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Natural Background Radiation: Health Effects

Radiation Epidemiology & Dosimetry Course

National Cancer Institute www.dceg.cancer.gov/RadEpiCourse

Natural Background Radiation – Health Effects

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Exposed Populations

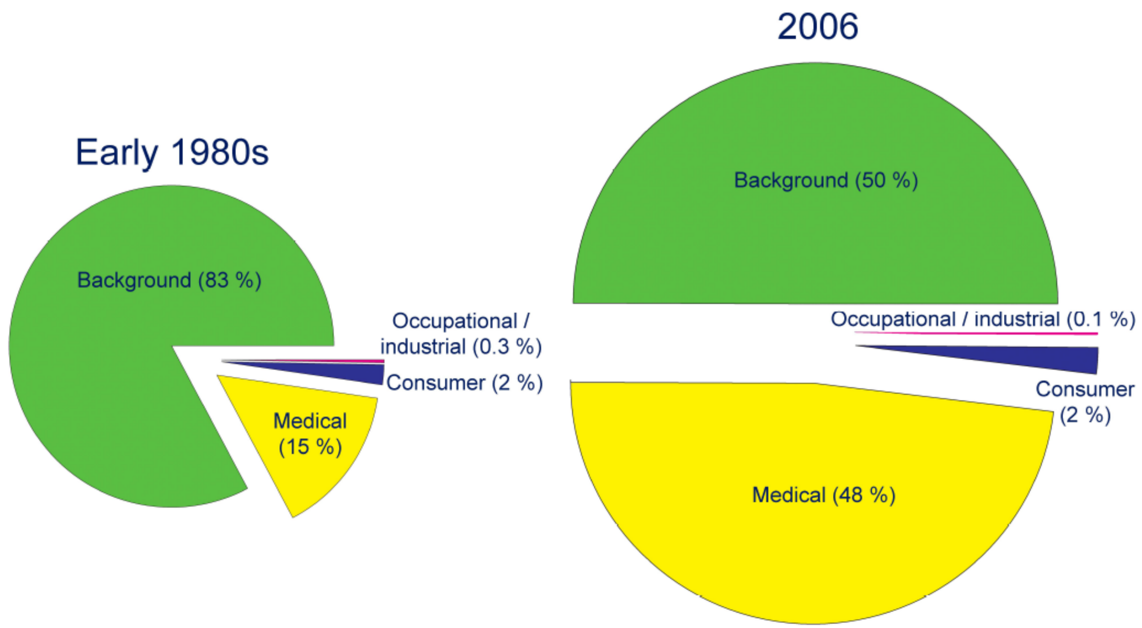
- Japanese atomic-bomb survivors
- Medically exposed groups
- Occupationally exposed groups
- Environmentally exposed groups

Environmentally Exposed Groups

- High natural background
  - external gamma
  - radon
- Weapons testing fallout
  - Utah, Marshall Islands, Nordic countries, USSR
- Contamination
  - Chernobyl, USSR, Hanford, Taiwanese steel, Fukushima

Medical Exposures in the USA

NCRP Report No. 160, *Ionizing Radiation Exposure of the Population of the United States*

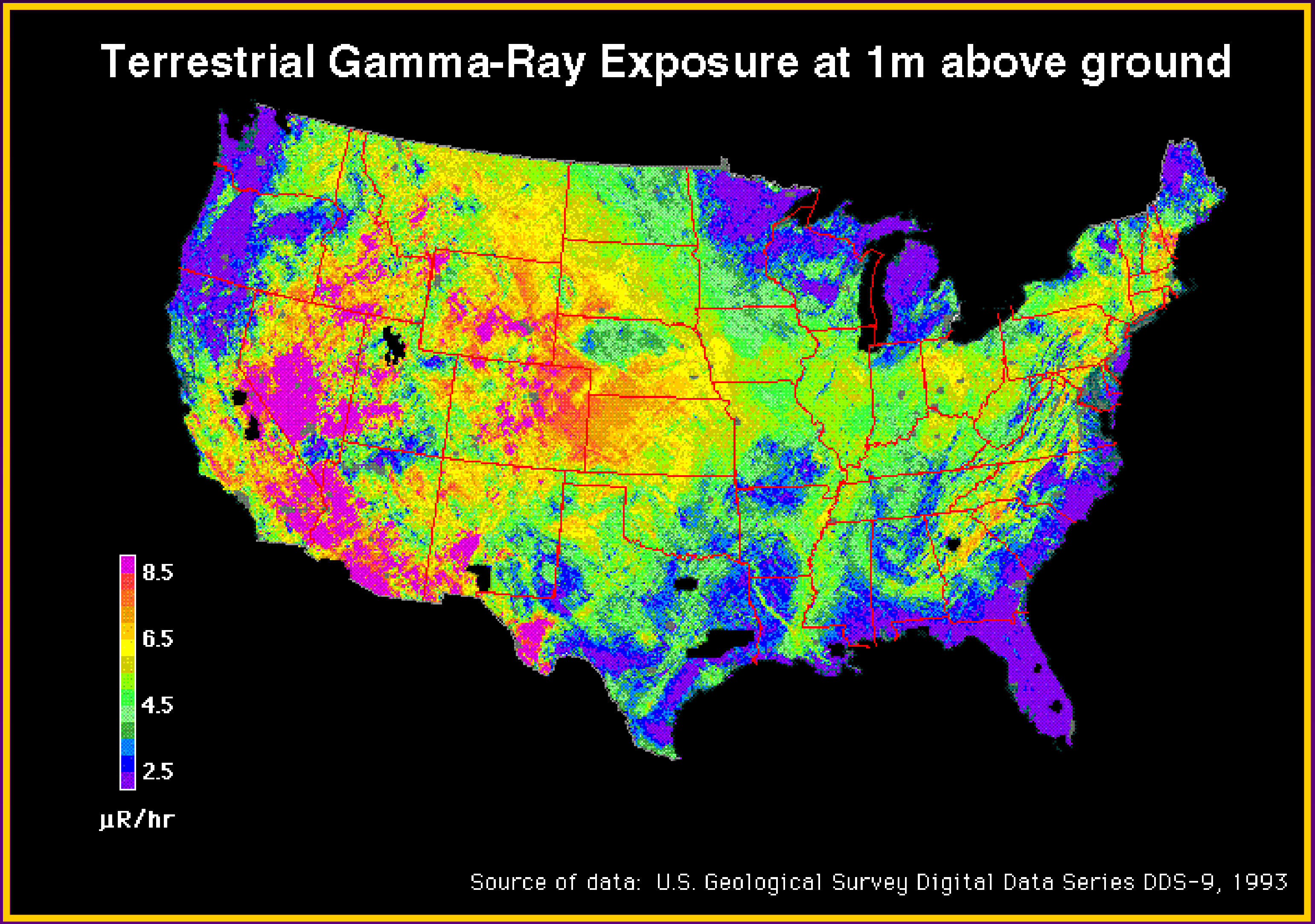


	Early 1980s	2006
Collective effective dose (person-Sv)	835,000	1,870,000
Effective dose per individual in the U.S. population (mSv)	3.6	6.2

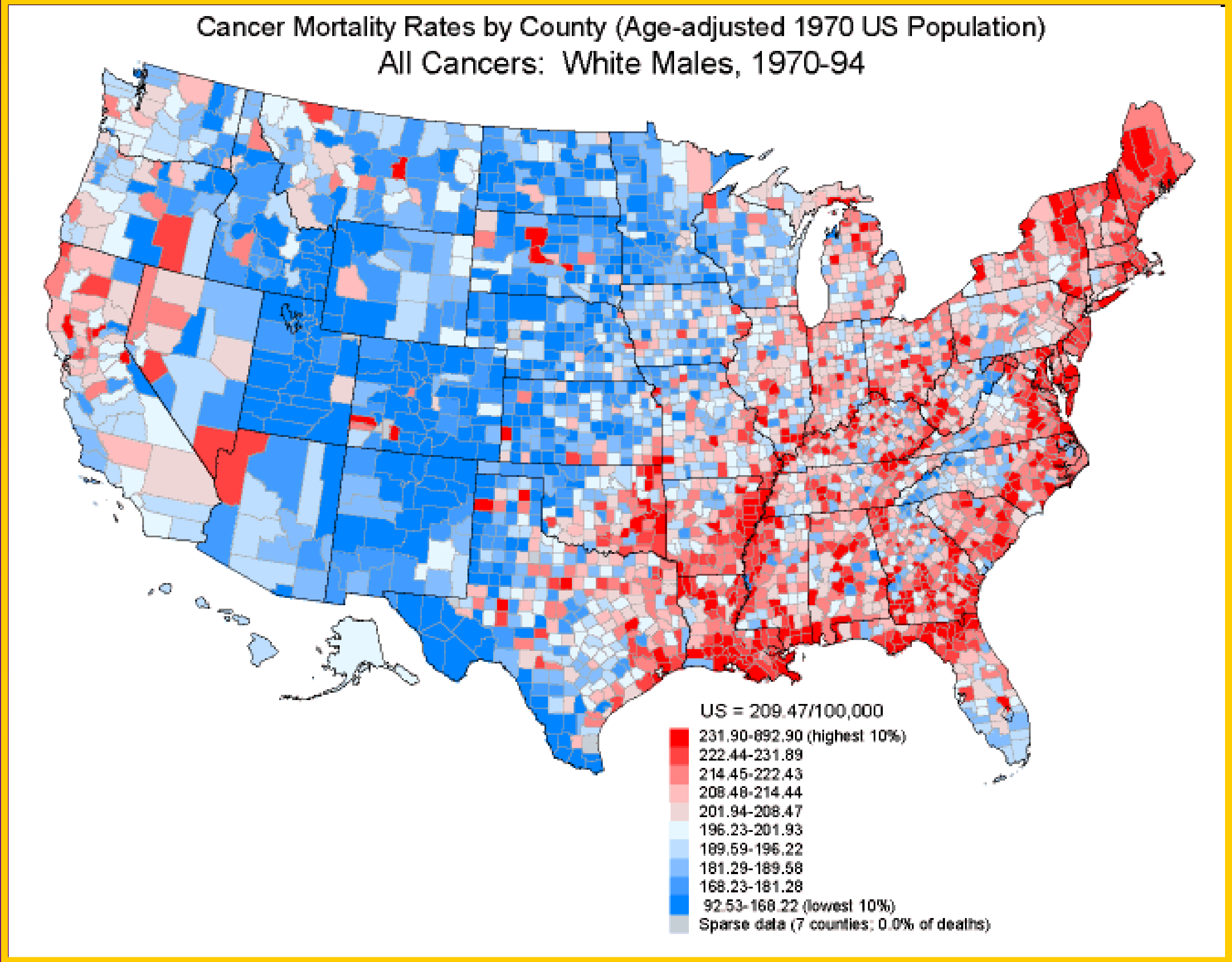
Naturally Occurring Sources of Radiation

- Cosmic radiation from the Sun and beyond
  - direct external exposure ("cosmic rays")
  - intakes of radionuclides (^{3}H, ^{14}C) produced in the upper atmosphere
- Terrestrial radiation from long-lived radionuclides and their decay products
  - direct external exposure
  - intakes of radionuclides (^{222}Rn/^{220}Rn in air; ^{238}U, ^{232}Th, ^{226}Ra, ^{210}Po, ^{210}Pb, ^{40}K in food and drink)

γ-ray Exposure in USA



Cancer Mortality in USA



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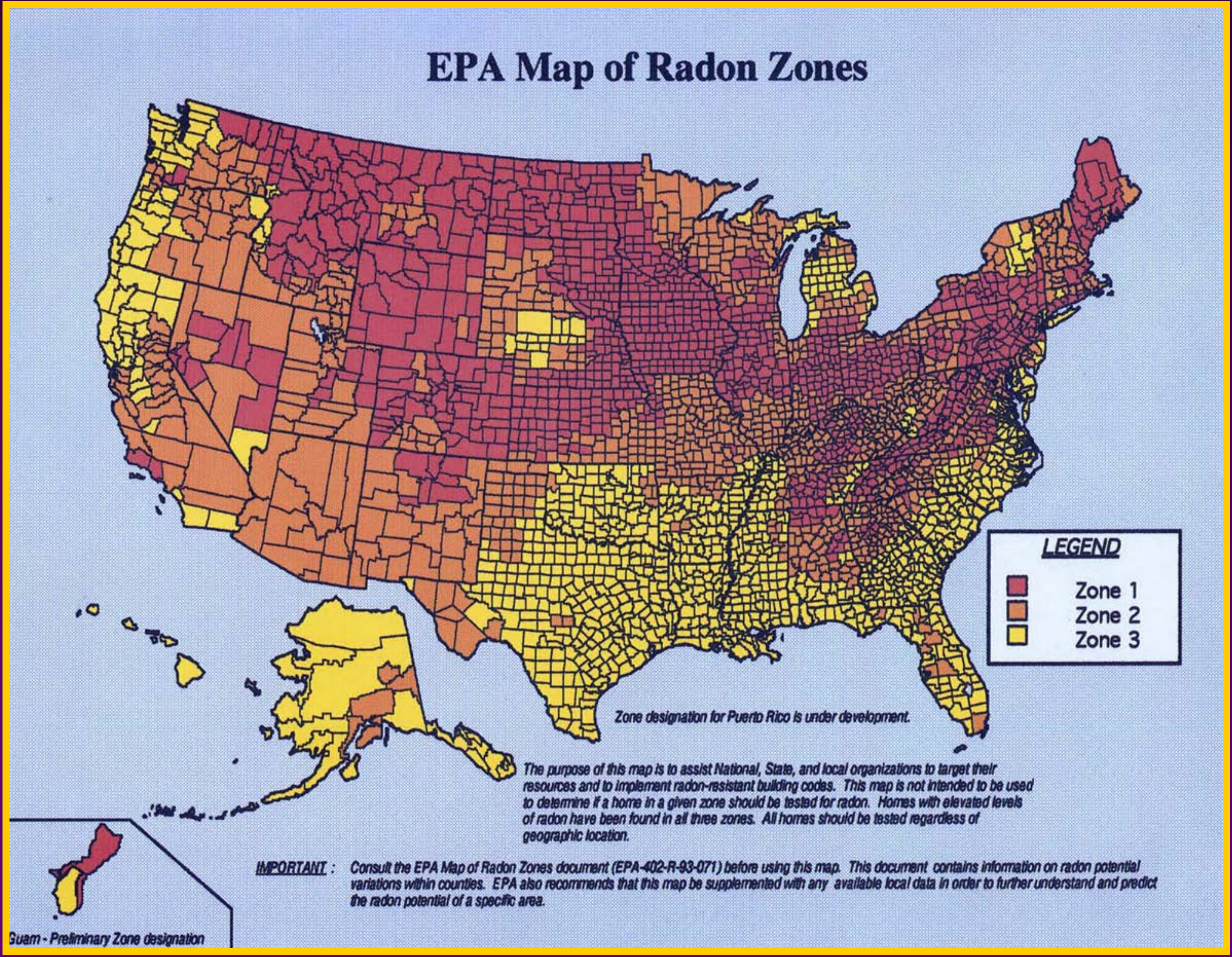
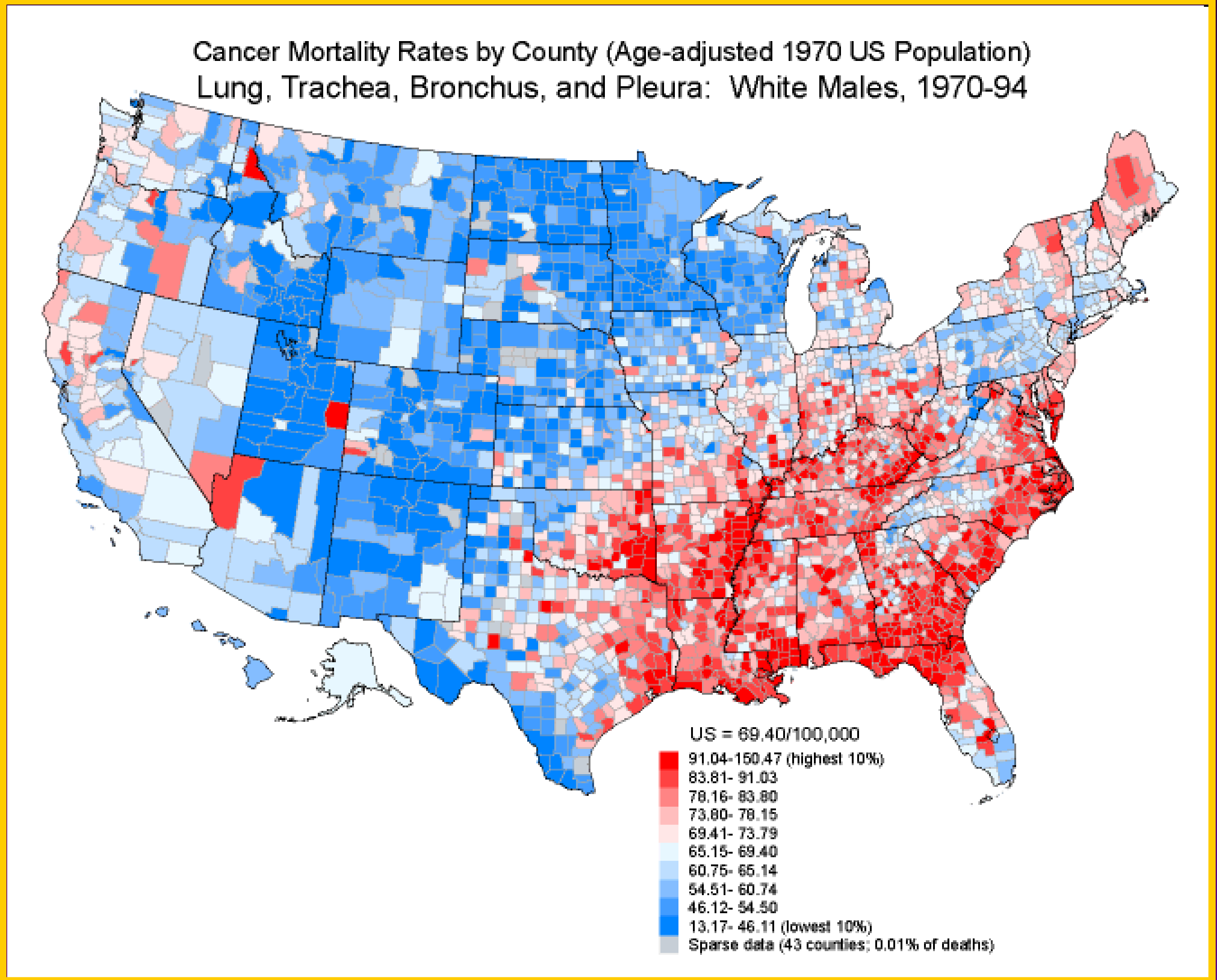
Radon Exposure in USA

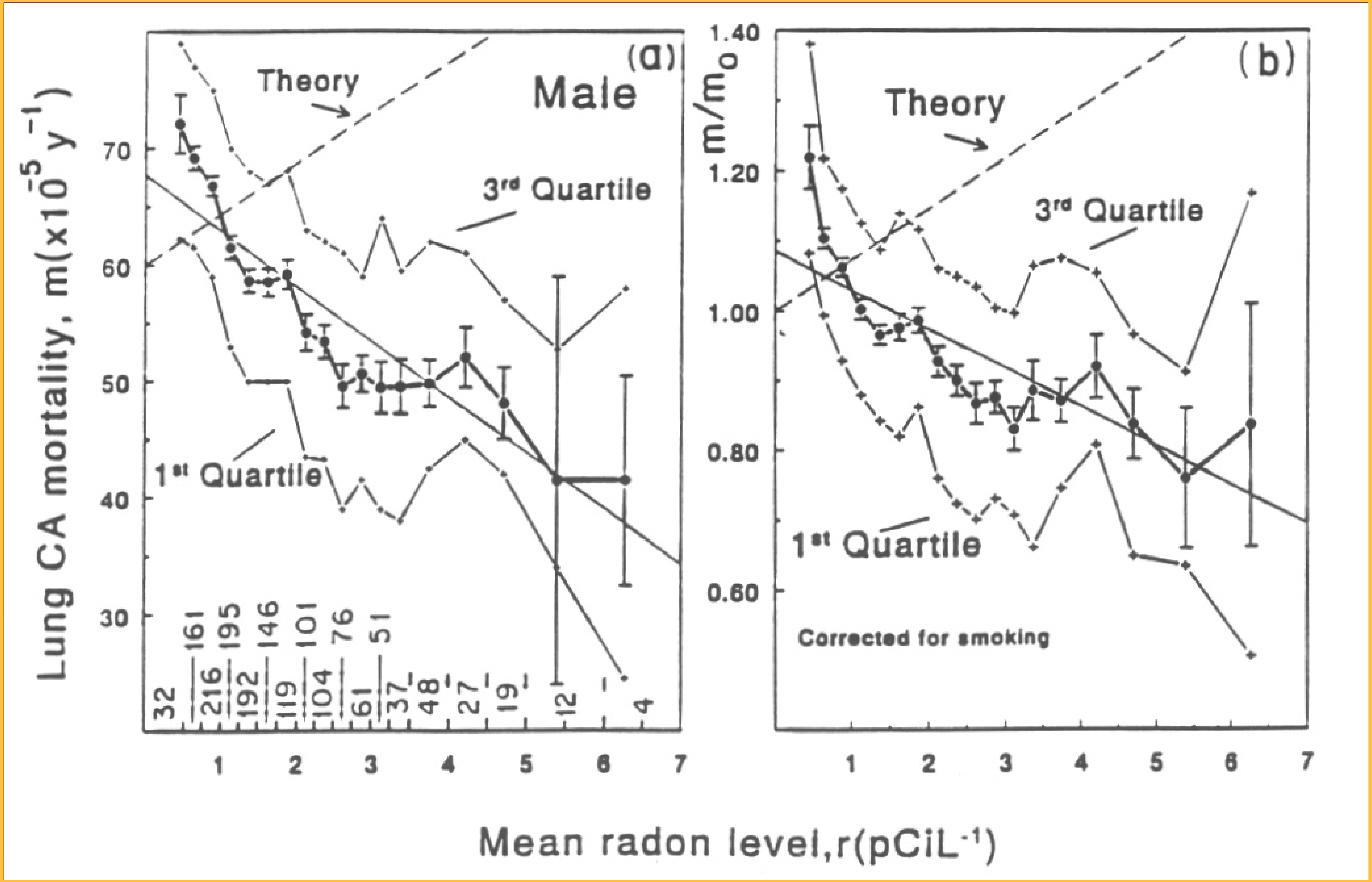


Lung Cancer Mortality in USA



Radon and Lung Cancer
(geographical correlation study, US counties)

(Cohen, *Health Phys* 1995; **68**: 157-74)

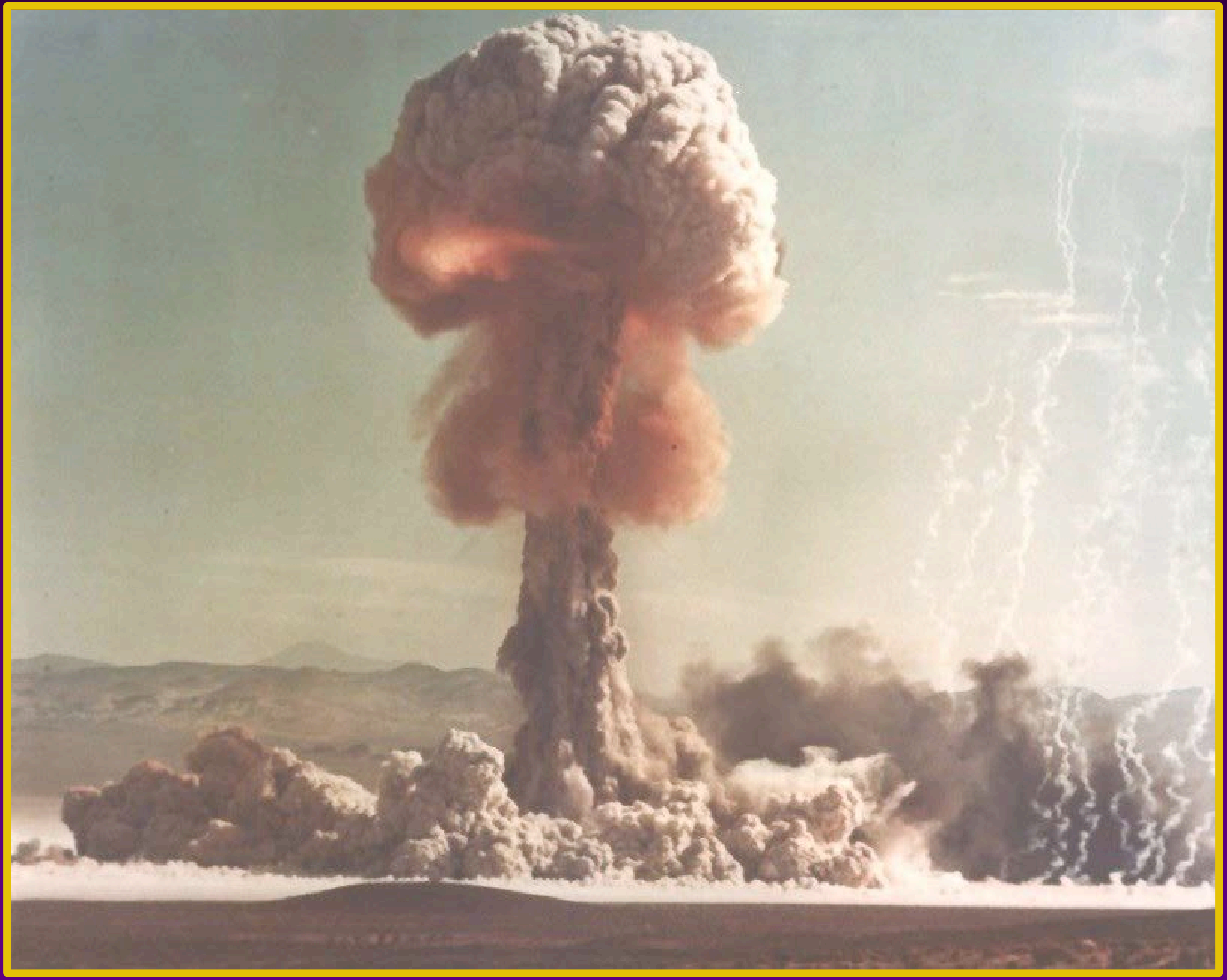


Study of Puskin

(JS Puskin, *Health Physics* 2003; **84**: 526-32)

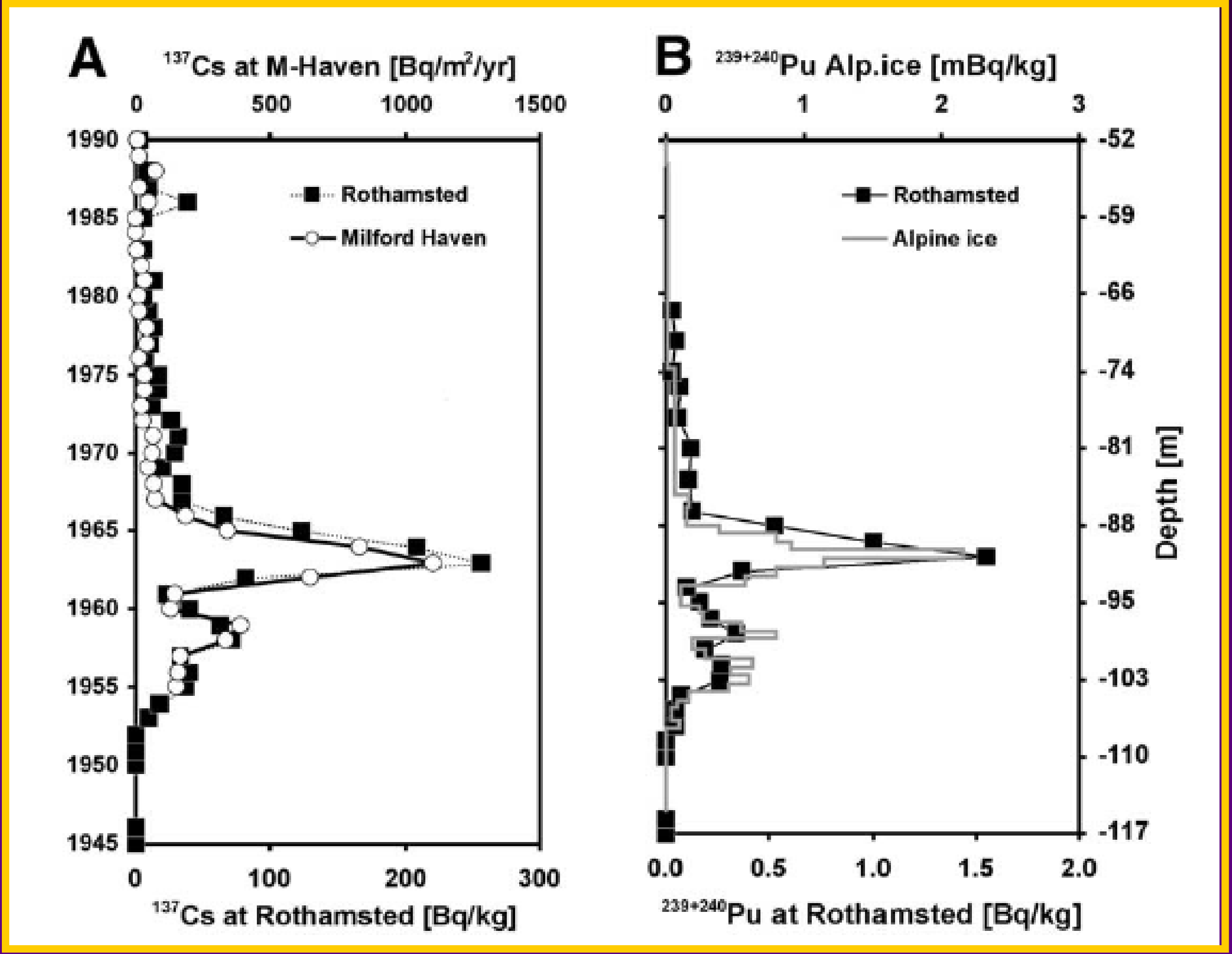
- Puskin applied the analysis structure of Cohen to cancers other than lung cancer.
- Found the same pattern as lung cancer for other *smoking-related* cancers, but not for cancers *unrelated to smoking*.
- These other smoking-related cancers are not found to be related to radon exposure in underground hard-rock miner studies.

Nuclear Weapons Testing

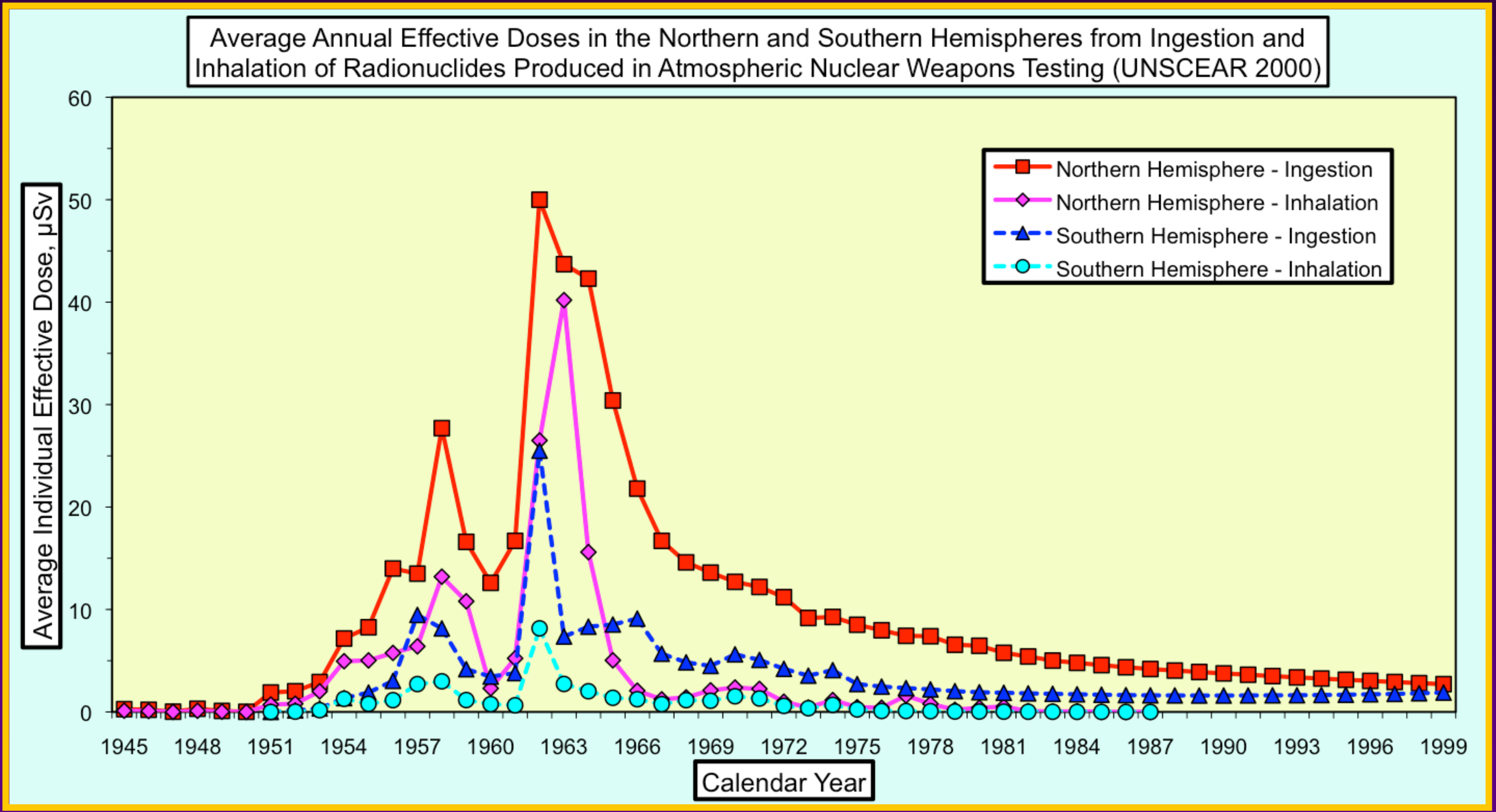


Cs-137 and Pu in Fallout

(Warneke *et al.*, *Earth Planet Sci Lett* 2002; **203**: 1047-57)

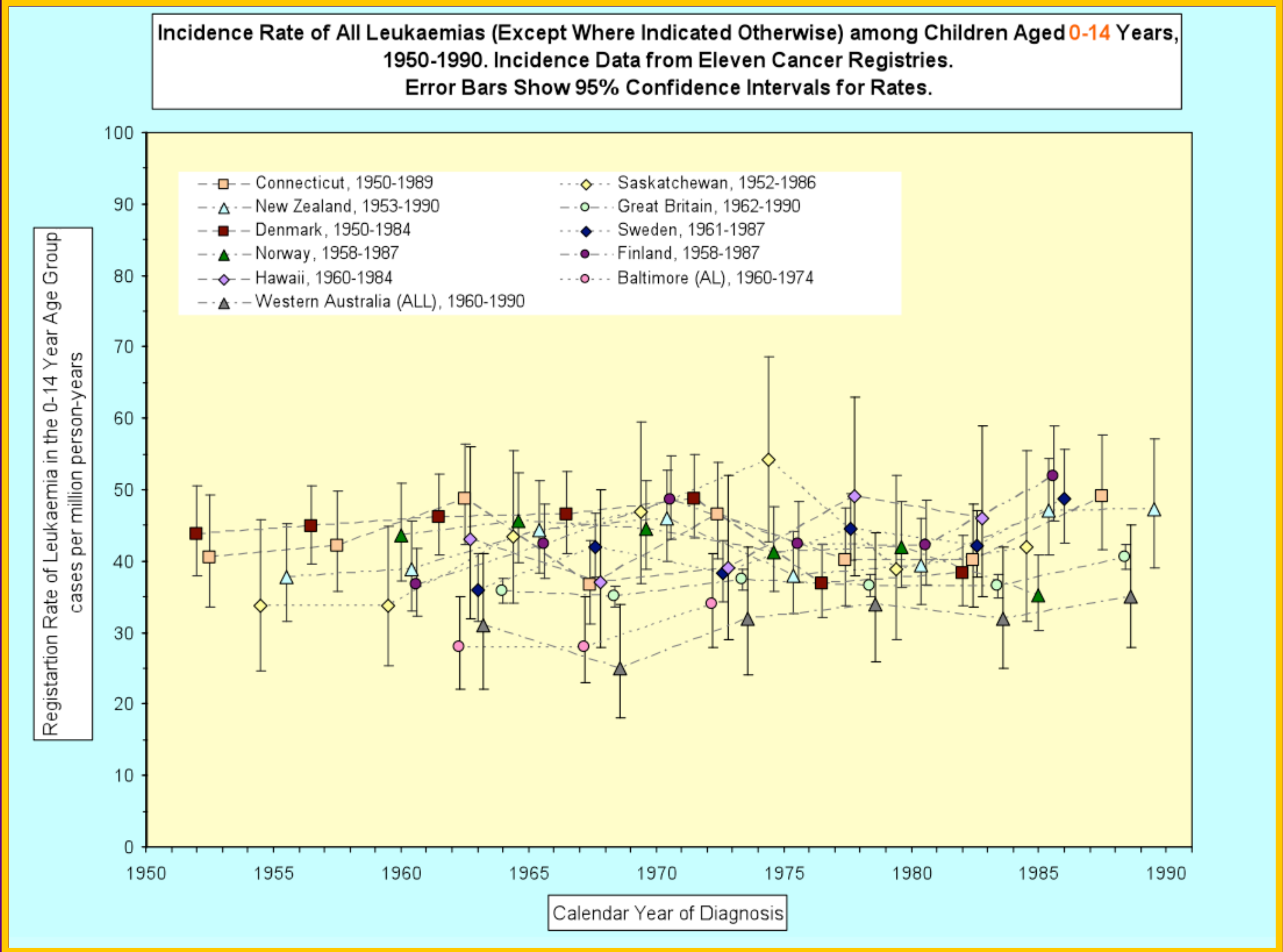


Weapons Testing Fallout



Childhood Leukaemia Incidence

(Wakeford *et al.*, *Radiat Environ Biophys* 2010; **49**: 213-27)



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Underground Hard-rock Miners

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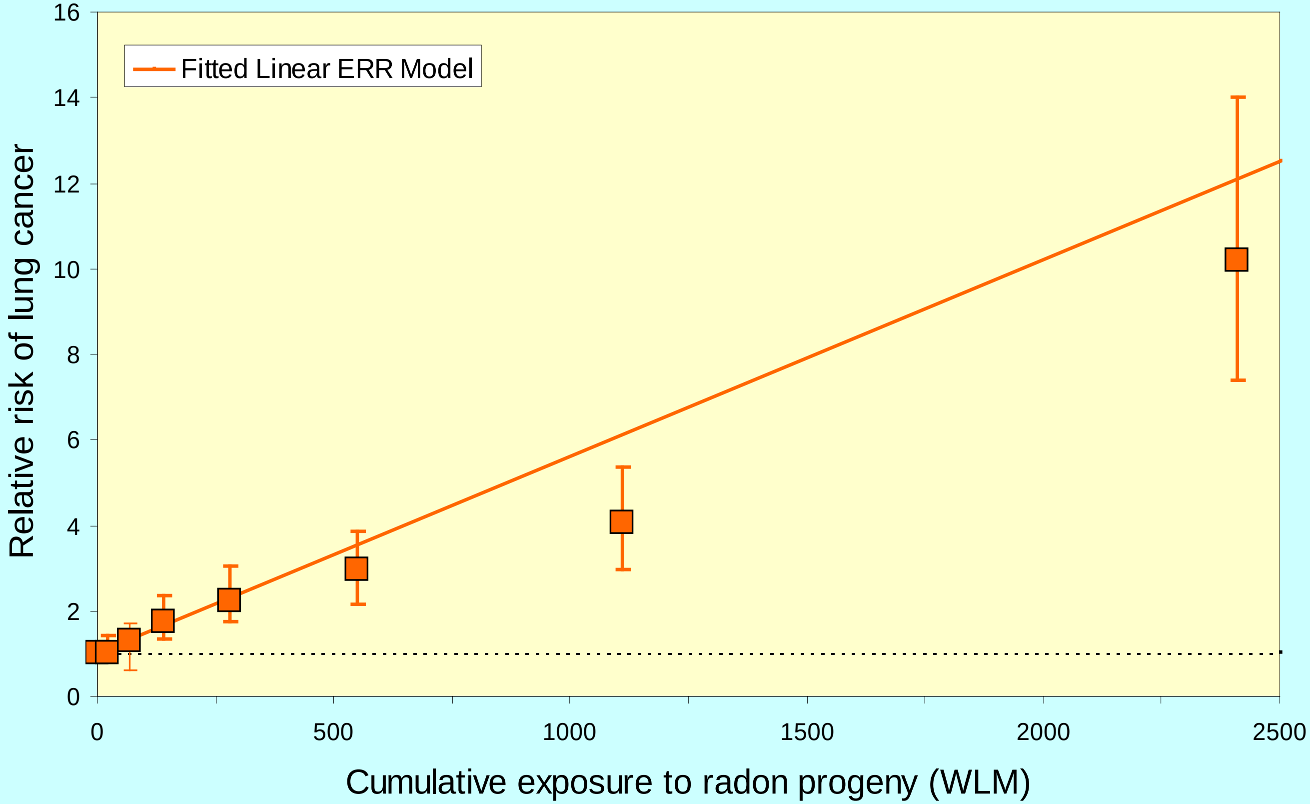
Underground Hard-rock Miners

- Underground hard-rock miners (e.g. uranium, iron, gold, tin miners) inhale radon (mainly ^{222}Rn) and its radioactive decay products.
- In the past, exposures have been high.
- A clear radon-related excess of lung cancer has been demonstrated in many groups of miners, but little evidence for an excess risk of other cancers associated with exposure.

Radon and Lung Cancer

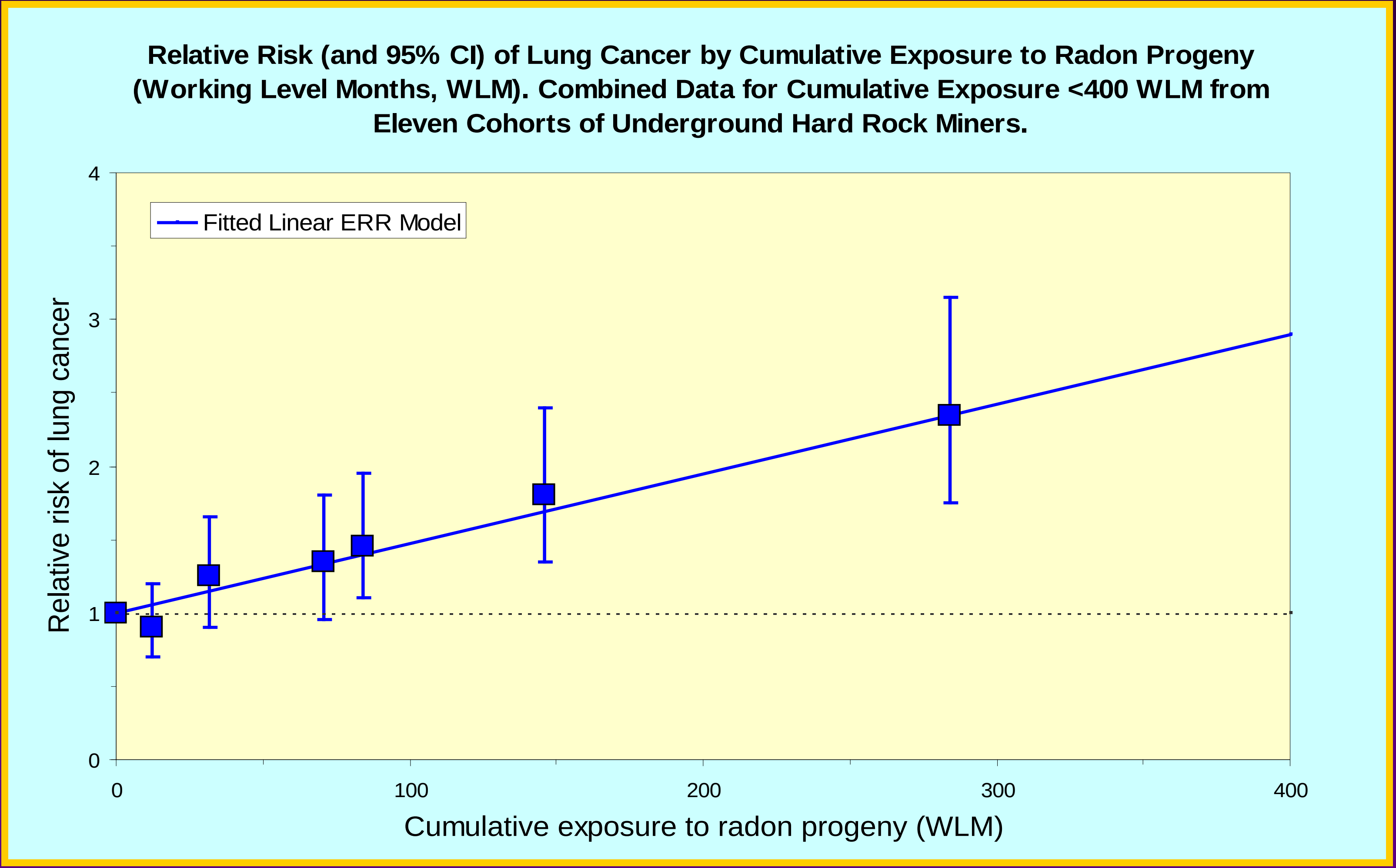
(Lubin *et al.*, *J Natl Cancer Inst* 1995; **87**: 817-27)

Relative Risk (and 95% CI) of Lung Cancer by Cumulative Exposure to Radon Progeny (Working Level Months, WLM). Combined Data from Eleven Cohorts of Underground Hard Rock Miners.



Radon and Lung Cancer

(Lubin *et al.*, *J Natl Cancer Inst* 1995; **87**: 817-27)



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Residential Radon

- Case-control (i.e. individual- rather than group-based) studies of residential radon exposure and lung cancer take account of both radon exposure and smoking histories.
- Appropriately pooled data from case-control studies in Europe, North America and China find associations between domestic exposure to radon and lung cancer.

Residential Radon

(Krewski *et al.*, *Epidemiol* 2005; **16**: 137-45)

- Pooled data from 7 North American case-control studies gives an odds ratio for lung cancer risk with radon concentration of

  1.11 (95% CI: 1.00, 1.28) at 100 Bq/m^3

- When data were restricted to radon measurements for those residing in just one or two houses the odds ratio becomes

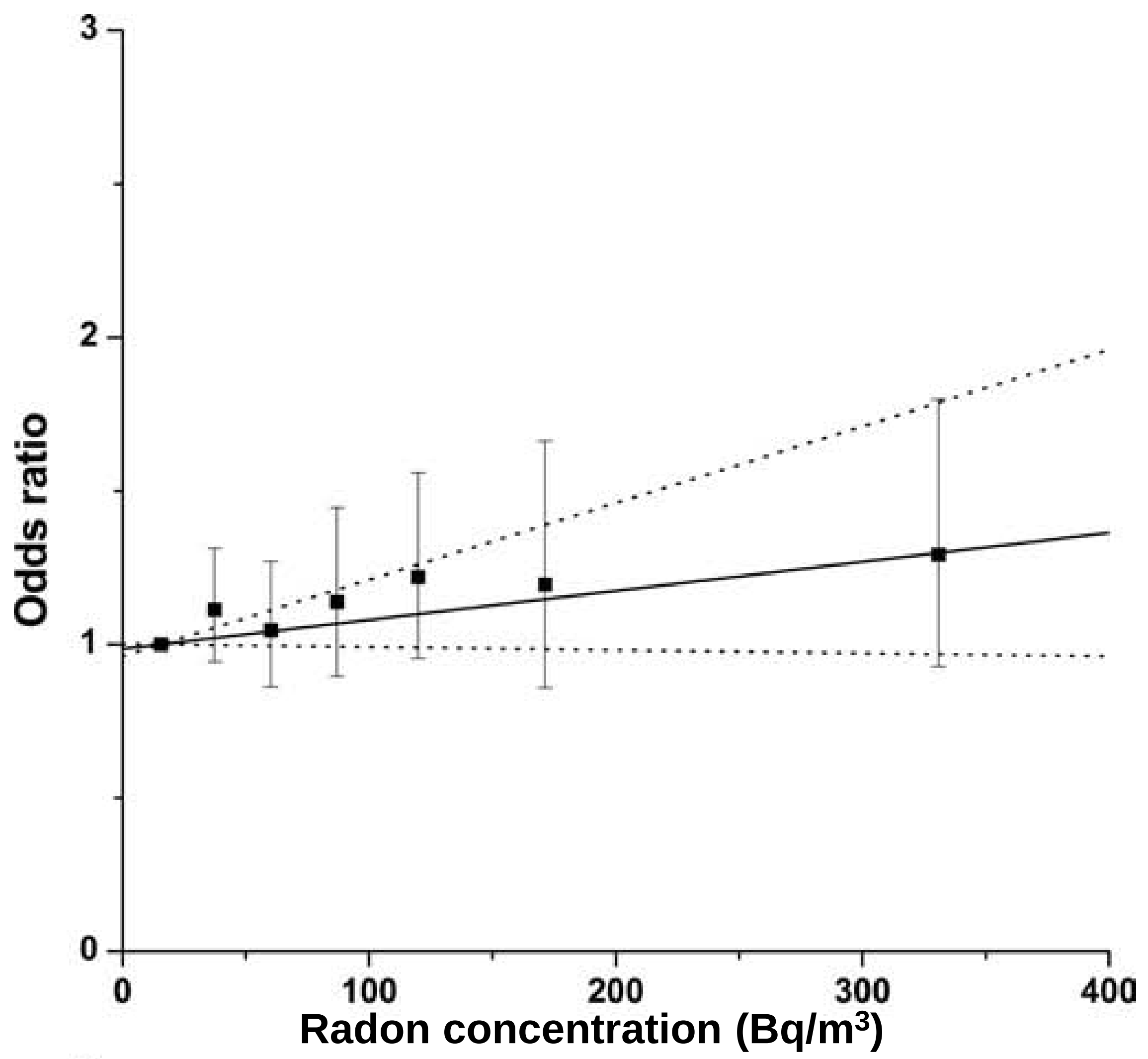
  1.15 (95% CI: 1.01, 1.37) at 100 Bq/m^3

- Miner studies predict

  1.12 (95% CI: 1.02, 1.25) at 100 Bq/m^3

Residential Radon

(Krewski *et al.*, *Epidemiol* 2005; **16**: 137-45)



Residential Radon

(Darby *et al.*, *BMJ* 2005; **330**: 223-8)

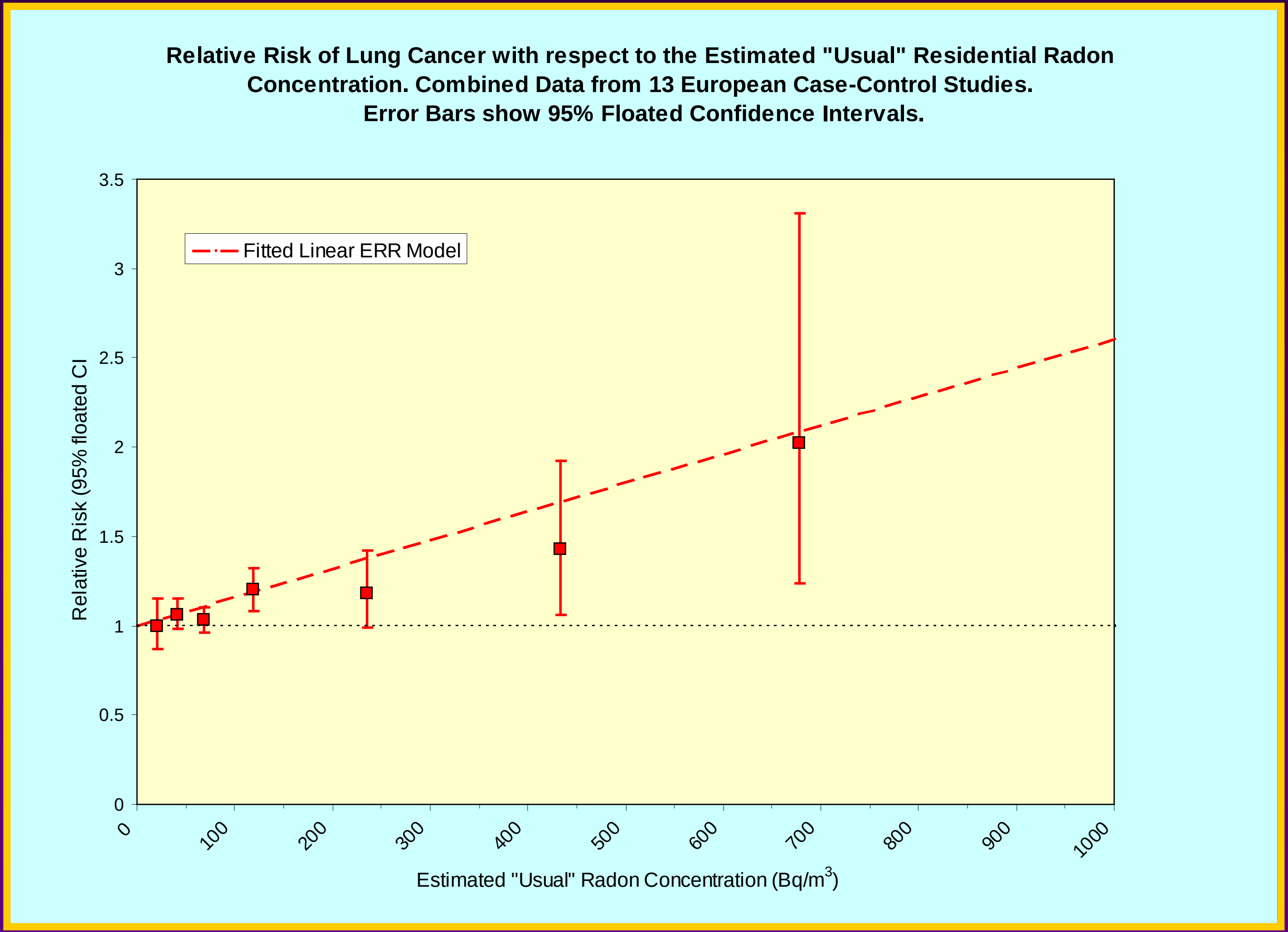
- Pooled data from 13 European case-control studies gives an odds ratio for lung cancer risk with radon concentration of

  1.08 (95% CI: 1.03, 1.16) per 100 Bq/m^3
- When corrected for random uncertainties in radon measurements this becomes

  1.16 (95% CI: 1.05, 1.31) per 100 Bq/m^3

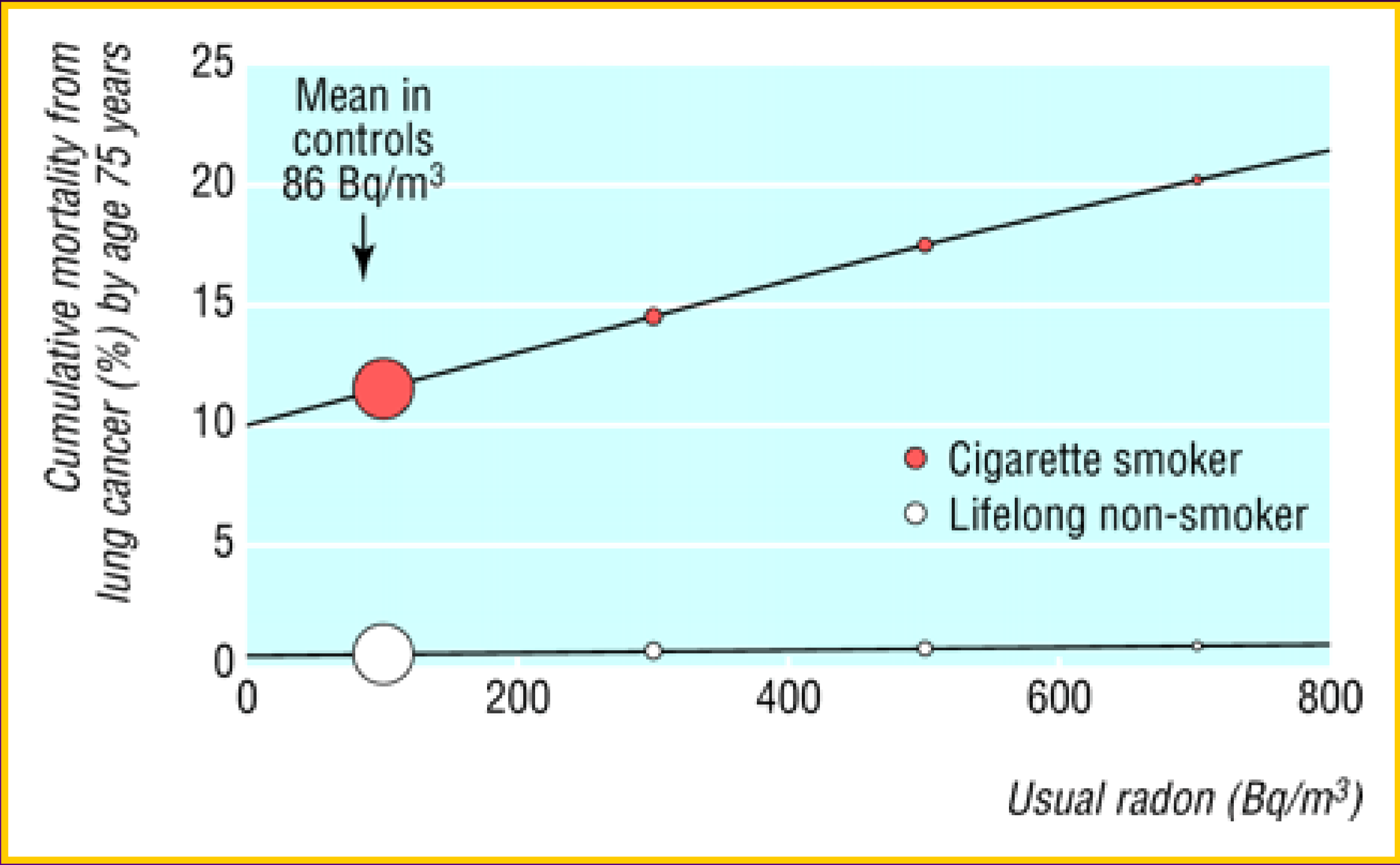
Residential Radon

(Darby *et al.*, *BMJ* 2005; **330**: 223-8)



Residential Radon

(Darby *et al.*, *BMJ* 2005; **330**: 223-8)



Radon and Childhood Leukaemia

- Several studies have examined the potential link between exposure to naturally-occurring inhaled radon and childhood leukaemia.
- Nationwide Danish case-control study of childhood cancer (1968-94) conducted by Raaschou-Nielsen *et al.* (2008)

(*Epidemiol* 2008; **19**: 536-43)

- This study used model-predicted radon concentrations, which avoids participation bias, but introduces exposure uncertainty.

Danish Radon Study

(Raaschou-Nielsen *et al.*, *Epidemiol* 2008; **19**: 536-543)

- Found a statistically significant association between radon exposure and childhood ALL, and inferred that 9% of cases in Denmark could be attributable to radon.
- However, <u>statistical power</u> is *low* (860 ALL cases), and the lower 95% CL for the attributable proportion is 1%, which is compatible with conventional models.
- Accuracy of model-predictions of radon concentrations needs further investigation.

Swiss Radon Study

(Hauri *et al.*, *Environ Health Perspect* 2013; **121**: 1239-44)

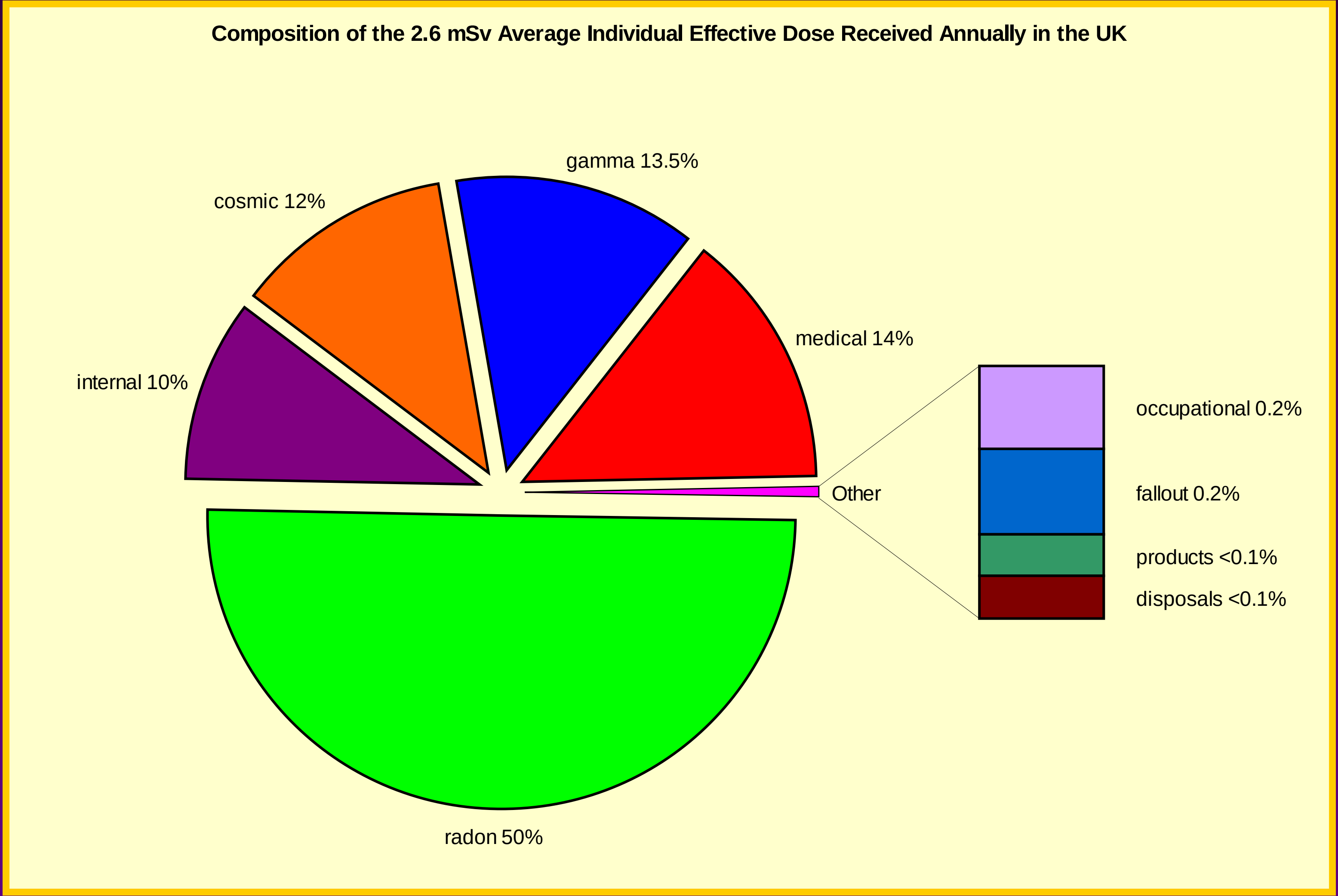
- Cohort of ~1.3 million children living in Switzerland at 2000 census.
- 997 cases of childhood cancer (283 leukaemia) during 2000-08 linked to cohort.
- Radon concentrations calculated from model based on >40,000 measurements.
- Adjustment for various potential confounders.
- No associations reported.

Norwegian Radon Study

(Del Risco Kollerud *et al.*, *Br J Cancer* 2014; 111: 1413-20)

- Cohort study of >700,000 children born in southern Norway during 1967-2009.
- 437 cases of childhood leukaemia and 427 brain/CNS tumours identified.
- Lifetime radon concentrations based on nearby measurements from database.
- No association for leukaemia, but marginally significant for brain/CNS cancer.

Radiation Doses in the UK
(in the early-2000s)



Intakes of Radionuclides

- Naturally occurring radionuclides (e.g. ^{40}K, ^{3}H, ^{14}C, ^{238}U, ^{226}Ra, ^{222}Rn, ^{210}Po, ^{232}Th, ^{220}Rn) are to be found in food and drink.
- Studies have been conducted of the potential influence of these on health.
- Accurate exposure information is difficult to establish, but opportunities have arisen, e.g. local wells supplying drinking water.

Intakes of Radionuclides

(reviewed by Guseva Canu *et al.*, *Environ Health Perspect* 2011; **119**: 1676-80)

- Ontario bone cancer case-control studies find some (weak) suggestion of association with radium in drinking water. No associations found in Wisconsin.
- Case-cohort study in Finland found no associations between radioactivity in drinking water and cases of stomach cancer, urinary cancer and leukaemia, but small numbers of cases.

Average Annual Radiation Dose

- The average annual **effective dose** received by an individual living in the UK is 2.6 mSv, 2.2 mSv of which is from natural sources. (These are early 2000s values – medical exposure will have increased).
- Around the world and within countries there are large variations in radiation doses from natural background radiation, largely from radon variations, but also from γ-radiation from naturally-occurring sources in the environment.

High Natural Background Radiation Areas (HNBR areas)

- Guarapari, Brazil; Kerala, India; Ramsar, Iran; Yangjiang, China, are all recognised HNBR areas that have been investigated to varying extents.
- Kerala and Yangjiang have been paid particular attention.

Ramsar, Northern Iran

Yangjiang, Guangdong, China

Yangjiang, Guangdong, China

Radiation Exposure in Yangjiang

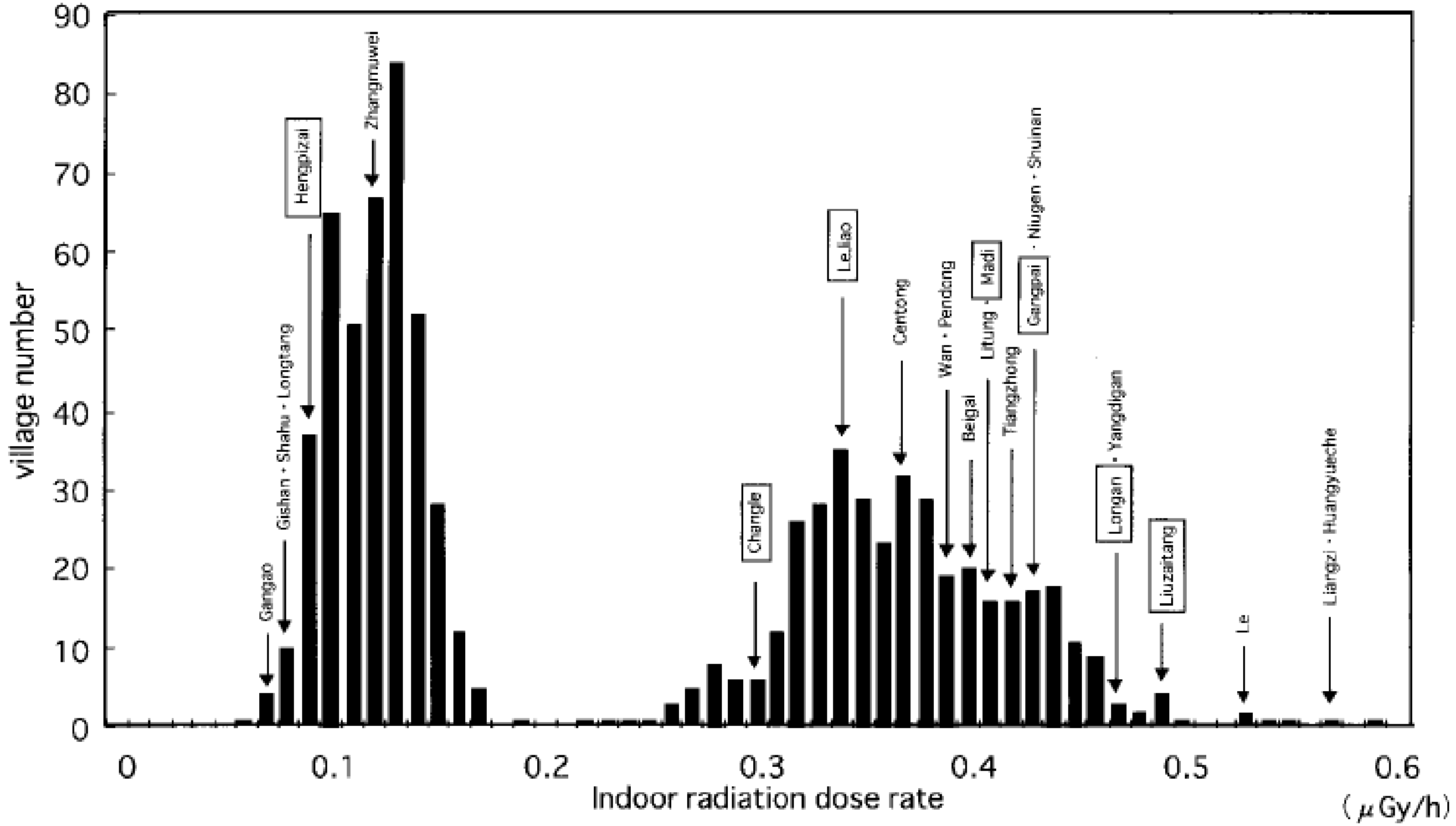


Fig. 2. Frequency distribution of indoor radiation dose rates in China.

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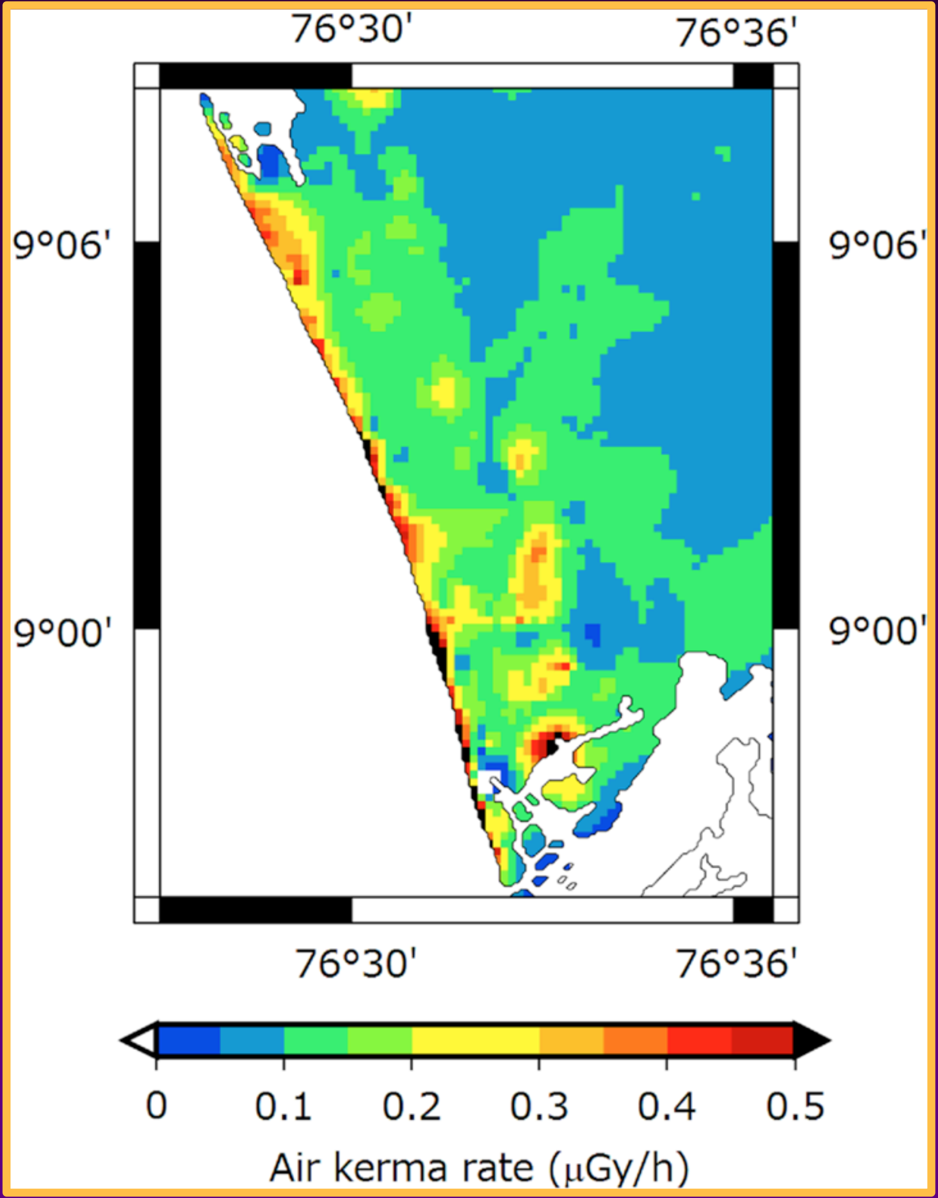
Yangjiang HNBR Area, China

- Tao *et al.* (*Health Phys* 2012; **102**: 173-81) examined mortality in 31 604 residents aged 30-74 years during 1979-1998.
- Cumulative gamma-ray doses by village.
- 6005 deaths (956 cancers) studied.
- No significant correlations, except a *negative* correlation between liver cancer mortality and cumulative dose.

Kerala, Southern India

Karunagappally Taluk



Fisherman in Kerala, India

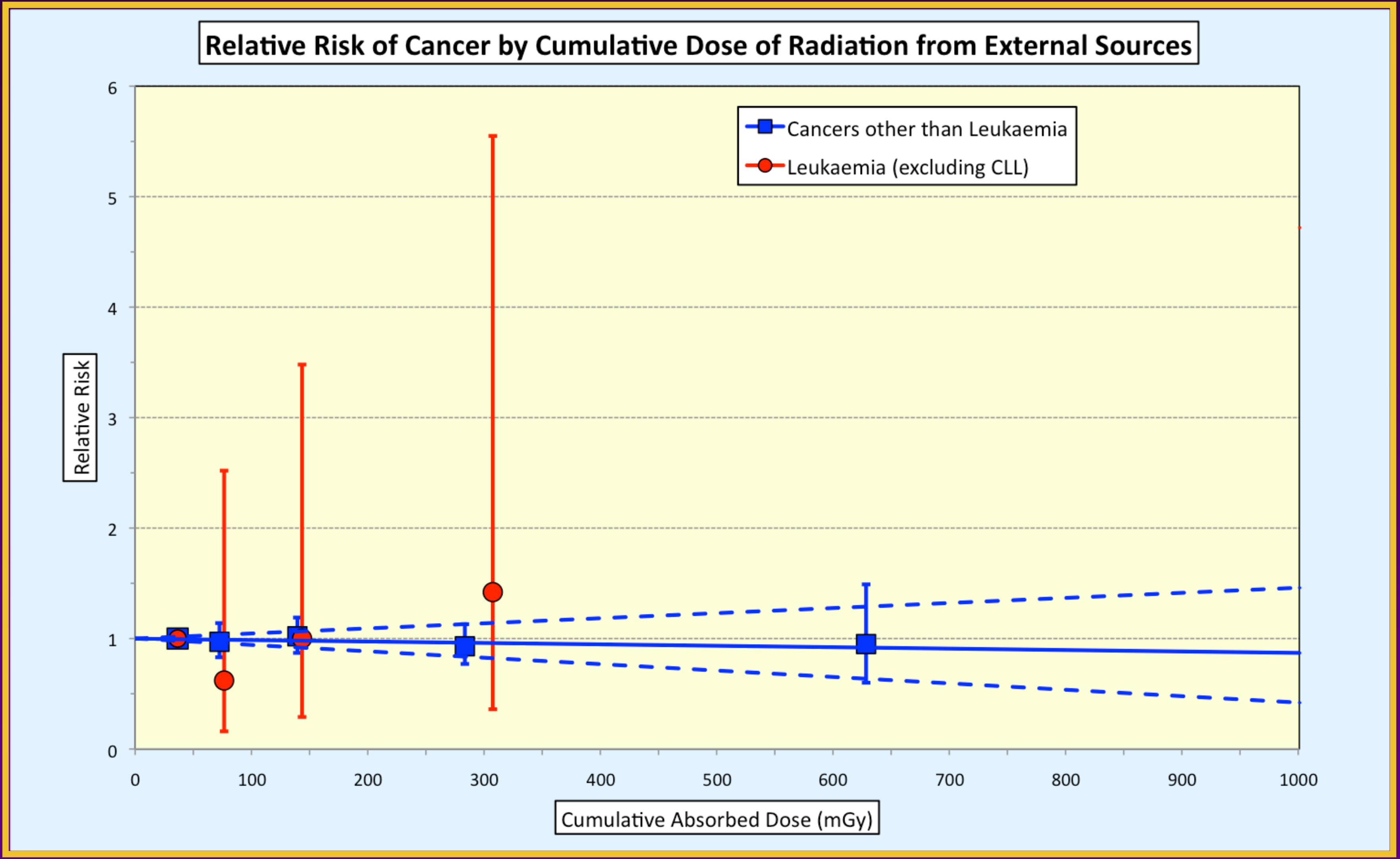
Bidi Smoking in Kerala

Kerala HNBR Area, India

- Nair *et al.* (*Health Phys* 2009; **96**: 55-66) examined cancer incidence (from a cancer registry) among 69 958 residents aged 30-84 years during 1990-2005.
- >70 000 gamma dose-rates measured.
- 1379 cases of cancer (30 leukaemia).
- No significant correlations.
- Cancer excluding leukaemia:

  ERR/Gy = -0.13 (95% CI: -0.58, 0.46)

Cancer Risk in Kerala



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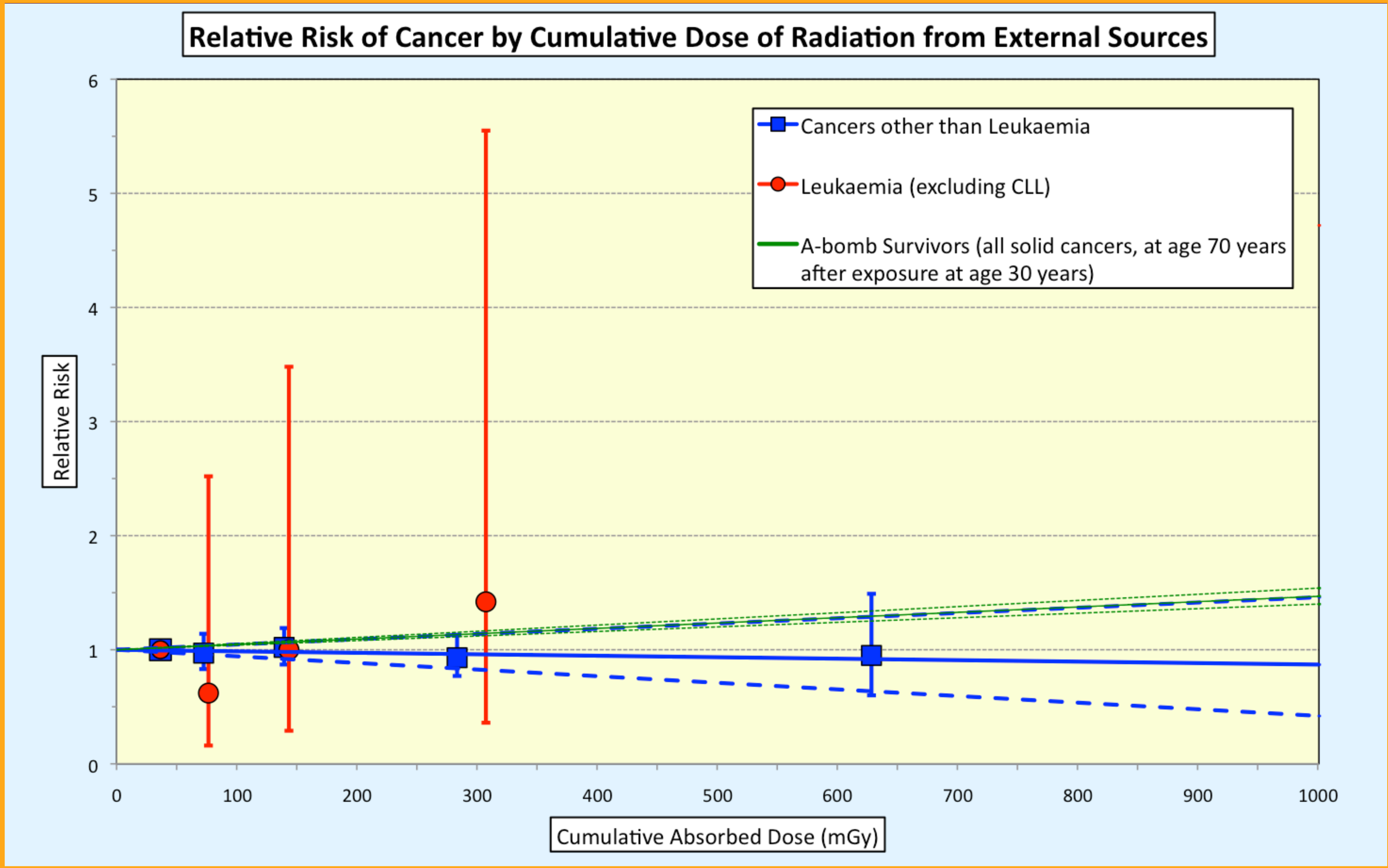
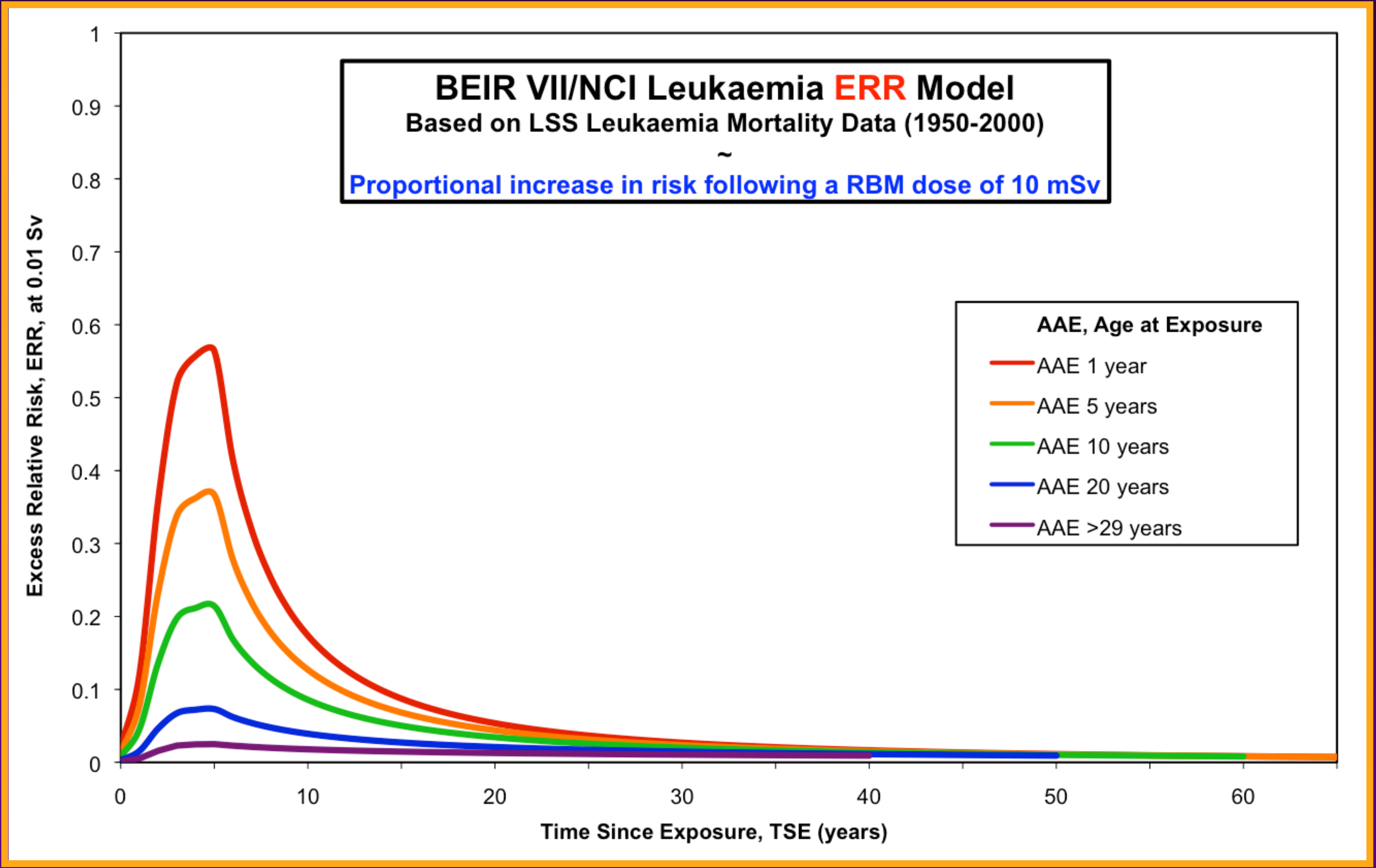
Cancer Risk in Kerala



Natural Background Radiation

- Perhaps a more focused investigation of the risk model-predicted effects of natural background radiation would be more informative?
- Childhood leukaemia has a predicted high ERR/Sv, but above a low background risk (1 in ~1800 live births affected in economically developed countries).

BEIR VII/NCI Leukaemia Mortality



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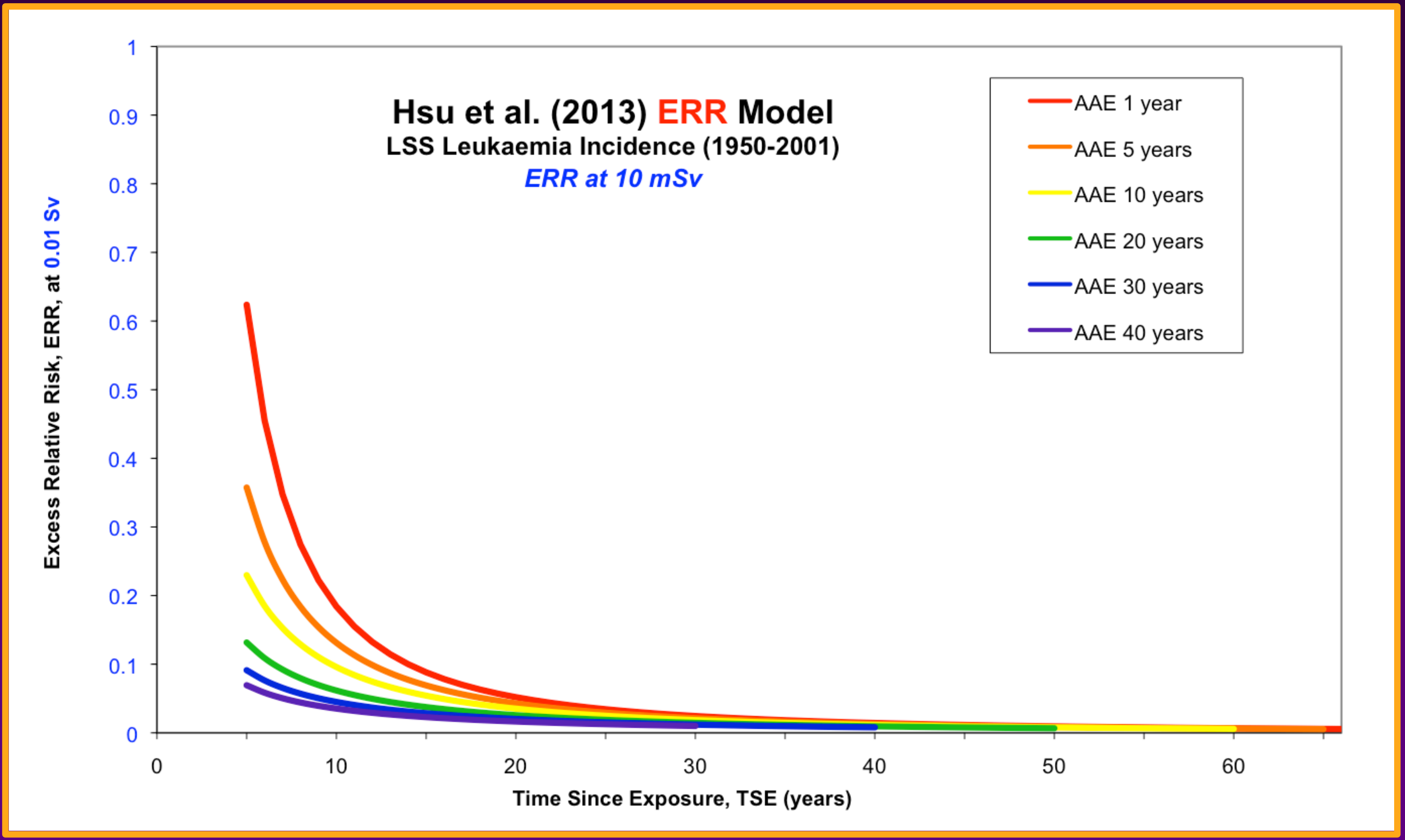
Leukaemia Incidence Model



Natural Background Radiation

(Wakeford *et al., Leukemia* 2009; **23**: 770-6.
Little *et al.*, *J Radiol Prot* 2009; **29**: 467-82.
Kendall *et al.*, *Leuk Res* 2011; **35**: 1039-43.)

- Recent risk models for radiation-induced leukaemia suggest that ~15-20% of cases of childhood (<15 years of age) leukaemia in Great Britain may be caused by natural background radiation.
  - red bone marrow dose ~1.4 mSv per annum
- Past epidemiological studies have been unable to reliably demonstrate this source of risk
  - probably have <u>insufficient statistical power</u>

Natural Background Radiation

(Little *et al.*, *Radiat Res* 2010; **174**: 387-402)

- Power calculations show that *large* studies are required to detect the predicted excess risk
  - to achieve >80% power, >8000 cases are needed in a case-control or geographical correlation study covering the whole of Great Britain.
- Greatest effect is from γ-rays, <u>not</u> radon.
- The extensive data from the UK National Registry of Childhood Tumours make such a study feasible.

Natural Background Radiation

(Kendall *et al.*, *Leukemia* 2013; **27**: 3-9)

- First results from a large nationwide record-based case-control study of childhood cancer in Great Britain have been published.
- What would be predicted from *prior evidence*?
  - Childhood leukaemia
    - A possibly detectable positive effect of γ-radiation
    - No detectable effect of radon
  - Childhood cancers other than leukaemia
    - No detectable effect of either γ-radiation or radon

Case-control Study

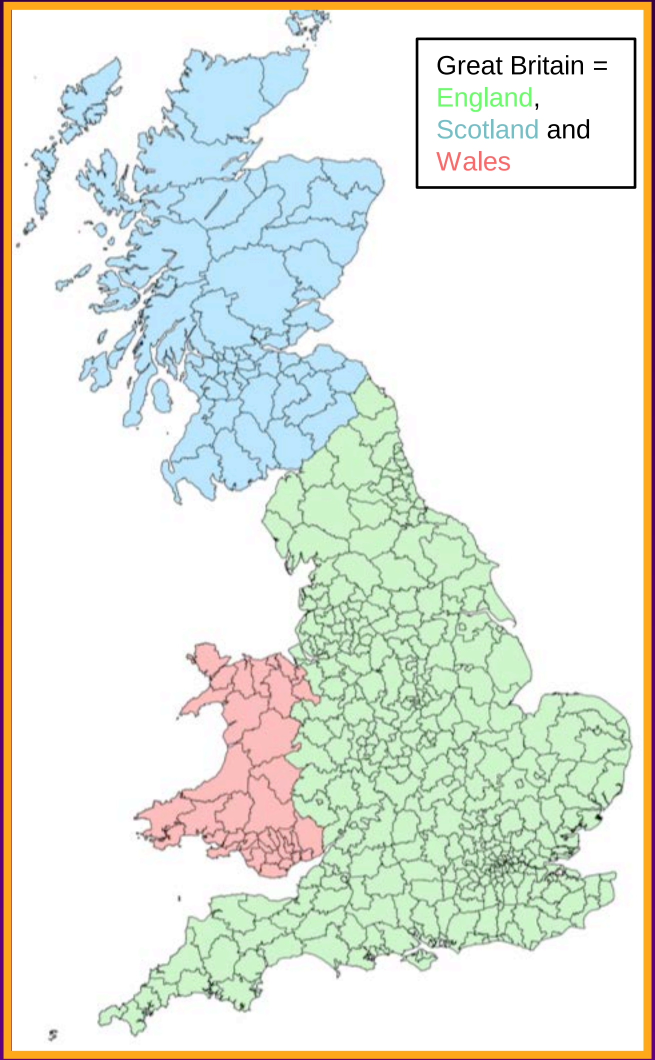
(Kendall *et al.*, *Leukemia* 2013; **27**: 3-9)

- Case-control study of 27,500 childhood cancer cases and 37,000 matched controls.
- 9058 cases of childhood leukaemia matched with 11,912 controls.
- Cumulative (birth to diagnosis) exposures to background γ-radiation and radon estimated for maternal residence at birth of the child from nationwide radiation survey data.

County Districts of Great Britain

(Kendall *et al.*, *Leukemia* 2013; **27**: 3-9)

- Average natural background gamma-ray dose-rates in 459 county districts (based on 2283 indoor measurements) were applied to maternal residences at birth of cases and matched controls.
- Indoor radon concentrations based on a predictive map generated from ~400,000 domestic radon measurements.
- Adjustments made for socio-economic status (based both on paternal occupation and census ward deprivation index).



Results for Childhood Cancer

(Kendall *et al. Leukemia* 2013; **27**: 3-9)

- **Gamma-rays** (RR per mGy)

	Cases	RR	95% CI	P
Total Leukaemia	*9058*	*1.09*	*(1.02, 1.17)*	*0.01*
Not Leukaemia	18 389	1.02	(0.98, 1.06)	0.38

- **Radon** (RR per 10^3 Bq/m^3 years)

	Cases	RR	95% CI	P
Total Leukaemia	9058	1.12	(0.88, 1.43)	0.35
Not Leukaemia	18 389	1.06	(0.91, 1.24)	0.43

Results for Childhood Leukaemia

(Kendall *et al. Leukemia* 2013; **27**: 3-9)

- **Gamma-rays** (RR per mSv RBM dose)

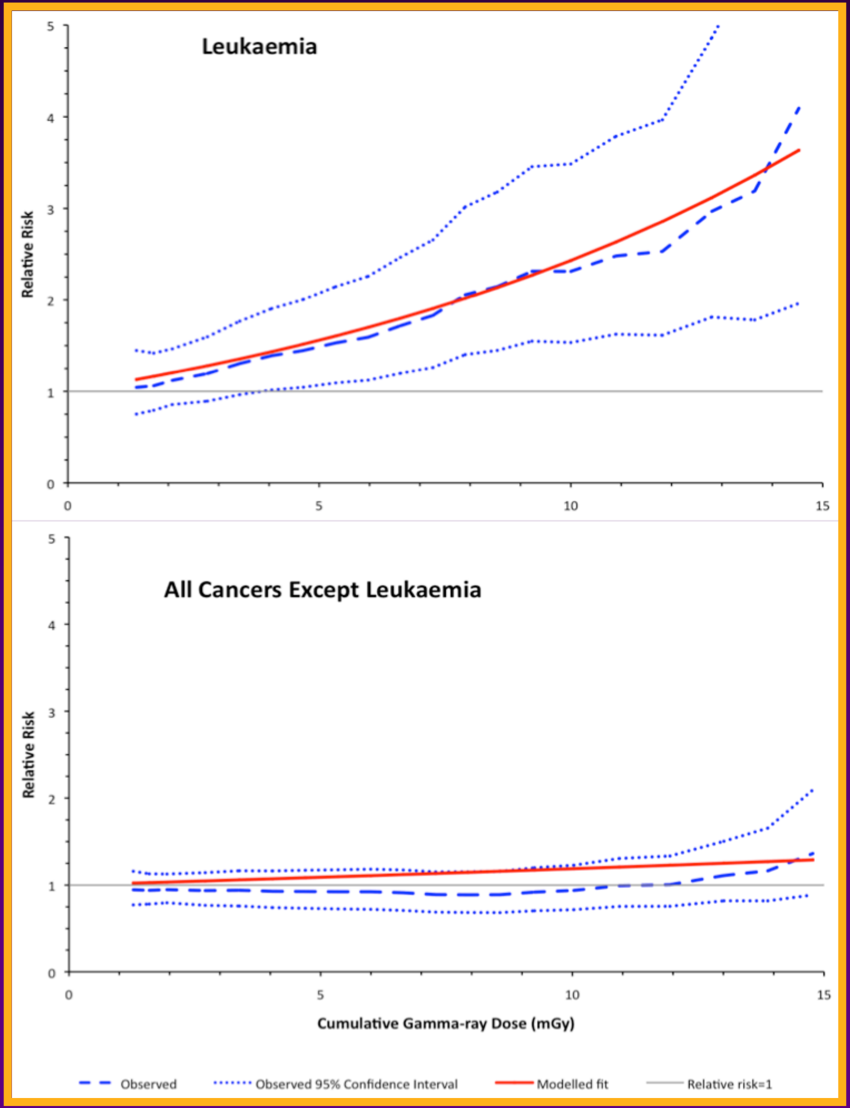
	RR	95% CI	P
Total leukaemia	*1.12*	*(1.03, 1.22)*	*0.01*

- **Radon** (RR per mSv RBM dose)

	RR	95% CI	P
Total leukaemia	1.03	(0.96, 1.11)	0.35

Natural Background γ-radiation

(Kendall *et al. Leukemia* 2013; **27**: 3-9)



ERR/Gy =
120 (95% CI: 30, 220)

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Leukaemia ERR/Gy Comparisons

- Oxford Survey of Childhood Cancers (<u>fetal</u>)

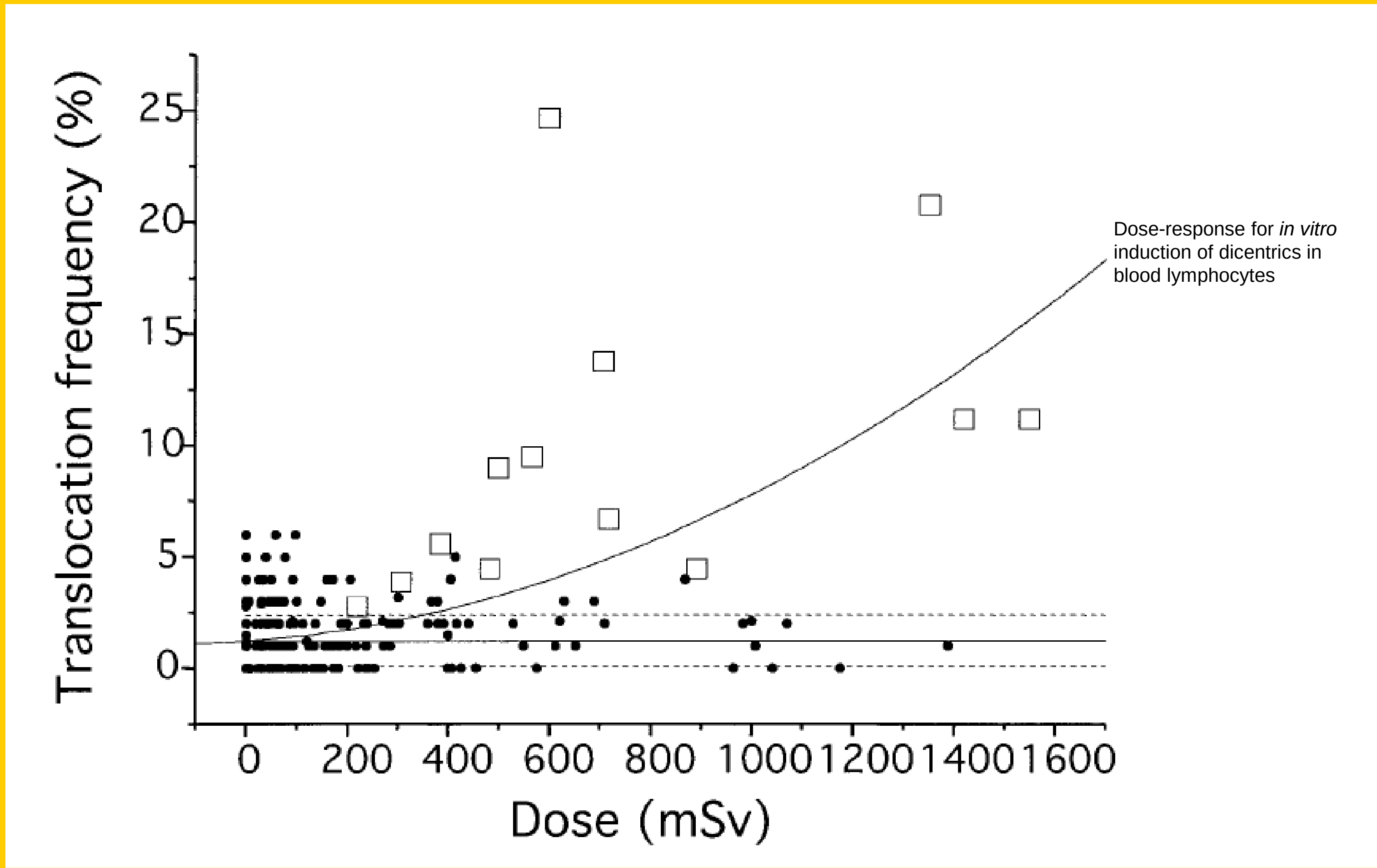
  51 (95% CI: 28, 76) Gy^{-1} at ~10 mGy (X-rays)
- UK CT scan study (<u>≤21 years of age</u>)

  36 (95% CI: 5,120) Gy^{-1} at ~10 mGy (X-rays)
- Natural background radiation study (<u>children</u>)

  120 (95% CI: 30, 220) Gy^{-1} at ~1½ mGy/y (γ-rays)
- Japanese A-bomb survivors (<u>children</u>)

  ~50 Gy^{-1} at an average ~0.25 Gy (mainly γ-rays)

Chromosome Translocation Frequencies in Atomic-Bomb Survivors Exposed *in utero* (●), and in some of their Mothers (□). (Ohtaki *et al.*, *Radiat Res* 2004; **161**: 373-9)



Natural Background γ-radiation

(Kendall *et al.*, *Leukemia* 2013; **27**: 3-9)

- γ radiation individual dose estimates currently based upon county district averages.
- Spatial averaging is undesirable and also leads to loss of ~50% case-control sets (with cases and controls drawn from same county district and so have the same doses).
- Doses only available for birth addresses.
- More γ radiation data now available and individual dose estimates will be used.
- More case-control sets now available.

Swiss γ-radiation Study

(Spycher *et al.*, *Environ Health Perspect* 2015 Epub)

- Cohort of >2 million children included in 1990 or 2000 census. Followed to 2008.
- 1782 cases of childhood cancer (530 leukaemia) linked to cohort.
- External radiation dose at address at census calculated from database of outdoor dose-rate measurements.
- Adjustments made for various potential confounding factors.

Swiss γ-radiation Study

(Spycher *et al.*, *Environ Health Perspect* 2015 Epub)

- Hazard ratios per mSv cumulative dose
  – Cancer: 1.03 (95% CI: 1.01, 1.05)
  – Leukaemia: 1.04 (95% CI: 1.00, 1.08)
  – Lymphoma: 1.01 (95% CI: 0.96, 1.05)
  – CNS tumours: 1.04 (95% CI: 1.00, 1.08)
- Restricting analysis to those having a "stable place of residence" resulted in larger hazard ratios.

Conclusions

- Epidemiological studies of natural background radiation must be carefully designed and conducted because of small predicted effects and the influence of confounding factors.
- The impact of residential radon on lung cancer risk has been demonstrated, but other effects are less certain, although sufficiently powerful studies of childhood leukaemia may prove of value.

Fin

Questions and Answers

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