Health effects of radon exposure, contribution of epidemiology

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Radon risk assessment

TaskGroup TG64 ICRP C1
Major contribution from

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Marsh JW (HPA)
Tirmarche M (IRSN)

• Revue of literature (epidemiology + dosimetry of alpha emitters and lung model)
• Lifelong risk calculation
Experience of ICRP C1 taskgroup64:

- Review over last 10-15 years publications (updated /Unscear)
- Selection of epidemiological studies with a good quality of individual exposure
  - to radon decay products (U miners + domestic exposure studies)
  Taking account of other concomittant exposures:
  - external gamma exposure, uranium dust, chemicals, tobacco
ICRP C1 taskgroup64:
Target organ: lung others?

- If Cancer risk related to dose at target organ: lung, bone marrow, others….in mGy per year (dose rate) or cumulated over life?
- Is it possible to take in account separate effects of alpha emitters and external gamma exposure (in miners studies)
- How should be modelised their influence on final risk, if both exposures are concomittant or separated over time period (initiator, promoter….)
- Is dosimetry on organ level influenced by concomittant smoking
- Quality factor of 20?
- Is comparison of cancer risk (lung cancer risk) from alpha emitters with H and N lung cancer risk possible?
Large Experience on international level from cohorts of uranium miners

**Individual annual exposure to radon decay products** in WLM ambiant measured

**Individual exposure of radon daughters in eq with radon gas multiplied by duration**;

**A large number of studies**, with individual assessment of exposure to external gamma, internal radon decay products and to uranium long lived dust:

**Modelisation of time dependancy** (dose rate effect, time since exposure, age at exposure)

Separate analysis for **smokers and non-smokers**.

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**Synthesis under WHO, BEIR 6,** and ICRP115:

- good agreement when comparing results from miners and from general population

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**Management of risk**:

- for domestic exposure: through Bq /m$^3$
- for occupational exposure: workers - /uranium miners
Radon

Major results during recent years

• Risk observed after exposure to low annual exposure (coherence of results from occupational and domestic exposure)

• How is risk declining with time since exposure (important for risk communication and risk management)

• Interaction with tobacco: risk communication different for nonsmokers or for smokers?
### Czech-French joint model

(Tomasek et al. Rad Res 2008)

#### Combined analysis of low exposed miners

<table>
<thead>
<tr>
<th>Name-place</th>
<th>Country</th>
<th>Type of mine</th>
<th>Follow-up period</th>
<th>Nb miners</th>
<th>Nb lung cancer deaths</th>
<th>Cumul expo WLM</th>
<th>Person-years</th>
<th>ERR per 100 WLM</th>
</tr>
</thead>
<tbody>
<tr>
<td>West Bohemia</td>
<td>Czech Republic</td>
<td>Uranium</td>
<td>1956-95</td>
<td>5002</td>
<td>449</td>
<td>57</td>
<td>133 521</td>
<td></td>
</tr>
<tr>
<td>CEA-AREVA</td>
<td>France</td>
<td>Uranium</td>
<td>1946-94</td>
<td>5098</td>
<td>125</td>
<td>37</td>
<td>115 261</td>
<td></td>
</tr>
<tr>
<td>Combined</td>
<td></td>
<td></td>
<td></td>
<td>10 100</td>
<td>574</td>
<td>47</td>
<td>248 782</td>
<td>1.6 [1.0 - 2.4]</td>
</tr>
</tbody>
</table>

- Agreement with a linear model
- **ERR \( \leq \) with Time Since Exposure
- **ERR \( \leq \) with Age at Exposure
- no inverse exposure rate effect
# Pooled nested case control study

<table>
<thead>
<tr>
<th></th>
<th>France</th>
<th>Czech Rep.</th>
<th>Germany</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cases / controls</td>
<td>100 / 500</td>
<td>672 / 1491</td>
<td>704 / 1398</td>
<td>1476 / 3389</td>
</tr>
<tr>
<td>Cases / controls with smoking information</td>
<td>60 / 310</td>
<td>672 / 1491</td>
<td>314 / 691</td>
<td>1046 / 2492</td>
</tr>
</tbody>
</table>

- Tomasek, *Rad Prot Dosim* 2011
- Schnelzer et al, *Health Phys* 2010
## European cohort of uranium miners

### Alpha risk project

<table>
<thead>
<tr>
<th></th>
<th>France</th>
<th>Czech Republic</th>
<th>Germany</th>
<th>Combined Cohort</th>
</tr>
</thead>
<tbody>
<tr>
<td>Population</td>
<td>5086</td>
<td>9979</td>
<td>35084</td>
<td>50149</td>
</tr>
<tr>
<td>Person-years</td>
<td>153,047</td>
<td>262,507</td>
<td>908,661</td>
<td>1,324,215</td>
</tr>
<tr>
<td>Follow-up duration</td>
<td>30.1</td>
<td>26.3</td>
<td>25.9</td>
<td>26.4</td>
</tr>
<tr>
<td>Attained age (y)</td>
<td>58.9</td>
<td>56.6</td>
<td>48.6</td>
<td>51.2</td>
</tr>
<tr>
<td>Number of deaths</td>
<td>1467</td>
<td>3947</td>
<td>4519</td>
<td>9,933</td>
</tr>
</tbody>
</table>

### Nested case-control study
Lung cancer risk associated to radon exposure and smoking

<table>
<thead>
<tr>
<th>Cumulative radon exposure (5-year lagged, WLM)</th>
<th>Never smoker</th>
<th>Ex-smoker ≥ 10 y</th>
<th>Ex-smoker &lt; 10 y + current smoker</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 50</td>
<td>1</td>
<td>1.9</td>
<td>7.2</td>
</tr>
<tr>
<td>50-100</td>
<td>2.1 (0.8-5.2)</td>
<td>3.9 (1.6-9.8)</td>
<td>12.0 (5.7-25.2)</td>
</tr>
<tr>
<td>100-200</td>
<td>2.0 (0.8-5.0)</td>
<td>5.0 (2.1-11.6)</td>
<td>18.6 (9.0-38.6)</td>
</tr>
<tr>
<td>200-400</td>
<td>4.9 (1.9-12.5)</td>
<td>6.3 (2.6-15.2)</td>
<td>21.0 (10.0-44.1)</td>
</tr>
<tr>
<td>≥ 400</td>
<td>7.1 (2.4-20.6)</td>
<td>16.8 (6.8-41.6)</td>
<td>36.7 (16.9-279.6)</td>
</tr>
</tbody>
</table>

WLM: Woking Level Month

Risk increases with both smoking and cumulative radon exposure (submultiplicative model)
Excess relative risk of lung cancer associated to radon exposure

<table>
<thead>
<tr>
<th></th>
<th>ERR per WLM (95%CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unadjusted on smoking</td>
<td>0.010 (0.006-0.018)</td>
</tr>
<tr>
<td>Adjusted on smoking</td>
<td>0.008 (0.004-0.014)</td>
</tr>
<tr>
<td>Among never and long term ex-smokers</td>
<td>0.012 (0.005-0.026)</td>
</tr>
<tr>
<td>Among short term ex- and current smokers</td>
<td>0.007 (0.003-0.013)</td>
</tr>
</tbody>
</table>

Risk increases with cumulative radon exposure among smokers and non-smokers.
Residential radon and smoking

Residential radon and lung cancer—detailed results of a collaborative analysis of individual data on 7148 persons with lung cancer and 14 208 persons without lung cancer from 13 epidemiologic studies in Europe

(Darby et al, Scand J Work Environ Health 2006)

- Relative Risk of lung cancer according to the time-weighted average residential radon concentration
**Pooled residential studies**

Indoor data – primary risk coefficients

<table>
<thead>
<tr>
<th>Joint analysis</th>
<th>Number of studies included</th>
<th>Cases</th>
<th>Controls</th>
<th>Relative risk per 100 Bq m$^{-3}$</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Chinese</strong> <em>(Lubin et al., Int J Cancer 2004)</em></td>
<td>2</td>
<td>1050</td>
<td>1995</td>
<td>1.13</td>
<td>(1.01-1.36)</td>
</tr>
<tr>
<td><strong>European</strong> <em>(Darby et al., BMJ 2005)</em></td>
<td>13</td>
<td>7148</td>
<td>14208</td>
<td>1.08</td>
<td>(1.03-1.16)</td>
</tr>
<tr>
<td><strong>North American</strong> <em>(Krewski et al., Epidemiol 2006)</em></td>
<td>7</td>
<td>3662</td>
<td>4966</td>
<td>1.10</td>
<td>(0.99-1.26)</td>
</tr>
</tbody>
</table>

Very good coherence of results from different indoor studies
Cumulated Excess Absolute Risk ($10^{-4}$ per WLM) - comparison of miners and indoor models

Mean Population (m+f/asian+euroamerican)

<table>
<thead>
<tr>
<th></th>
<th>Beir 6c</th>
<th>CzFr 2008</th>
<th>Darby 2005</th>
</tr>
</thead>
<tbody>
<tr>
<td>18-59</td>
<td>1.64</td>
<td>1.30</td>
<td>0.73</td>
</tr>
<tr>
<td>18-69</td>
<td>3.53</td>
<td>2.72</td>
<td>2.71</td>
</tr>
<tr>
<td>18-89</td>
<td>5.58</td>
<td>4.68</td>
<td>7.58</td>
</tr>
</tbody>
</table>

Good agreement of estimated cumulated risk if results of miners are considered under conditions comparable to the selected criteria used in the case control studies considering domestic radon exposure in general population.

Scenario: 0.43 WLM (100 Bq/m3) per y from age 40 to 64
Radon risk other than lung cancer risk- Miner studies

No consistent pattern

German Wismut cohort: exposure risk relationship

- **All extra-pulmonary cancers** (*Kreuzer, BJC 2008, Walsh, HP 2010*)
  \[\text{ERR per 100 WLM} = 0.014 \quad 95\% \text{CI}=[0.006–0.023]\]
  linear model with modifying effect of attained age

- **Stomach cancer** (*Kreuzer et al., ERRS 2010*)
  absorbed dose from radon, long-lived radionuclides and gamma
  \[\text{ERR/Gy} = 1.53 \quad 95\% \text{CI}=[0.23-2.73]\]
  no more significant after adjustment for arsenic and fine dust exposure

Circulatory system diseases

exposure-risk relationship for cerebrovascular diseases in the French cohort
\[\text{ERR per 100 WLM} = 0.49 \quad 95\% \text{CI}=[0.07–1.23] \quad (Nusinovici, SJWEH 2010)\]
no association in other studies (*Villeneuve, HP 2007; Kreuzer, REB 2006*)
Radon and leukaemia risk - Miner studies

Czech uranium miners *(Rericha, EHP 2006)*
- 84 leukemia cases
- Leukemia risk associated with cumulative radon exposure (non-CLL and CLL)
- Other sources of exposure not considered

German Wismut uranium miners *(Mohner, HP 2010)*
- 377 leukemia cases and 980 controls
- Absorbed RBM dose from Rn+RDP, LLR, Gamma + medical X-rays
- Contribution of radon inhalation to dose = 31%
- Non significant increased risk above 200 mGy
- No difference between CLL and non-CLL

Alpha-Risk European project *(Tirmarche, Alpha-Risk 2010; Tomasek, IRPA 2010)*
- 69 leukaemia deaths
- Equivalent RBM dose from Rn+RDP, LLR, Gamma
  - (Wr=20 for alpha)
- Mean RBM dose = 90 mSv
- Contribution of radon inhalation = 40%
- ERR per Sv = 3.7  95%CI=[1.1–8.8]
- Similar results for CLL and non-CLL
Radon and childhood leukaemia

Several ecological studies suggest an increased risk
(Laurier HP 2004, Evrard HP 2006, Raaschou-Nielsen, RPD 2008)

Danish case control study (Raaschou-Nielsen et al, Epidemiology 2008)
1153 cases / 2306 controls – children < 15 years old
Radon concentrations estimated through a model –gamma exposure ignored
a significant association with acute lymph. leukaemia (ALL)
9% of ALL attributable to radon in Denmark (m=59 Bq.m⁻³)

Case-control study in Great Britain (Kendall et al, Epidemiology 2012)
• estimate : natural background radiation may explain 15 to 20% of childhood leukaemia (Wakeford, Leukemia 2009; Little, JRP 2009; Wakeford, Rad Prot 2010)
• national case-control study 1980-2006
27 447 cases / 36 793 controls - < 15 years old
  gamma + radon concentration
  bone marrow dose calculation
  radon contributes for 10% to total bone marrow dose (UK = 20 Bq.m⁻³)
  positive association with gamma significative : ERR per mSv = 0.12 IC95% [0.03;0.22]
  no significant association with radon : ERR per mSv = 0.03 IC95% [-0.04;0.11]
Childhood leukemia risk?

- Childhood leukaemia risk in high natural background regions?
- How to learn more
  - Radon or external gamma exposure?
    Comment: natural background radiation = gamma + radon, bone marrow dose mainly influenced by external gamma exposure.
    Adjustment and co-factors is complicated (genetics, in utero exposure...)
    ➔ We should favour research on international level. Necessary for risk communication.
Thanks for your attention