Cancer Risks from Natural Background Radiation and Radon

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DCEG Radiation Epidemiology and Dosimetry Course 2019
If it’s Natural it must be good for you!
If it’s Natural it must be good for you!

- Adder bite
- Aids
- Aflatoxins
- Alligators
- Angina
- Anthrax
- Arsenic
- Asbestos
- Asteroid impact
Why is this topic important?

Evidence on effects of low-dose radiation

Epidemiology difficult if

- Inadequate power
  - Not enough cases
  - Few induced effects (doses low)
  - Background cancer rates high
- Biases in cases/controls
- Important confounders not measured
Topics to cover

- Background radiation
  - Natural and other

- Radon and Lung Cancer
  - Radon and lung cancer in miners
  - Radon and lung cancer in homes

- Natural background and other cancers
  - High Natural Background Areas
  - Register based studies of childhood cancer

The field is huge. This is an overview with pointers to literature
Radiation Exposure of the US Population

NCRP Report 93 (1987)
Exposures in early 1980s  Mean 3.6 mSv pa

NCRP Report 160 (2009)
Exposures in 2006  Mean 6.2 mSv pa

Effective doses in milli Sv (mSv)
NB Exposures may be to only part of body
US mean exposure early 1980s. Total 3.6 mSv
US mean Exposure 2006  Total 6.2 mSv
Medical Exposures 1980s and 2006

![Bar chart showing mean annual dose (mSv) for different categories: Total, Nuclear Med, Interventional, Conventional, and Comp Tomog. The chart compares data from 2006 and 1980s.](chart.png)
Components of effective dose background radiation 2006

- Radon
- Space
- Internal
- Terrestrial
## Components of effective dose from natural background 2006

**Contributions to effective dose (mSv) and interpretation**

<table>
<thead>
<tr>
<th>Component</th>
<th>Value (mSv)</th>
<th>Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radon</td>
<td>2.28</td>
<td>$2.28 / 0.12 = 19$ mSv to lung</td>
</tr>
<tr>
<td>Space</td>
<td>0.33</td>
<td>whole body</td>
</tr>
<tr>
<td>Internal</td>
<td>0.29</td>
<td>~ whole body</td>
</tr>
<tr>
<td>Terrestrial</td>
<td>0.21</td>
<td>whole body</td>
</tr>
<tr>
<td>Total</td>
<td>3.11</td>
<td></td>
</tr>
</tbody>
</table>
Components of Natural Background Radiation

Radon (Rn-222) and Thoron (Rn-220)
  Most dose from Decay Products (DP) to respiratory tract

Space
  Cosmic rays (complex at altitude)
  Particles

Terrestrial
  Gamma rays from K-40, U-238, Th-232 etc

Internal
  Radionuclides in food and drink
Measuring Radiation at Ground Level

Radon - Easy to measure [Rn]
Thoron - Not as easy as radon (less important)
Cosmic - Ionising component easy
  - Neutrons difficult
Terrestrial - Easy
Internal - Difficult (many nuclides)

For epidemiology: Radon, Ionising Cosmic, Terrestrial. Not Internal
Principal Decay Scheme: Radon-222 to Lead-206

- $^{222}\text{Rn}$
- $^{210}\text{Po}$
- $^{214}\text{Po}$
- $^{218}\text{Po}$
- $^{206}\text{Pb}$

Decay times:
- 30 min
- 20 min
- 3 min
- 4 days
- 30 minutes
- 20 years
Radon Dosimetry

[Rn] is easy to measure (but very variable)

Most dose from Rn decay products (DP) attached to particles

DP emit short-ranged alphas
  Most dose to respiratory tract as deposited DP are being cleared

Dose calculations can be undertaken
  Where are the DP?
  Where are the target cells?

Or you could estimate dose (risk) directly from epidemiology
Working Level Month (WLM)

One WL is conc of short-lived DP in equilibrium with 3,700 Bq/m³ Rn. (3,700 Bq/m³ = 100 pCi/L)

WLM is exposure to one WL for 170 hours.

1 WLM ≈ 10 mSv
Radon and Lung Cancer

Radon (decay products) give much the largest doses to respiratory tract

Epidemiology has detected excess lung cancer following both

  - occupational (underground hard rock miners)
  - domestic exposure to radon

Several outstanding questions:
  - eg how does radon interact with smoking?
Reviews of Radon Miners

Health Effects of Exposure to Radon: BEIR VI.
Lubin et al 1995 JNCI 87 817-827 Lung Cancer in Radon-Exposed Miners

UNSCEAR 2006 Volume 2 Annex E
Sources-to-effects assessment for radon in homes and workplaces

ICRP Publication 115 Lung Cancer Risk from Radon (2010)
BEIR VI Report

BEIR VI Models
11 miner studies involving ~68,000 men (2,700 fatal lung cancers)
Two models for lung-cancer risk from radon exposure.
(Exposure, Age, Duration; Exposure, Age, Concentration)
Cigarette smoke and radon - sub-multiplicative synergistic effect.

Total fatal lung cancer 157,400 (11,000 never smokers)
Radon-related 15,400 or 21,800 (3,000 - 33,000)
(National Academy of Sciences 1999 BEIR VI Radon)
Lung cancer in radon exposed miners

<table>
<thead>
<tr>
<th>Study</th>
<th>Observed</th>
<th>Expected</th>
<th>ERR per 100 WLM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Colorado Plateau uranium</td>
<td>327</td>
<td>74</td>
<td>0.42 (0.3, 0.7)</td>
</tr>
<tr>
<td>Ontario uranium</td>
<td>282</td>
<td>221</td>
<td>0.89 (0.5, 1.5)</td>
</tr>
<tr>
<td>Czech uranium</td>
<td>915</td>
<td>240.8</td>
<td>1.60 (1.2, 2.2)</td>
</tr>
<tr>
<td>Swedish iron</td>
<td>79</td>
<td>44.7</td>
<td>0.95 (0.1, 4.1)</td>
</tr>
<tr>
<td>Beaverlodge uranium</td>
<td>279</td>
<td>217.8</td>
<td>0.96 (0.6, 1.6)</td>
</tr>
<tr>
<td>Port Radium uranium</td>
<td>230</td>
<td>142.7</td>
<td>0.37 (0.2, 0.6)</td>
</tr>
<tr>
<td>French</td>
<td>125</td>
<td>83.1</td>
<td>0.80 (0.3, 1.4)</td>
</tr>
<tr>
<td>Newfoundland fluor spar</td>
<td>206</td>
<td>-</td>
<td>0.47 (0.3, 0.7)</td>
</tr>
<tr>
<td>Chinese tin</td>
<td>936</td>
<td>649</td>
<td>0.16 (0.1, 0.2)</td>
</tr>
<tr>
<td>Wismut uranium</td>
<td>2 328</td>
<td>NA</td>
<td>0.21 (0.2, 0.2)</td>
</tr>
</tbody>
</table>

UNSCEAR 2006 Annex E - Table 21
East German Uranium Miners - Summary

Kreuzer 2015
26,766 miners hired 1960 or later.
    ERR 0.013 WLM-1 (CI 0.007 - 0.021).

Kreuzer 2018
58,974 miners <100 WLM
    ERR 0.006 WLM-1 (CI 0.003 - 0.010).

Kreuzer 2015 BJC 113 1367-69
Kreuzer 2018 Radiat Res 189 165-176
French and Czech Uranium miners

French and Czech uranium miners exposed to low radon levels (mean cumulative exposure <60 WLM).

95% of annual exposures based on measurements.

Fatal lung cancers  O=574, E= 200.

Risk strongly associated with total Rn exposure.

Consistent with BEIR VI estimates using concentration model at exposure rates < 0.5 WL.

Tomasek et al 2006 Radiat Res 169 125-37
Domestic Studies of Radon and Lung Cancer

Many individual studies of domestic radon in homes and lung cancer.

Three main reviews pooling individual studies

- Chinese, Lubin 2004, IJC 109 132-137
- European, Darby 2005, BMJ 330 223-229
- N American, Krewski 2005, Epidemiology 16 137-45
## Domestic radon pooling studies

<table>
<thead>
<tr>
<th>Joint analysis</th>
<th>No. of studies</th>
<th>Cases</th>
<th>Controls</th>
<th>RR</th>
</tr>
</thead>
<tbody>
<tr>
<td>European</td>
<td>13</td>
<td>7148</td>
<td>14,208</td>
<td>1.08 (1.03–1.16)</td>
</tr>
<tr>
<td>N American</td>
<td>7</td>
<td>3662</td>
<td>4966</td>
<td>1.10 (0.99–1.26)</td>
</tr>
<tr>
<td>Chinese</td>
<td>2</td>
<td>1050</td>
<td>1995</td>
<td>1.13 (1.01–1.36)</td>
</tr>
<tr>
<td>Total</td>
<td>22</td>
<td>11860</td>
<td>21169</td>
<td>1.09 (UNSCEAR)</td>
</tr>
</tbody>
</table>

RR = Relative Risk per 100 Bq/m3 (95% CI)

ICRP 115 table 2.2
Domestic radon pooling studies - Conclusions

• Smoking is the main cause of lung cancer
  Allowance for smoking is vital in analysis

• Association with lung cancer even in non-smokers

• RR greater after allowance for [Rn] uncertainties
  European RR 1.08 →1.16

• “World pooling imminent” (ICRP 115, 2010)
Cohen’s study of radon and lung cancer

Cohen’s ecological study found very strong inverse relationship between mean [Rn] and mean lung cancer rates in US Counties

Cohen 1995 Health Phys. 68 157–174

Puskin found all smoking related cancers show -ve association with Rn, regardless of whether the organ gets a dose from radon.

“The results indicate that the negative trend previously reported for lung cancer can be largely accounted for by a negative correlation between smoking and radon levels across counties.”

Puskin 2003 Health Physics 84 526-532
Natural background and other cancers

Does radon induce cancers other than lung cancer?

Do terrestrial gamma rays (with or without cosmic rays) induce cancer?
Does Radon induce other cancers?

Skin Cancer?
Doses possibly non-trivial. Epidemiology difficult and inconclusive

Gastric Cancer?
Dose from Rn in water possibly non-trivial. Some evidence from epidemiology but inconclusive

Epidemiological studies of miners find no evidence of other adult cancers (Darby 1995 JNCI 87 378-384)

Childhood Cancers?

UNSCEAR 2008 Annex E
Does Radon induce Childhood Cancer, in particular Leukaemia?

Target tissues not lung and doses smaller!
Very large studies needed

Childhood leukaemia is relatively rare; relatively easily induced by radiation.

Some positive ecological studies
# Case/Control studies of Radon and Childhood Cancer

<table>
<thead>
<tr>
<th>Author</th>
<th>Year</th>
<th>Reference</th>
<th>Endpoint</th>
<th>Cases</th>
<th>Findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lubin</td>
<td>1998</td>
<td>JNCI 90(4) 294-300</td>
<td>ALL</td>
<td>505</td>
<td>Nothing significant</td>
</tr>
<tr>
<td>Steinbuch</td>
<td>1999</td>
<td>BJC 81(5) 900-906</td>
<td>AML</td>
<td>173</td>
<td>Nothing significant overall</td>
</tr>
<tr>
<td>Kaletsch</td>
<td>1999</td>
<td>REB 38(3) 211-215</td>
<td>All cancers</td>
<td>82+82</td>
<td>XS solid cancers (chance?)</td>
</tr>
<tr>
<td>UKCCS</td>
<td>2002</td>
<td>BJC 86(11) 1721-26</td>
<td>All cancers</td>
<td>3838</td>
<td>Dominated by response bias</td>
</tr>
<tr>
<td>Raaschou - Nielsen</td>
<td>2008</td>
<td>Epidemi. 19(4) 536-43</td>
<td>Most</td>
<td>2400</td>
<td><strong>Significant ALL elevation</strong></td>
</tr>
<tr>
<td>Kendall</td>
<td>2013</td>
<td>Leukaemia 27(1) 3-9</td>
<td>All cancers</td>
<td>27447</td>
<td>Nothing significant</td>
</tr>
</tbody>
</table>
Do Terrestrial Gamma Rays induce cancer?

Studies in areas with high natural background (HNBR)

Studies of childhood cancer
Studies in HNBR Areas

Kerala, India (Nair 2009)
1379 cancers in 70,000 adults followed for 10.5y
Mean Cumulative dose to end of follow-up ~161 mGy
ERR (excl. leukemia) -0.13 Gy-1 (95% CI: -0.58, 0.46).

Yangjiang, China (Tao 2012)
956 cancer deaths in 31,604 adults followed for 19 years.
Mean cumulative doses to end of follow-up 84.8 mGy
ERR (excl. leukemia) 0.19 Gy-1 (95% CI: -1.9, 3.0).

NCRP Commentary 27, 2018
NCI Review (2019??)
Studies in HNBR Areas - problems

High background rates of adult cancers

Several potent other causes (potential confounders eg smoking)

Comparability of control groups

Comparability of cancer registration between groups

Accuracy of dose estimation
Register Based Studies of Childhood Cancer and Background Radiation

Childhood cancers are relatively rare (low background)
Relative risks higher

National Registers of Childhood Cancers provide large numbers of cases free of participation bias

Lack of known confounders for childhood leukaemia

But

Radiation Exposures must be estimated

No interview-based data on confounders
Are Register Based Studies all the same?

Study Design – case-control; case-cohort; ecological

Endpoints – Leukaemia, all cancers, CNS, …

Type of radiation – Gamma? CR? Radon?

Dose – Dose rate?
  - Cumulative based on diagnosis?
  - Cumulative based on birthplace?

Method for estimating dose rates
## Register Based Studies of NBR and childhood leukaemia

<table>
<thead>
<tr>
<th>Country</th>
<th>Study</th>
<th>Leukemias</th>
<th>RR - Radon</th>
<th>RR - Gamma</th>
</tr>
</thead>
<tbody>
<tr>
<td>Denmark</td>
<td>Raaschou-Nielsen 2008</td>
<td>1,153</td>
<td>1.34 (0.97 - 1.85)</td>
<td></td>
</tr>
<tr>
<td>Great Britain</td>
<td>Kendall 2013</td>
<td>9,058</td>
<td>1.03 (0.96 - 1.11)</td>
<td>1.12 (1.03 - 1.22)</td>
</tr>
<tr>
<td>Switzerland</td>
<td>Haurii 2013</td>
<td></td>
<td></td>
<td>1.04 (1.00 - 1.08)</td>
</tr>
<tr>
<td></td>
<td>Spycher 2015</td>
<td>530</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Finland</td>
<td>Nikkilä 2016</td>
<td>1,093</td>
<td></td>
<td>0.97 (0.89 - 1.06)</td>
</tr>
<tr>
<td>France</td>
<td>Demoury 2017</td>
<td>2,763</td>
<td>1.00 (0.97 - 1.02)</td>
<td>1.00 (0.99 - 1.01)</td>
</tr>
<tr>
<td>Germany</td>
<td>Spix 2017</td>
<td>13,374</td>
<td></td>
<td>1.04 (0.91 - 1.20)</td>
</tr>
</tbody>
</table>
NCRP on Childhood Leukaemia Studies (not just register based)

“Some compatibility with LNT model” but

- Applicability of ambient radiation measurements?
- Potential for uncontrolled confounding,
- Participation rates,
- Migration,
- Limited statistical power

NCRP Commentary 27, 2018
Cancer and Natural Radiation
Summary

Natural radiation is ubiquitous and dominant
  Only medical exposures can compete

Epidemiology demonstrates that radon causes lung cancer

Natural radiation might be expected to cause small numbers of other cancers. So far the evidence is only suggestive, but perhaps increasingly suggestive.
Quiz 1

For most people the most important component of exposure to radiation is usually

- Cosmic Rays
- Nuclear Power
- Radon
Quiz 1

For most people the most important component of exposure to radiation is usually

• Cosmic Rays
• Nuclear Power
• Radon
Quiz 2

Epidemiology of adult cancers in areas of High Natural Background shows

- A clear link with leukaemia
- A clear link with all other cancers
- Both of the above
- Neither of the above
Quiz 2

Epidemiology of adult cancers in areas of High Natural Background shows

- A clear link with leukaemia
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- Both of the above
- Neither of the above
Quiz 3

Epidemiology has demonstrated a link between exposure to radon and lung cancer in

• Occupational exposures in mines
• Domestic exposures in homes
• Both of the above
• Neither of the above
Quiz 3

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- Domestic exposures in homes
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- Neither of the above