Risk of ionising radiation – an introduction
Basics, facts, recent research

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(IPPNW Feb. 27th, 2016)
Natural radiation – no risk ?!
Average effective dose: Radon (2013)

(1 m above ground)
(outdoor time 5 h/d)
**Indoor radon - status**

Pooled analysis of 7 US-studies (New Jersey, Winnipeg, Missouri, Iowa, Connecticut, Utah, Idaho)

N=3662 cases (of these 2556 women), N=4966 controls (3596 women)

- nuclear track dosimeter, 12 months measurement, living room, bedroom; address with longest duration

Conditional logistic regression (cum. exposure 5-30 years prior to 1\textsuperscript{st} Dx)

- Age at 1\textsuperscript{st} Dx (<60, 60-64, 65.69, 70-74, 75+ years)
- Cigarette smoking
  - cigarettes/d: Never-smokers, 1-9, 10-19, 20-29, 30+ /d
  - duration of smoking: Never-smokers, 1-24, 25-34, 35-44, 45+ years
- total number of livelong addresses (<3, 3+)

BEIR VI: 10-15\% of all lung cancers (US: 15,000-23,000 of a total of 157,400/J)

[Extrapolation from results for miners: 1.12 (1.02-1.25)]

(n.s. tendency toward higher risks for SCLC, lower risks for older ages; no difference: gender, years of education, smoking status, specific studies)

**Increased risks in subgroups with better exposure assessment**

(e.g. time in residence >25 J: 0.21 (0.03-0.52))
Attributable fraction for lung cancer due to indoor radon in Switzerland and Germany, compared to outdoor air concentrations of 10 Bq/m$^3$ (Switzerland) and 9 Bq/m$^3$ (Germany). Based on European indoor model after measurement error correction and likewise corrected radon distribution, calculated separately for gender and smoking.

<table>
<thead>
<tr>
<th>Gender</th>
<th>Smoking status</th>
<th>PAF in %</th>
<th>95% CI</th>
<th># cases per year</th>
<th>95% CI</th>
</tr>
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<tbody>
<tr>
<td></td>
<td></td>
<td>Switzerland</td>
<td></td>
<td>Germany</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Men</td>
<td>Non-smoker</td>
<td>8.8</td>
<td>3.3</td>
<td>23.2</td>
<td>5</td>
</tr>
<tr>
<td>Men</td>
<td>Smoker</td>
<td>8.2</td>
<td>3.1</td>
<td>21.5</td>
<td>164</td>
</tr>
<tr>
<td>Women</td>
<td>Non-smoker</td>
<td>8.8</td>
<td>3.3</td>
<td>23.2</td>
<td>8</td>
</tr>
<tr>
<td>Women</td>
<td>Smoker</td>
<td>8.6</td>
<td>3.2</td>
<td>22.6</td>
<td>54</td>
</tr>
<tr>
<td>Sum</td>
<td></td>
<td>8.3</td>
<td></td>
<td></td>
<td>231</td>
</tr>
</tbody>
</table>

Outdoor environmental radiation exposure 2013 in Germany
(assumption: 5 hours/d, based on ground level γ-dose rate measurements)

Updated estimates of the proportion of childhood leukaemia incidence in Great Britain that may be caused by natural background ionising radiation

Mark P Little¹,⁴, Richard Wakeford² and Gerald M Kendall³

Abstract
The aetiology of childhood leukaemia remains generally unknown, although

Using the newer dosimetry we calculate that the best estimate of the proportion of cases of childhood leukaemia in Great Britain predicted to be attributable to this source of exposure is 15–20%.

In this paper we employ the same set of published leukaemia risk models used previously, but use recently published revised estimates of natural background radiation doses received by the red bone marrow of British children to update the previous results. Using the newer dosimetry we calculate that the best estimate of the proportion of cases of childhood leukaemia in Great Britain predicted to be attributable to this source of exposure is 15–20%, although the uncertainty associated with certain stages in the calculation (e.g. the nature of the transfer of risk between populations and the pertinent dose received from naturally occurring alpha-particle-emitting radionuclides) is significant. The slightly lower attributable proportions compared with those previously derived by Wakeford et al (Leukaemia 2009 23 770–6) are largely due to the lower doses (and in particular lower high LET doses) for the first year of life.

Background Ionizing Radiation and the Risk of Childhood Cancer: A Census-Based Nationwide Cohort Study

Ben D. Spycher, Judith E. Lupatsch, Marcel Zwahlen, Martin Röösli, Felix Niggli, Michael A. Grotzer, Johannes Rischewski, Matthias Egger, and Claudia E. Kuehni for the Swiss Pediatric Oncology and the Swiss National Cohort Study Group

http://dx.doi.org/10.1289/ehp.1408548

Received: 11 April 2014
Accepted: 28 January 2015
Advance Publication: 23 February 2015
Figure 2. Hazard ratios for cancer by dose rate of external ionizing radiation among children aged <16 years in the Swiss National Cohort. Results from Cox proportional hazards models adjusting for sex and birth year using a categorized exposure (points and bars [95% CIs] placed along the x-axis at mean dose rates within categories; categories delineated by vertical lines) and a linear exposure term (red line). Dose rates <100 nSv/h are the reference category. CNS central nervous system.

0.95 mSv/J  2.19 mSv/J
Radiation from nuclear disasters
Nuclear accidents

Health detriment of Chernobyl:

→ 16,000 (3,400-72,000) incident thyroid cancers

→ 25,000 (11,000-59,000) incident other cancers

→ 15,000 excess cancer deaths

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

Elisabeth Cardis, Daniel Krewski, Mathieu Boniol, Vladimir Drozdovitch, Sarah C. Darby, Ethel S. Gilbert, Suminori Akiba, Jacques Benichou, Jacques Ferlay, Sara Gandini, Catherine Hill, Geoffrey Howe, Ausrele Kesminiene, Mirjana Moser, Marie Sanchez, Hans Storni, Laurent Voisin, and Peter Boyle

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9Department of Epidemiology, Mailman School of Public Health, Columbia University, New York, NY, USA
10Federal Office of Public Health, Bern, Switzerland
11Danish 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 elsewhere in Europe is less clear. The objective of the present study was to evaluate the human cancer burden caused by the Chernobyl accident in Europe as a whole from radioactivity 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 2050 about 4,000 (95% U.I. 3,200-71,000) cases of thyroid cancer and 25,000 (95% U.I. 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 increase in risk of thyroid cancer and exposure to radioactive iodines from the Chernobyl fallout among those who were children or adolescents when the accident happened. Other types of cancer, including leukemia, have also been investigated 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 and a small increase in the incidence of premenopausal breast cancer 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 estimated that about 9,000 deaths from cancers and leukaemia might be expected over the course of a lifetime in the most exposed populations in Belarus, the Russian Federation and
Fig. 1. Cesium-137 deposition maps. (A) Relative deposition contributions between March 11 and 19, showing the areas potentially effected by $^{137}$Cs before the start of measurements. The sums of the depositions during the period were divided by the maximum deposition in the accumulated field. (B) The same as in A, but for March 20–April 19. (C) An example of estimated daily deposition of $^{137}$Cs on March 21. Squares in black denote the observation locations in each prefecture (Table S2). (D) Daily accumulated rainfall on March 21 by TRMM.

The first Fukushima-cancer case

Government recognizes causation by occupational radiation exposure
CANUPIS study strengthens evidence of increased leukaemia rates near nuclear power plants
From ALFRED KOERBLEIN

### Table 1 SIR and RR near Swiss, British and German nuclear power stations

<table>
<thead>
<tr>
<th>Data set</th>
<th>O</th>
<th>E</th>
<th>SIR</th>
<th>P-value*</th>
<th>RR</th>
<th>P-value**</th>
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<tbody>
<tr>
<td><strong>Switzerland (CH)</strong></td>
<td></td>
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<tr>
<td>0–5 km</td>
<td>11</td>
<td>7.87</td>
<td>1.40</td>
<td>0.3431</td>
<td>1.46</td>
<td>0.3334</td>
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<tr>
<td>5–15 km</td>
<td>54</td>
<td>56.40</td>
<td>0.96</td>
<td></td>
<td></td>
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<tr>
<td><strong>Great Britain (GB)</strong></td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>&lt;5 km</td>
<td>20</td>
<td>14.74</td>
<td>1.36</td>
<td>0.2216</td>
<td>1.41</td>
<td>0.1715</td>
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<tr>
<td>&gt;5 km</td>
<td>1579</td>
<td>1640.44</td>
<td>0.96</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Germany (D)</strong></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>&lt;5 km</td>
<td>34</td>
<td>24.09</td>
<td>1.41</td>
<td>0.0656</td>
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<td>0.0549</td>
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<tr>
<td>&gt;5 km</td>
<td>585</td>
<td>599.58</td>
<td>0.98</td>
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<td></td>
</tr>
<tr>
<td><strong>CH + GB + D</strong></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>&lt;5 km</td>
<td>65</td>
<td>46.70</td>
<td>1.39</td>
<td>0.0130</td>
<td>1.44</td>
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<td>&gt;5 km</td>
<td>2218</td>
<td>2296.42</td>
<td>0.97</td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

*P-value (Poisson distribution).
**P-value (Binomial distribution).
Epidemiology: „Classical“ cohorts

Atomic bomb survivors in Hiroshima and Nagasaki

**Cohort**: Life Span Study (LSS) of the RERF (establ. 1950-’52)

**N** ≈ 100,000 participants (all ages)

**Average dose of the exposed**: 270 mSv

**Problems:**

- up to 200,000 casualties – survivors are selection of healthy/resilient
- initiation of assessment 5-7 years after the nuclear bomb
- „unexposed“ control group sampled from fallout-area

Shimizu, JAMA 1990 (pap 4174)
Selection Bias in Cancer Risk Estimation from A-Bomb Survivors

Donald A. Pierce, Michael Vaeth and Yukiko Shimizu

Department of Statistics, Radiation Effects Research Foundation, Hiroshima, Japan; Department of Biostatistics, Aarhus University, Aarhus, Denmark; and Department of Epidemiology, Radiation Effects Research Foundation, Hiroshima, Japan

FIG. 1. Solid cancer apparent radiation risk in terms of both dose and distance from the bombs.

FIG. 2. Solid cancer risk estimation based on restricted dose–distance ranges to reduce differential selection. Error bars are 90% confidence limits.

We consider the possible bias in cancer risk estimation from A-bomb survivors due to selection of the cohort by survival.

For solid cancer this would correspond to bias in the excess relative risk at 1 Sv of at most about 15–20%.
Radiation epidemiology: quantifying risk

A. cancer
Childhood cancer (<15 years) following prenatal exposure

Excess relative risk

### Table 1. Details of the case–control studies that have investigated the influence upon the risk of leukaemia in childhood of antenatal diagnostic exposure to ionising radiation, and the unadjusted relative risk of childhood leukaemia associated with such exposure that may be derived from each study.

<table>
<thead>
<tr>
<th>Case–control study</th>
<th>Study Précis</th>
<th>Number of cases (exposed/total)</th>
<th>Amount of statistical information</th>
<th>Relative risk (unadjusted)</th>
<th>95% confidence interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bithell and Stewart, 1972</td>
<td>GB (OSCC); deaths, 1953–1967</td>
<td>569/4052</td>
<td>297</td>
<td>1.49</td>
<td>(1.33, 1.67)</td>
</tr>
<tr>
<td>Hirayama, 1979</td>
<td>Japan; incident cases, 1969–1977</td>
<td>738/4628</td>
<td>296</td>
<td>1.60</td>
<td>(1.42, 1.79)</td>
</tr>
<tr>
<td>Monson and MacMahon, 1965</td>
<td>NE USA; deaths, 1947–1960</td>
<td>94/704</td>
<td>76</td>
<td>1.48</td>
<td>(1.18, 1.85)</td>
</tr>
<tr>
<td>Robnett and Jablon, 1976</td>
<td>USA (military hospitals); deaths, 1960–1969</td>
<td>64/429</td>
<td>44</td>
<td>1.08</td>
<td>(0.80, 1.46)</td>
</tr>
<tr>
<td>Naumburg et al., 2001</td>
<td>Sweden; incident cases, 1973–1989</td>
<td>68/624</td>
<td>29</td>
<td>1.13</td>
<td>(0.78, 1.63)</td>
</tr>
<tr>
<td>Roman et al., 2005</td>
<td>England &amp; Wales (UKCSS); incident cases, 1992–1996</td>
<td>37/1196</td>
<td>28</td>
<td>1.05</td>
<td>(0.73, 1.52)</td>
</tr>
<tr>
<td>Shu et al., 2002</td>
<td>North America (CCGG); ALL incident cases, 1989–1993</td>
<td>55/1809</td>
<td>26</td>
<td>1.16</td>
<td>(0.79, 1.71)</td>
</tr>
<tr>
<td>Polhemus and Koch, 1989</td>
<td>Los Angeles; incident cases, 1950–1967</td>
<td>66/251</td>
<td>23</td>
<td>1.23</td>
<td>(0.82, 1.85)</td>
</tr>
<tr>
<td>Infante-Rivard, 2003</td>
<td>Quebec; ALL incident cases, 1980–1998</td>
<td>42/791</td>
<td>21</td>
<td>0.85</td>
<td>(0.56, 1.30)</td>
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<tr>
<td>Hepton et al., 1985</td>
<td>N. England; leukaemia and lymphoma, incident cases, 1980–1983</td>
<td>37/245</td>
<td>19</td>
<td>1.35</td>
<td>(0.86, 2.11)</td>
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<td>Kaplan, 1958</td>
<td>California; acute leukaemia deaths, 1955–1956</td>
<td>40/150</td>
<td>17</td>
<td>1.60</td>
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<td>Graham et al., 1960</td>
<td>USA ‘tri-state’; incident cases, 1959–1962</td>
<td>27/313</td>
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<td>van Steenel-Moll et al., 1985</td>
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<td>41/517</td>
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<td>Ford et al., 1959</td>
<td>Louisiana; deaths, 1951–1955</td>
<td>21/78</td>
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<td>1.71</td>
<td>(0.96, 3.06)</td>
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<td>Stewart, 1973</td>
<td>GB (OSCC) twins; deaths, 1953–1964</td>
<td>51/70</td>
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<td>2.17</td>
<td>(1.19, 3.95)</td>
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<td>Salonen, 1976</td>
<td>Finland; incident cases, 1959–1968</td>
<td>15/300</td>
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<td>(0.54, 1.90)</td>
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<td>Agar et al., 1965</td>
<td>Minnesota; deaths, 1953–1957</td>
<td>20/107</td>
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<td>1.27</td>
<td>(0.68, 2.37)</td>
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<td>Roman et al., 1973</td>
<td>S England; incident cases, 1962–1992</td>
<td>16/143</td>
<td>10</td>
<td>0.72</td>
<td>(0.39, 1.34)</td>
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<td>Golding et al., 1992</td>
<td>SW England; incident cases, 1971–1991</td>
<td>14/63</td>
<td>9</td>
<td>2.03</td>
<td>(1.06, 3.88)</td>
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<td>Fajardo-Gutiérrez et al., 1993</td>
<td>Mexico City; incident cases, 1971–1991</td>
<td>16/80</td>
<td>7</td>
<td>1.89</td>
<td>(0.91, 3.95)</td>
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<tr>
<td>Magrini et al., 1990</td>
<td>Turin; AL incident cases, 1981–1984</td>
<td>10/146</td>
<td>6</td>
<td>1.09</td>
<td>(0.49, 2.24)</td>
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<tr>
<td>Rodvall et al., 1999</td>
<td>Swedish twins; incident cases, 1952–1983</td>
<td>10/27</td>
<td>5</td>
<td>1.83</td>
<td>(0.77, 4.17)</td>
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<tr>
<td>Gunz and Atkinson, 1964</td>
<td>New Zealand; incident cases, 1954–1961</td>
<td>14/102</td>
<td>5</td>
<td>1.11</td>
<td>(0.47, 2.61)</td>
</tr>
</tbody>
</table>

**Table 1. Continued**

<table>
<thead>
<tr>
<th>Case–control study</th>
<th>Study Précis</th>
<th>Number of cases (exposed/total)</th>
<th>Amount of statistical information</th>
<th>Relative risk (unadjusted)</th>
<th>95% confidence interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shu et al., 1988</td>
<td>Shanghai; incident cases, 1974–1986</td>
<td>8/309</td>
<td>4</td>
<td>1.86</td>
<td>(0.71, 4.87)</td>
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<tr>
<td>Roman et al., 1993</td>
<td>S England; leukaemia plus NHL incident cases, 1972–1989</td>
<td>5/37</td>
<td>4</td>
<td>1.12</td>
<td>(0.40, 3.15)</td>
</tr>
<tr>
<td>Shu et al., 1994</td>
<td>North America (CCGG); infant AL incident cases, 1983–1988</td>
<td>7/291</td>
<td>4</td>
<td>1.10</td>
<td>(0.43, 2.83)</td>
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<tr>
<td>Harvey et al., 1985</td>
<td>Connecticut twins; incident cases, 1935–1981</td>
<td>5/13</td>
<td>3</td>
<td>1.81</td>
<td>(0.55, 5.99)</td>
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<tr>
<td>Wells and Steer, 1961</td>
<td>New York; incident cases, 1961</td>
<td>4/77</td>
<td>3</td>
<td>0.72</td>
<td>(0.22, 2.34)</td>
</tr>
<tr>
<td>Kjeldsberg, 1957</td>
<td>Norway; incident cases, 1946–1956</td>
<td>5/55</td>
<td>3</td>
<td>0.59</td>
<td>(0.18, 1.93)</td>
</tr>
<tr>
<td>McKinney et al., 1999</td>
<td>Scotland (UKCSS), incident cases, 1991–1994</td>
<td>6/144</td>
<td>3</td>
<td>2.31</td>
<td>(0.69, 7.70)</td>
</tr>
<tr>
<td>van Duijn et al., 1994</td>
<td>Netherlands; ANLL incident cases, 1973–1979</td>
<td>6/80</td>
<td>3</td>
<td>2.35</td>
<td>(0.78, 6.99)</td>
</tr>
<tr>
<td>Murray et al., 1959</td>
<td>New York; deaths, 1940–1957</td>
<td>3/65</td>
<td>2</td>
<td>0.92</td>
<td>(0.25, 3.36)</td>
</tr>
<tr>
<td>Gardner et al., 1990</td>
<td>NW England; incident cases, 1950–1985</td>
<td>3/20</td>
<td>2</td>
<td>1.19</td>
<td>(0.31, 4.55)</td>
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<tr>
<td>Meiner et al., 1999</td>
<td>Germany; incident cases, 1980–1994</td>
<td>3/1184</td>
<td>2</td>
<td>0.93</td>
<td>(0.24, 3.60)</td>
</tr>
<tr>
<td>Shu et al., 1994</td>
<td>Shanghai; AL incident cases, 1986–1994</td>
<td>7/166</td>
<td>2</td>
<td>2.39</td>
<td>(0.61, 9.41)</td>
</tr>
</tbody>
</table>

The studies are ranked by the amount of statistical information used in the derivation of the relative risk (after Bithell et al.). UKCSS, United Kingdom Childhood Cancer Study; CCG, Children’s Cancer Group; AL, acute leukemia; ALL, acute lymphoblastic leukaemia; ANLL, acute non-lymphoblastic leukaemia; NHL, non-Hodgkin’s lymphoma.

1 The reciprocal of the sum of the reciprocals of the number of exposed cases, the number of unexposed cases, the number of exposed controls and the number of unexposed controls.
2 The crude odds ratio derived from the reported case–control study data, which is approximately the unadjusted relative risk.
3 Woolf approximate 95% confidence interval for the crude odds ratio.
4 Reported in conference proceedings only.
5 Reported in an abstract only.
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 and the international study group

Fig 1 Distribution of cumulative radiation doses among workers included in the analyses
(N= 407,591; 5.2 mio. person years)

>90 % < 50 mSv
< 0.1% >500 mSv
Abstract: 1-2% of all cancer deaths in the cohort caused by occupational radiation exposure (appr. 1000-2000) (roughly 110,000 cancer deaths for other reasons)

BMJ, Vol. 331, 9 July 2005, 77-80
Is cancer risk as expected?

P Jacob,1 W Rühm,1 L 

ABSTRACT
Occupational exposures to ionising at low-dose rates and may occur up to several hundred milligray. The objective of the present study is evidence of cancer risks from such moderate-dose (LDRMD) exposures. Our literature search for primary occupational cancer incidence and mortality. Exposures included publications on an update of the UK National Research Workers study. For each (LDRMD) type, the risk for the same types of cancer in the same country, bomb survivors with the same genders and matched quantities for dose, mean age at exposure. A combination of the excess relative risk per dose was 1.21 (CI 0.51 to 1.90). The present analysis does not contain data for LDRMD exposures for atomic bomb survivors. This risk values currently assumed for

Figure 3  Ratio Q of excess relative risk-per-dose values for cancer after low-dose-rate, moderate-dose exposures and after acute, high-dose exposures as recommended by the International Commission on Radiological Protection (ICRP),2 used by BEIR VII (95% CI),3 and derived in the present analysis from epidemiological studies (epi-risk, 90% CI).
What this paper adds

► Occupational exposures to ionising radiation occur normally at low-dose rate and may sum up to moderate doses in the order of 100 mGy.
► Limits of occupational exposures are based on the assumption that cancer risk factors are lower than for the atomic bomb survivors by a factor of two.
► Twelve recent epidemiological studies on cancer after low-dose-rate, moderate-dose exposures were included in this analysis of cancer risks related to such exposures.
► The studies provide evidence that cancer risk factors for occupational exposures are not lower than for atomic bomb survivors.
► The new evidence for cancer risks should be taken into account in optimisation procedures for the use of radionuclides and ionising radiation at the work place and in medicine.
Ionising radiation and risk of death from leukaemia and lymphoma in radiation-monitored workers (INWORKS): an international cohort study


Methods We assembled a cohort of 308,297 radiation-monitored workers employed for at least 1 year by the Atomic Energy Commission, AREVA Nuclear Cycle, or the National Electricity Company in France, the Departments of Energy and Defence in the USA, and nuclear industry employers included in the National Registry for Radiation Workers in the UK. The cohort was followed up for a total of 8.22 million person-years. We ascertained deaths caused by leukaemia, lymphoma, and multiple myeloma. We used Poisson regression to quantify associations between estimated red bone marrow absorbed dose and leukaemia and lymphoma mortality.

Findings Doses were accrued at very low rates (mean 1.1 mGy per year, SD 2.6). The excess relative risk of leukaemia mortality (excluding chronic lymphocytic leukaemia) was 2.96 per Gy (90% CI 1.17–5.21; lagged 2 years), most notably because of an association between radiation dose and mortality from chronic myeloid leukaemia (excess relative risk per Gy 10.45, 90% CI 4.48–19.65).

Interpretation This study provides strong evidence of positive associations between protracted low-dose radiation exposure and leukaemia.
Figure: Relative risk of leukaemia excluding chronic lymphocytic leukaemia associated with 2-year lagged cumulative red bone marrow dose. The lines are the fitted linear dose–response model and the shading represents the 90% CIs.
Implications of all the available evidence

The present study provides strong evidence of a positive association between radiation exposure and leukaemia even for low-dose exposure. This finding shows the importance of adherence to the basic principles of radiation protection—to optimise protection to reduce exposures as much as reasonably achievable and—in the case of patient exposure—to justify that the exposure does more good than harm.
Distribution of red bon marrow dose: Males

Kalenderjahre

<table>
<thead>
<tr>
<th>Time Period</th>
<th>0-9 years old</th>
<th>10-19 years old</th>
<th>20-29 years old</th>
<th>30-39 years old</th>
<th>40-49 years old</th>
<th>50-59 years old</th>
<th>60-69 years old</th>
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<td>1950-1959</td>
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<td>1990-1999</td>
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<td></td>
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<td></td>
</tr>
</tbody>
</table>
Projected Cancer Risks From Computed Tomographic Scans Performed in the United States in 2007

Amy Berrington de González, DPhil; Mahadevappa Mahesh, MS, PhD; Kwang-Pyo Kim, PhD; Mythreyi Bhargavan, PhD; Rebecca Lewis, MPH; Fred Mettler, MD; Charles Land, PhD

Background: The use of computed tomographic (CT) scans in the United States (US) has increased more than 3-fold since 1993 to approximately 70 million scans annually. Despite the great medical benefits, there is concern about the potential radiation-related cancer risk. We conducted detailed estimates of the future cancer risks from current CT scan use in the US according to age, sex, and scan type.

Methods: Risk models based on the National Research Council’s “Biological Effects of Ionizing Radiation” report and organ-specific radiation doses derived from a national survey were used to estimate age-specific cancer risks for each scan type. These models were combined with age- and sex-specific scan frequencies for the US in 2007 obtained from survey and insurance claims data. We estimated the mean number of radiation-related incident cancers with 95% uncertainty limits (UL) using Monte Carlo simulations.

Results: Overall, we estimated that approximately 29 000 (95% UL, 15 000-45 000) future cancers could be related to CT scans performed in the US in 2007. The largest contributions were from scans of the abdomen and pelvis (n=14 000) (95% UL, 6900-25 000), chest (n=4100) (95% UL, 1900-8100), and head (n=4000) (95% UL, 1100-8700), as well as from chest CT angiography (n=2700) (95% UL, 1300-5000). One-third of the projected cancers were due to scans performed at the ages of 35 to 54 years compared with 15% due to scans performed at ages younger than 18 years, and 66% were in females.

Conclusions: These detailed estimates highlight several areas of CT scan use that make large contributions to the total cancer risk, including several scan types and age groups with a high frequency of use or scans involving relatively high doses, in which risk-reduction efforts may be warranted.

Arch Intern Med. 2009;169(22):2071-2077

Results: Overall, we estimated that approximately 29,000 (95% UL, 15,000-45,000) future cancers could be related to CT scans performed in the US in 2007. The largest contributions were from scans of the abdomen and pelvis (n=14,000) (95% UL, 6,900-25,000), chest (n=4100) (95% UL, 1900-8100), and head (n=4000) (95% UL, 1100-8700), as well as from chest CT angiography (n=2700) (95% UL, 1300-5000). One-third of the projected cancers were due to scans performed at the ages of 35 to 54 years compared with 15% due to scans performed at ages younger than 18 years, and 66% were in females.

Table 3. Sensitivity Analysis of the Impact of Varying the Assumptions and Parameters Expressed as Maximum Percentage of Change in the Mean Projected Number of Cancers

<table>
<thead>
<tr>
<th>Alternative Parameter or Assumption</th>
<th>Maximum Change, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relative biological effectiveness of x-rays, 2.0</td>
<td>+100</td>
</tr>
<tr>
<td>Inclusion of cancer sites without detailed risk models</td>
<td>+20</td>
</tr>
<tr>
<td>Exclusion of cancer sites that are not confirmed radiation inducible</td>
<td>−17</td>
</tr>
<tr>
<td>Radiation-related solid cancer latency, 10 y</td>
<td>−4</td>
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<tr>
<td>Uncertainty in organ dose estimates</td>
<td>±15</td>
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<tr>
<td>Pediatric scans obtained with adult settings(^a)</td>
<td>+5</td>
</tr>
<tr>
<td>Uncertainty in CT scan frequency</td>
<td>±30</td>
</tr>
<tr>
<td>All-cause mortality rates 10% higher than general population</td>
<td>−5</td>
</tr>
<tr>
<td>All-cause mortality rates 50% higher than general population</td>
<td>−20</td>
</tr>
<tr>
<td>Inclusion of CT scans with a diagnosis code of cancer</td>
<td>+13</td>
</tr>
</tbody>
</table>

\(^a\)A detailed description of these alternative assumptions is provided in the “Methods” and Comment” sections. CT indicates computed tomographic.

CT Scans: Balancing Health Risks and Medical Benefits

Computed tomography (CT) has been a boon for medical care. By generating detailed anatomical pictures, the technology can improve diagnoses, limit unnecessary medical procedures, and enhance treatment. However, CT scans also dose patients with ionizing radiation, a known human carcinogen, posing a potential downside for public health. Mounting health worries over radiation risks are now driving efforts to limit avoidable CT scans and to reduce radiation doses when possible. "There’s a national focus on this issue right now," says Marilyn Crooks, a professor of radiology at Cincinnati Children’s Hospital Medical Center and chairwoman of the Image Gently campaign, a pediatric education and awareness campaign from the Alliance for Radiation Safety in Pediatric Imaging.

In December 2011 the Institute of Medicine (IOM) published a report concluding that ionizing radiation contributes more to the development of breast cancer than any other type of routine environmental exposure. About half the U.S. annual exposure to ionizing radiation comes from natural sources, including cosmic rays, but most of the rest comes from medical imaging and from CT scans in particular. The IOM cited research by Amy Bernstein de Conti, a senior investigator in the Radiation Epidemiology Branch of the National Cancer Institute (NCI), whose calculations suggest that the CT scans performed in the United States in 2007 might produce up to 25,000 cancers in the future, about 8% of them in the breast and the remainder in the lungs, brain, and other organs. But the spotlight on CT safety has also drawn a backlash from those who say the risks are overblown. On 15 December 2011 the American Association of Physicists in Medicine (AAPM) issued a statement claiming that...
Is Computed Tomography Safe?
Rebecca Smith-Bindman, M.D.

"... We found that the risk of cancer from a single CT scan could be as high as 1 in 80 — unacceptably high, given the capacity to reduce these doses. ...

"... Evidence suggests the radiation dose from CT could be reduced by 50% or more without reducing diagnostic accuracy. 4

"... We need to establish diagnostic reference levels, on the basis of clinically relevant outcomes and safety, not the creation of the greatest-quality images, if such quality does not improve outcomes. ...

"... the FDA could take the lead in creating standards and assessing compliance. Facilities that could not meet the standards should not be certified to conduct CT. ..."
Radiation exposure from CT scans in childhood and subsequent risk of leukaemia and brain tumours: a retrospective cohort study

Mark S Pearce, Jane A Salotti, Mark P Little, Kieran McHugh, Choonsik Lee, Kwang Pyo Kim, Nicola L Howe, Cecile M Ronckers, Preetha Rajaraman, Sir Alan W Craft, Louise Parker, Amy Berrington de Gonzalez

Summary
Background Although CT scans are very useful clinically, potential cancer risks exist from associated ionising radiation, in particular for children who are more radiosensitive than adults. We aimed to assess the excess risk of leukaemia and brain tumours after CT scans in a cohort of children and young adults.

Methods In our retrospective cohort study, we included patients without previous cancer diagnoses who were first examined with CT in National Health Service (NHS) centres in England, Wales, or Scotland (Great Britain) between 1985 and 2002, when they were younger than 22 years of age. We obtained data for cancer incidence, mortality, and loss to follow-up from the NHS Central Registry from Jan 1, 1985, to Dec 31, 2008. We estimated absorbed brain and red bone marrow doses per CT scan in mGy and assessed excess incidence of leukaemia and brain tumours cancer with Poisson relative risk models. To avoid inclusion of CT scans related to cancer diagnosis, follow-up for leukaemia began 2 years after the first CT and for brain tumours 5 years after the first CT.

Findings During follow-up, 74 of 178 604 patients were diagnosed with leukaemia and 135 of 176 587 patients were diagnosed with brain tumours. We noted a positive association between radiation dose from CT scans and leukaemia (excess relative risk [ERR] per mGy 0.036, 95% CI 0.005–0.120; p=0.029) and brain tumours (0.023, 0.010–0.049; p<0.0001). Compared with patients who received a dose of less than 5 mGy, the relative risk of leukaemia for patients who received a cumulative dose of at least 30 mGy (mean dose 51–13 mGy) was 3.18 (95% CI 1.46–6.94) and the relative risk of brain cancer for patients who received a cumulative dose of 50–74 mGy (mean dose 60–42 mGy) was 2.82 (1.33–6.03).

Interpretation Use of CT scans in children to deliver cumulative doses of about 50 mGy might almost triple the risk of leukaemia and doses of about 60 mGy might triple the risk of brain cancer. Because these cancers are relatively rare, the cumulative absolute risks are small: in the 10 years after the first scan for patients younger than 10 years, one excess case of leukaemia and one excess case of brain tumour per 10 000 head CT scans is estimated to occur. Nevertheless, although clinical benefits should outweigh the small absolute risks, radiation doses from CT scans ought to be kept as low as possible and alternative procedures, which do not involve ionising radiation, should be considered if appropriate.

Figure: Relative risks of leukaemia and brain tumours estimated from a dose–response model (excess relative risk per mGy). Bars show 95% CIs.
What is already known on this topic

CT scanning rates have risen substantially since the 1980s. Although large doses of ionising radiation are known to cause cancer, there is uncertainty about the risks following the lower doses from CT scans (5-50 mGy per organ).

A recent study of 180 000 young people exposed to CT scans in the United Kingdom found an increasing risk of leukaemia and brain cancer with increasing radiation dose.

What this study adds

Among 680 000 Australians exposed to a CT scan when aged 0-19 years, cancer incidence was increased by 24% (95% confidence interval 20% to 29%) compared with the incidence in over 10 million unexposed people. The proportional increase in risk was evident at short intervals after exposure and was greater for persons exposed at younger ages.

By 31 December 2007, with an average follow-up of 9.5 years after exposure, the absolute excess cancer incidence rate was 9.38 per 100 000 person years at risk.

Incidence rates were increased for most individual types of solid cancer, and for leukaemias, myelodysplasias, and some other lymphoid cancers.

Individuals exposed to three or more scans was 5.5. (Web figure A shows corresponding results based on lag periods of five and 10 years)
Exposure to diagnostic radiation and risk of breast cancer among carriers of BRCA1/2 mutations: retrospective cohort study (GENE-RAD-RISK)

Anouk Pijpe postdoctoral research fellow¹, Nadine Andrieu senior researcher²³⁴, Douglas F Easton professor⁵, Ausrele Kesminiene study coordinator⁶, Elisabeth Cardis professor⁷, Catherine Nougès oncogeneticist⁸, Marion Gauthier-Villars oncogeneticist⁹, Christine Lasset oncogeneticist¹⁰, Jean-Pierre Fricker oncogeneticist¹¹, Susan Peock study coordinator⁵, Debra Frost research assistant⁵, D Gareth Evans professor¹², Rosalind A Eeles clinical cancer geneticist¹³, Joan Paterson clinical geneticist¹⁴, Peggy Manders postdoctoral research fellow¹¹⁵, Christi J van Asperen clinical geneticist¹⁶, Margreet G E M Ausems clinical geneticist¹⁷, Hanne Meijers-Heijboer clinical geneticist¹⁸, Isabelle Thierry-Chef researcher⁶, Michael Hauptmann statistician¹, David Goldgar senior researcher¹⁹, Matti A Rookus senior research fellow¹, Flora E van Leeuwen professor¹, on behalf of GENEPSO, EMBRACE, and HEBON
<table>
<thead>
<tr>
<th>Exposure</th>
<th>Person years</th>
<th>Cases</th>
<th>Unweighted hazard ratio (95% CI)†</th>
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<td>1679</td>
<td>57</td>
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<td>Ever</td>
<td>1412</td>
<td>58</td>
<td>1.65 (1.11 to 2.46)</td>
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</tbody>
</table>

Dose category:

<table>
<thead>
<tr>
<th>Dose category</th>
<th>Person years</th>
<th>Cases</th>
<th>Unweighted hazard ratio (95% CI)†</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;0.0020 Gy</td>
<td>874</td>
<td>33</td>
<td>1.48 (0.94 to 2.33)</td>
</tr>
<tr>
<td>0.0020-0.0065 Gy</td>
<td>280</td>
<td>12</td>
<td>1.55 (0.81 to 2.98)</td>
</tr>
<tr>
<td>0.0066-0.0173 Gy</td>
<td>147</td>
<td>6</td>
<td>1.90 (0.69 to 5.21)</td>
</tr>
<tr>
<td>≥0.0174 Gy</td>
<td>109</td>
<td>7</td>
<td>4.16 (2.01 to 8.62)</td>
</tr>
</tbody>
</table>

* Subcohort includes carriers diagnosed or censored within five years before questionnaire completion, with follow-up being counted only during this five year period.

† Unweighted time varying Cox proportional hazards model, stratified for gene (BRCA1 and BRCA2), country, and birth cohort (<1955, 1955-61, 1962-68, >1968), clustered on family (816 clusters), and adjusted for age at entry in subcohort, parity (no children; 1-2 children; ≥2 children; time varying), and menopause (premenopausal; natural menopause; bilateral prophylactic oophorectomy; time varying); proportional hazards assumption for each covariate evaluated by inspecting In(−ln(survival)) curve, and using goodness of fit test; missing values were coded as additional category.
3 Radiation epidemiology: quantifying risk

B. unexpected additional diseases
Ionizing Radiation and Chronic Lymphocytic Leukemia

David B. Richardson,1 Steve Wing,1 Jane Schroeder,1 Inge Schmitz-Feuerhake,2 and Wolfgang Hoffmann3

1Department of Epidemiology, School of Public Health, University of North Carolina at Chapel Hill, Chapel Hill, North Carolina, USA; 2Department of Physics (retired), University of Bremen, Germany; 3Institute for Community Medicine, Division of Health Care Epidemiology and Community Health, Ernst-Moritz-Arndt-University Greifswald, Greifswald, Germany

The U.S. government recently implemented rules for awarding compensation to individuals with cancer who were exposed to ionizing radiation while working in the nuclear weapons complex. Under these rules, chronic lymphocytic leukemia (CLL) is considered to be a nonradiogenic form of cancer. In other words, workers who develop CLL automatically have their compensation claim. We note that current understanding of radiation-induced tumorigenesis and the etiology of lymphatic neoplasia provides a strong mechanistic basis for expecting that ionizing radiation exposure increases CLL risk. The clinical characteristics of CLL, including prolonged latency and morbidity periods and a low case fatality rate, make it relatively difficult to evaluate associations between ionizing radiation and CLL risk via epidemiologic methods. The epidemiologic evidence of association between external exposure to ionizing radiation and CLL is weak. However, epidemiologic findings are consistent with a hypothesis of elevated CLL mortality risk after a latency and morbidity period that spans several decades. Our findings in this review suggest that there is not a persuasive basis for the conclusion that CLL is a nonradiogenic form of cancer. Key words: chronic lymphocytic leukemia, compensation, ionizing radiation, radiogenicity. Environ Health Perspect 113:1–5 (2005). doi:10.1289/ehp.7433 available via http://dx.doi.org/ [Online 21 October 2004]
Editorial

Have we been wrong about ionizing radiation and chronic lymphocytic leukemia?

Terry J. Hamblin
Department of Cancer Studies, University of Southampton, Tremona Rd., Southampton, SO9 6YD, UK
E-mail address: terjoha@aol.com

20 August 2007
Available online 29 October 2007
DEPARTMENT OF HEALTH AND HUMAN SERVICES

42 CFR Part 81

[Docket Number NIOSH–209]

RIN 0920–AA39


SUMMARY: The Department of Health and Human Services (HHS) is proposing to treat chronic lymphocytic leukemia (CLL) as a radiogenic cancer under the Energy Employees Occupational Illness Compensation Program Act of 2000 (EEOICPA). Under current guidelines HHS promulgated as regulations in 2002, all types of cancers except for CLL are treated as being potentially caused by radiation and hence as potentially compensable under EEOICPA. HHS
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.
What is already known on this topic

High doses of ionising radiation to the developing human brain cause mental retardation

It is unknown whether low level exposure in infancy has more subtle effects on cognitive function

What this study adds

Intellectual development is adversely affected when the infant brain is exposed to ionising radiation at doses equivalent to those from computed tomography of the skull

Diagnostic evaluation of children with minor head injuries needs to be re-evaluated
Maternal occupational exposure to ionizing radiation and birth defects

Awi Wiesel · Claudia Spix · Andreas Mergenthaler · Annette Queisser-Luft

In 3,816 births (including 165 infants with BDs; 4.3%), maternal answers concerning possible exposures to medical and occupational ionizing radiation were available. Relative risk (RR) estimates in mothers surveyed for occupational exposure to ionizing radiation (wearing a radiation dosimeter) and BDs in the offspring were calculated exploratively. A higher prevalence of infants with BDs ($n = 4$; 13.8%) was documented in newborns of the increased to 4.0 (1.5–10.7). Adjustment for possible confounders did not change the results substantially.
Conclusions: We conclude that occupational exposure to ionizing radiation is related to the risk of AITD. The usage of thyroid protection shields by radiation workers is strongly recommended. (J Clin Endocrinol Metab 90: 4587–4592, 2005)
Radiation Dose-Response Relationships for Thyroid Nodules and Autoimmune Thyroid Diseases in Hiroshima and Nagasaki Atomic Bomb Survivors 55-58 Years After Radiation Exposure

JAMA. 2006;295:1011-1022

JAMA. 2006;295:1011-1022
Risk of Cataract after Exposure to Low Doses of Ionizing Radiation: A 20-Year Prospective Cohort Study among US Radiologic Technologists

In conclusion, our study provides evidence that exposure to relatively low doses of ionizing radiation may be harmful to the lens of the eye and increases the long-term risk of cataract formation. Our findings and the results of recent studies suggest that likelihood of cataract formation increases with increasing exposure to ionizing radiation with no apparent threshold level, a finding that challenges the National Council on Radiation Protection and International Commission on Radiological Protection assumptions that a radiation dose of at least 2 Gy is associated with increased cataract risk.
Radiation exposure and circulatory disease risk: Hiroshima and Nagasaki atomic bomb survivor data, 1950-2003

Yukiko Shimizu, visiting research associate, Kazunori Kodama, chief scientist, Nobuo Nishi, assistant department chief, Fumiyoshi Kasagi, assistant department chief, Akihiko Suyama, department chief, Midori Soda, assistant department chief, Eric J Grant, associate senior scientist, Hiromi Sugiyama, research scientist, Ritsu Sakata, research scientist, Hiroko Moriwaki, research assistant, Mikiko Hayashi, research assistant, Manami Konda, research assistant, Roy E Shore, vice chairman and chief of research

<table>
<thead>
<tr>
<th>Circulatory disease</th>
<th>No of deaths</th>
<th>% ERR/Gy unadjusted for confounders*</th>
<th>% ERR/Gy adjusted for all confounders†</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>7907</td>
<td>10.0</td>
<td>9.6</td>
</tr>
<tr>
<td>Stroke</td>
<td>3366</td>
<td>8.1</td>
<td>7.2</td>
</tr>
<tr>
<td>Heart disease</td>
<td>4204</td>
<td>12.2</td>
<td>12.3</td>
</tr>
<tr>
<td>Other</td>
<td>337</td>
<td>2.4</td>
<td>0.9</td>
</tr>
</tbody>
</table>

ERR=excess relative risks.
*All analyses adjusted for city, sex, age at exposure, and attained age.
†Additionally adjusted for smoking, alcohol intake, education, type of household occupation, obesity (body mass index), and diabetes mellitus (on basis of about 52 000 participants).

Quelle: BMJ 2010, 340:b5349
Fig 2 | Radiation dose-response relation (excess relative risk) for death from heart disease, showing linear and linear-quadratic functions. Shaded area is 95% confidence region for fitted linear line. Vertical lines are 95% confidence intervals for specific dose category risks. Point estimates of risk for each dose category are indicated by circles.
Cardio-vascular deaths:
1 – 13% / Sv

Similar excess mortality due to non-cancer diseases as from cancers (5% / Sv)
Lassen Sie sich Ihren Fuß hier kostenlos durchleuchten.
Get Scanned
Early Detection of Cancer & Heart Disease Can Mean A Cure!

1-87-R-U-AT-RISK

Bodyscan-Lastwagen: Wanderheiler vor der Dorfkirche

Der Spiegel 30/2002
The truth about Alzheimer

Alzheimer can be cured
Interdisciplinary workshop with physicians, physicists, biologists, mathematicians, epidemiologists

Agenda: Review and compilation of scientific evidence on health effects of ionising radiation

http://www.ippnw.de/commonFiles/pdfs/Atomenergie/Ulmer_Experten treffen_-_Gefahren_ionisierender_Strahlung.pdf