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# Studien und Statistiken

Dr. med. Alex Rosen
Vorsitzender IPPNW Deutschland

Sommerakademie Atomares Erbe
Wolfenbüttel
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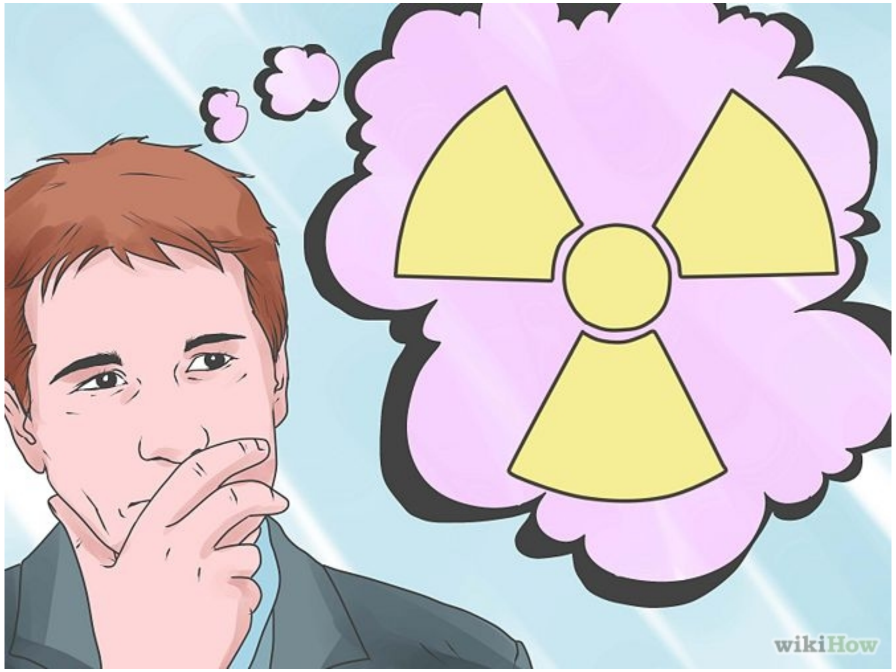
# Zentrale Fragestellungen

- Was bedeutet Risiko?
- Wie lassen sich Strahlenrisiken für größere Bevölkerungen errechnen?
- Welche Risikokoeffizienten nutzen wir?
- Wie ist die neuere Datenlage?



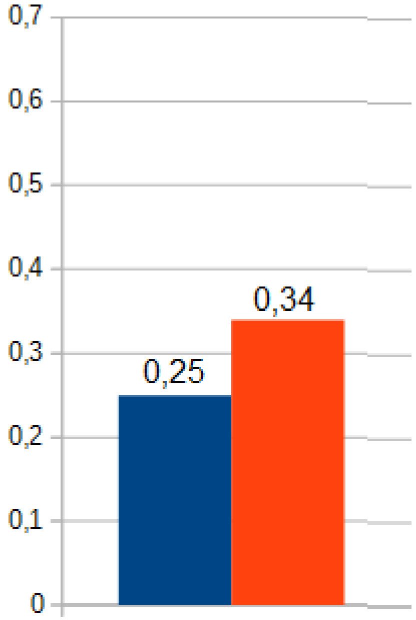
# Was bedeutet „Risiko"?

**Definitionen:**

**Risiko**: Wahrscheinlichkeit für das Eintreten eines bestimmten Ereignisses während eines definierten Zeitraums

**Relatives Risiko:** Verhältnis zwischen dem Risiko für ein bestimmtes Ereignis in zwei definierten Gruppen

# Was bedeutet „Risiko“?




- Wie hoch ist das Risiko in der blauen Gruppe?

  0,25 / 25%

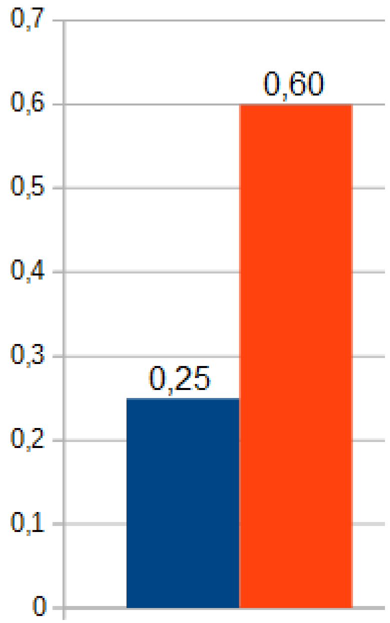
- Wie hoch ist das Risiko in der roten Gruppe?

  0,34 / 34%

- Wie hoch ist das relative Risiko der roten zur blauen Gruppe?

  1,36

# Was bedeutet „Risiko“?




- Wie hoch ist das Risiko in der blauen Gruppe?

  0,25 / 25%

- Wie hoch ist das Risiko in der roten Gruppe?

  0,6 / 60%

- Wie hoch ist das relative Risiko der roten zur blauen Gruppe?

  2,4 / 240%

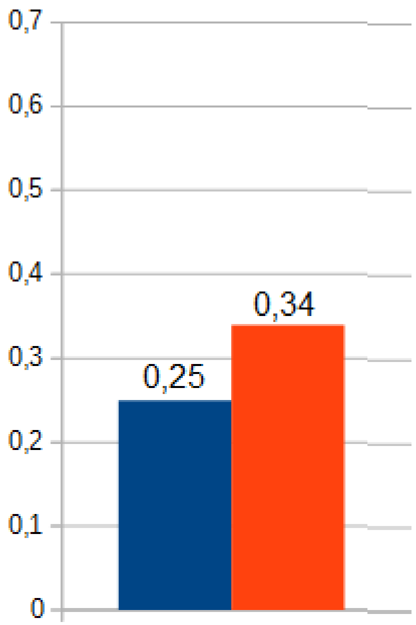
# Was bedeutet „Risiko“?

**Definitionen:**

- **Zusätzliches absolutes Risiko**
  **Excess absolute risk (EAR)**:
  Differenz zwischen dem Risiko zweier Gruppen

- **Zusätzliches relatives Risiko**
  **Excess relative risk (ERR):**
  Verhältnis zwischen dem Risiko in der einer Gruppe zum Risiko in der anderen Gruppe

# Was bedeutet „Risiko“?




- Wie hoch ist das zusätzliche absolute Risiko (EAR) zwischen roter und blauer Gruppe?

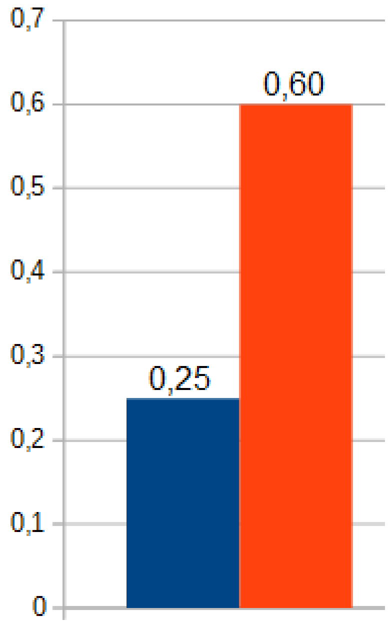
0,09 / 9%

- Wie hoch ist das zusätzliche relative Risiko (ERR) zwischen roter und blauer Gruppe?

0,36 / 36%

- Welchen Wert empfindet ihr als hilfreicher in der Bewertung?

# Was bedeutet „Risiko“?




- Wie hoch ist das zusätzliche absolute Risiko (EAR) zwischen roter und blauer Gruppe?

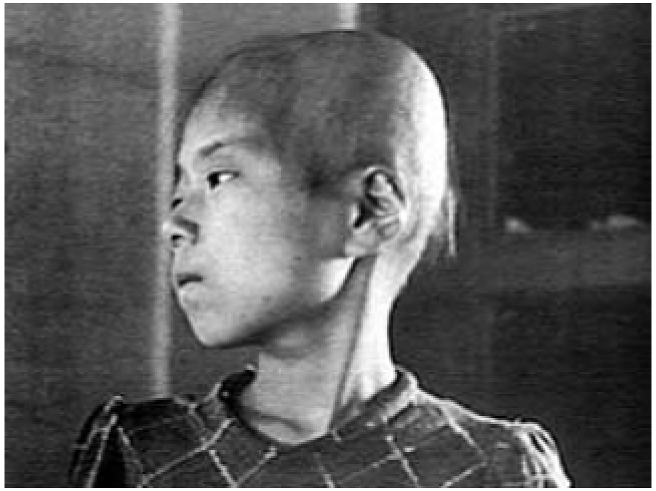
0,35 / 35%

- Wie hoch ist das zusätzliche relative Risiko (ERR) zwischen roter und blauer Gruppe?

1,4 / 140%

- Welchen Wert empfindet ihr als hilfreicher in der Bewertung?

# Strahlenrisiken quantifizieren



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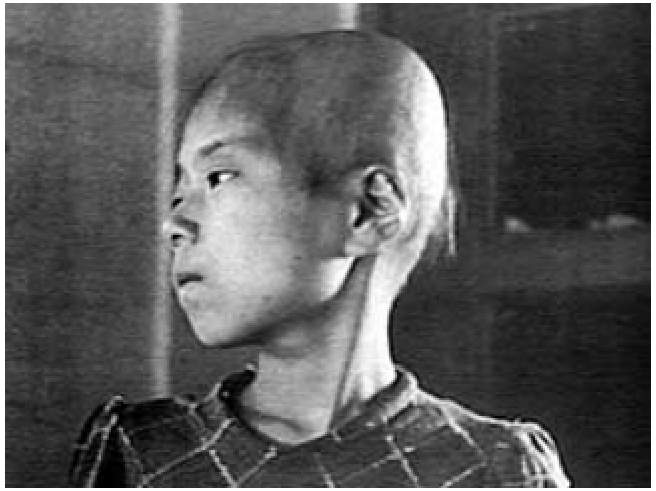
# Strahlenrisiken quantifizieren

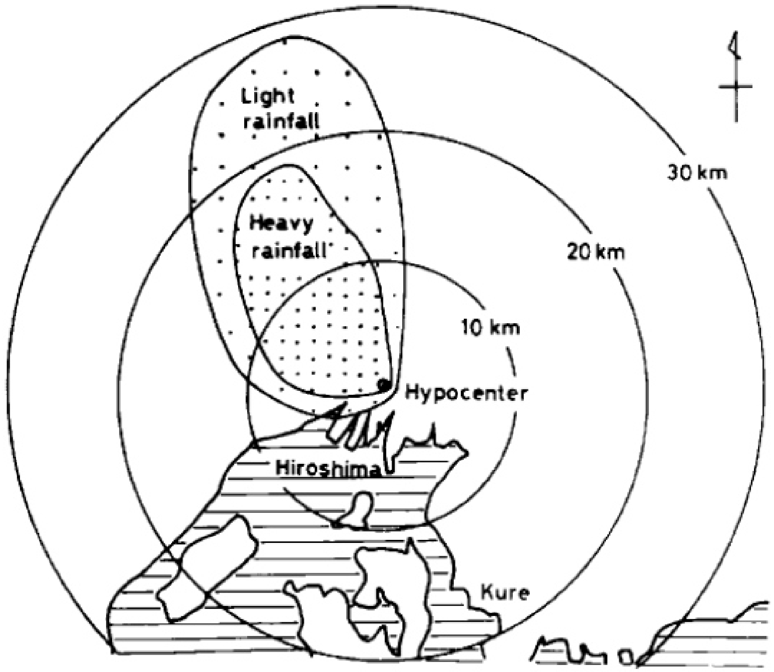
Die ICRP Risikofaktoren der Hiroshima- und Nagasaki-Überlebenden in der Lifetime Span Study (LSS) eignen sich nicht für die Berechnung von gesundheitlichen Folgen niedrig dosierter ionisierender Strahlung



# Strahlenrisiken quantifizieren

Strahlendosen durch radioaktiven Niederschlag und Neutronenaktivierung wurden in den Dosisabschätzungen nicht berücksichtigt

Bevölkerungsgruppen, die niedrig dosierter Strahlung ausgesetzt wurden, wurden als Referenzgruppen herangezogen




Takada J et al. „Uranium Isotopes in Hiroshima“. Journal of Radiation Research”, Vol.24,Vo.3(1983)pp.229-23

# Strahlenrisiken quantifizieren

Dies führte zu einer systematischen Unterschätzung der strahlungs-bedingten gesundheitlichen Risiken

Environmental Health and Preventive Medicine

## Hiroshima survivors exposed to very low doses of A-bomb primary radiation showed a high risk for cancers

2009

Tomoyuki Watanabe · Masaru Miyao ·
Ryumon Honda · Yuichi Yamada

Received: 24 December 2007 / Accepted: 15 May 2008 / Published online: 5 July 2008
© The Japanese Society for Hygiene 2008

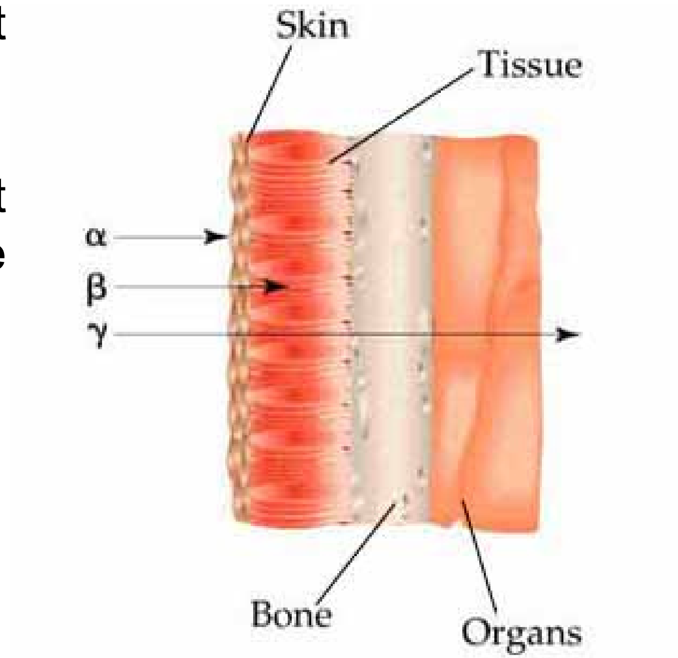
**Abstract**
*Objectives* The aim of this study was to compare the risk for cancers of A-bomb survivors in the ongoing life span study (LSS) with unexposed groups consisting of the entire populations of Hiroshima prefecture and neighboring Okayama prefecture.
*Methods* The subjects consisted of the Hiroshima group reported in LSS report 12 (LSS-H group) and a control group (the entire populations of Hiroshima and Okayama—HPCG and OPCG, respectively). We estimated the expected number of deaths due to all causes and to cancers of various causes among the exposed survivors of the Hiroshima bombing in the LSS report 12 who died in the follow-up interval at ages similar to those of people in Hiroshima and Okayama prefectures who were aged 0–34 years at the time of the bombing in 1945. We compared the standardized mortality ratio (SMR) of the LSS-H group to that of the HPCG and OPCG (SMR-H and SMR-O, respectively).
... subjects, and for uterus and liver cancers in female subjects, respectively. The results show that, if the dose estimations of the dosimetry system 1986 (DS86) are correct, there are significantly increased risks of cancer among even survivors exposed to the very low dose level.
*Conclusions* The dose assumptions of DS86 have been criticized for underestimating doses in areas distant from the hypocenter. The contribution of residual radiation, ignored in LSS, and that of neutrons, underestimated by DS86, is suggested to be fairly high.

**Keywords** Atomic bomb · Cancer · Hiroshima survivors · Radiation · SMR

# Strahlenrisiken quantifizieren

Eine kurzzeitige Exposition mit hoch-energetischen Gammastrahlen kann weniger gesundheitsschädlich sein als eine kontinuierliche innere Exposition mit inkorporierten Alpha- und Beta-Strahlern.

Der DDREF von 2 für niedrig-dosierte Strahlung ist daher nicht akzeptabel. (siehe WHO-Stellungnahme 2013)



# Strahlenrisiken quantifizieren

Die Sammlung von Daten begann erst 5 Jahre nach den Bombardierugen, im Jahr 1950.

Viele Befragten gaben zu, in den Fragebögen falsche Antworten gegeben zu haben, um Diskriminierungen zu entgehen.

# Strahlenrisiken quantifizieren

Die Überlebenden stellen eine vorselektierte Gruppe an besonders resilienten Menschen dar.

Dies führte zu einer zusätzlichen Unterschätzung des Strahlen-risikos um etwa 30%.

International Journal of **Epidemiology**

## A-bomb survivors: factors that may lead to a re-assessment of the radiation hazard

Alice M Stewart and George W Kneale

**Background** The study cohort of the survivors of the A-bombs in Japan, used as the basis of the internationally accepted estimates of cancer radiation risk, was collected more than 5 years after the bombing and did not include those who died of bomb-related injuries before that date. This paper tests whether the people who survived, in spite of bomb-related injuries, are homogeneous in respect of variation of cancer risk with age with survivors without such injuries.

**Methods** Appropriate statistical models are derived and fitted to survivor data by maximum likelihood and the resultant statistics used to test the homogeneity assumption.

**Results** Significant differences were found between those with no injuries and those with multiple injuries and shown to be largely due to exposures before 10 or after 55 years of age having exceptionally high risks of late effects of radiation for survivors showing early effects, i.e. bomb-related injuries.

**Conclusions** Certain accepted dogmas about the biology of radiation risks in humans, such as 'cancer is the only late effect of radiation' and 'leukaemia is uniquely radiogenic amongst cancers', may be significantly in error. These are discussed.

**Keywords** A-bomb survivors, radiation biology, cancer, age, effects, selection

2000

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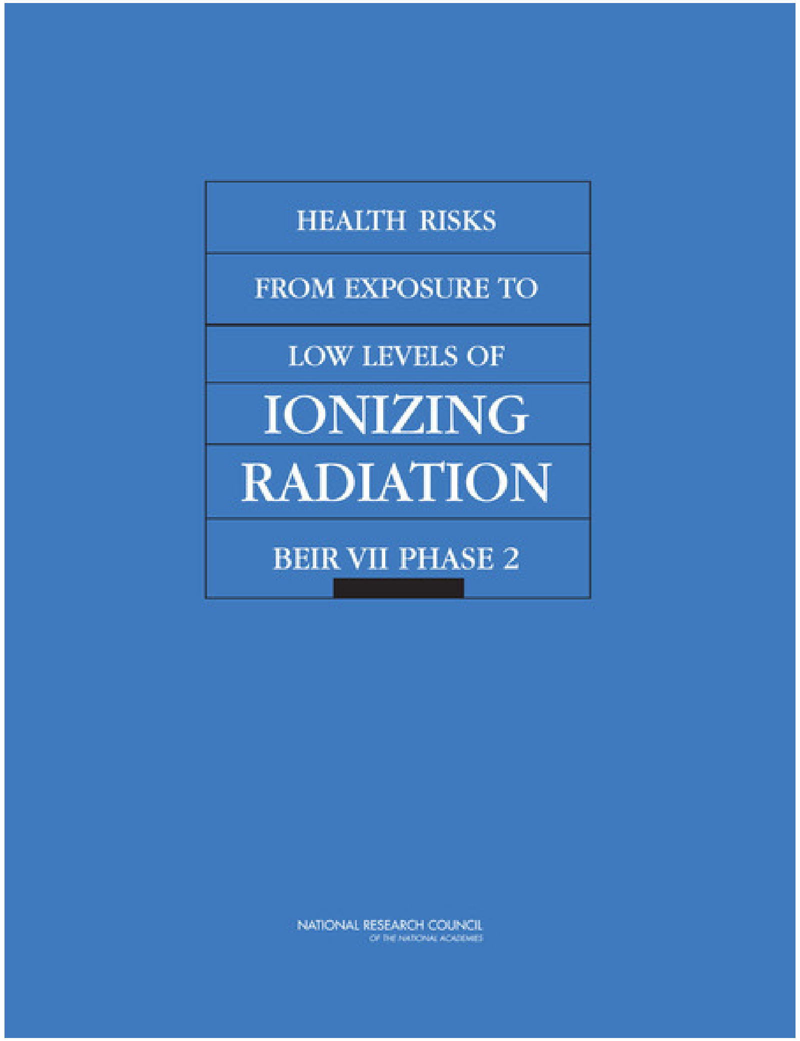
# Strahlenrisiken quantifizieren



# Strahlenrisiken quantifizieren

**Berechnung der attributalen Krebsinzidenz (EAR) laut BEIR VII:**

- Epidemiologische Daten

- Berechnung:
  - Zahl der betroffenen Personen
  - Effektive (individuelle) Dosis in Sv
  - Personen x Sv = Personensievert (PSv)

- Dosis-Effektivität (DDREF) ?

"A DDREF of 1 would be reasonable." WHO Fukushima Report, 28.02.13
www.who.int/ionizing_radiation/pub_meet/fukushima_report/en/index.html

- Rohdaten von Krebserkrankungen tatsächlicher Menschen, mit einer zusätzlichen Strahlenexposition von 0,1 Sv (100.000 Männer, 100.000 Frauen)

# Strahlenrisiken quantifizieren

## Berechnung der attributalen Krebsinzidenz (EAR) laut BEIR VII:

TABLE 12-5A Lifetime Attributable Risk of Solid Cancer Incidence

| Cancer Site | Males: LAR Based on Relative Risk Transport[a] | Males: LAR Based on Absolute Risk Transport[b] | Males: Combined and Adjusted by DDREF[c] (Subjective 95% CI[d]) | Females: LAR Based on Relative Risk Transport[a] | Females: LAR Based on Absolute Risk Transport[b] | Females: Combined and Adjusted by DDREF[c] (Subjective 95% CI[d]) |
|---|---|---|---|---|---|---|
| *Incidence* | | | | | | |
| Stomach | 25 | 280 | 34 (3, 350) | 32 | 330 | 43 (5, 390) |
| Colon | 260 | 180 | 160 (66, 360) | 160 | 110 | 96 (34, 270) |
| Liver | 23 | 150 | 27 (4, 180) | 9 | 85 | 12 (1, 130) |
| Lung | 250 | 190 | 140 (50, 380) | 740 | 370 | 300 (120, 780) |
| Breast | | | | 510 Not used | 460 | 310 (160, 610) |
| Prostate | 190 | 6 | 44 (<0, 1860) | | | |
| Uterus | | | | 19 | 81 | 20 (<0, 131) |
| Ovary | | | | 66 | 47 | 40 (9, 170) |
| Bladder | 160 | 120 | 98 (29, 330) | 160 | 100 | 94 (30, 290) |
| Other | 470 | 350 | 290 (120, 680) | 490 | 320 | 290 (120, 680) |
| Thyroid | 32 | No model | 21 (5, 90) | 160 | No model | 100 (25, 440) |
| Sum of site-specific estimates | 1400 | 1310[e] | 800 | 2310[f] | 2060[e] | 1310 |
| All solid cancer | 1550 | 1250 | 970 (490, 1920) | 2230 | 1880 | 1410 (740, 2690) |

Quelle: "BEIR VII report, phase 2: Health risks from exposure to low levels of ionizing radiation." National Academies Press, Washington, 2006, p. 279f

# Strahlenrisiken quantifizieren

## Berechnung der attributalen Krebsinzidenz (EAR) laut BEIR VII:

TABLE 12-5A Lifetime Attributable Risk of Solid Cancer Incidence

| | Males | | | Females | | |
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# Strahlenrisiken quantifizieren

**Berechnung der attributalen Krebsinzidenz (EAR) laut BEIR VII:**

970 zusätzliche Krebsfälle pro 100.000 Männern mit einer Exposition von 0,1 Sv
1.410 zusätzliche Krebsfälle pro 100.000 Frauen mit einer Exposition von 0,1 Sv

Berechnung pro Personen-Sv:
970 pro 10.000 PSv = 0,097 pro PSv
1.410 pro 10.000 PSv = 0,141 pro PSv

Herausrechnen des mittlerweile obsoleten Dosisreduktionsfaktors von 1,5:
0,097/PSv x 1,5 = 0,1455/PSv
0,141/PSv x 1,5 = 0,2115/PSv

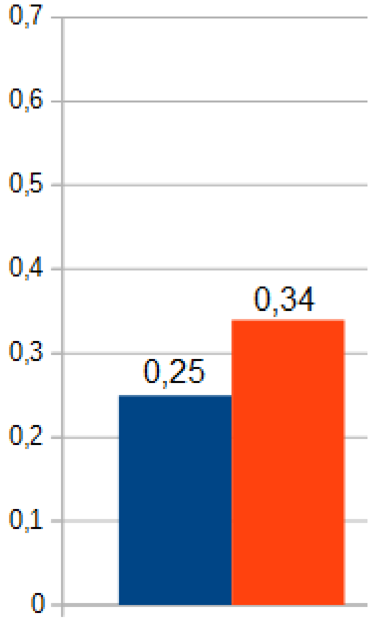
Geschlechterneutraler Durchschnittswert: 0,1785/PSv (CI 0,09-0,35)



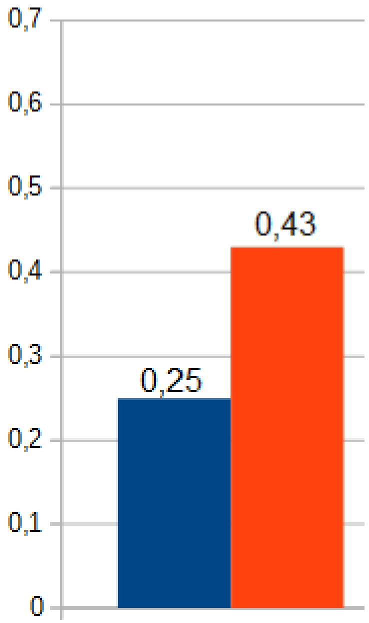
Quelle: "BEIR VII report, phase 2: Health risks from exposure to low levels of ionizing radiation." National Academies Press, Washington, 2006, p. 279f

# Strahlenrisiken quantifizieren

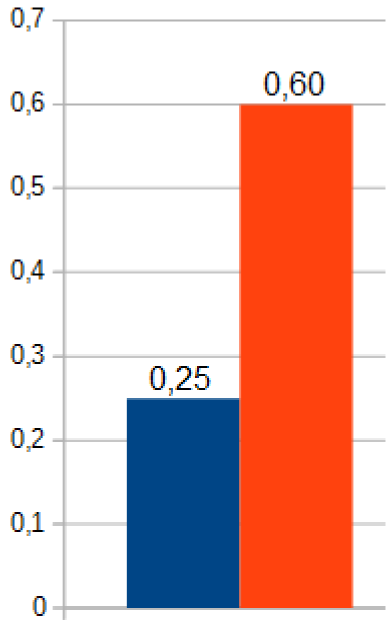
**Berechnung der attributalen Krebsinzidenz (EAR) laut BEIR VII:**




EAR = 0,09/PSv




EAR = 0,18/PSv




EAR = 0,35/PSv

# Strahlenrisiken quantifizieren

**Berechnung der attributalen Krebsmortalität (EAR) laut BEIR VII:**

- Niedrigste Schätzung:
305/10.000 PSv x 1.5 DDREF-Korrektur = 458/10.000 PSv = 0,05 pro PSv

- Durchschnittliche Schätzung:
610/10.000 PSv x 1.5 DDREF-Korrektur = 915/10.000 PSv = 0,09 pro PSv

- Höchste Schätzung:
1.240/10.000 PSv x 1.5 DDREF-Korrektur = 1.860/10.000 PSv = 0,19 pro PSv

*BEIR VII report, table 12-5B, p. 280*

# Strahlenrisiken quantifizieren

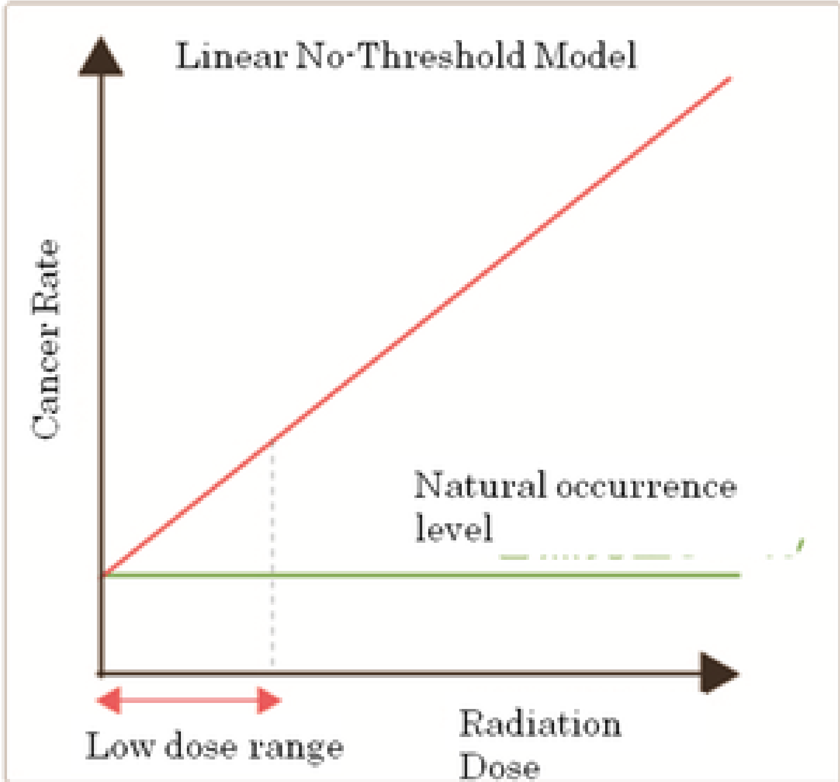
**Pragmatische Rechengrößen laut BEIR VII:**

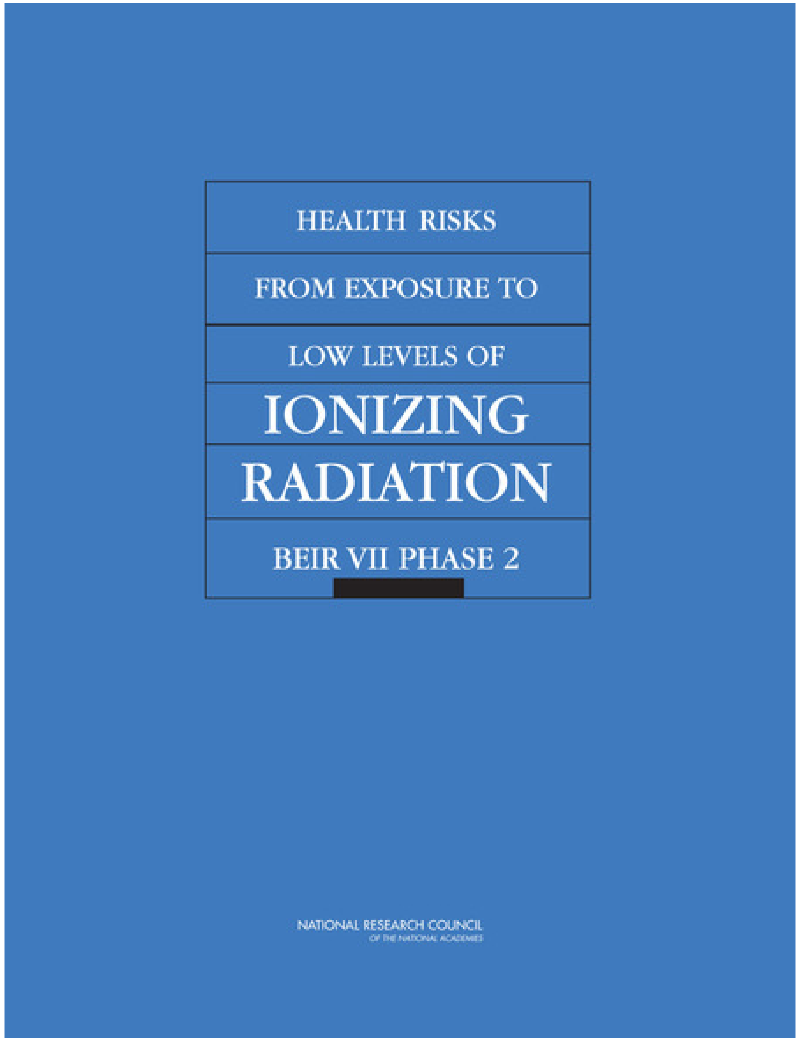
~ 0,2 zusätzliche Krebsfälle pro PSv
~ 0,1 zusätzliche Krebstodesfälle pro PSv

Neuere Studien zeigen, dass eher von der doppelten Menge an Krebs- und Krebstodesfällen auszugehen ist:
~ 0,4 zusätzliche Krebsfälle pro PSv
~ 0,2 zusätzliche Krebstodesfälle pro PSv

# Strahlenrisiken quantifizieren

## Linear No-Threshold Model (LNT):



# Strahlenrisiken quantifizieren

**Linear No-Threshold Model (LNT):**

| | |
|---|---|
| 1.000 mSv = 1 Sv | 2 von 10 entwickeln Krebs (0,9-3,5) |
| 100 mSv = 0,1 Sv | 2 von 100 entwickeln Krebs (0,9-3,5) |
| 10 mSv = 0,01 Sv | 2 von 1.000 entwickeln Krebs (0,9-3,5) |
| 1 mSv = 0,001 Sv | 2 von 10.000 entwickeln Krebs (0,9-3,5) |

# Strahlenrisiken quantifizieren

**Individuelles vs. Bevölkerungsbezogenes Risiko:**

Szenario 1: 100 Menschen werden einer Strahlendosis von je 1 Sv ausgesetzt

Gesamtdosis: 100 PSv

Berechnung der Krebsfälle: 0,18 pro PSv (CI 0,09-0,35) → 18 Fälle (CI 9-35)

Individuelles Risiko, an Krebs zu erkranken: 18% (CI 9-35%)

# Strahlenrisiken quantifizieren

**Individuelles vs. Bevölkerungsbezogenes Risiko:**

Szenario 2: 100.000 Menschen werden einer Strahlendosis von 0,001 Sv ausgesetzt

Gesamtdosis: 100 PSv

Berechnung der Krebsfälle: 0,18 pro PSv (CI 0,09-0,35) → 18 Fälle (CI 9-35)

Individuelles Risiko, an Krebs zu erkranken: 0,018% (CI 0,009-0,035%)

# Strahlenrisiken quantifizieren

**Wo war der Fehler?**

Szenario 1: Individuelles Risiko, an Krebs zu erkranken 18% (CI 9-35%)
Szenario 2: Individuelles Risiko, an Krebs zu erkranken 0,018% (CI 0,009-0,035%)

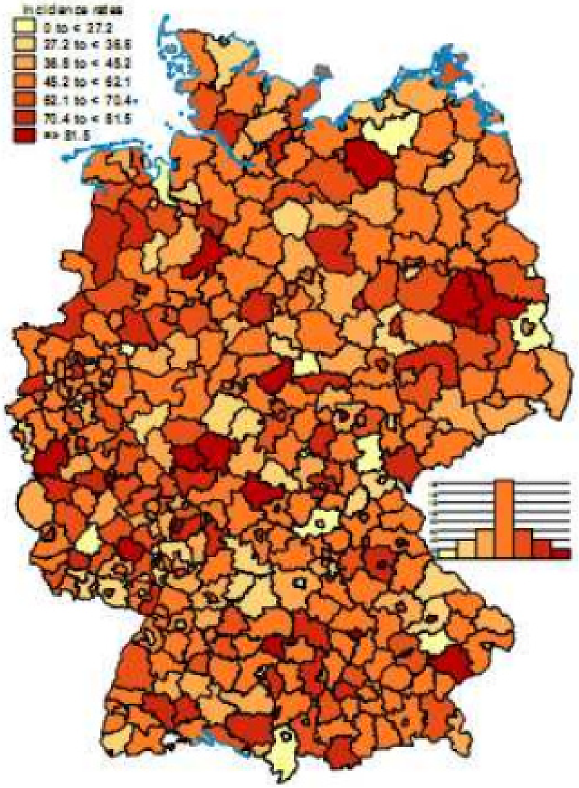
Grundrisiko, an Krebs zu erkranken: 25%

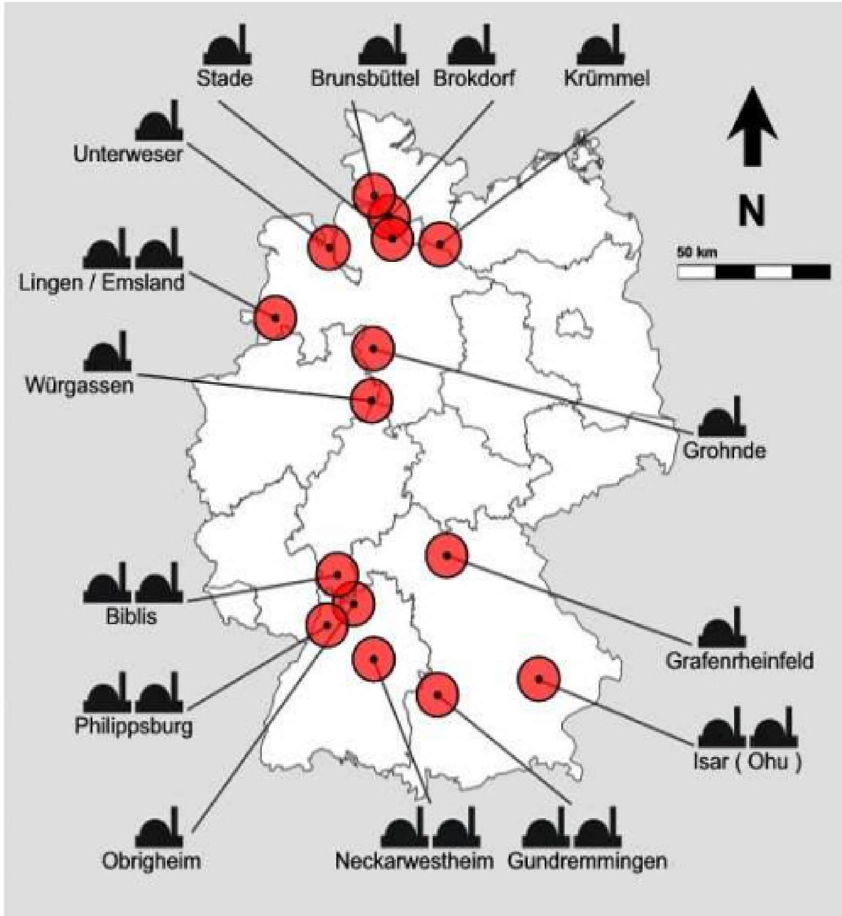
Szenario 1:
Individuelles Risiko, wegen der zusätzlichen Strahlenbelastung an Krebs zu erkranken 18% (CI 9-35%). Individuelles Risiko an Krebs zu erkranken 43% (CI 34-60%)

Szenario 2:
Individuelles Risiko, wegen der zusätzlichen Strahlenbelastung an Krebs zu erkranken 0,018% (CI 0,009-0,035%). Individuelles Risiko an Krebs zu erkranken 25,018% (CI 25,009-25,035%)

# Strahlenrisiken quantifizieren

## Beispiel Kinderleukämie um AKWs:





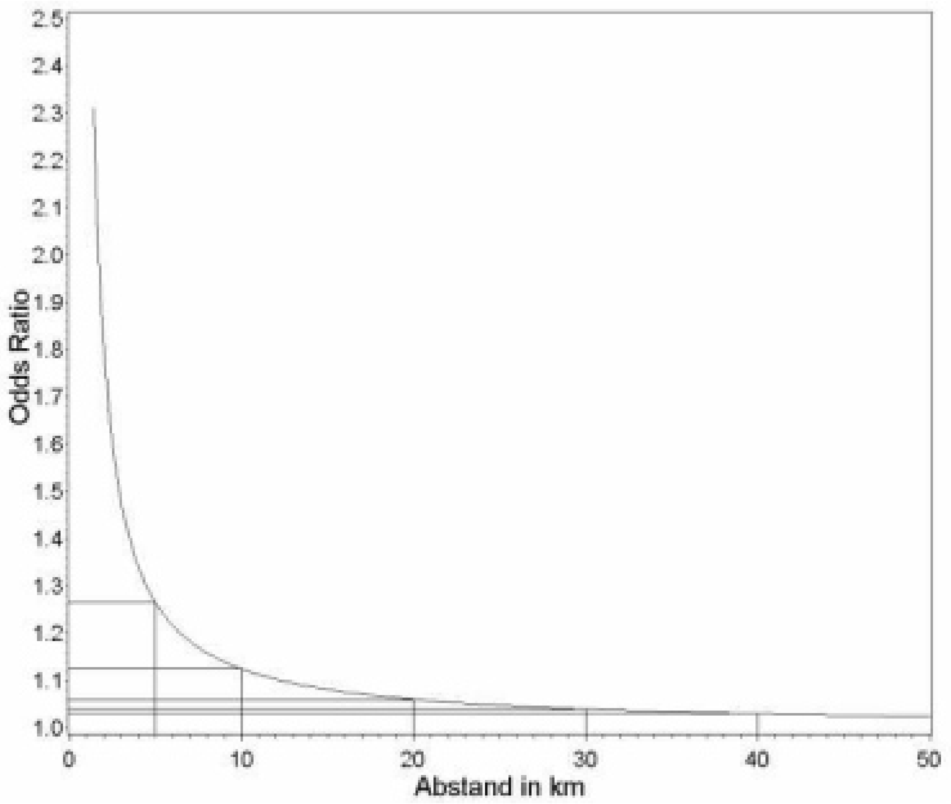
# Strahlenrisiken quantifizieren

**Beispiel Kinderleukämie um AKWs:**

- Im Schnitt 256 neue Kinderleukämiefälle < 5 Jahren im Jahr
- Zwischen 1980 und 2003 5.893 Fälle in ganz Deutschland
- Im 5 km-Radius um deutsche Atomkraftwerke wären daher 17 Fälle zu erwarten
- Tatsächlich gefundene Fälle: 37
- EAR: 37-17 = 20 zusätzliche Fälle (0,8 pro Jahr)
- ERR: 20/17 = 1,176 (117,6%)
- Anstieg der absoluten Zahl der Kinderleukämiefälle: 20/5.893 = 0,34%

# Strahlenrisiken quantifizieren

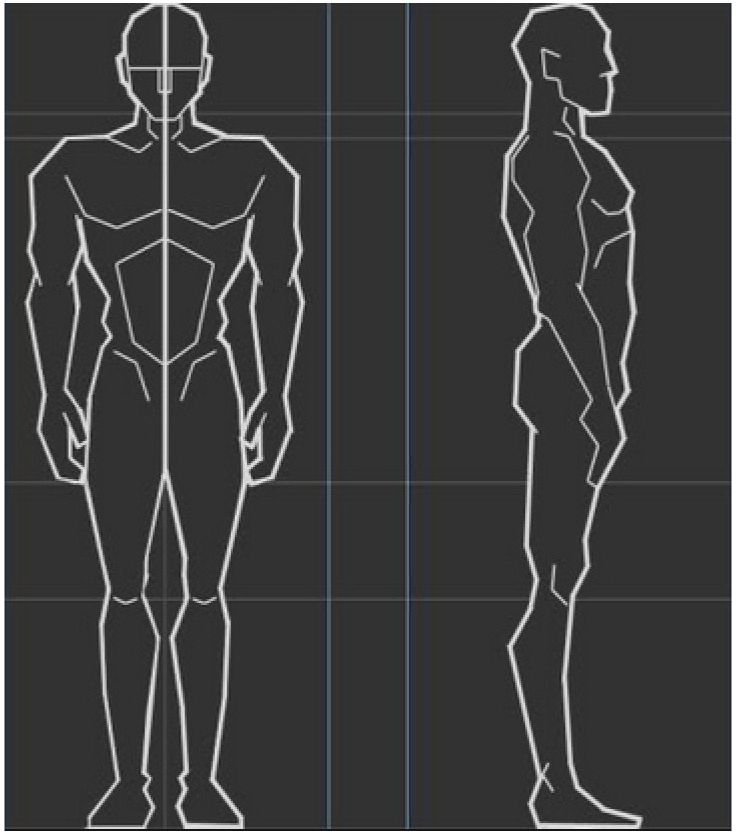
**Beispiel Kinderleukämie um AKWs:**



# Strahlenrisiken quantifizieren

**Risikokalkulation**

Die Risikofaktoren der ICRP beziehen sich auf den sog. „Reference-Man“ von 1975:



20-30 Jahre

Weiß

Männlich

Größe 170 cm

Gewicht 70 kg

# Strahlenrisiken quantifizieren

## Risikokalkulation

“Die relativen Risiken für spezielle Bevölkerungsgruppen (vor allem bei Exposition in der Fötalzeit oder als Kleinkind) sind höher als die des Bevölkerungsdurchschnitts" (UNSCEAR, 2014)

Strahlenschutz muss jenseits herkömmlicher Erwachsenenmodelle die besondere Vulnerabilität des ungeborenen Lebens und des Kleinkinds in Betracht ziehen.

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# Wie gefährlich ist Strahlung?

**Hintergrundstrahlung**

16% höheres Risiko pro 100 $Bq/m^3$ (95% CI 5 - 31%)

Rauchen ist kein confounder

Es gibt keine Schwelle

Lineare Dosis-Wirkungs-Kurve, weit unter aktuellen Grenzwerten

Radon kann verantwortlich sein für
9% aller Lungenkrebsfälle
2% aller Krebstodesfälle

BMJ Helping doctors make better decisions

## Radon in homes and risk of lung cancer: collaborative analysis of individual data from 13 European case-control studies

S Darby, D Hill, A Auvinen, J M Barros-Dios, H Baysson, F Bochicchio, H Deo, R Falk, F Forastiere, M Hakama, I Heid, L Kreienbrock, M Kreuzer, F Lagarde, I Mäkeläinen, C Muirhead, W Oberaigner, G Pershagen, A Ruano-Ravina, E Ruosteenoja, A Schaffrath Rosario, M Tirmarche, L Tomášek, E Whitley, H E Wichmann, R Doll

Abstract

**Objective** To determine the risk of lung cancer associated with exposure at home to the radioactive disintegration products of naturally occurring radon gas

**Design** Collaborative analysis of individual data from 13 case-control studies of residential radon and lung cancer.

**Setting** Nine European countries.

**Subjects** 7148 cases of lung cancer and 14 208 controls.

**Main outcome measures** Relative risks of lung cancer and radon gas concentrations in homes inhabited during the previous 5-34 years measured in becquerels (radon disintegrations per second) per cubic metre ($Bq/m^3$) of household air.

**Results** The mean measured radon concentration in homes of people in the control group was 97 $Bq/m^3$, with 11% measuring > 200 and 4% measuring > 400 $Bq/m^3$. For cases of lung cancer the mean concentration was 104 $Bq/m^3$. The risk of lung cancer

present throughout the earth's crust. It has a half life of four days, allowing it to diffuse through soil and into air before decaying by emission of an α particle into a series of short lived radioactive progeny. Two of these, polonium-218 and polonium-214, also decay by emitting α particles. If inhaled, radon itself is mostly exhaled immediately. Its short lived progeny, however, which are solid, tend to be deposited on the bronchial epithelium, exposing cells to α irradiation.

Air pollution by radon is ubiquitous. Concentrations are low outdoors but can build up indoors, especially in homes, where most exposure of the general population occurs. The highest concentrations to which workers have been routinely exposed occur underground, particularly in uranium mines. Studies of exposed miners have consistently found associations between radon and lung cancer.[1 2] Extrapolation from these studies is uncertain but suggests that residential radon, which involves lower exposure to many more people, could cause a substantial minority of all lung cancers. This is of practical relevance because radon concentrations in existing buildings can usually be reduced at moderate

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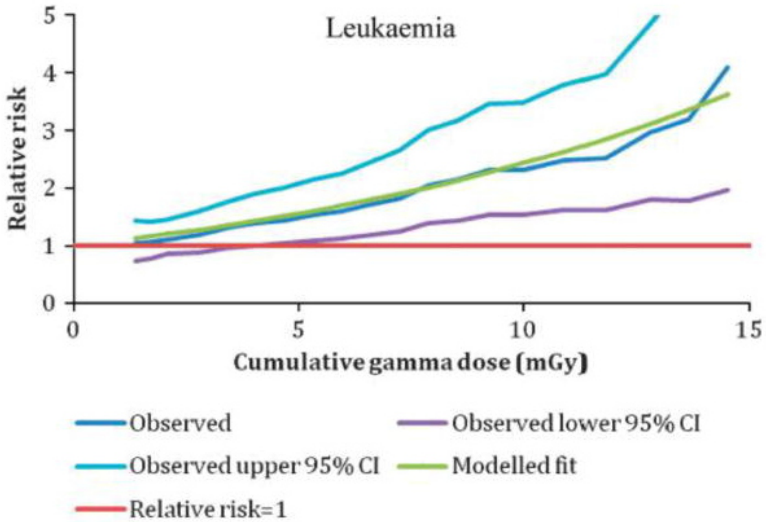
# Wie gefährlich ist Strahlung?

## Hintergrundstrahlung

Korrelation zwischen Hintergrundstrahlung und dem Leukämierisiko

12% höheres Risiko pro mSv Knochenmarkdosis (95% CI 3 – 22%)





A record-based case–control study of natural background radiation and the incidence of childhood leukaemia and other cancers in Great Britain during 1980–2006


G M Kendall, M P Little, R Wakeford, K J Bunch, J C H Miles, T J Vincent, J R Meara and M F G Murphy



We conducted a large record-based case–control study testing associations between childhood cancer and natural background radiation. Cases (27 447) born and diagnosed in Great Britain during 1980–2006 and matched cancer-free controls (36 793) were from the National Registry of Childhood Tumours. Radiation exposures were estimated for mother's residence at the child's birth from national databases, using the County District mean for gamma rays, and a predictive map based on domestic measurements grouped by geological boundaries for radon. There was 12% excess relative risk (ERR) (95% CI 3, 22; two-sided P=0.01) of childhood leukaemia per millisievert of cumulative red bone marrow dose from gamma radiation; the analogous association for radon was not significant, ERR 3% (95% CI −4, 11; P=0.35). Associations for other childhood cancers were not significant for either exposure. Excess risk was insensitive to adjustment for measures of socio-economic status. The statistically significant leukaemia risk reported in this reasonably powered study (power ∼50%) is consistent with high-dose rate predictions. Substantial bias is unlikely, and we cannot identify mechanisms by which confounding might plausibly account for the association, which we regard as likely to be causal. The study supports the extrapolation of high-dose rate risk models to protracted exposures at natural background exposure levels.



P=0.01) of childhood leukaemia per millisievert of cumulative red bone marrow dose from gamma radiation; the analogous

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## Medizinische Strahlung

10,9 Millionen Patienten 1985-2005

Ein CT (4,5 mSv) erhöhte das Krebsrisiko um rund 24%

Jedes zusätzliche CT erhöhte das Risiko um weitere 16%

Je jünger, desto höher das Risiko:
1-4 Jahre: 35% höheres Krebsrisiko
5-9 Jahre: 25% höheres Krebsrisiko
10-14 Jahre: 14% höheres Krebsrisiko

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### Cancer risk in 680 000 people exposed to computed tomography scans in childhood or adolescence: data linkage study of 11 million Australians

John D Mathews *epidemiologist*[1], Anna V Forsythe *research officer*[1], Zoe Brady *medical physicist*[1,2], Martin W Butler *data analyst*[3], Stacy K Goergen *radiologist*[4], Graham B Byrnes *statistician*[5], Graham G Giles *epidemiologist*[6], Anthony B Wallace *medical physicist*[7], Philip R Anderson *epidemiologist*[8,9], Tenniel A Guiver *data analyst*[8], Paul McGale *statistician*[10], Timothy M Cain *radiologist*[11], James G Dowty *research fellow*[1], Adrian C Bickerstaffe *computer scientist*[1], Sarah C Darby *statistician*[10]

[1]School of Population and Global Health, University of Melbourne, Carlton, Vic 3053, Australia; [2]Department of Radiology, Alfred Health, Prahran, Vic, Australia; [3]Medical Benefits Scheme Analytics Section, Department of Health and Ageing, Canberra, ACT, Australia; [4]Department of Diagnostic Imaging, Southern Health, and Monash University Southern Clinical School, Clayton, Vic, Australia; [5]Biostatistics Group, International Agency for Research on Cancer, Lyon, France; [6]Cancer Epidemiology Centre, Cancer Council Victoria, Carlton, Vic, Australia; [7]Diagnostic Imaging and Nuclear Medicine Section, Australian Radiation Protection and Nuclear Safety Agency, Yallambie, Vic, Australia; [8]Data Linkage Unit, Australian Institute of Health and Welfare, Canberra, Australia; [9]Faculty of Health, University of Canberra, Canberra, Australia; [10]Clinical Trial Service Unit and Epidemiological Studies Unit, University of Oxford, Oxford, UK; [11]Medical Imaging, Royal Children's Hospital Melbourne, Parkville, Vic, Australia

#### Abstract

**Objective** To assess the cancer risk in children and adolescents following exposure to low dose ionising radiation from diagnostic computed tomography (CT) scans.

**Design** Population based, cohort, data linkage study in Australia.

**Cohort members** 10.9 million people identified from Australian Medicare records, aged 0-19 years on 1 January 1985 or born between 1 January 1985 and 31 December 2005; all exposures to CT scans funded by Medicare during 1985-2005 were identified for this cohort. Cancers diagnosed in cohort members up to 31 December 2007 were obtained through linkage to national cancer records.

**Main outcome** Cancer incidence rates in individuals exposed to a CT scan more than one year before any cancer diagnosis, compared with cancer incidence rates in unexposed individuals.

**Results** 60 674 cancers were recorded, including 3150 in 680 211 people exposed to a CT scan at least one year before any cancer diagnosis. The mean duration of follow-up after exposure was 9.5 years. Overall cancer incidence was 24% greater for exposed than for unexposed at younger ages ($P<0.001$ for trend). At 1-4, 5-9, 10-14, and 15 or more years since first exposure, IRRs were 1.35 (1.25 to 1.45), 1.25 (1.17 to 1.34), 1.14 (1.06 to 1.22), and 1.24 (1.14 to 1.34), respectively. The IRR increased significantly for many types of solid cancer (digestive organs, melanoma, soft tissue, female genital, urinary tract, brain, and thyroid); leukaemia, myelodysplasia, and some other lymphoid cancers. There was an excess of 608 cancers in people exposed to CT scans (147 brain, 356 other solid, 48 leukaemia or myelodysplasia, and 57 other lymphoid). The absolute excess incidence rate for all cancers combined was 9.38 per 100 000 person years at risk, as of 31 December 2007. The average effective radiation dose per scan was estimated as 4.5 mSv.

**Conclusions** The increased incidence of cancer after CT scan exposure in this cohort was mostly due to irradiation. Because the cancer excess was still continuing at the end of follow-up, the eventual lifetime risk from CT scans cannot yet be determined. Radiation doses from contemporary CT scans are likely to be lower than those in 1985-2005, but some increase in cancer risk is still likely from current scans. Future CT scans should be limited to situations where there is a definite clinical indication,

# Wie gefährlich ist Strahlung?

## Uranbergbau

59.000 ehemalige Uranbergleute

Signifikant Korrelation zwischen Arbeistzeit und Krebsrisiko

21% höheres Krebsrisiko pro working level month (95% CI 18 – 24)

Rauchen ist kein Confounder

Die wahren Effekte sind vermutlich noch viel höher

BJC British Journal of Cancer

### Lung cancer risk among German male uranium miners: a cohort study, 1946–1998

B Grosche*,[1], M Kreuzer[1], M Kreisheimer[1], M Schnelzer[1] and A Tschense[1]
[1]Federal Office for Radiation Protection, Department 'Radiation Protection and Health', Ingolstaedter Landstr. 1, 85764 Oberschleissheim, Germany

From 1946 to 1990 extensive uranium mining was conducted in the southern parts of the former German Democratic Republic. The overall workforce included several 100 000 individuals. A cohort of 59 001 former male employees of the Wismut Company was established, forming a large retrospective uranium miners' cohort for the time period 1946–1998. Mean duration of follow-up was 30.5 years with a total of 1 801 630 person-years. Loss to follow-up was low at 5.3%. Of the workers, 16 598 (28.1%) died during the study period. Based on 2388 lung cancer deaths, the radon-related lung cancer risk is evaluated. The excess relative risk (ERR) per working level month (WLM) was estimated as 0.21% (95% CI: 0.18–0.24). It was dependent on time since exposure and on attained age. The highest ERR/WLM was observed 15–24 years after exposure and in the youngest age group (<55 years of age). While a strong inverse exposure-rate effect was detected for high exposures, no significant association was detected at exposures below 100 WLM. Excess relative risk /WLM was not modified by duration of exposure. The results would indicate the need to re-estimate the effects of risk modifying factors in current risk models as duration of exposure did not modify the ERR/WLM and there was only a modest decline of ERR/WLM with increasing time since exposure.
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**Keywords:** epidemiology; cohort study; uranium miners; lung cancer; radon

From 1946 to 1990 there was extensive uranium mining in the southern parts of the former German Democratic Republic (GDR). It was conducted by the Soviet-German Incorporated Company Wismut. Some 231 000 metric tons of uranium ore were produced (Wismut, 1999) and incorporated into the former Soviet Union's nuclear programme. About 400 000 persons may have worked with the company, most of them underground or in uranium ore processing facilities (Otten and Schulz, 1998). Approximately 130 000 of the workers are known. Up to 1999, 7695 workers with radiation-induced lung cancers had been compensated (Schröder *et al*, 2002). In 2000, the annual number of newly compensated cases was still almost 200 although with a decreasing trend (Koppisch *et al*, 2004).

*et al*, 2004; Kreisheimer, 2006), yet further follow-up was only conducted for the Czech (Tomásek, 2002; Tomásek and Zarska, 2004) and the French cohort (Rogel *et al*, 2002; Laurier *et al*, 2004). Although the evidence of a radon-related lung cancer risk among miners is large, it is based upon various heterogeneous cohorts for which the cohort-specific risk estimates vary by more than an order of magnitude. The new German cohort is as big as all the 11 cohorts put together, but less heterogeneous in various aspects: same societal and geographical background, same way of follow-up, and one system for exposure estimation.

The aim of the present analysis was to evaluate the lung cancer risk associated with radon and its progeny due to cumulative radon exposure, exposure rate, duration of exposure, time since exposure, and attained age.

# Wie gefährlich ist Strahlung?

## Atomindustrie

154 Lokalitäten
598.000 Arbeiter
> 90% hatten Exposition < 50 mSv

Solide Tumoren: 97% höheres Risiko pro Sv (95% CI 14 - 197)

Leukämie: 193% höheres Risiko pro Sv (95% CI 0 - 847)

1-2% aller Todesfälle bei Atomarbeiter waren vermutlich strahlenbedingt

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### Risk of cancer after low doses of ionising radiation: retrospective cohort study in 15 countries

E Cardis, M Vrijheid, M Blettner, E Gilbert, M Hakama, C Hill, G Howe, J Kaldor, C R Muirhead, M Schubauer-Berigan, T Yoshimura, F Bermann, G Cowper, J Fix, C Hacker, B Heinmiller, M Marshall, I Thierry-Chef, D Utterback, Y-O Ahn, E Amoros, P Ashmore, A Auvinen, J-M Bae, J Bernar Solano, A Biau, E Combalot, P Deboodt, A Diez Sacristan, M Eklof, H Engels, G Engholm, G Gulis, R Habib, K Holan, H Hyvonen, A Kerekes, J Kurtinaitis, H Malker, M Martuzzi, A Mastauskas, A Monnet, M Moser, M S Pearce, D B Richardson, F Rodriguez-Artalejo, A Rogel, H Tardy, M Telle-Lamberton, I Turai, M Usel, K Veress

#### Abstract

**Objectives** To provide direct estimates of risk of cancer after protracted low doses of ionising radiation and to strengthen the scientific basis of radiation protection standards for environmental, occupational, and medical diagnostic exposures.
**Design** Multinational retrospective cohort study of cancer mortality.
**Setting** Cohorts of workers in the nuclear industry in 15 countries.
**Participants** 407 391 workers individually monitored for external radiation with a total follow-up of 5.2 million person years.
**Main outcome measurements** Estimates of excess relative risks per sievert (Sv) of radiation dose for mortality from cancers other than leukaemia and from leukaemia excluding chronic lymphocytic leukaemia, the main causes of death considered by radiation protection authorities.
**Results** The excess relative risk for cancers other than leukaemia was 0.97 per Sv, 95% confidence interval 0.14 to 1.97. Analyses of causes of death related or unrelated to smoking indicate that, although confounding by smoking may be present, it is unlikely to explain all of this increased risk. The excess relative risk for leukaemia excluding chronic lymphocytic leukaemia was 1.93 per Sv (< 0 to 8.47). On the basis of these estimates, 1-2% of deaths from cancer among workers in this cohort may be attributable to radiation.
**Conclusions** These estimates, from the largest study of nuclear workers ever conducted, are higher than, but statistically compatible with, the risk estimates used for current radiation protection standards. The results suggest that there is a small excess risk of cancer, even at the low doses and dose rates typically received by nuclear workers in this study.

by the public in the general environment, by patients through repeated diagnostic procedures,[4] and by radiation workers.

The effects of low dose chronic exposure to external radiation have been directly estimated in several cohorts of workers in the nuclear industry,[5] but the sample size has limited the precision of these estimates. Analyses of combined cohorts have improved precision.[6-9] Estimates from these analyses, however, are compatible with a range of possibilities, from a reduction of risk at low doses to risks higher than those underlying current radiation protection recommendations.

The 15 country study, an international collaborative study of cancer risk among radiation workers in the nuclear industry, was carried out to further improve the precision of direct estimates of risk after protracted low dose exposures and to strengthen the scientific basis of radiation protection.[1] We present risk estimates for mortality from all cancers, excluding leukaemia, and from leukaemia excluding chronic lymphocytic leukaemia and compare them with estimates derived from data on survivors of the A bomb. We have used the term nuclear industry to refer to facilities engaged in production of nuclear power, manufacture of nuclear weapons, enrichment and processing of nuclear fuel, production of radioisotopes, or reactor or weapons research. Uranium mining is not included.

#### Methods

This multinational retrospective cohort study used a common protocol in 15 countries and collected information on nearly 600 000 workers. Study cohorts were defined from employment or dosimetric records of participating facilities or, where available, from centralised national dose registries. The a priori eligibility criteria for inclusion of cohorts[1] were essentially complete and non-selective follow-up for mortality;

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## Atomindustrie

Signifikant erhöhtes Krebsrisiko bei Kindern < 5 Jahren innerhalb von 50 km rund um AKWs

Confounder konnten nicht identifiziert werden.

IJC International Journal of Cancer

### Leukaemia in young children living in the vicinity of German nuclear power plants

Peter Kaatsch*, Claudia Spix, Renate Schulze-Rath, Sven Schmiedel and Maria Blettner
*Institute for Medical Biostatistics, Epidemiology and Informatics, German Childhood Cancer Registry, Obere Zahlbacher Strasse 69, 55131 Mainz, Germany*

**A case control study was conducted where cases were children younger than 5 years (diseased between 1980 and 2003) registered at the german childhood cancer registry (GCCR). Population-based matched controls (1:3) were selected from the corresponding registrar's office. Residential proximity to the nearest nuclear power plant was determined for each subject individually (with a precision of about 25 m). The report is focused on leukaemia and mainly on cases in the inner 5-km zone around the plants. The study includes 593 leukaemia cases and 1,766 matched controls. All leukaemia combined show a statistically significant trend for 1/distance with a positive regression coefficient of 1.75 [lower 95%-confidence limit (CL): 0.65]; for acute lymphoid leukaemia 1.63 (lower 95%-CL: 0.39), for acute non-lymphocytic leukaemia 1.99 (lower 95%-CL: −0.41). This indicates a negative trend for distance. Cases live closer to nuclear power plants than the randomly selected controls. A categorical analysis shows a statistically significant odds ratio of 2.19 (lower 95%-CL: 1.51) for residential proximity within 5 km compared to residence outside this area. This result is largely attributed to cases in previous studies of the GCCR (especially in the inner zone) as there is clearly some overlap between those studies. The result was not to be expected under current radiation-epidemiological knowledge. Considering that there is no evidence of relevant accidents and that possible confounders could not be identified, the observed positive distance trend remains unexplained.**
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**Key words:** childhood; leukaemia; nuclear power plants; population-based; cancer registry

reports prompted a study of almost identical design that was based on the data of the German Childhood Cancer Registry (GCCR) and was conducted in the late 1980s. This was an ecological study comparing disease rates within 15 km (roughly 10 miles) of German nuclear plants with those seen in specified control areas. The study period extended from 1980 through 1990 (Study 1). An increased rate of all cancer or, more specifically, leukaemia in children younger than 15 years within a 15-km zone of West German nuclear plants was not confirmed. However, exploratory analyses indicated that, for example, in children younger than 5 years living within the inner 5-km zone, the increase in leukaemia rate was statistically significant.[15] As these results gave rise to controversial discussion and as at the same time a statistically significant leukaemia cluster was seen near the North German nuclear power plant of Krümmel,[16] the study period was extended to cover the years 1991 through 1995 (Study 2).

Study 2 failed to reproduce statistically significant results regarding the subgroup for which results were significantly increased in the exploratory analysis of Study 1. Nevertheless, a tendency was seen towards an increased relative risk (RR) for leukaemia to occur in under 5-year-olds within the 5-km vicinity.[17]

Even after these results had been published, discussions on a potential relationship between the occurrence of childhood leukaemia and close proximity to nuclear plants in routine operation have not ceased. For this reason, a case control study was initiated by the Federal government and started at the GCCR in 2003.

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# Wie gefährlich ist Strahlung?

## Atomindustrie

16.000 (3.400-72.000) Schilddrüsenkrebsfälle in Europa durch Tschernobyl

25.000 (11.000-59.000) andere Krebsfälle in Europa

> 15.000 strahlenbedingte Krebstodesfälle in Europa

IJC International Journal of Cancer

### Estimates of the cancer burden in Europe from radioactive fallout from the Chernobyl accident

Elisabeth Cardis[1*], Daniel Krewski[2], Mathieu Boniol[1], Vladimir Drozdovitch[1], Sarah C. Darby[3], Ethel S. Gilbert[4], Suminori Akiba[5], Jacques Benichou[6], Jacques Ferlay[1], Sara Gandini[7], Catherine Hill[8], Geoffrey Howe[9], Ausrele Kesminiene[1], Mirjana Moser[10], Marie Sanchez[1], Hans Storm[11], Laurent Voisin[1] and Peter Boyle[1]

[1]*International Agency for Research on Cancer, Lyon, France*
[2]*McLaughlin Centre for Population Health Risk Assessment, Institute of Population Health, University of Ottawa, Ottawa, Ontario, Canada*
[3]*Clinical Trial Service Unit, University of Oxford, United Kingdom*
[4]*Radiation Epidemiology Branch, Division of Epidemiology and Genetics, National Cancer Institute, Bethesda, MD, USA*
[5]*Kagoshima University, Graduate School of Medical and Dental Sciences, Kagoshima, Japan*
[6]*Biostatistics Unit, University of Rouen Medical School and Rouen University Hospital, Rouen, France*
[7]*European Institute of Oncology, Milano, Italy*
[8]*Institut Gustave-Roussy, Villejuif, France*
[9]*Department of Epidemiology, Mailman School of Public Health, Columbia University, New York, NY, USA*
[10]*Federal Office of Public Health, Bern, Switzerland*
[11]*Danish Cancer Society, Copenhagen, Denmark*

**The Chernobyl accident, which occurred April 26, 1986, resulted in a large release of radionuclides, which were deposited over a very wide area, particularly in Europe. Although an increased risk of thyroid cancer in exposed children has been clearly demonstrated in the most contaminated regions, the impact of the accident on the risk of other cancers as well as elsewhere in Europe is less clear. The objective of the present study was to evaluate the human cancer burden in Europe as a whole from radioactive fallout from the accident. Average country- and region-specific whole-body and thyroid doses from Chernobyl were estimated using new dosimetric models and radiological data. Numbers of cancer cases and deaths possibly attributable to radiation from Chernobyl were estimated, applying state-of-the-art risk models derived from studies of other irradiated populations. Simultaneously, trends in cancer incidence and mortality were examined over time and by dose level. The risk projections suggest that by now Chernobyl may have caused about 1,000 cases of thyroid cancer and 4,000 cases of other cancers in Europe, representing about 0.01% of all incident cancers since the accident. Models predict that by 2065 about 16,000 (95% UI 3,400–72,000) cases of thyroid cancer and 25,000 (95% UI 11,000–59,000) cases of other cancers may be expected due to radiation from the accident, whereas**

Epidemiological studies focusing on the most contaminated regions of the 3 most affected countries have confirmed a causal relationship between the observed increased risk of thyroid cancer and exposure to radioactive iodines from the Chernobyl fallout among those who were children or adolescents when the accident happened.[3–5] Other types of cancer, including leukemia, have also been investigated,[1,6–17] but as yet no association with radiation exposure has been clearly demonstrated. Recent studies suggest a possible doubling of the risk of leukemia among Chernobyl cleanup workers[18] and a small increase in the incidence of premenopausal breast cancer[19] in the most contaminated districts (with average whole-body doses above 40 mSv), both of which appear to be related to radiation dose. These findings need confirmation in further epidemiological studies with careful individual dose reconstruction.

The full extent of the health impact of Chernobyl on the population is difficult to gauge. Ten years ago, Cardis and collaborators[20] estimated that about 9,000 deaths from cancers and leukemia might be expected over the course of a lifetime in the most exposed populations in Belarus, the Russian Federation and

# Wie gefährlich ist Strahlung?

## Nicht-Krebserkrankungen

Meta-Analyse von 10 peer-reviewed Studien von:

- Atomarbeitern
- Berufsmäßig strahlenexponierten
- Hibakusha

Das Risiko von kardiovaskulären Erkrankungen stieg um 1–13 % pro Sv

Korrelation von kardiovaskulärer Mortalität und Strahlendois ähnlich zur Korrelation von Krebsmortalität und Strahlendosis (~5 % pro Sv)

ehp ENVIRONMENTAL HEALTH PERSPECTIVES

### Systematic Review and Meta-analysis of Circulatory Disease from Exposure to Low-Level Ionizing Radiation and Estimates of Potential Population Mortality Risks

*Mark P. Little,[1] Tamara V. Azizova,[2] Dimitry Bazyka,[3] Simon D. Bouffler,[4] Elisabeth Cardis,[5] Sergey Chekin,[6] Vadim V. Chumak,[3] Francis A. Cucinotta,[7] Florent de Vathaire,[8] Per Hall,[9] John D. Harrison,[4] Guido Hildebrandt,[10,11] Victor Ivanov,[6] Valeriy V. Kashcheev,[6] Sergiy V. Klymenko,[3] Michaela Kreuzer,[12] Olivier Laurent,[13] Kotaro Ozasa,[14] Thierry Schneider,[15] Soile Tapio,[16] Andrew M. Taylor,[17] Ioanna Tzoulaki,[18] Wendy L. Vandoolaeghe,[18] Richard Wakeford,[19] Lydia B. Zablotska,[20] Wei Zhang,[4] and Steven E. Lipshultz[21]*

[1]Radiation Epidemiology Branch, National Cancer Institute, National Institutes of Health, Department of Health and Human Services, Rockville, Maryland, USA; [2]Southern Urals Biophysics Institute, Ozyorsk, Russia; [3]Research Center for Radiation Medicine, Kyiv, Ukraine; [4]Health Protection Agency, Centre for Radiation, Chemical and Environmental Hazards, Chilton, United Kingdom; [5]Center for Research in Environmental Epidemiology (CREAL), Barcelona, Spain; [6]Medical Radiological Research Center of Russian Academy of Medical Sciences, Obninsk, Russia; [7]NASA Johnson Space Center, Space Radiation Program, Houston, Texas, USA; [8]Radiation Epidemiology Group, INSERM (Institut National de la Santé et de la Recherche Médicale) Unité U1018, Institut Gustave Roussy, Villejuif, France; [9]Department of Medical Epidemiology and Biostatistics, Karolinska Institute, Stockholm, Sweden; [10]Department of Radiotherapy and Radiation Oncology, University of Leipzig, Leipzig, Germany; [11]Department of Radiotherapy and Radiation Oncology, University of Rostock, Rostock, Germany; [12]Federal Office for Radiation Protection, Department of Radiation Protection and Health, Oberschleissheim, Germany; [13]Laboratoire d'Epidémiologie, Institut de Radioprotection et de Sûreté Nucléaire, Fontenay-aux-Roses, France; [14]Department of Epidemiology, Radiation Effects Research Foundation, Hiroshima City, Japan; [15]CEPN (Nuclear Evaluation Protection Center), Fontenay-aux-Roses, France; [16]Helmholtz Zentrum München, German Research Centre for Environmental Health, Institute of Radiation Biology (ISB), Radiation Proteomics, Oberschleissheim, Germany; [17]University College London Institute of Cardiovascular Sciences & Great Ormond Street Hospital for Children, London, United Kingdom; [18]Department of Epidemiology and Biostatistics, Imperial College Faculty of Medicine, London, United Kingdom; [19]Dalton Nuclear Institute, University of Manchester, Manchester, United Kingdom; [20]Department of Epidemiology and Biostatistics, University of California San Francisco School of Medicine, San Francisco, California, USA; [21]Department of Pediatrics, Leonard M. Miller School of Medicine, University of Miami, Miami, Florida, USA

BACKGROUND: Although high doses of ionizing radiation have long been linked to circulatory disease, evidence for an association at lower exposures remains controversial. However, recent analyses suggest excess relative risks at occupational exposure levels.

OBJECTIVES: We performed a systematic review and meta-analysis to summarize information on circulatory disease risks associated with moderate- and low-level whole-body ionizing radiation exposures.

METHODS: We conducted PubMed/ISI Thomson searches of peer-reviewed papers published since 1990 using the terms "radiation" AND "heart" AND "disease," OR "radiation" AND "stroke," OR "radiation" AND "circulatory" AND "disease." Radiation exposures had to be whole-body, with a cumulative mean dose of < 0.5 Sv, or at a low dose rate (< 10 mSv/day). We estimated population risks of circulatory disease from low-level radiation exposure using excess relative risk estimates from this meta-analysis and current mortality rates for nine major developed countries.

RESULTS: Estimated excess population risks for all circulatory diseases combined ranged from 2.5%/Sv [95% confidence interval (CI): 0.8, 4.2] for France to 8.5%/Sv (95% CI: 4.0, 13.0) for Russia.

CONCLUSIONS: Our review supports an association between circulatory disease mortality and low and moderate doses of ionizing radiation. Our analysis was limited by heterogeneity among studies (particularly for noncardiac end points), the possibility of uncontrolled confounding in some occupational groups by lifestyle factors, and higher dose groups (> 0.5 Sv) generally driving the observed trends. If confirmed, our findings suggest that overall radiation-related mortality is about twice that currently estimated based on estimates for cancer end points alone (which range from 4.2% to 5.6%/Sv for these populations).

KEY WORDS: cancer, circulatory disease, heart disease, radiation, stroke. *Environ Health Perspect* 120:1503–1511 (2012). http://dx.doi.org/10.1289/ehp.1204982 [Online 22 June 2012]

a review by the Health Protection Agency's AGIR in the United Kingdom estimated substantial excess risks for ischemic heart disease (IHD) and stroke, but concluded that a significantly elevated risk was detectable only for exposures above about 0.5 Gy (AGIR 2010).

Address correspondence to M.P. Little, Radiation Epidemiology Branch, National Cancer Institute, Executive Plaza South, 6120 Executive Blvd. MSC 7238, Rockville, MD 20852-7238 USA. Telephone: (301) 402-9138 (office); (301) 875-3413 (mobile). Fax: (301) 402-0207. E-mail: mark.little@nih.gov

Supplemental Material is available online (http://dx.doi.org/10.1289/ehp.1204982).

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# Wie gefährlich ist Strahlung?

## Nicht-Krebserkrankungen

Ca. 3.000 Kinder nach Strahlentherapie für kutane Hämangiome

Exakte Dosiskalukation
(durchschnittl. Hirndosis < 100 mGy)

Negative Dosis-Wirkungs-Kurve:
- Lernfähigkeit
- Logisches Denken
- Räumliche Vorstellungskraft
- Oberschulreife

BMJ Helping doctors make better decisions

### Effect of low doses of ionising radiation in infancy on cognitive function in adulthood: Swedish population based cohort study

Per Hall, Hans-Olov Adami, Dimitrios Trichopoulos, Nancy L Pedersen, Pagona Lagiou, Anders Ekbom, Martin Ingvar, Marie Lundell, Fredrik Granath

Abstract

**Objective** To determine whether exposure to low doses of ionising radiation in infancy affects cognitive function in adulthood.
**Design** Population based cohort study.
**Setting** Sweden.
**Participants** 3094 men who had received radiation for cutaneous haemangioma before age 18 months during 1930-59.
**Main outcome measures** Radiation dose to frontal and posterior parts of the brain, and association between dose and intellectual capacity at age 18 or 19 years based on cognitive tests (learning ability, logical reasoning, spatial recognition) and high school attendance.
**Results** The proportion of boys who attended high school decreased with increasing doses of radiation to both the frontal and the posterior parts of the brain from about 32% among those not exposed to around 17% in those who received >250 mGy. For the frontal dose, the multivariate odds ratio was 0.47 (95% confidence interval 0.26 to 0.85, P for trend 0.0003) and for the posterior dose it was 0.59 (0.23 to 1.47, 0.0005). A negative dose-response relation was also evident for the three cognitive tests for learning ability and logical reasoning but not for the test of spatial recognition.
**Conclusions** Low doses of ionising radiation to the brain in infancy influence cognitive abilities in adulthood.

We analysed cognitive function in a large population based cohort of men at the time of military enlistment who had received low dose ionising radiation for cutaneous haemangioma before age 18 months. Based on previous experience, we hypothesised that damage to the frontal part of the brain would have a more severe effect on mental capacity than damage to the posterior part.[11]

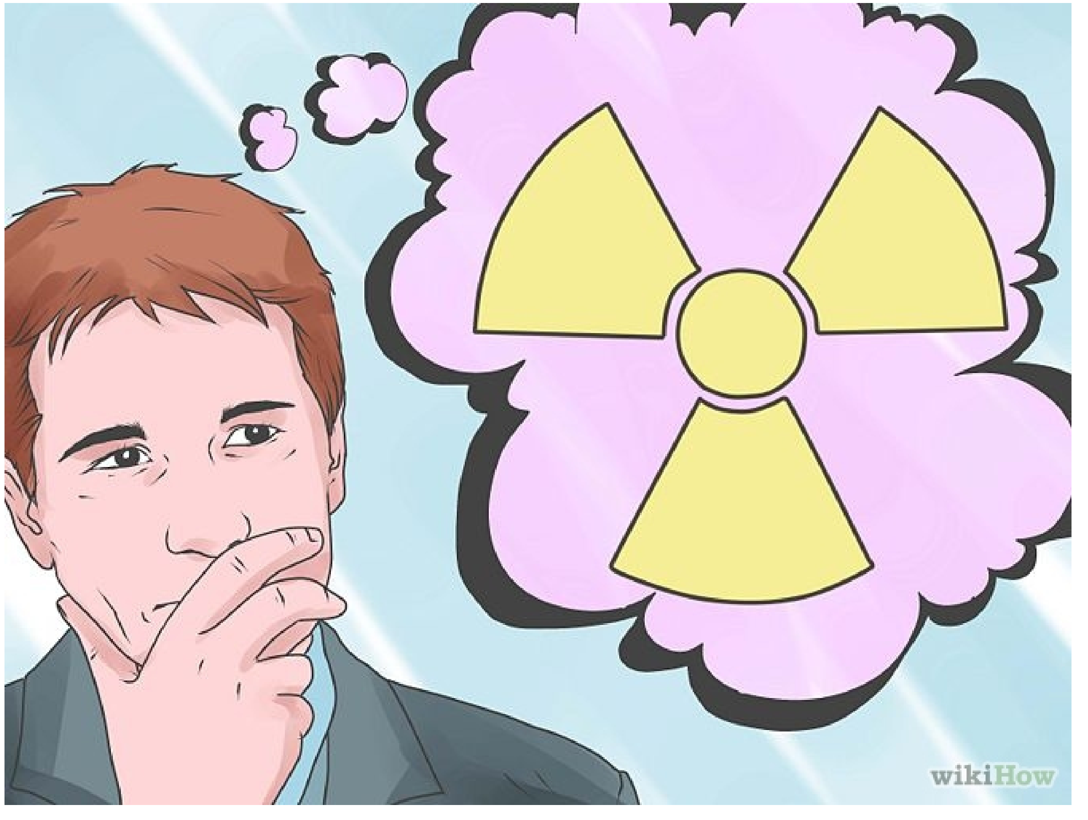
#### Participants and methods

Our cohort comprised all boys treated by radiotherapy for cutaneous haemangioma aged under 18 months at the Karolinska University Hospital in Stockholm. This cohort has been described in detail previously.[12-17]

Around 95% of Swedish men aged 18 or 19 years are tested before military service. During the period of our study, about 2% of the men tested were exempted from military service for medical or psychological reasons. We were given permission to search the Swedish war archives.

From the military register we obtained information on age at enlistment, education, number of siblings, birth order, father's occupation, and cognitive test results. Father's occupation, a proxy for socioeconomic status, was categorised into four groups: unknown and farmers, blue collar workers, low level white collar workers, and high level white collar workers. Categorisation was based on the socioeconomic index, which takes education into consideration.

# Vielen Dank für eure Aufmerksamkeit

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