

# Leukaemia risk among Czech uranium miners in dependence on doses from radon, external gamma, and long lived radionuclides

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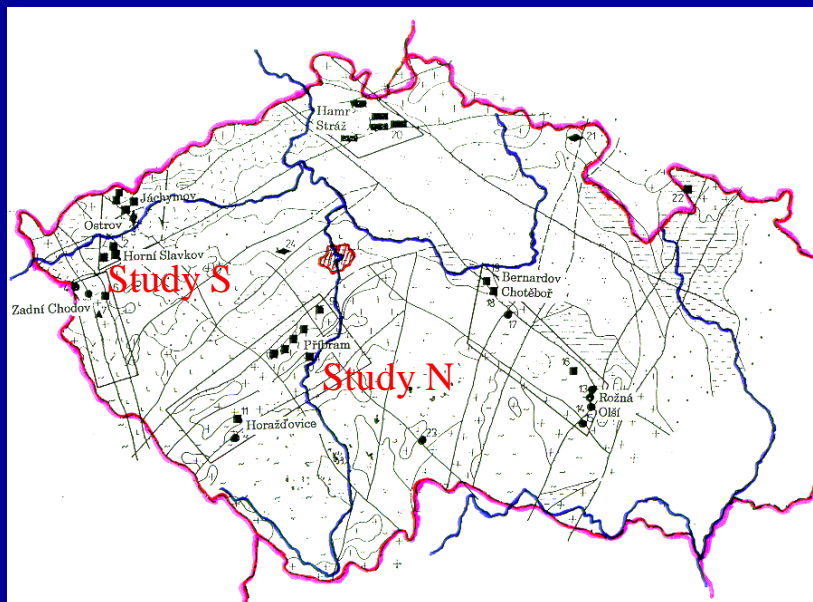
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# Definition of the Study



Cases obtained from  
 (1) death registry  
 (2) compensation claim files

|                                | S         | N         | S+N       |
|--------------------------------|-----------|-----------|-----------|
| Cohort size                    | 4353      | 5626      | 9979      |
| Exposed in                     | 1948-63   | 1968-86   |           |
| Alive in 2000                  | 18%       | 84%       | 56%       |
| Mean time since first exposure | 33        | 25        | 29        |
| <b>Leukaemia</b>               | <b>34</b> | <b>14</b> | <b>48</b> |

# Estimation of exposures in Czech Uranium Mines

radon & progeny

external gamma

long lived alpha radionuclides

dust content

uranium content

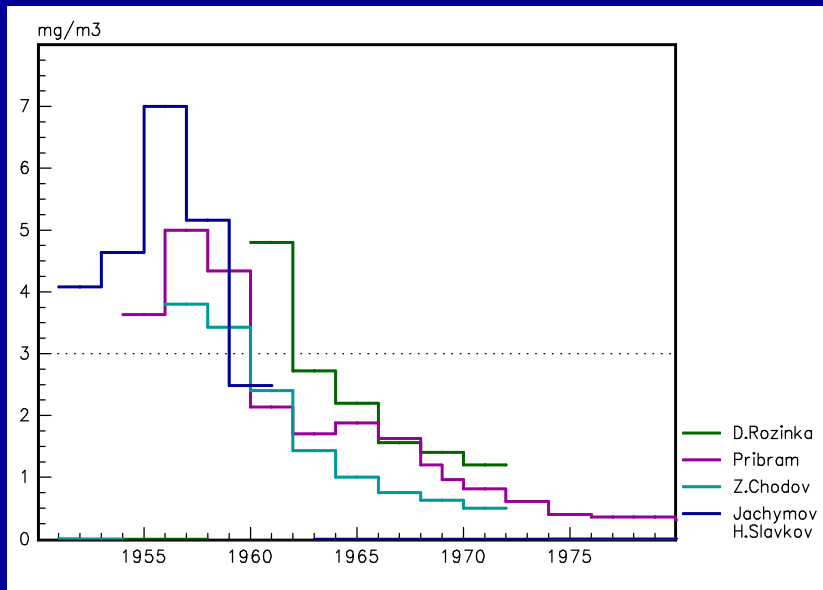
- measured since 1949

- measured since 1961

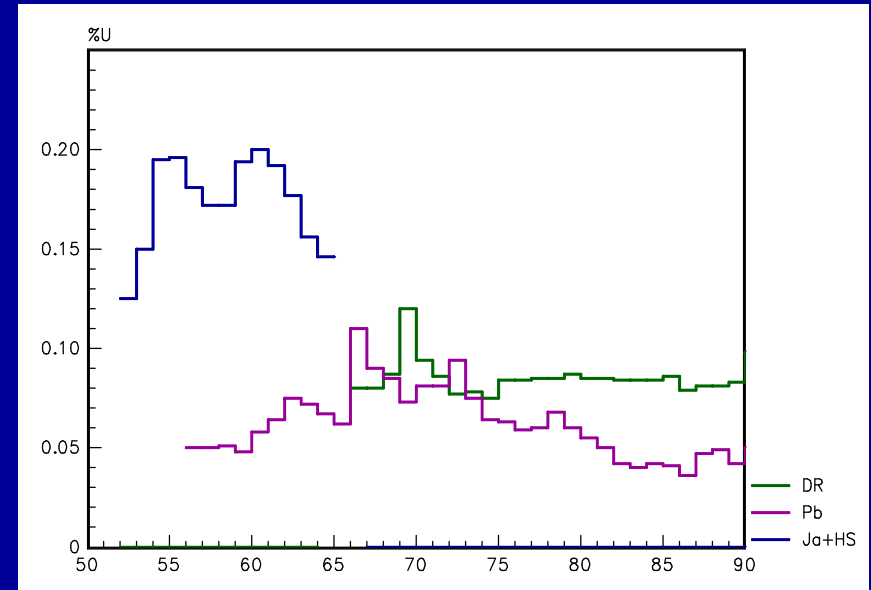
- measured since 1969

- measured since 1951

- available since 1952

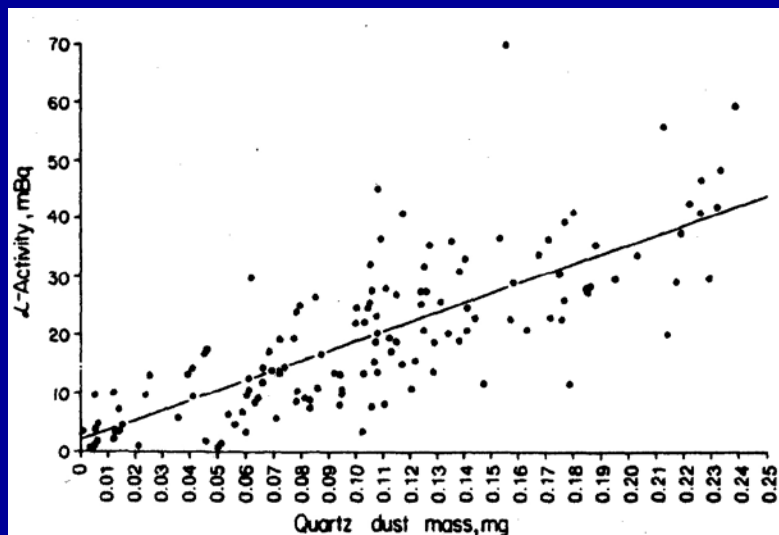


Dust content



Uranium content

# Relationship between dust content and activity of long lived radionuclides



Elliot Lake A [ $\text{Bq/m}^3$ ]  $\sim 0.160$  Q [ $\text{mg/m}^3$ ]

## Czech U mines

|        | $\text{Bq/m}^3$ | dust<br>$\text{mg/m}^3$ | $\text{Bq/mg}$ |
|--------|-----------------|-------------------------|----------------|
| 1976-7 | 0.130           | 1.01                    | 0.129          |
| 1978-9 | 0.122           | 0.81                    | 0.151          |
| 1980-1 | 0.118           | 0.77                    | 0.153          |
| 1982-3 | 0.122           | 0.82                    | 0.149          |
| 1984-5 | 0.118           | 0.93                    | 0.127          |
| 1986-7 | 0.148           | 0.77                    | 0.192          |

## Relationship between uranium content and external gamma

External gamma before 1961  
from U content

0.2 %  $\sim 16$  mSv

0.1 %  $\sim 8$  mSv

0.05 %  $\sim 4$  mSv

(for hewers, non-hewers 1/2)

Data obtained from measurements  
since 1961 correspond to these figures  
in terms of personal dose equivalent

Film dosimeters are calibrated to  
correspond  $H_p(10)$

## HRTM absorption parameters for radon progeny

|                                                       | Unattached | Attached |
|-------------------------------------------------------|------------|----------|
| Rapid dissolution fraction $f_r$                      | 1          | 0.06     |
| Rapid dissolution rate $s_r$ (d <sup>-1</sup> )       | 1000       | 66.5     |
| half-time                                             | 1 min      | 15 min   |
| Slow dissolution rate $s_s$ (d <sup>-1</sup> )        |            | 1.386    |
| half-time                                             |            | 12 h     |
| Bound fraction $f_b$                                  | 0.8        |          |
| Uptake rate from bound state $s_b$ (d <sup>-1</sup> ) | 1.664      |          |
| half-time                                             | 10 h       |          |

## Rn progeny aerosol parameters (wet drilling)

| Ventilation | F   | $f_p$ | AMAD (nm) |
|-------------|-----|-------|-----------|
| good        | 0.3 | 0.03  | 350       |
| medium      | 0.5 | 0.01  | 250       |
| bad         | 0.7 | 0.01  | 250       |

## Red bone marrow dose

|            | mGy/WLM |
|------------|---------|
| Rn gas     | 0.029   |
| Rn progeny | 0.0027  |
| Total      | 0.032   |

# Dose calculations from long-lived radionuclides

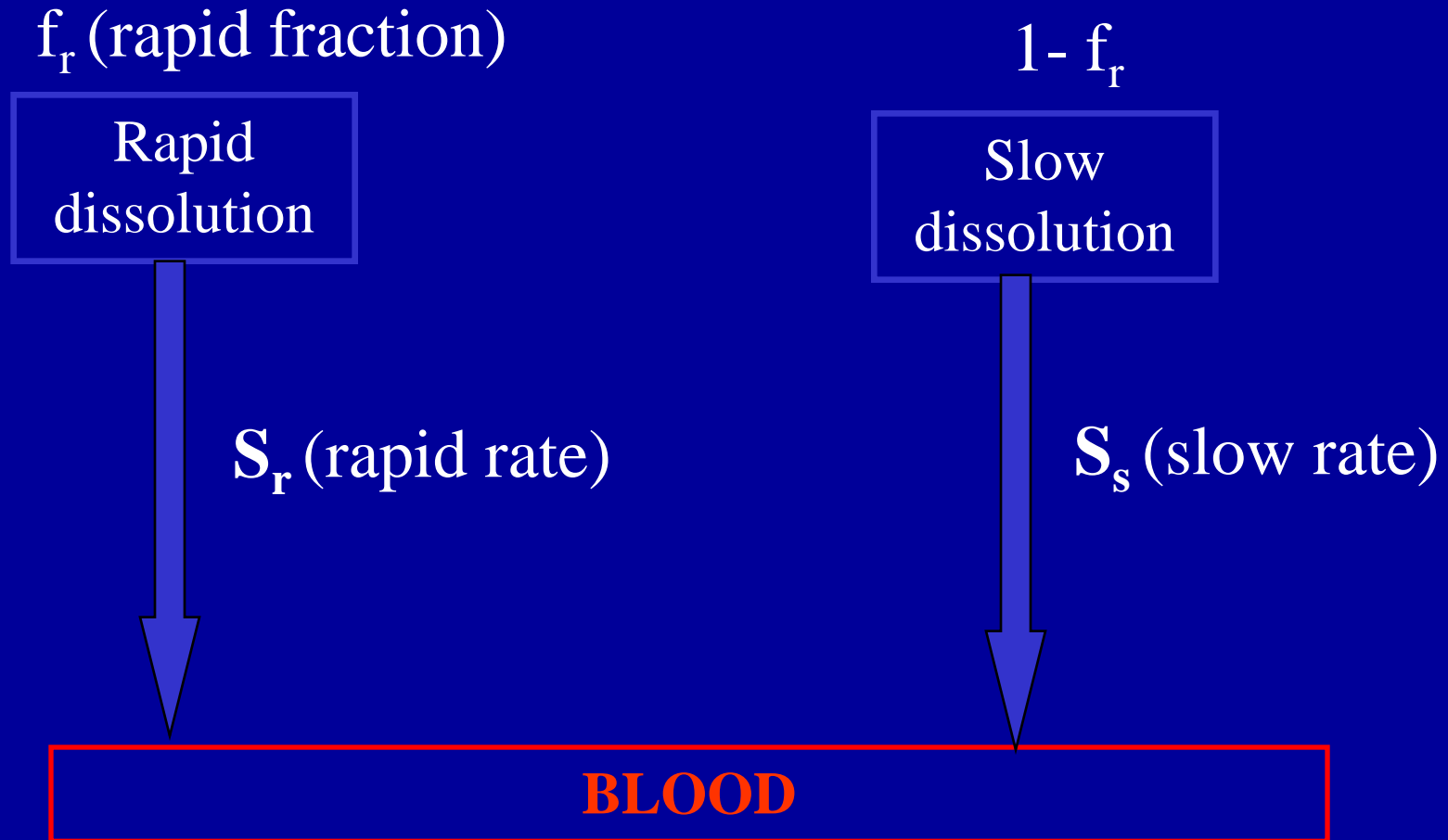
## Models

- ICRP Publication 66 Human Respiratory Tract Model (HRTM)
- ICRP Publication 30 model Gastrointestinal (GI) model
- ICRP Publication 67 biokinetic models for polonium, lead, and radium
- ICRP Publication 69 biokinetic models for uranium and thorium

## Assumptions:

- Activity ratios:  $^{235}\text{U}/^{238}\text{U} = 5/95 = 0.053$  and  $^{232}\text{Th}/^{238}\text{U} = 0.04$
- 25% of radon gas and thoron gas escapes from the particle
- Constant chronic intake over 365 days
- Breathing rates 1.4, 1.2, 1.0  $\text{m}^3 \text{h}^{-1}$  in dependence on physical activity
- Specific HRTM absorption parameter values (about 80% relatively insoluble & remaining 20% very soluble)
- Density = 3  $\text{g cm}^{-3}$       shape factor = 1.5      (ICRP default)
- AMAD = 7  $\mu\text{m}$        $\sigma_g = 2.5$       (ICRP default)

# Human Respiratory Tract's compartment model for absorption into blood



# Long lived radionuclides

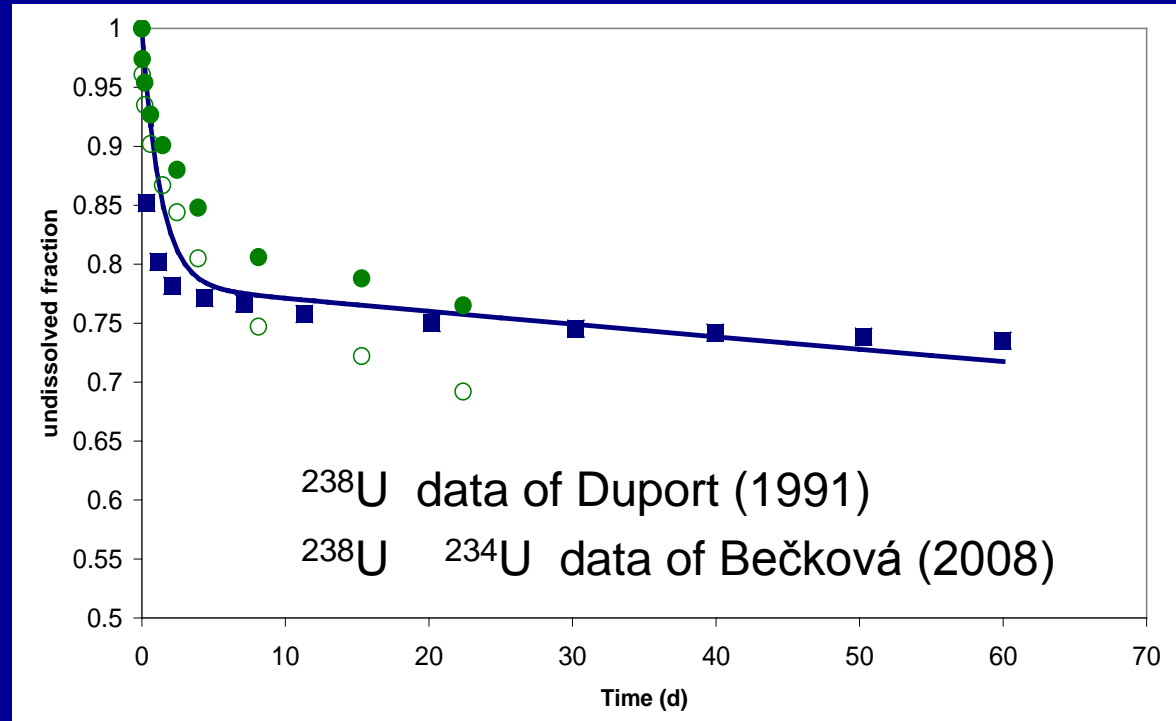
## Solubility of $^{234}\text{U}$ and $^{238}\text{U}$ in lung fluid

for high grade ore and  
particle sizes  $< 38 \mu\text{m}$

$$f_r = 0.22$$

$$S_r = 0.78 \text{ d}^{-1}$$

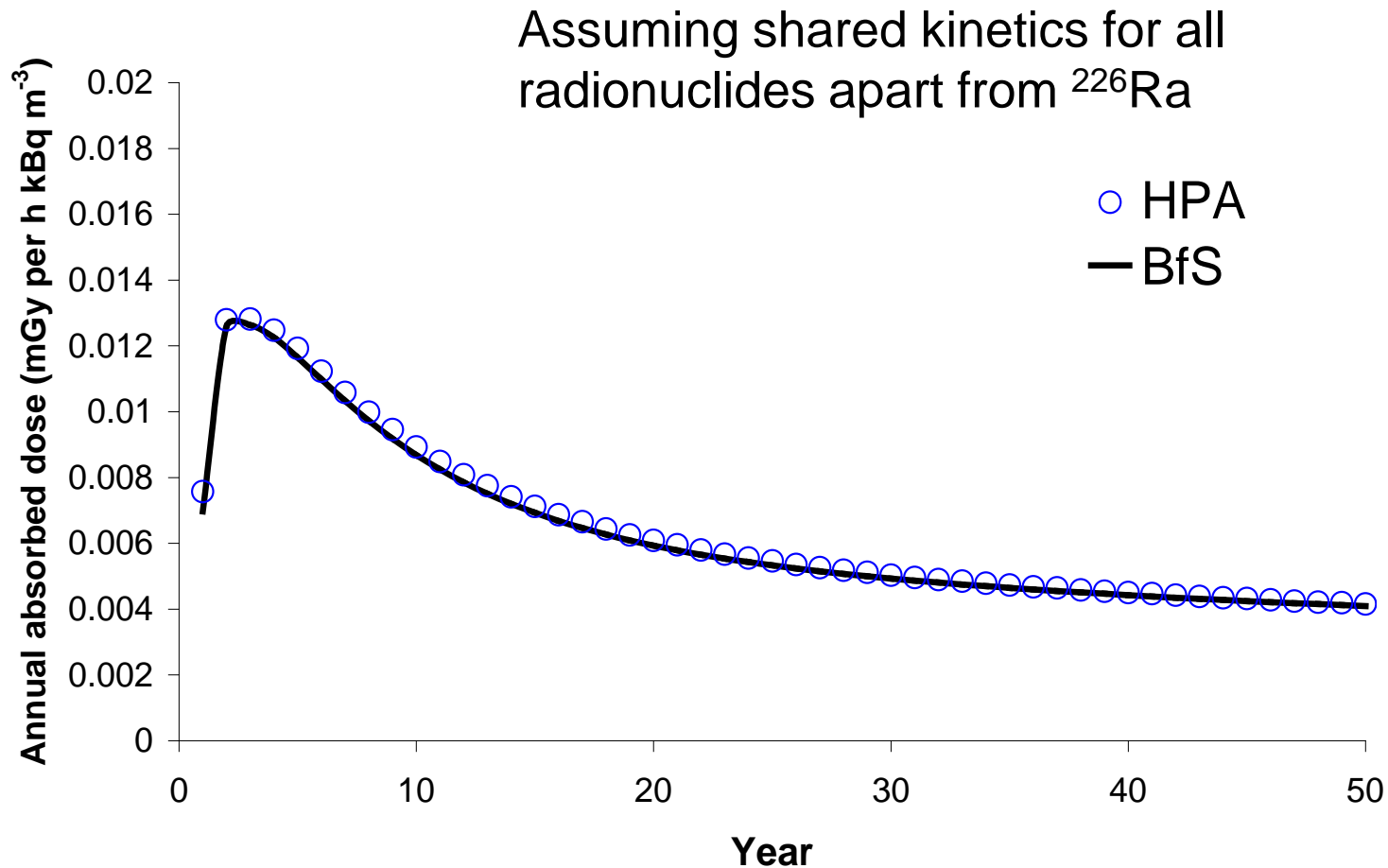
$$S_s = 1.4 \cdot 10^{-3} \text{ d}^{-1}$$



## HRTM absorption parameter values

|                                                       | Fraction dissolved rapidly $f_r$ | Fast dissolution rate $s_r$ ( $\text{d}^{-1}$ ) | Slow dissolution rate $s_s$ ( $\text{d}^{-1}$ ) |
|-------------------------------------------------------|----------------------------------|-------------------------------------------------|-------------------------------------------------|
| $^{234}\text{U}$ $^{235}\text{U}$ $^{238}\text{U}$    | 0.22                             | 0.78                                            | $1.4 \cdot 10^{-3}$                             |
| $^{230}\text{Th}$ $^{232}\text{Th}$                   | 0.14                             | 4.56                                            | $6.8 \cdot 10^{-4}$                             |
| $^{226}\text{Ra}$ $^{228}\text{Ra}$ $^{224}\text{Ra}$ | 0.11                             | 7.32                                            | $4.1 \cdot 10^{-4}$                             |
| $^{210}\text{Pb}$                                     | 0.26                             | 3.91                                            | $1.0 \cdot 10^{-3}$                             |

# RBM annual absorbed dose to the RBM for unit exposure of LLR (gross alpha)



# Number of alpha disintegrations per Bq of $^{238}\text{U}$

➤  $^{238}\text{U}$ ,  $^{234}\text{U}$ ,  $^{230}\text{Th}$ ,  $^{226}\text{Ra}$ ,  $^{222}\text{Rn}$ ,  $^{218}\text{Po}$ ,  $^{214}\text{Po}$ ,  $^{210}\text{Po}$  (25% Rn-222 escapes)

4 alpha emitters +  $0.75 \times (4 \text{ alpha emitters}) = 7$  alphas

➤  $^{235}\text{U}$ ,  $^{231}\text{Pa}$ ,  $^{227}\text{Th}$ ,  $^{223}\text{Ra}$ ,  $^{219}\text{Rn}$ ,  $^{215}\text{Po}$ ,  $^{211}\text{Bi}$

7 alpha emitters = 7 alphas

➤  $^{232}\text{Th}$ ,  $^{228}\text{Th}$ ,  $^{224}\text{Ra}$ ,  $^{220}\text{Rn}$ ,  $^{216}\text{Po}$ ,  $^{212}\text{Po}$  (25% Rn-220 escapes)

3 alpha emitters +  $0.75 \times (3 \text{ alpha emitters}) = 5.25$  alphas

Total number of alpha disintegrations per Bq of  $^{238}\text{U}$

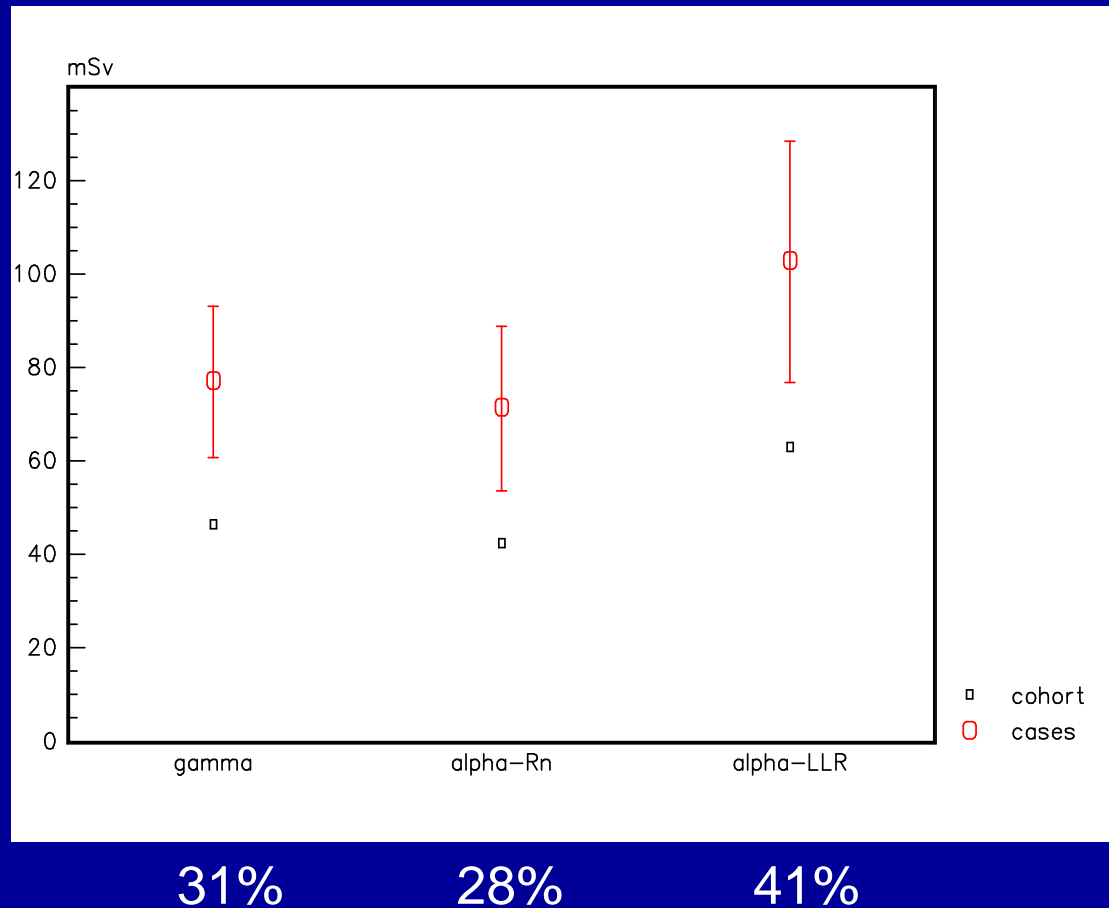
$$= 7 + 7 \left( \frac{^{235}\text{U}}{^{238}\text{U}} \right) + 5.25 \left( \frac{^{232}\text{Th}}{^{238}\text{U}} \right)$$

$$= 7.6 \quad \text{for} \quad \frac{^{235}\text{U}}{^{238}\text{U}} = 0.053 \quad \text{and} \quad \frac{^{232}\text{Th}}{^{238}\text{U}} = 0.04$$

# Individual estimates of exposures based on

- year and location    mean WLM
  - mine ventilation (poor, medium, good)
  - equilibrium factor ( $F = 0.7 - 0.2$ )
- job (physical activity)    breathing rates (1.4, 1.2, 1.0 m<sup>3</sup>/h)
- duration of exposure (annual recorded shifts)

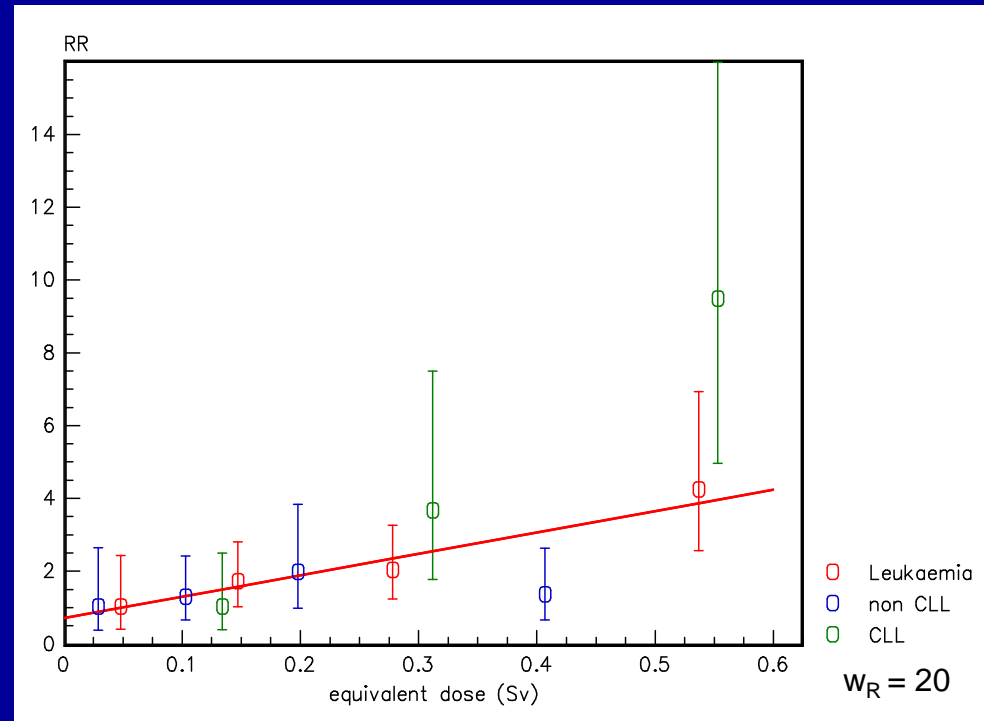
# Mean equivalent cumulated doses to red bone marrow among cases and in the cohort



# Leukaemia relative risks from cumulated equivalent doses

| dose (mSv) | cases | RR  | 90% CI*   |
|------------|-------|-----|-----------|
| 1 – 84     | 12    | 1.0 | 0.4 – 2.4 |
| 85 – 199   | 12    | 1.7 | 1.0 – 2.8 |
| 200 – 389  | 12    | 2.0 | 1.2 – 3.3 |
| 390 +      | 12    | 4.2 | 2.6 – 6.9 |
| Total      | 48    |     |           |

\* CI derived for floating risks



$w_R = 20$

**ERR/Sv = 8.1**  
**95% CI: 2.7 – 13.6**

$w_R = 10$

**ERR/Sv = 12.5**  
**95% CI: 4.3 – 20.4**

doses lagged by 2 years  
background rates estimated internally

$w_R = 16$  95% CI: 0 - 128  
estimated from data

# Conclusions

- Main contribution to the red bone marrow equivalent dose is from long lived radionuclides (about 40%)
- Leukaemia risk is significantly related to cumulated equivalent dose and is consistent with other studies
- NonCLL and CLL leukaemia types show similar patterns
- Pooled studies are needed to reduce uncertainty of risk estimates