RC 16. Radon Refresher Course Part 2, June 6th 2018.
The Hague, The Netherlands

"Residential Radon Lung Cancer Risk Estimation"

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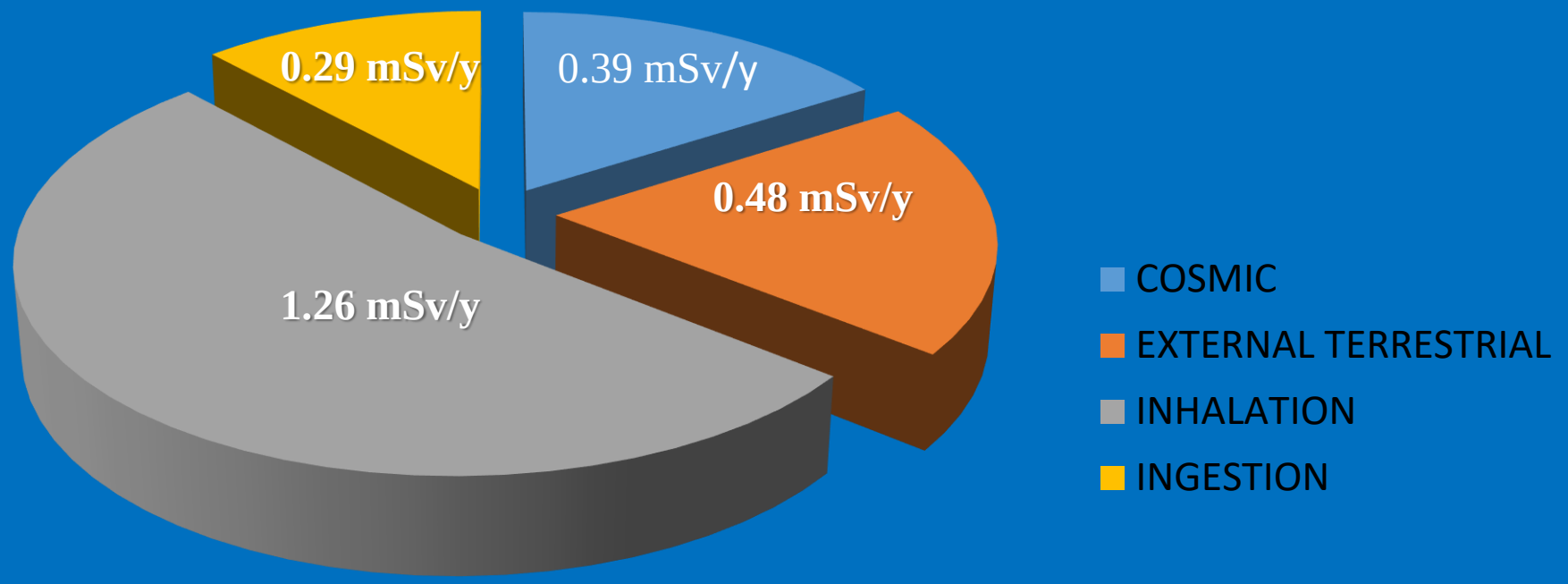
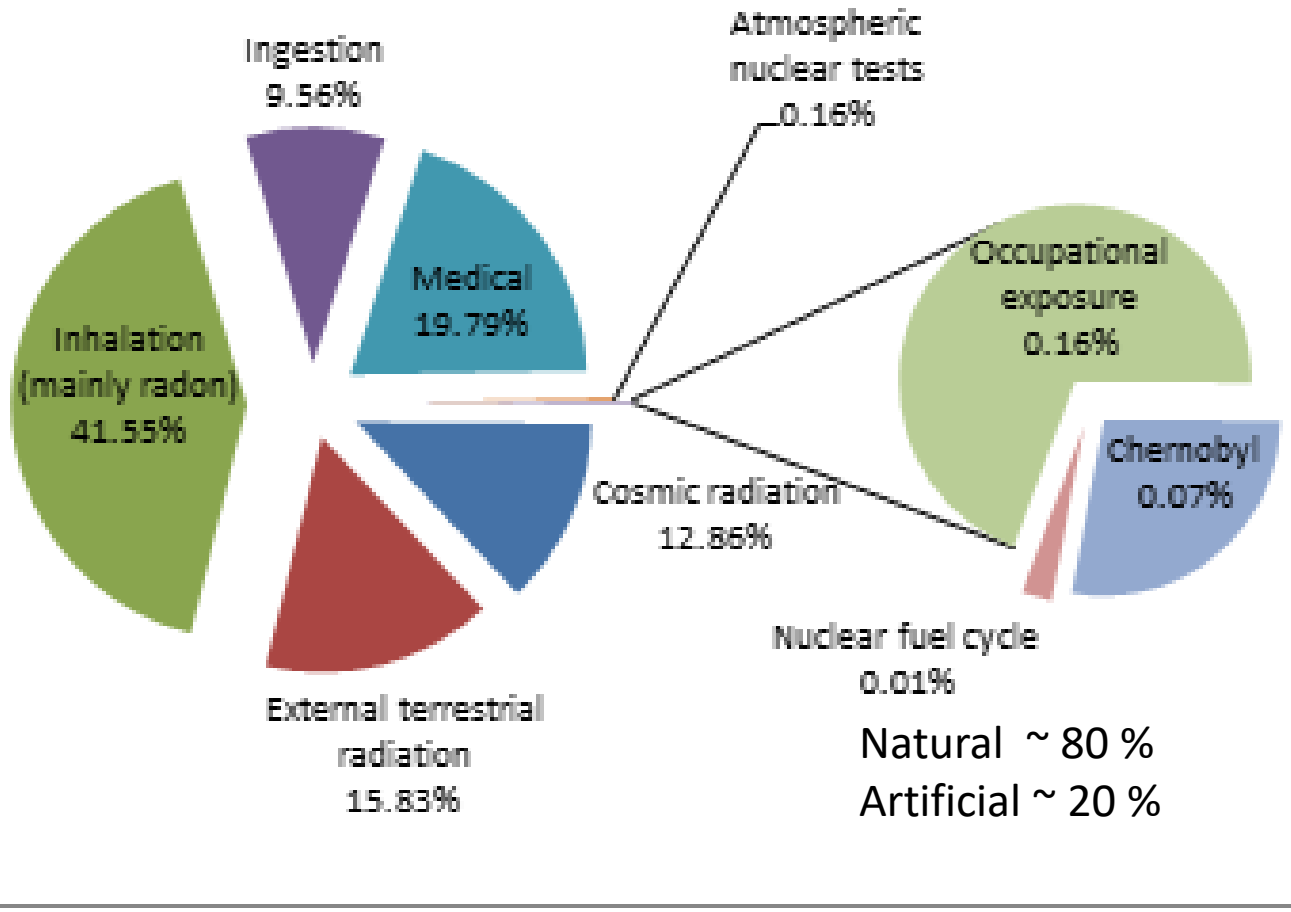
Global Annual doses to public from Natural Radiation (UNSCEAR 2008)



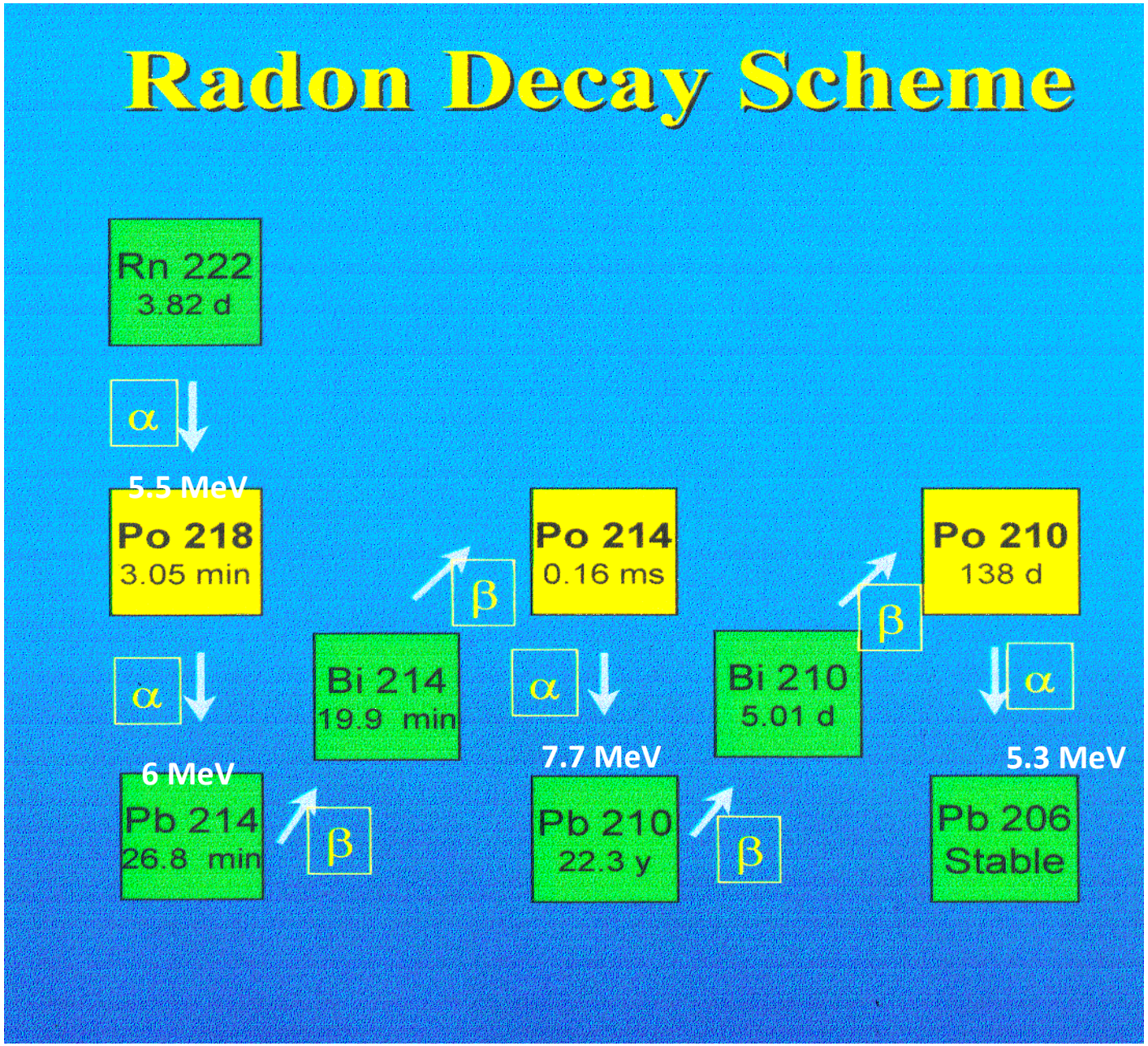
TOTAL DOSE = 2.4 mSv /y

CONTRIBUTIONS TO MEAN GLOBAL DOSES (UNSCEAR 2008)

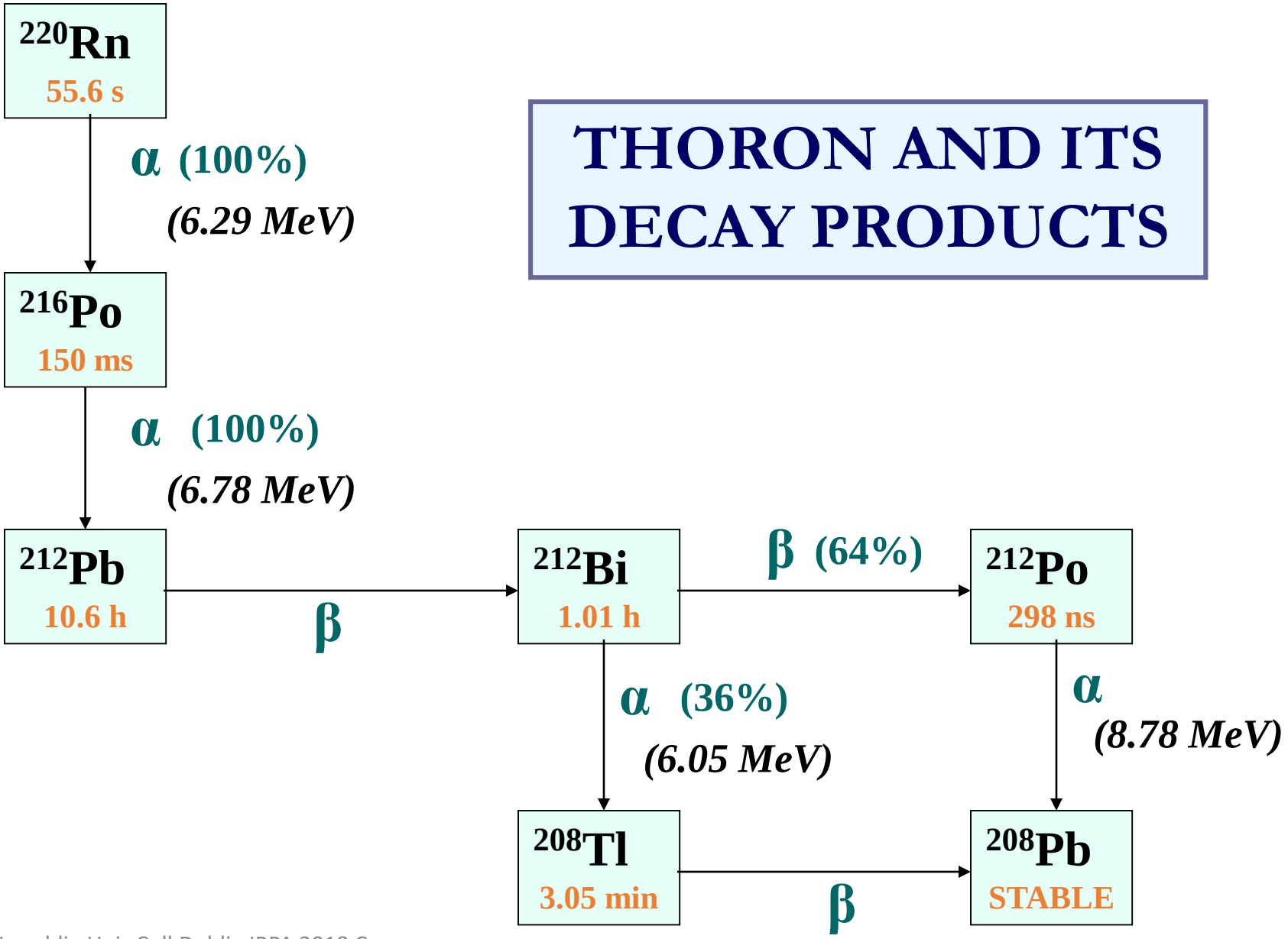
Total (all sources) ~ 3.00 mSv /year



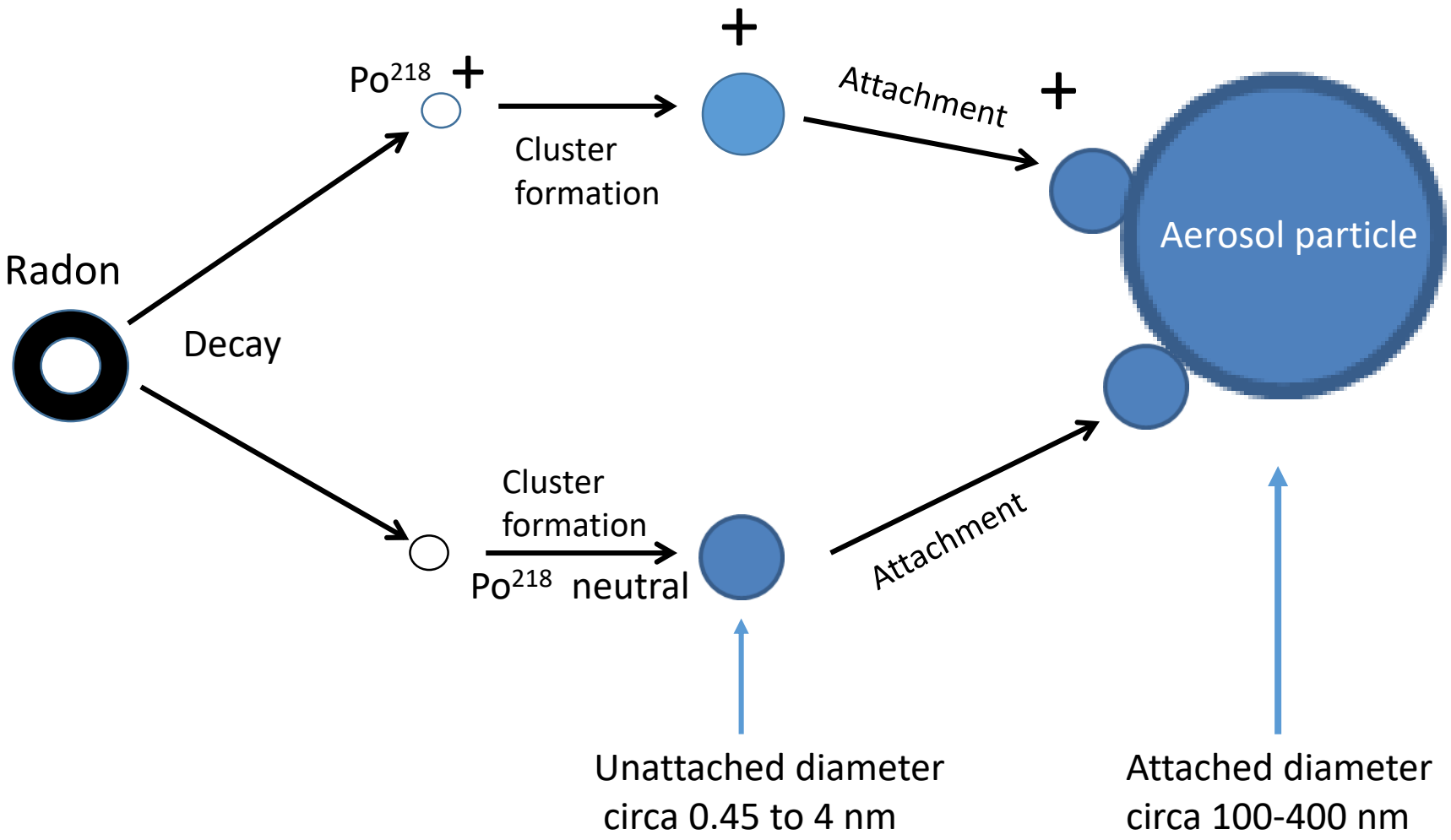
Natural ~ 80 %
Artificial ~ 20 %


Radon Decay Scheme
Rn 222
3.82 d
α
5.5 MeV
Po 218
3.05 min
α
6 MeV
Pb 214
26.8 min
β
Bi 214
19.9 min
β
Po 214
0.16 ms
α
7.7 MeV
Pb 210
22.3 y
β
Bi 210
5.01 d
β
Po 210
138 d
α
5.3 MeV
Pb 206
Stable

THORON AND ITS DECAY PRODUCTS

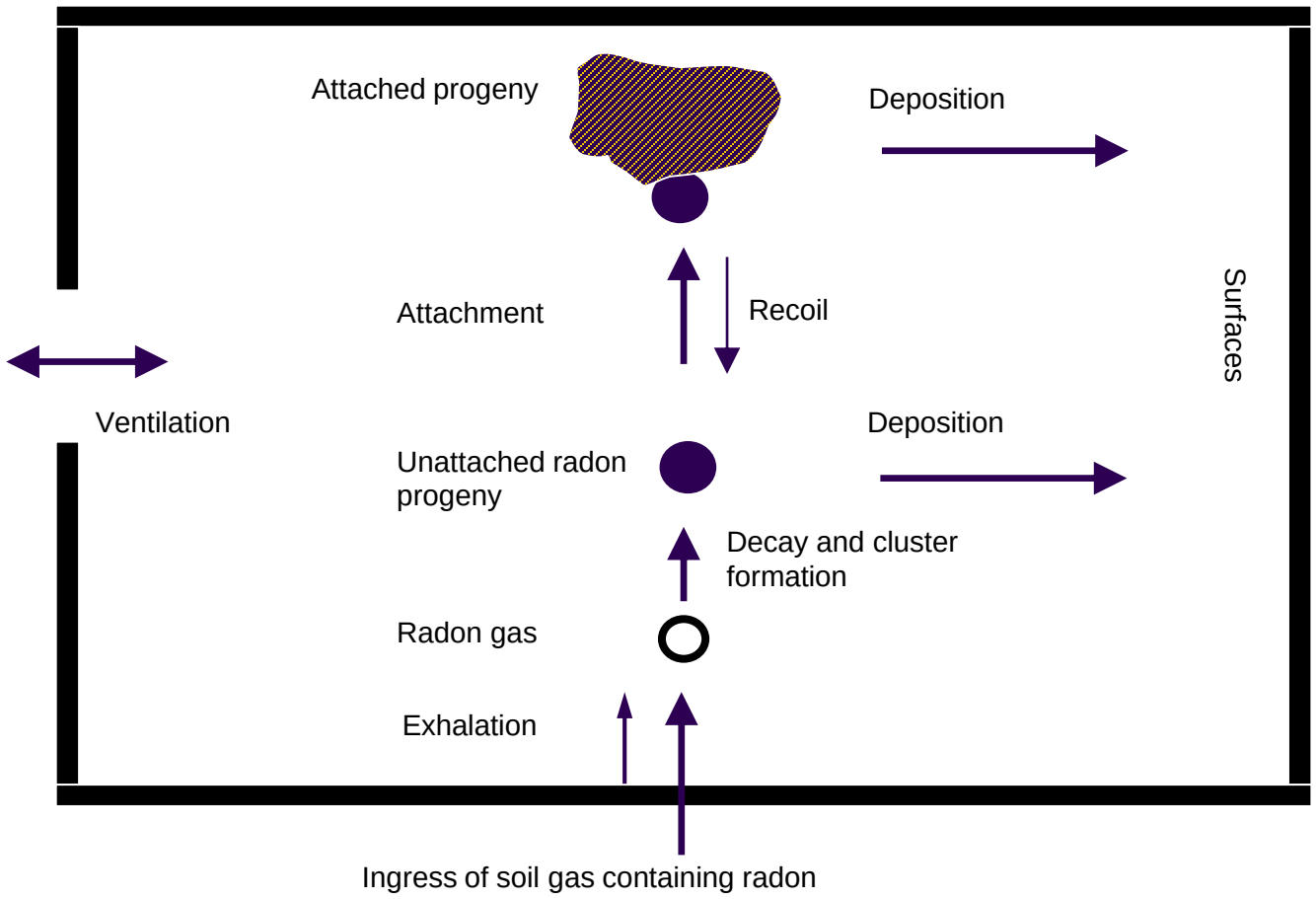


SIMPLIFIED DIAGRAM OF UNATTACHED AND ATTACHED RADON PROGENY FORMATION*



Based on : Porstendörfer, J.Aero.Sci. 1994

Schematic Diagram of Radon and Progeny behaviour in an Enclosed Space (ICRU Report 88 (2015))



STEADY STATE WELL MIXED ROOM MODEL EQUATIONS FOR UNATTACHED AND ATTACHED RADON PROGENY
(ICRU Report 88 (2015))

For C_j^u the activity concentration of the jth radon progeny in the unattached state we may write:

$$dC_j^u/dt = \lambda_j C_{j-1}^u + \lambda_{j\ j-1} C_{j-1}^a - (\lambda_j + X + q^u + v) C_j^u$$

For C_j^a the activity concentration of the jth radon progeny in the attached state we may write:

$$dC_j^a/dt = v C_j^{a,o} + (1 - R_{j-1}) \lambda_j C_{j-1}^a + X C_{j-1}^u - (\lambda_j + q^a + v) C_j^a$$

Under steady state conditions we obtain :

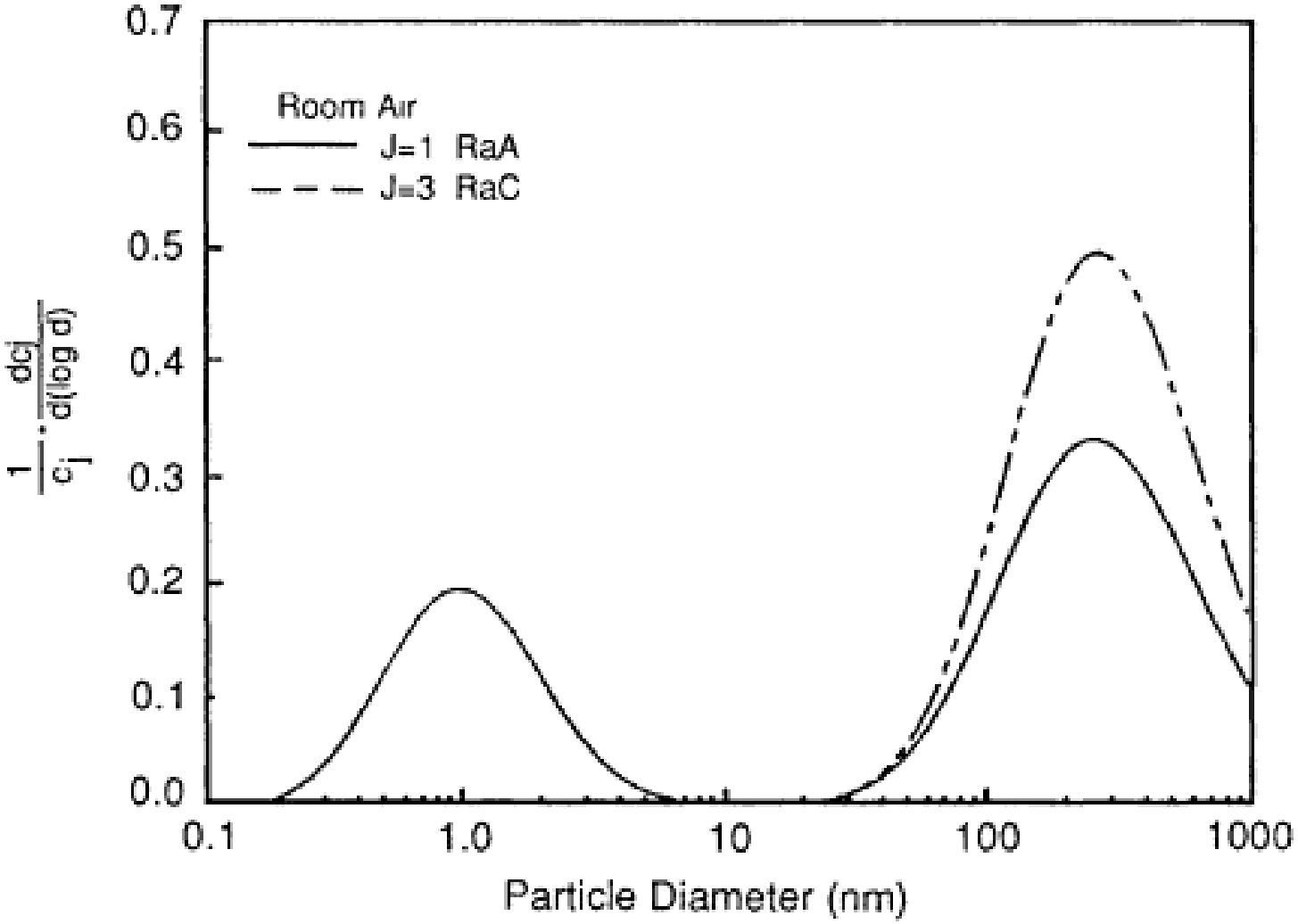
$$C_j^u = (\lambda_j C_{j-1}^u + \lambda_{j\ j-1} C_{j-1}^a) / (\lambda_j + \beta Z + q^u + v)$$

and

$$C_j^a = (v C_j^{a,o} + (1- R_{j-1}) \lambda_j C_{j-1}^a + \beta Z C_{j-1}^u) / (\lambda_j + q^a + v)$$

with $C_0^a = 0$ and $C_0^u = C_o$ (radon gas activity concentration).
Here attachment Rate $X = \beta Z$ where β is the attachment coefficient and Z is the aerosol conc and R_{j-1} is the recoil factor of the j-1th attached radon progeny.

SIZE DISTRIBUTION OF RADON PROGENY IN INDOOR AIR *



*Reineking and Porstendörfer. J.Aero.Sci (1986)

LUNG DOSIMETRY SUB MODELS*

(1) Morphometric lung model

(2) Respiratory physiology model

(3) Particle deposition model

(4) Bronchial clearance model

(5) Dosimetry model

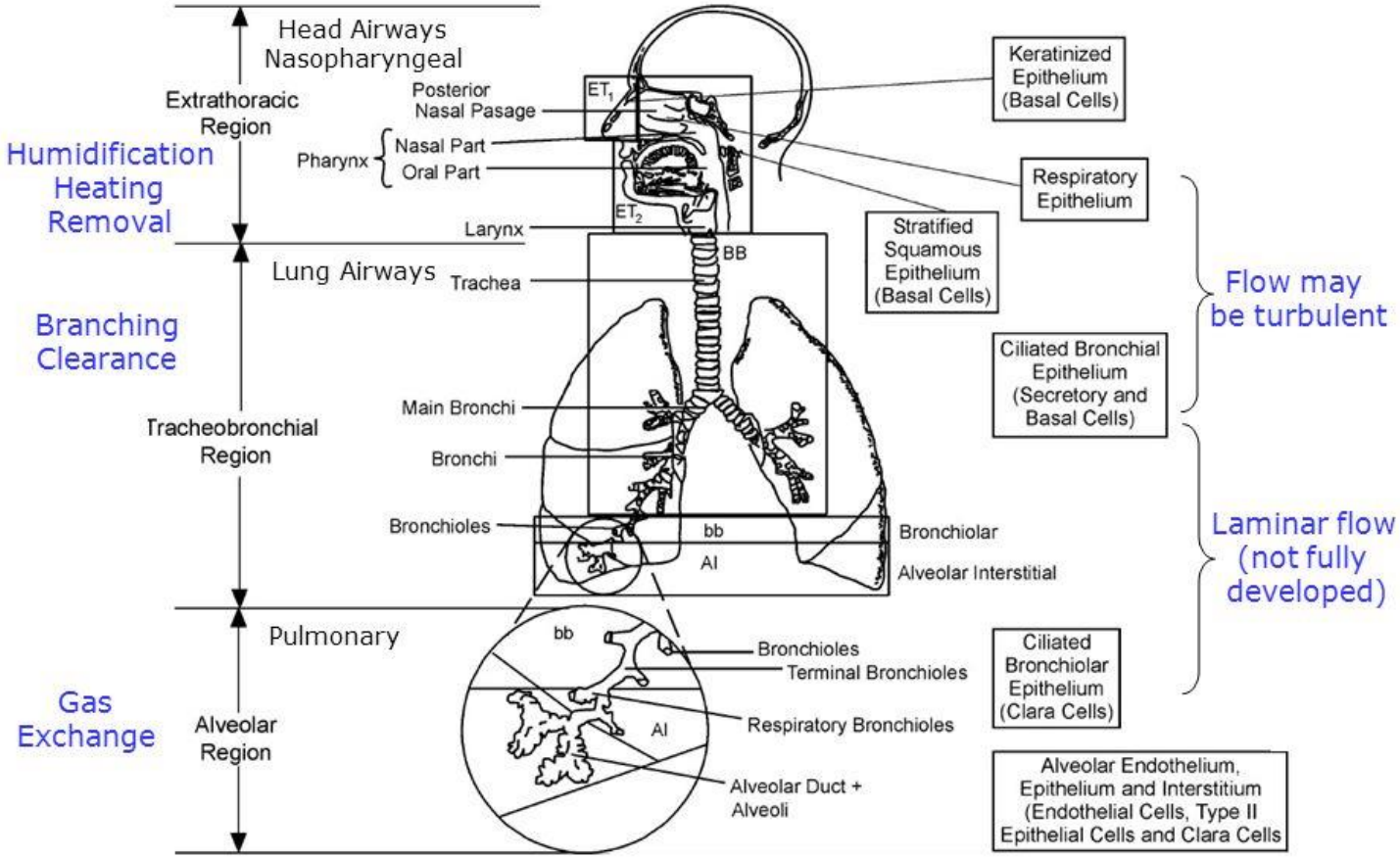
*ICRU Report 88 (2015)

PRINCIPAL CATEGORIES OF LUNG DOSIMETRY MODELS

SEMI-EMPIRICAL COMPARTMENT MODELS

AIRWAY GENERATION MODELS: DETERMINISITIC AND STOCHASTIC

The Human Respiratory Tract (ICRP 65 (1994))



LUNG DEPOSITION MECHANSIMS

MAJOR MECHANISMS

Diffusion : $< 1\ \mu m$

Sedimentation : 0.5 to 5 μm

Inertial Impaction : $> 5\ \mu m$

MINOR MECHANISMS

Interception

Electrostatic

MAJOR PARAMETERS IN RADON PROGENY LUNG DOSE MODELLING

Breathing rate

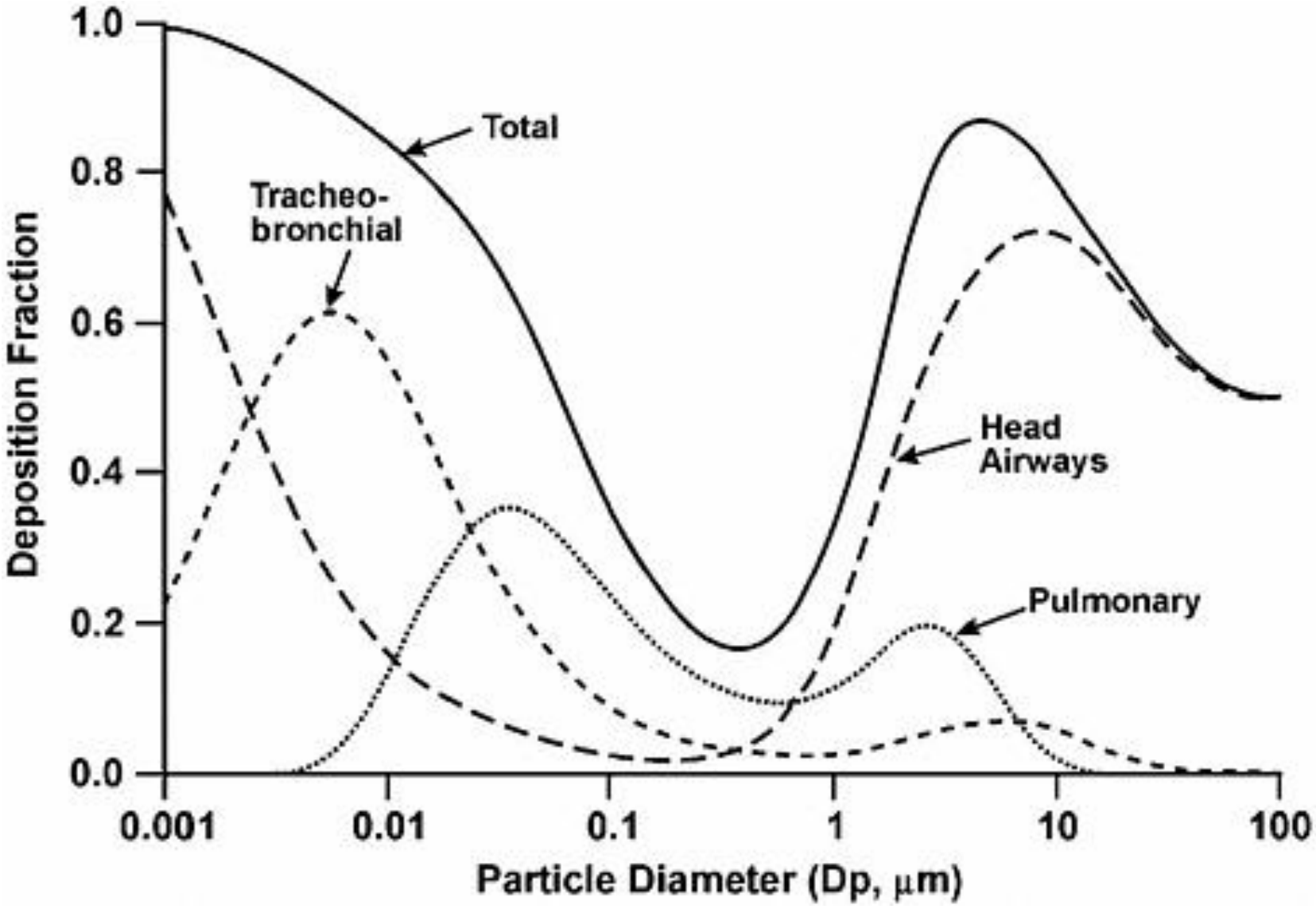
Inhaled activity particle size distribution

Particle deposition in airways

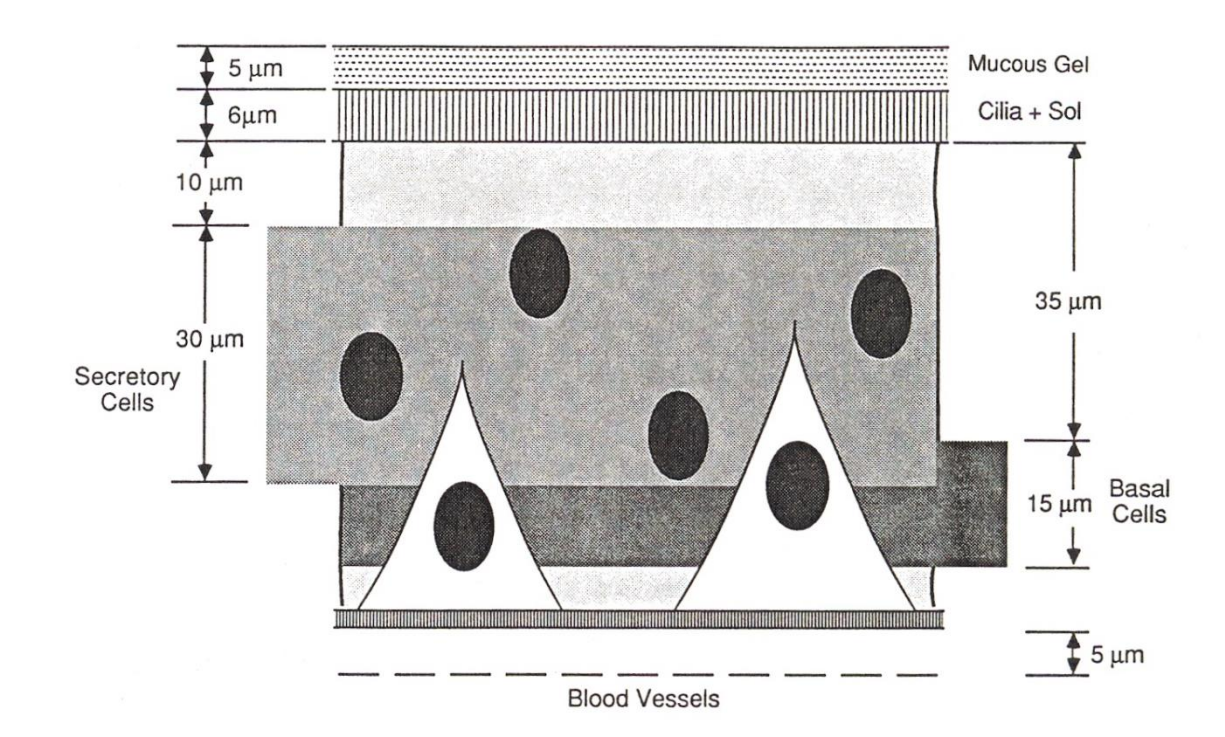
Particle clearance from airways

Target cells and depth distribution within the bronchial epithelium

DEPOSITION OF INHALED PARTICLES



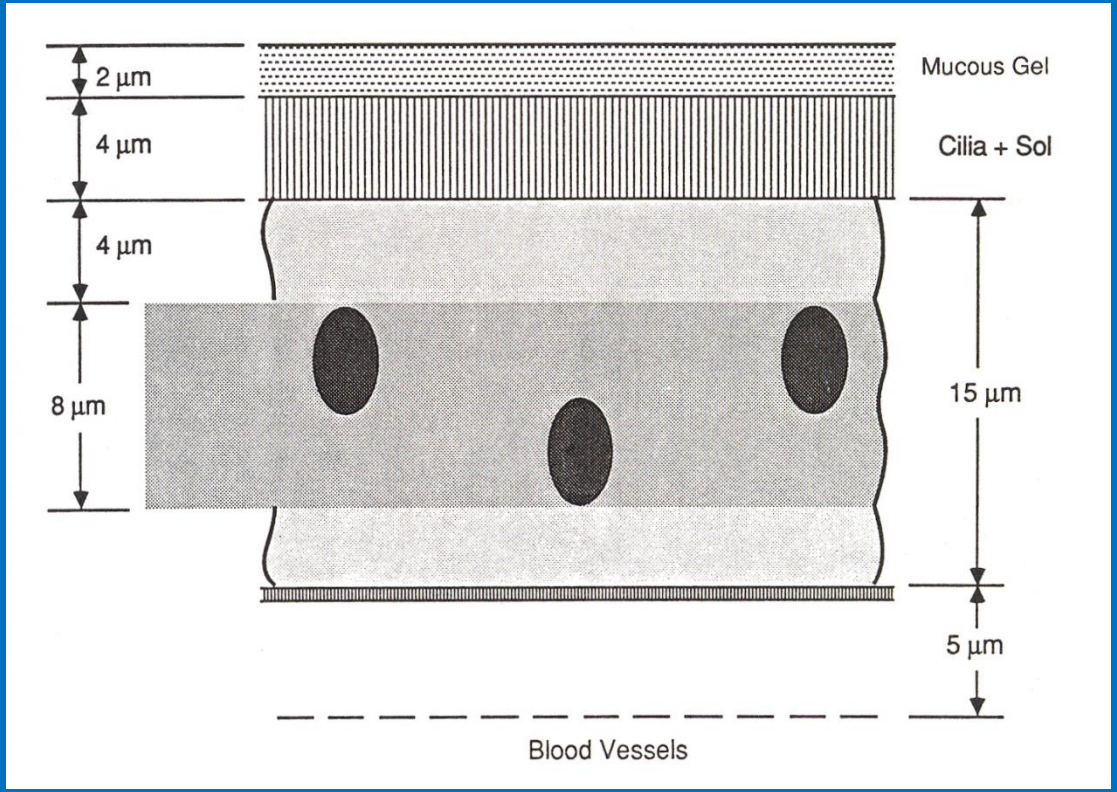
Idealised model of secretory and basal cells in the bronchial epithelium.



Alpha particle ranges in tissue
Po-218 (Eα=6.00 MeV) 48 µm
Po-214 (Eα=7.68 MeV) 71 µm

Ref: BEIR IV Report . U.S. National Research Council 1988.

Idealised model of secretory cell nuclei in bronchiolar epithelium.



Alpha particle ranges in tissue
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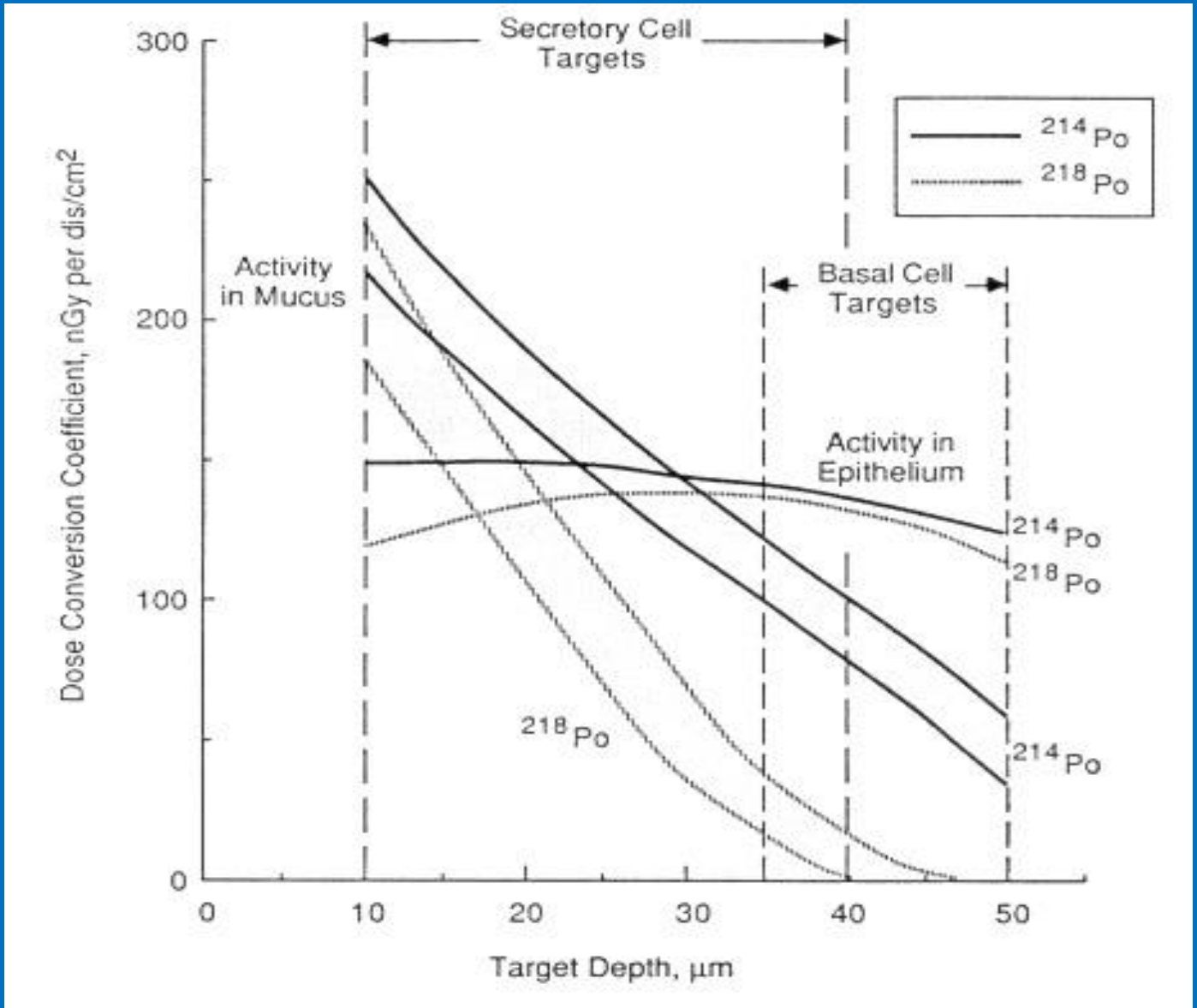
Ref: BEIR IV Report . U.S. National Research Council 1988.

Dose depth distribution in bronchial tissue



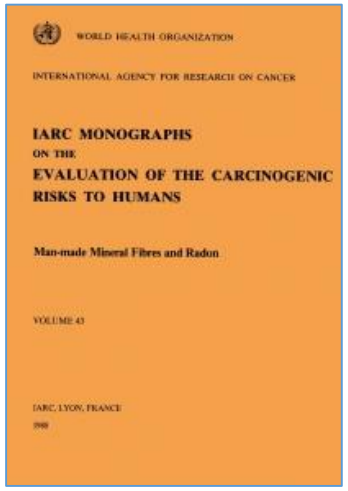
KEY DATES IN RADON HEALTH EFFECT STUDIES

1879 : **Identification of Lung Cancer in Miners**.
(Härtling, F.H. and Hesse,W. Vjschr. Gerichte.Med. 31, 102, (1879))

1932 : **Radon suggested as primary cause of the miner lung cancer**.
(Pirchan,A. and Sikl,H. Cancer of the lung in the miners of Jachymov. The Amer.J of Cancer. 16, 681-722 (1932)).

1956 :**Elevated radon found in houses.**
(Hultqvist, Bengt. Studies on Naturally Occurring ionizing Radiations, with special reference to radiation doses in Swedish houses of various types. Fjarde Serien. Band 6. Nr 3. (1956)).

1988 : Radon Classified as Group 1 human carcinogen by IARC .
(Man-made mineral fibres and radon. IARC Monographs on the Evaluation of Carcinogenic Risks to Humans, Vol 43 (1988)).


WORLD HEALTH ORGANIZATION

INTERNATIONAL AGENCY FOR RESEARCH ON CANCER

IARC MONOGRAPHS
ON THE
EVALUATION OF THE CARCINOGENIC RISKS TO HUMANS

Man-made Mineral Fibres and Radon

VOLUME 43

IARC, LYON, FRANCE
1988

Lung Cancer Risk in German Uranium Miners (Kreuzer et al BJC (2015))

Variable	
Miners, *n*	26 766
Follow-up period	1960–2008
Person-years	846 809
Vital status, *n* (%)	
Alive	22 357 (83.5)
Deceased	3820 (14.3)
Lost to follow-up	589 (2.2)
Duration of follow-up in years, mean (range)	32 (0.5–49)
Availability of cause of death, *n* (%)	3671 (96.1)
Lung cancer deaths, *n*	334
Age in years, mean (range)	
At death among deceased subjects	52 (17–99)
At 31 December 2008 for living subjects	54 (36–95)
Smoking status, *n* (%)	
Non-smoker	3533 (13.2)
Light	2831 (10.6)
Moderate/heavy	8702 (32.5)
Unknown	11 700 (43.7)
Cumulative exposure to, mean (range)	
Radon in WLM[a]	17 (>0–334)
External gamma radiation in mSv[a]	30 (>0–480)
Long-lived radionuclides in kBq h m^{-3}[a]	0.8 (>0–30)
Silica dust in mg m^{-3}-years[b]	0.8 (>0–16)
Individual average radon exposure rate in WL, mean (range)[a]	0.2 (>0–3.9)

Abbreviations: WL = working level; WLM = working level months.
[a]Mean (unweighted, on individual data set) among radiation exposed miners ($n = 22\,574$; 84%), the remaining employees are surface workers without radon exposure.
[b]Mean (unweighted, on individual data set) among silica dust-exposed miners ($n = 26\,766$).

WORKING LEVEL (WL) and WORKING LEVEL MONTH (WLM)

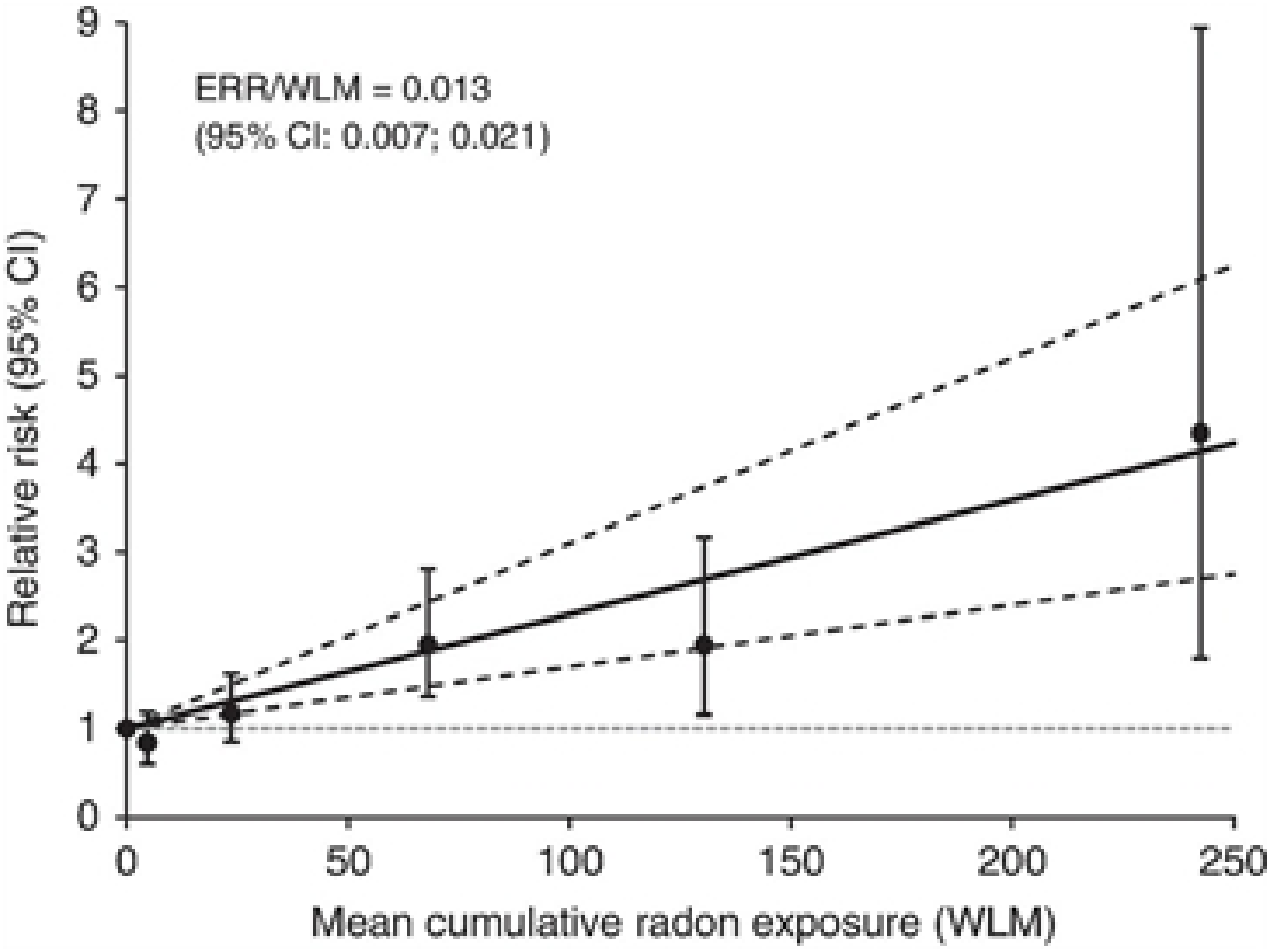
Working Level (WL) is an historical non-SI unit of concentration of radioactive decay products of radon, applied to mining environments . One Working Level refers to the concentration of short-lived decay products of radon in equilibrium with 3700 Bq/m^3 (100 pCi/l) in air. To complete decay these decay products would emit 1.3×10^5 MeV of energy.

Working Level Month (WLM) is a closely related quantity, referring to exposure to one Working Level for 170 hours per month.

NOTE : In most situations radon and its decay products are **not** in equilibrium and this must be taken into account in calculating WL or WLM based on radon gas measurements. For homes/offices etc where the concept of WLM is actually of no relevance we would generally use an Equilibrium Factor of 0.4 if we wished to calculate WL or WLM.

Example : A 1 year (7000 hr or 80% occupancy) exposure in a home to a radon concentration of 200 Bq/m^3 (F = 0.4) is equivalent to approx. 0.9 WLM

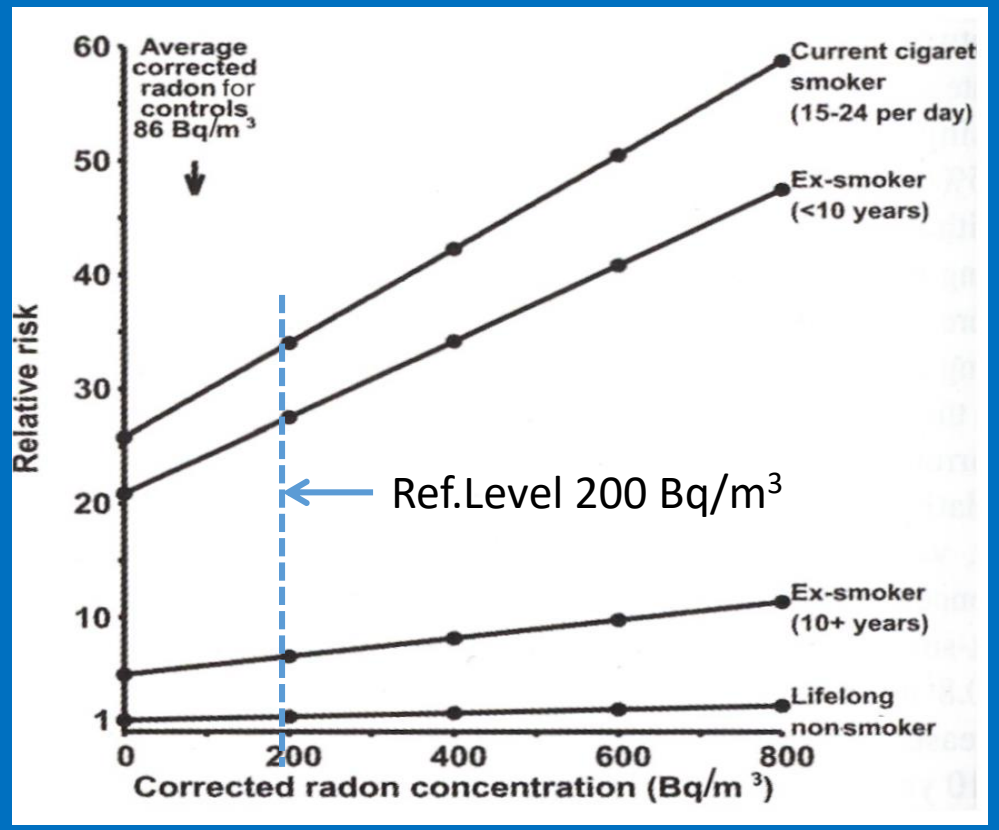
LUNG CANCER RISK IN GERMAN URANIUM MINERS*



*Kreuzer et al. Brit.J. of Cancer Vol 113 (2015)

Residential Radon Epidemiology

Pooling of 13 European residential case-control studies *



7148 Cases

14208 Controls

PRINCIPAL FINDING : Excess Relative Risk (ERR) = 0.16 (95% CI 0.05-0.31) per 100 Bq/m^3 with no evidence of a threshold or that the ERR varied with age,sex or smoking history.

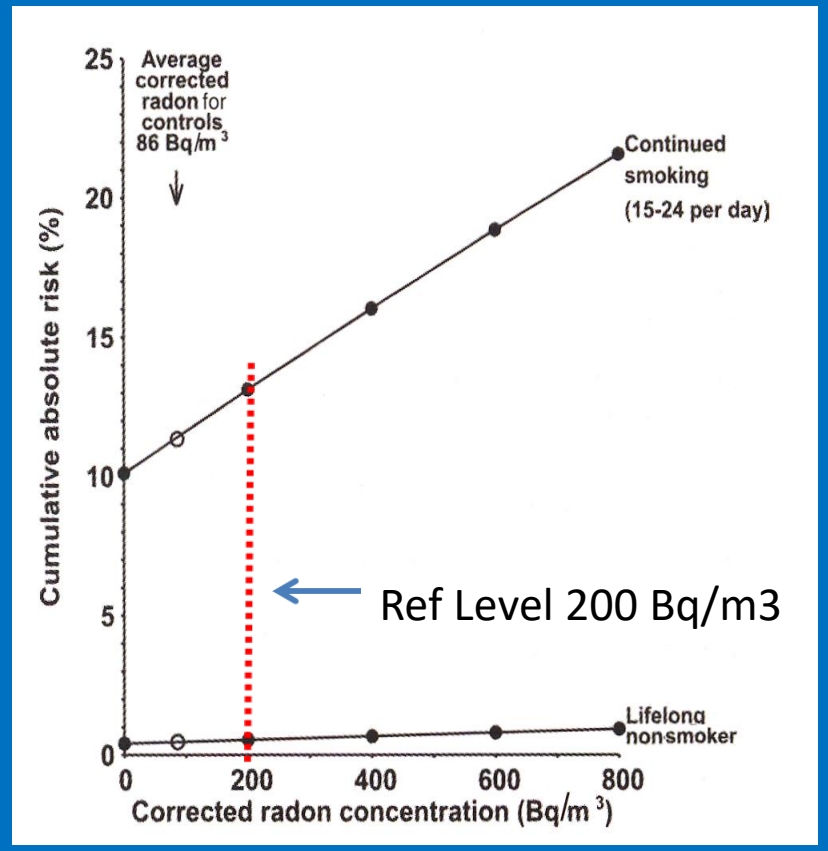
* Darby et al .Br. Med.J. 330,223-228 (2005)

and

Darby et al Scand.J. of Work,Envir.& Health. Vol 32. Suppl 1. (2006)

Cumulative absolute risk of death from lung cancer to age 75 years

Pooling of 13 European residential case-control studies*

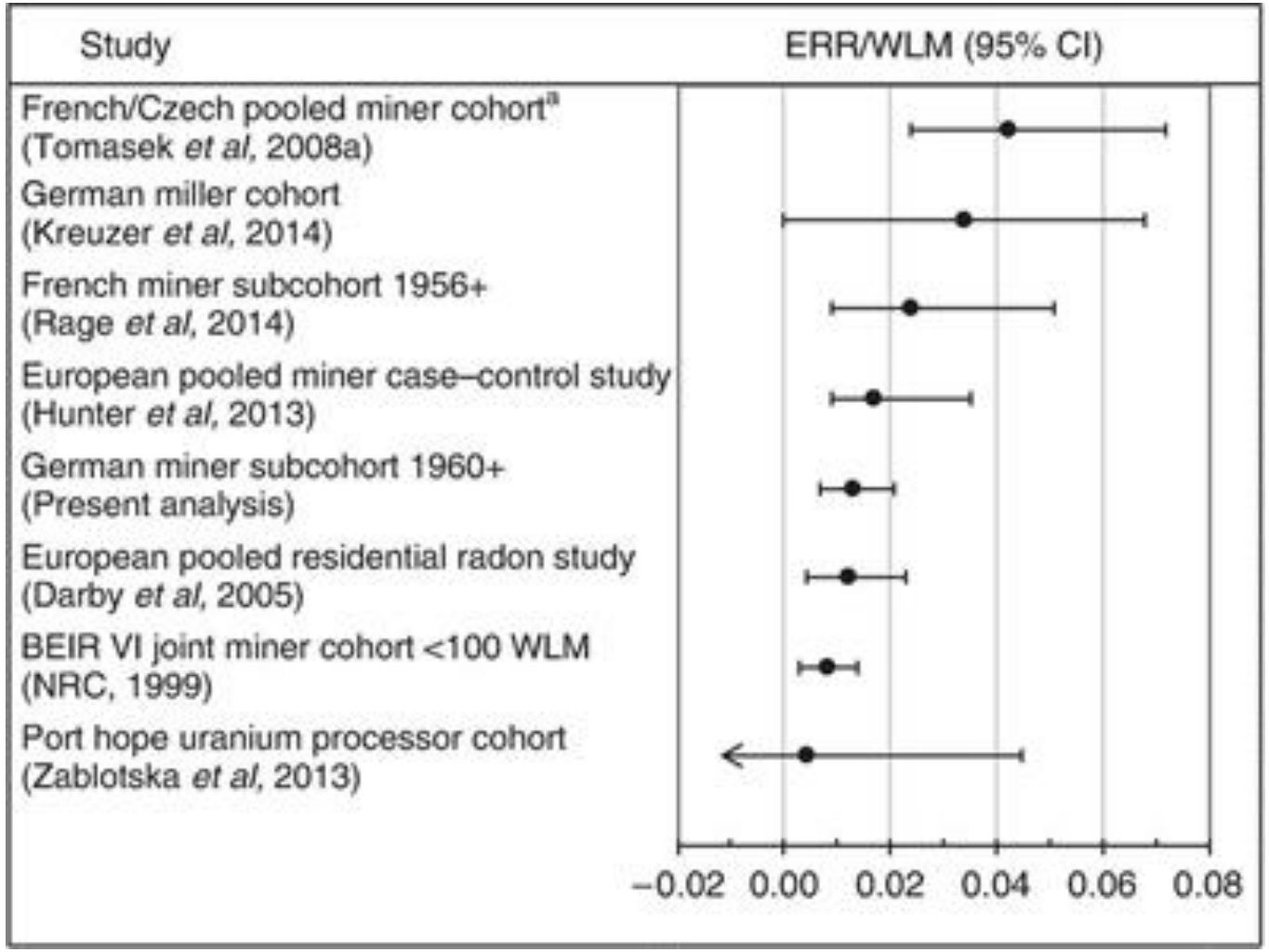


7148 Cases

14208Controls

* Darby et al Br. Med.J. 330,223-228 (2005) and
Darby et al Scand.J. of Work,Envir.& Health. Vol 32. Suppl 1. 2006

Lung Cancer Mortality Risks (Kreuzer et al BJC (2015))



* ERR :Excess Relative Risk

Risk of Radon Exposure-Induced Lung Cancer Death (REID)* due to annual radon exposure D from age *a* to age *t* years

$$REID = \int_a^t .[\mu_c(s,t|a,D) - \mu_c(s,t)]S(s,t|a,D)dt$$

Lung cancer mortality rate at age t

Baseline lung cancer mortality rate in the absence of radon exposure.

Probability of survival to age t from **all** causes

Where : $S(s,t|a,D) = \exp\left[- \int_a^t \mu(s,t)|a,D)\, dt \right]$

and

$\mu(s,t)|a,D) = \mu_c(s,t|a,D) + \sum \mu_l(s,t)$ is the mortality rate for **all** causes combined

* Ref : Hunter, N et al. J.Radiol Prot **35**, 539 (2015)

$$REID(s,a,D) = \int_a^t [\mu_c(s,t|a,D) - \mu_c(s,t)S(s,t|a,D)]\,dt$$

Where : $S(s,t|a,D) = \exp[-\int_a^t \mu(s,t)|a,D)\,dt]$

$\mu_c(s,t|a,D) = \mu_c(s,t)\,[1 + ERR(a,y,D]$

is the annual lung cancer mortality rate for gender s at age t due to annual radon exposure D from age a to age t and y = t-a

$\mu_c(s,t)$ is the corresponding baseline rate in the absence of radon exposure.

and $\mu(s,t) = \mu_c(s,t|a,D) + \sum_{l \neq c} \mu_l(s,t)$

(Ref : Hunter, N et al. J.Radiol Prot 35, 539 (2015)

INDOOR RADON AND THORON IN THE NETHERLANDS

RIVM Survey 2013-2014 *, **

2500 dwellings surveyed . Average Radon = 15.6 Bq/m^3 and Average Thoron Progeny = 0.64 Bq/m^3

There are also estimated to be circa 24000 dwellings in the Netherlands above 100 Bq/m^3. **

These are mainly in southern Limburg and in the Meuse-Rhine-Waal delta regions.

National Lung Cancer Incidence : circa 12000 cases per year

Estimated Radon/Thoron Attributable Lung Cancer Incidence *

400 cases per year (Uncertainty range 100 - 800)

(70% from Radon and 30 % from Thoron)

*RIVM Report 2015 0087, Smetsers RCGM, Blaauboer RO, Dekkers F, van der Schaaf M, Slaper H

**RIVM Report 2017- 0032. Smetsers RCGM

ICRP Radon Dose Coefficients (DCFs) 1993-2010 *

Coefficients	ICRP 60 (1991)	ICRP 65 (1993)	ICRP 103 (2007)	ICRP 115 (2010)
Total Detriment	5.6 x10^{-2} Sv (Workers) 7.3 x 10^{-2} Sv^{-1} (Public)		4.2x10^{-2} Sv^{-1} (Workers) 5.7 x 10^{-2} Sv^{-1}(Public)	
Lung Cancer Risk		2.83 x10^{-4}/WLM (Miners)		5 x 10^{-4} /WLM (Miners)
Dose Coefficient		5 mSv /WLM (Workers) 4 mSv/WLM (Public)		12 mSv/WLM (Workers) 9 mSv/WLM (Public)

NOTE : The approach used by ICRP here essentially compares the detriment per Sv evaluated for Japanese bomb survivors following acute low LET radiation external exposures with the detriment (lung cancer mortality)per WLM in male adult miner cohorts due to chronic internal exposures to high LET radiation (alpha particles). This raises a number of questions regarding the applicability of these DCFs to radiation protection for residential radon exposures .

ICRP RADON DOSE COEFFICIENTS (DCFs) AND THEIR IMPLICATIONS FOR RADIATION PROTECTION

- Over past decades ICRP in deriving these DCFs has used two approaches. These are the so-called epidemiological approach and the dosimetric approach.

- Using the epidemiological approach the DCFs recommended by the ICRP have approximately doubled between 1993 and 2010 (see previous slide) but for a given radon exposure scenario the actual (but unknown) lifetime excess absolute risk (LEAR) of lung cancer for an exposed individual has not changed.

- It is now recommended that radon DCFs in the future should be derived using reference biokinetic and dosimetic models.

- As dose pie charts or tables are commonly used risk communication tools changes in the DCFs have implications for risk communication not only for radon exposure but also for artificial exposures and in particular for medical exposures.

- For protection of the public against indoor radon (as distinct from individuals defined to be occupationally exposed to radon) perhaps it would be more appropriate and logical to avoid the use of DCFs and simply set radon reference levels based on radon exposure risks derived from the results of residential radon epidemiological studies.