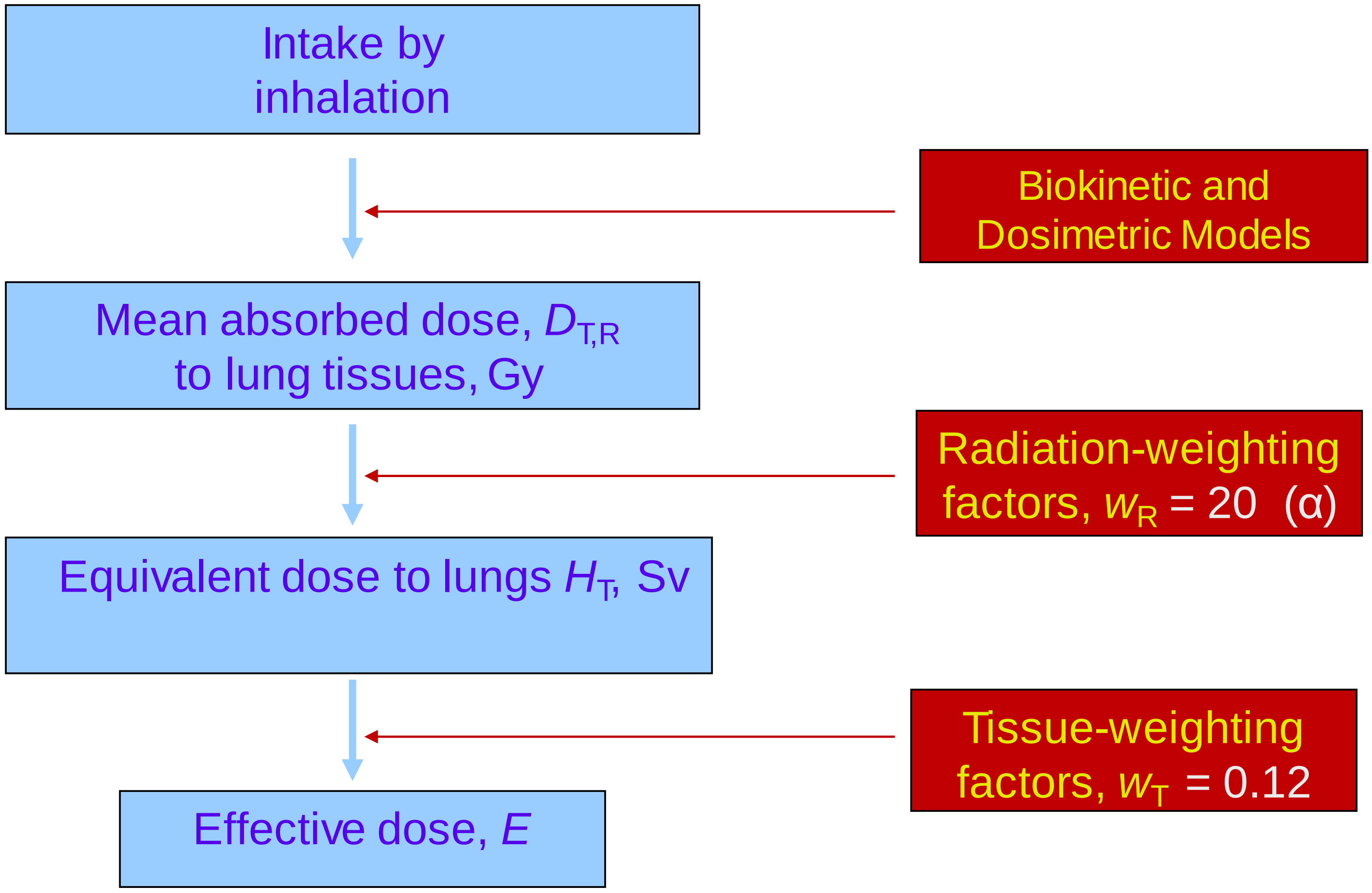
Smoking Status and DCC (mSv/WLM) for Occupational Exposure.

Receptor	Sex	Age of First Exposure	Age of Last Exposure	mSv/WLM						
				GSF (ICRP 65) [5]	BEIR VI [17]	FrenchCzech [22]	Ontario [18]	Wismut [21]	Eldorado [20]	Darby [3]
CanadaAll	F	18	64	7.1	15	13	6.3	8	18	6.7
CanadaAll	M	18	64	12	23	20	10	13	29	11
CanadaEver	F	18	64	12	24	22	10	13	31	11
CanadaEver	**M**	**18**	**64**	**15**	**30**	**26**	**13**	**16**	**38**	**14**
CanadaNever	F	18	64	2.1	4.2	3.9	1.9	2.4	4.8	1.9
CanadaNever	**M**	**18**	**64**	**1.6**	**3.2**	**3.1**	**1.5**	**1.9**	**3.3**	**1.5**

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

Calculation for inhaled ^{222}Rn + progeny



Effective Doses from Inhalation of Radon and Progeny in Workplaces

	Unattached fraction, f_p	Equilibrium factor, F	mSv/WLM
Indoor Workplace	0.08	0.4	20
Tourist cave	0.15	0.4	24
Mine	0.01	0.2	12

Observations

- Radon levels have decreased over time and exposures in modern uranium mines are quite low
- Radon can be an issue in many types of mines
- Epidemiology forms the basis of assessing risks
  - Dosimetric models are well developed and provide a basis for assessing factors that affect dose
  - In broad terms, modern epidemiology and dosimetry provide compatible estimates of risk
- Smoking prevalence is a key consideration (most of the risk accrues to smokers)
  - Recent epidemiology models are relative risk models and sensitive to smoking prevalence in reference populations
- Social factors need to be considered in setting national standards

South Africa Underground Miners: Annual Exposures: 2001