Radiation Epidemiology and Reflections on Fukushima

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Outline – Radiation Epidemiology

• Overview
• Atomic Bomb Survivors
• Medical Exposures
• Nuclear Workers
• Radon (Miners, Home)
• Environmental: Chernobyl
• Fukushima
“And it was so typically brilliant of you to have invited an epidemiologist.”

Airport “Backscatter” X-ray Scanner

A Reflection on You
The technology of X-rays for whole-body scanning in airports involves tiny doses of radiation and technology to record how it bounces off the skin. Here’s how it differs from medical X-rays.

Transmission
TYPICAL DOSE 4 milliems

Backscatter
TYPICAL DOSE: .005 milliems

Transmission X-rays, such as
Backscatter X-rays, such as

Source: Health Physics Society; American Society and Engineering Inc.

NCRP Commentary 16 (2003)
Screening of Humans for Security Purposes Using Ionizing Radiation Scanning Systems
CT use on the rise.

Also PET scans

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A 35% Spike in Infant Mortality in Northwest Cities Since Meltdown

Is the Dramatic Increase in Baby Deaths in the US a Result of Fukushima Fallout?

By JANETTE D. SHERMAN, MD and JOSEPH MANGANO

U. S. babies are dying at an increased rate. While the United States spends billions on medical care, as of 2006, the US ranked 28th in the world in infant mortality, more than twice that of the lowest ranked countries. (DHHS, CDC, National Center for Health Statistics. Health United States 2010, Table 20, p. 131, February 2011.)
Bad “science” scares people

Radiation Units

- 1 mSv - background from terrestrial gamma rays/per year
- 10 mSv - from “typical” CT scan
- 150-200 mSv - detectable by epidemiologic methods
- 3,500 mGy - LD50/30 - death of 50% in 30 days (3.5 Gy)
- 40,000 mGy - treat cancer (40 Gy)
- 0.04 mSv - chest x-ray (4 mrem)
- 0.000005 mSv - backscatter x-ray scan (0.005 mrem)

10 mSv = ~10 mGy = 1 cGy = 1 rad = ~1 rem
Epidemiology is the study of the distribution and causes of disease in humans.

Radiation Epidemiology Dates Back 100 Years

Epidemiologic Studies of Exposed Human Populations

**JAPANESE ATOMIC BOMB SURVIVORS**

<table>
<thead>
<tr>
<th>RADIOThERAPY - CANcer</th>
<th>RADIOThERAPY - NON-MALIGnant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cervical</td>
<td>Spondylitis</td>
</tr>
<tr>
<td>Endometrial</td>
<td>Thymus</td>
</tr>
<tr>
<td>Childhood</td>
<td>Tonsils</td>
</tr>
<tr>
<td>Breast</td>
<td>Menstrual Disorders</td>
</tr>
<tr>
<td>Hodgkin Lymphoma</td>
<td>Scalp Ringworm</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>DIAGNOSTIC</th>
<th>OCCUPATION</th>
<th>ENVIRONMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>TB - Fluoroscopy</td>
<td>Ra Dial Painters</td>
<td>Chemobyl</td>
</tr>
<tr>
<td>Pelvimetry</td>
<td>Miners (Radon)</td>
<td>Weapons Fallout</td>
</tr>
<tr>
<td></td>
<td>Radiologists</td>
<td>Natl Background</td>
</tr>
<tr>
<td>RADIONUCLIDES</td>
<td>Technologists</td>
<td>Techa River</td>
</tr>
<tr>
<td>Thorotrast</td>
<td>Nuclear Workers</td>
<td></td>
</tr>
<tr>
<td>I - 131</td>
<td>Atomic Veterans</td>
<td></td>
</tr>
<tr>
<td>Uranium</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plutonium</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Radiation epidemiology (UNSCEAR 2008) tells us that:

- a single exposure can increase your cancer risk for life
- the young are more susceptible than the old
- in utero susceptibility is no greater than early childhood
- females are more susceptible than males.
- risks differ by organ or tissue and
- some sites have not been convincingly increased after exposure.

Radiation epidemiology is highly uncertain about low dose and low dose rate risks.

Early Radiologists and Technicians 1898 - Sudan
Leukemia Among Early Radiologists / Technologists

Years | No. cases | British | USA | China | USA Tech | Normal Occurrence
--- | --- | --- | --- | --- | --- | ---
1897-1979 | 9 | 1.9 | | | | 0.93
1915-1954 | 17 | 2.5 | | | | 1.0
1926-1985 | 34 | 2.4 | | | | 2.0
1926-1980 | 158 | | | | | 3.0

Early radiation workers

Berrington, Br J Radiol 74:507, 2001
Wang, Int J Cancer 45:889, 1990
Seltzer, Am J Epidemiol 81:2, 1965
Mohan, Int J Cancer, 2003

Radium Dial Painters

Vanderbilt-Ingram Cancer Center
Bone Cancer in Radium Dial Painters (UNSCEAR 2000)

Epidemiologic Studies are the Basis for Cancer Risk Estimates.

“Radiation risk estimates are derived for incidence data for specific tumour sites when adequate dose response data are available from the Japanese Life Span Study (LSS), pooled analyses of multiple studies, or other sources.” ICRP Publ 103, 2007
The "solid cancer" dose response combines non-linear age-adjusted specific sites.

LSS Dose Response for Solid Cancer Mortality, 1950-2003

Ozasa et al, Rad Res 177; 2012
Leukemia has much higher risk coefficient than solid cancer. Excess occurs early.

The “solid cancer” dose response combines cancers altered by other factors.

Liver Cancer Risk From Hepatitis C Virus (HCV+) and Radiation

Sharp et al., Int J Cancer, 103:531-37, 2003

The “solid cancer” dose response combines cancers altered by other factors.
Lung collapse therapy for tuberculosis and associated multiple chest fluoroscopic x-rays (1930-1954)
Breast Cancer
TB - Fluoroscopy, Massachusetts

<table>
<thead>
<tr>
<th></th>
<th>Exposed</th>
<th>Nonexposed</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of women</td>
<td>2,573</td>
<td>2,367</td>
</tr>
<tr>
<td>No. chest fluoroscopies (ave)</td>
<td>88</td>
<td>--</td>
</tr>
<tr>
<td>Dose (ave) [Dale Trout]</td>
<td>790 mGy</td>
<td>--</td>
</tr>
<tr>
<td>Breast cancers</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Observed (O)</td>
<td>147</td>
<td>87</td>
</tr>
<tr>
<td>Expected (E)</td>
<td>114</td>
<td>101</td>
</tr>
<tr>
<td>O/E</td>
<td>1.29</td>
<td>0.86</td>
</tr>
</tbody>
</table>

29% Excess


Age at Exposure
Radiation-Induced Breast Cancer Studies

UNSCAR, p. 155, 1994
Preston et al. Rad Res 2002
Dose Response – Pooled Analysis of Breast Cancer Studies

Breast Cancer

Consistent with linearity

Boice, Radiology 131:589, 1979

Lung and Leukemia
TB - Fluoroscopy, Massachusetts

<table>
<thead>
<tr>
<th></th>
<th>Lung</th>
<th>Leukemia</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. exposed</td>
<td>6,285</td>
<td>6,285</td>
</tr>
<tr>
<td>No. unexposed</td>
<td>7,100</td>
<td>7,100</td>
</tr>
<tr>
<td>No. chest fluoroscopies (ave)</td>
<td>77</td>
<td>77</td>
</tr>
<tr>
<td>Dose to lung or marrow</td>
<td>840 mGy</td>
<td>90 mGy</td>
</tr>
<tr>
<td>Observed (O)</td>
<td>69</td>
<td>17</td>
</tr>
<tr>
<td>Expected (E)</td>
<td>86</td>
<td>19</td>
</tr>
<tr>
<td>RR (95% CI)</td>
<td>0.8 (0.6-1.0)</td>
<td>0.9 (0.5-1.8)</td>
</tr>
</tbody>
</table>

No excess lung or leukemia

Not all tissues respond similarly to fractionation.

Davis et al, Cancer Res 49:6130, 1989
### Lung
**TB - Fluoroscopy, Canada Compared with Japanese LSS**

<table>
<thead>
<tr>
<th>Lung Dose (mGy)</th>
<th>Multiple Fluoroscopy</th>
<th>Atomic Bomb</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td># Lung Ca</td>
<td>RR (95% CI)</td>
</tr>
<tr>
<td>&lt; 10</td>
<td>723</td>
<td>1.0</td>
</tr>
<tr>
<td>10 -</td>
<td>180</td>
<td>0.87 (0.7-1.0)</td>
</tr>
<tr>
<td>500 -</td>
<td>92</td>
<td>0.82 (0.7-1.0)</td>
</tr>
<tr>
<td>1000 -</td>
<td>114</td>
<td>0.94 (0.8-1.2)</td>
</tr>
<tr>
<td>2000 -</td>
<td>41</td>
<td>1.09 (0.8-1.5)</td>
</tr>
<tr>
<td>3000+</td>
<td>28</td>
<td>1.04 (0.7-1.5)</td>
</tr>
</tbody>
</table>

| ERR/Gy (95% CI) | 0.00 (-0.06–0.07) | 0.60 (0.27–0.99) |


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### Summary
**TB Fluoroscopy**

- Low-dose fractions increase breast cancer
- Age at exposure modifies effect
- Linearity fits the breast cancer data
- Low-dose fractions NOT found to increase
  - Lung cancer
  - Leukemia
  - Heart disease
- Be cautious when generalizing

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A Comprehensive Cancer Center supported by the National Cancer Institute.
Breast Cancer Thymus Irradiation

1918: Thymus thought that the large thymus in children was abnormal and suggested radiation treatment to shrink it.

Immature breast tissue at risk but risk manifests many years later.

Radiotherapy for Ringworm
5 treatments, 3-12 minutes each
Thyroid Tinea Capitis - Israel

Number Exposed: 10,834
Number Nonexposed: 16,226
Thyroid Dose (mean): 90 mGy
Observed Thyroid Cancers: 43
Expected: 10.7
RR (95% CI): 4.0 (2.3 - 7.9)


Some Uncertainties of Epidemiology...

- Effect primarily among immigrants, mainly from Morocco, not Israeli born (Ron, Rad Res, 1989)
- “Irradiation for tinea capitis was given to many Jews in Morocco prior to immigration…” (Modan, JNCI, 1980)
- Genetic susceptibility & family clustering (4 sisters thyroid disease)
- Wiggle could increase dose x 3
- Immigrants from Morocco came from Atlas Mt region, and diets deficient in stable iodine
Thyroid Cancer after Exposure to External Radiation: A Pooled Analysis of Seven Studies

Ron et al, 1995

Thyroid Cancer & External Radiation Risk
Dose Response by Age at Exposure

Ron et al, 1995
Radiation Treatments
Multiple Primary Cancers

Warren and Gates, 1932, Definitions

Risk Quantification


NCRP Report
In Press 2012

- 420 pages
- 12 Committee members
- Work: 2006-2011
- http://www.NCRPonline.org


Travis et al. JNCI 2012;104:1-14
### Radiotherapy for Breast Cancer

**Breast Cancers in Connecticut (1935-82)**

**Second Breast Cancer**

<table>
<thead>
<tr>
<th></th>
<th>RR</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>All Subjects*</td>
<td>1.19</td>
<td>0.9-1.5</td>
</tr>
<tr>
<td>Time After Exposure (Yr)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5-9</td>
<td>0.99</td>
<td>0.7-1.4</td>
</tr>
<tr>
<td>≥10</td>
<td>1.33</td>
<td>1.0-1.8</td>
</tr>
<tr>
<td>Age at Exposure (Yr)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;35</td>
<td>2.26</td>
<td>0.9-5.7</td>
</tr>
<tr>
<td>35 -</td>
<td>1.46</td>
<td>0.9-2.3</td>
</tr>
<tr>
<td>≥45</td>
<td>1.01</td>
<td>0.8-1.4</td>
</tr>
</tbody>
</table>

*655 Cases, 1,189 Controls

Risk after 10 years among young. Example of age modification.

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**Diagram:**

- **Tangential Field Block**
- **Anterior Field Block**

**Radiotherapy Do to Contralateral Breast**

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Vanderbilt-Ingram Cancer Center: A Comprehensive Cancer Center Designated by the National Cancer Institute
Genetic Susceptibility?
Second Breast Cancer

WECARE, 2\textsuperscript{nd} breast (n~600) to study Interaction Between Radiation and Genes*

<table>
<thead>
<tr>
<th>Exposure</th>
<th>RR</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>BRCA1 mutation</strong></td>
<td>4.5</td>
<td>2.8-7.1</td>
</tr>
<tr>
<td><strong>BRCA2 mutation</strong></td>
<td>3.4</td>
<td>2.0-5.8</td>
</tr>
<tr>
<td><strong>ATM (common variants)</strong></td>
<td>0.8</td>
<td>0.7-1.0</td>
</tr>
<tr>
<td>1 Gy (age &lt;40 y)</td>
<td>1.6</td>
<td>1.1-2.5</td>
</tr>
<tr>
<td>1 Gy (age &gt;45 y)</td>
<td>1.0</td>
<td>0.9-1.3</td>
</tr>
</tbody>
</table>

*BRCA, ATM, CHEK2*1100delC

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Risk of Second Primary Breast Cancer by \textit{ATM} Variant and Radiation Dose

<table>
<thead>
<tr>
<th>ATM</th>
<th>Dose</th>
<th>Case</th>
<th>Control</th>
<th>RR</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Variants Broadly Classified</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wild type</td>
<td>No</td>
<td>112</td>
<td>72</td>
<td>1.0</td>
<td>0.7-1.6</td>
</tr>
<tr>
<td></td>
<td>&lt;1.0Gy</td>
<td>57</td>
<td>177</td>
<td>1.0</td>
<td>0.7-1.7</td>
</tr>
<tr>
<td></td>
<td>≥1.0Gy</td>
<td>54</td>
<td>169</td>
<td>1.1</td>
<td>0.7-1.7</td>
</tr>
<tr>
<td>Missense</td>
<td>No</td>
<td>26</td>
<td>30</td>
<td>1.0</td>
<td>0.7-1.7</td>
</tr>
<tr>
<td></td>
<td>&lt;1.0Gy</td>
<td>21</td>
<td>45</td>
<td>2.7</td>
<td>1.2-6.4</td>
</tr>
<tr>
<td></td>
<td>≥1.0Gy</td>
<td>21</td>
<td>38</td>
<td>3.3</td>
<td>1.4-8.0</td>
</tr>
<tr>
<td><strong>SIFT Classified</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tolerated</td>
<td>No</td>
<td>12</td>
<td>16</td>
<td>1.0</td>
<td>0.7-1.7</td>
</tr>
<tr>
<td></td>
<td>&lt;1.0Gy</td>
<td>9</td>
<td>29</td>
<td>1.4</td>
<td>0.4-4.7</td>
</tr>
<tr>
<td></td>
<td>≥1.0Gy</td>
<td>10</td>
<td>20</td>
<td>2.1</td>
<td>0.6-7.1</td>
</tr>
<tr>
<td>Deleterious</td>
<td>No</td>
<td>14</td>
<td>14</td>
<td>1.0</td>
<td>0.7-1.7</td>
</tr>
<tr>
<td></td>
<td>&lt;1.0Gy</td>
<td>12</td>
<td>17</td>
<td>5.3</td>
<td>1.6-17.3</td>
</tr>
<tr>
<td></td>
<td>≥1.0Gy</td>
<td>11</td>
<td>15</td>
<td>5.8</td>
<td>1.8-19.0</td>
</tr>
</tbody>
</table>

Bernstein et al JNCI 2010
Conclusions

Women who carry rare deleterious ATM missense variants and who are treated with radiation may have an elevated risk of developing contralateral breast cancer.

However, the rarity of these deleterious missense variants in human populations implies that ATM mutations could account for only a small portion of second primary breast cancers.


Cervical Cancer and Leukemia
Blood Studies and Clinical Follow-up
30 Radiotherapy Centers in 9 Countries

<table>
<thead>
<tr>
<th>Number</th>
<th>30,000 women</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dose</td>
<td>5-15 Gy (marrow)</td>
</tr>
<tr>
<td>Leukemia</td>
<td></td>
</tr>
<tr>
<td>Observed</td>
<td>13</td>
</tr>
<tr>
<td>Expected</td>
<td>15.5</td>
</tr>
<tr>
<td>Risk</td>
<td>No excess</td>
</tr>
</tbody>
</table>

Boice & Hutchison, JNCI 65:115, 1980  Huge dose, but no risk
Bone Marrow Dosimetry
Downturn at High Doses


International Cervical Cancer Study
Expansion – 16 Radiotherapy Centers and 17 Cancer Registries in 14 Countries

Average excess RR per gray for leukemia = 0.14

Characteristic wave-like pattern over time

Boice et al, *JNCI* 74:955, 1985
Long Minimum Latency - Solid Cancers

Lung Cancer Following Hodgkin Lymphoma
International Case - Control Study (2002)

Definition of Cohort:
- Diagnosis of Hodgkin lymphoma: 1965-1994
- Survival of 1 or more years
Final Cohort: 22,977 (222 cases, 444 controls)

Travis et al. JNCI 94:182, 2002
Lung Cancer After Hodgkin Lymphoma
Radiotherapy and Environmental Factor Effects

Gilbert et al., Rad Res 159:161, 2003
Travis et al., JNCI 94:182, 2002

<1 pack/day has greater risk than ≥40 Gy

2nd Cancers After Childhood Cancer (CCSS)

Incidence, 5 year survivors
N = 13,581
CCSS (2001)

Neglia, JNCI 93:618, 2001
Second Cancer after Retinoblastoma

Possible high dose interaction with genetic susceptibility

Years since retinoblastoma diagnosis

Updated. Yu et al.  
*JNCI* 101:581, 2009

Updated. Kleinerman et al.  
*JCO* 23:2272, 2005

Wong et al.  
*JAMA* 278:1262, 1997

Thyroid Cancers After Childhood Cancer (CCSS)

Cell Killing

Relative risk

Dose (Gy)

Meadows, *JCO* 27, 2009
Bhatti, *Rad Res* 174, 2010
Variants at 6q21 are associated with both radiation therapy–induced SMNs and PRDM1 protein abundance before and after radiation exposure.

Survivors of pediatric Hodgkin’s lymphoma are at risk for radiation therapy–induced second malignant neoplasms (SMNs). Two variants at chromosome 6q21 were associated with SMNs in survivors treated with radiation therapy as children but not as adults. The variants comprise a risk locus associated with decreased basal expression of PRDM1 and impaired induction of the PRDM1 protein after radiation exposure. These data suggest a new gene-exposure interaction that may implicate PRDM1 in the etiology of radiation therapy-induced SMNs. Best et al. Nature Med 2011
Pregnancy and A-Bomb Radiation

Atomic Bomb Survivors In Utero and Post-Natal Cancer Risk

Risk of Cancer

- Childhood irradiation: No apparent increased sensitivity
- In utero irradiation: No childhood leukemia

Preston et al. JNCI 100:428, 2008
No Dose-Response for Chromosome Aberrations after In Utero Exposure, RERF

Oxford Prenatal X-ray Survey
Is the low-dose association causal?

<table>
<thead>
<tr>
<th>Childhood cancer</th>
<th>Cases</th>
<th>% X-ray</th>
<th>RR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leukemia</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lymphatic</td>
<td>2,007</td>
<td>14</td>
<td>1.5</td>
</tr>
<tr>
<td>Myeloid</td>
<td>866</td>
<td>14</td>
<td>1.5</td>
</tr>
<tr>
<td>Lymphoma</td>
<td>719</td>
<td>13</td>
<td>1.4</td>
</tr>
<tr>
<td>All leukemia/lymphoma</td>
<td>4,771</td>
<td>14</td>
<td>1.47</td>
</tr>
<tr>
<td>Wilms</td>
<td>590</td>
<td>15</td>
<td>1.6</td>
</tr>
<tr>
<td>CNS</td>
<td>1,332</td>
<td>13</td>
<td>1.4</td>
</tr>
<tr>
<td>Neuroblastoma</td>
<td>720</td>
<td>14</td>
<td>1.5</td>
</tr>
<tr>
<td>Bone</td>
<td>244</td>
<td>11</td>
<td>1.1</td>
</tr>
<tr>
<td>Other solid</td>
<td>856</td>
<td>15</td>
<td>1.6</td>
</tr>
<tr>
<td>All solid</td>
<td>3,742</td>
<td>14</td>
<td>1.47</td>
</tr>
</tbody>
</table>

Biologically plausible to have same RR?

“Although the arguments fall short of being definitive because of the combination of biological and statistical uncertainties involved, they raise a serious question of whether the great consistency in elevated RRs, including embryonal tumours and lymphomas, may be due to biases in the OSCC study rather than a causal association.”

Christian Streffer, Chairman

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Low Dose Studies are More Susceptible to – Bias and Confounding and Chance

81. ... there are a number of studies of occupationally exposed persons, who generally receive low doses of ionizing radiation at low dose rates. For example, in the IARC 15-country study, average cumulative doses were 19.4 mSv, and fewer than 5% of workers received cumulative doses exceeding 100 mSv.
Leukemia and Cancer Dose Response


11 Underground Miner Studies
68,000 Miners – 2,700 Lung Cancers

Lubin et al, 1993

1 pCi/l ~ 0.2 WLM / yr.

Washington Post, February 6, 1986

New Meaning to “The Nuclear Family”
### Radon Studies in Homes
#### (Case-Control)

<table>
<thead>
<tr>
<th>United States</th>
<th>Nordic Countries</th>
</tr>
</thead>
<tbody>
<tr>
<td>✓ New Jersey</td>
<td>✓ Sweden</td>
</tr>
<tr>
<td>✓ Missouri</td>
<td>✓ Finland</td>
</tr>
<tr>
<td>✓ Iowa</td>
<td>✓ Shenyang</td>
</tr>
<tr>
<td>✓ Connecticut</td>
<td>✓ Gansu</td>
</tr>
<tr>
<td>✓ Utah/Idaho</td>
<td></td>
</tr>
<tr>
<td>Canada</td>
<td></td>
</tr>
<tr>
<td>✓ Winnipeg</td>
<td></td>
</tr>
<tr>
<td>Europe</td>
<td></td>
</tr>
<tr>
<td>✓ Southwest England</td>
<td>✓ North America (Krewski, 2005)</td>
</tr>
<tr>
<td>✓ Western Germany</td>
<td>✓ Europe (Darby, 2005)</td>
</tr>
<tr>
<td>Czech (cohort)</td>
<td>✓ China (Lubin, 2004)</td>
</tr>
<tr>
<td></td>
<td>World (Darby, in progress)</td>
</tr>
</tbody>
</table>

**BEIR VI, 1999; Field, Rev Envir Health 16, 2001**
People’s Republic of China
Gansu Province

Gansu Province
Underground Dwellings
Gansu Province
Underground Dwelling

Gansu China - Radon Study

\[ OR = 1 + 0.0032 \times X \]

OR = 1 + 0.0025 X

RR = 1


Lubin et al. *Int J Cancer* 109:132, 2004

4 pCi/l = 150 Bq/m³

Consistent with linearity
Indoor Radon Meta-Analysis
Lung Cancer

Difficult to detect low-dose risks, yet significant trend when studies combined

Radon Interacts with Smoking to Enhance Risk

A nearly multiplicative interaction
## Smoking Compared with Radiation/Radon

<table>
<thead>
<tr>
<th>RR</th>
<th>Cigarettes Per Day</th>
<th>A-Bomb Dose, 1000 mSv</th>
<th>Miners WLM</th>
<th>Radon Indoor Bq/m³</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>&lt; 40</td>
</tr>
<tr>
<td>4.6</td>
<td>1-9</td>
<td>3.4</td>
<td>735</td>
<td>4,500*</td>
</tr>
</tbody>
</table>

*140 pCi/L

---

**Boice, Radiat Res, 146:356, 1996**

Smoking <10 cig/day equivalent to being high dose A-bomb survivor
Thyroid Cancers in Children in Belarus

Prospective cohort study, < 18 yr
Individual measurements within 2 month
Dose from short-lived radioiodines not included
Participation rate 44% for screening.
Lower RR at 1000 mSv than studies of external irradiation (2.91 vs. 8.7)

Ukrainian – American Thyroid Study

Prospective cohort study, < 18 yr
Individual measurements within 2 month
Dose from short-lived radioiodines not included
Participation rate 44% for screening.
Lower RR at 1000 mSv than studies of external irradiation (2.91 vs. 8.7)
Descriptive Studies
Nuclear Facilities (Sellafield, U.K.)

Cancer in Populations
Living Near Nuclear Facilities
JAMA 256: 1991
Overall Relative Risk of Leukemia Before and After Nuclear Facility Startup

Before Startup | After Startup | Relative Risk
---|---|---
Childhood Leukemia | 1.08 | 1.03
Leukemia All Ages | 1.02 | 0.98

Risk higher before than after facilities began operating.

What is the major unanswered question in radiation epidemiology?

- What is the level of risk when exposure received gradually over time and not briefly
- Being considered in U.S. by studying One Million Radiation Workers and Veterans

When Exposure is Spread Over Time

One Million U.S. Radiation Workers and Veterans
- Manhattan Project
- Atomic veterans
- Nuclear utility workers
- Medical and other occupational
- Nuclear navy workers

The 8th Series - Trinity
- First weapons test, Alamagordo, NM, 16 July 1945
- Longer follow-up than Japanese atomic bomb survivor study
- Historical figures:
  Robert Oppenheimer
  General Leslie Groves
  Enrico Fermi, Hans Bethe
  Theodore Hall
Before your flight to Tokyo, you’re sitting in a freshly dry-walled house, drinking coffee from a Styrofoam cup, talking on a cell phone while fish from Japan is cooking on the grill – Which of these is most likely to be a cancer risk? (AP July 15, 2011)

Carcinogens are things that can cause cancer, but that label doesn’t mean that they will or that they pose a meaningful risk.

Better communication and understanding of radiation health effects needed. (Vano et al. JRP, 2011)

A Perspective on Fukushima
Summary

- Fukushima is not Chernobyl – doses to people much lower
- Japanese acted quickly – to reduce population dose
- “It is the dose that makes the poison” (Paracelsus)
- “… know which way the wind blows” (Dylan)
- “… and miles to go…” (Frost) – the immediate crisis over Dec 2011 but cleanup and societal problems are not
- Health surveys being conducted

Fukushima is not Chernobyl

UNSCEAR 2011 (Feb)
134 workers had Acute Radiation Sickness with doses > 2000 mGy, some > 10,000 mG, highest 16,000 mG. 28 died in a few months.

Chernobyl firemen

Thanks - Fred Mettler

530,000 Recovery Workers (liquidators) were used in the cleanup over 3 years – mean dose 100 mSv

Radioactive iodines in the environment caused epidemic of thyroid cancer.

**Iodine-131 Releases**

(8 day half-life)

- Three Mile Island: 0.005 PBq
- Fukushima: 160 PBq
- Chernobyl: 1760 PBq
- Atmospheric testing: 675,000 PBq

Iodine-131, Cesium-137, other releases mainly seaward and lower than Chernobyl

PBq = Peta Bq = $1 \times 10^{15}$ Bq  
1 PBq = 27kCi
Radiation was released at Fukushima but ...

- "the poison is in the dose" (Paracelsus)
- And population exposure appears low (at the moment)

Population Exposure

Quick action taken to minimize adverse health consequences

- Evacuation
- Recommend to stay indoors
- Food restrictions
- Monitoring, masks
- Extensive population screening (200,000)

1,080 children examined for thyroid dose – lower than the screening level.
Worker Exposure

- Number of workers (23 May): 7,800
- Average exposure dose: 8 mSv
- Number between 100-250 mSv (external): 30
- Number > 250 mSv (external + internal): at least 2
- Lifetime risk of developing cancer may be 1-2% for those > 100 mSv

Internal Exposure and External Exposure in Highly Exposed Plant Workers

<table>
<thead>
<tr>
<th>WORKER</th>
<th>Total (mSv)</th>
<th>External (mSv)</th>
<th>Internal (mSv)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>678</td>
<td>88 (13%)</td>
<td>590 (87%)</td>
</tr>
<tr>
<td>B</td>
<td>643</td>
<td>103 (16%)</td>
<td>540 (84%)</td>
</tr>
</tbody>
</table>
U.S. Military Exposure
Internal Monitoring Preliminary

- Number monitored (2 Aug) 7,740 of 61,000
- Number > MDA 183 (2.4%)
- Average internal dose .04 mSv
- Highest internal dose 0.25 mSv

What about food?

Regulated values of radioactive materials in food (Bq/kg)

<table>
<thead>
<tr>
<th>Item</th>
<th>I-131</th>
<th>Cs</th>
<th>U</th>
<th>Pu, Am, Cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drinking water</td>
<td>300</td>
<td>200</td>
<td>20</td>
<td>1</td>
</tr>
<tr>
<td>Milk</td>
<td>300</td>
<td>200</td>
<td>20</td>
<td>1</td>
</tr>
<tr>
<td>Vegetables, etc</td>
<td>2000</td>
<td>500</td>
<td>100</td>
<td>10</td>
</tr>
</tbody>
</table>

† Belarus 32,000 Bq/L 3 days after Chernobyl!
Population exposures appear low -- but

- To show compassion and provide assurance, health surveys are planned
- Provide medical care
- Mental health problems most likely consequence

Health Survey – Fukushima Residents

BASIC STUDY

- 2 Million Residents sent 10 Page Questionnaire
- To learn location, intake of food, baseline data
- 30 year follow-up planned, first year to cost 96 Billion Yen
- Purposed stated to alleviate anxiety

KOSHU EISEI JOHO (Public Health Information) 41(6):18-21, Sep 2011
Health Survey – Fukushima Residents

DETAILED STUDIES

- (1) Thyroid study of 360,000 <18y, 2 ½ y started Oct 2011
- (2) Health exam, including blood samples of ~ 80,000 in the evacuation zone
- (3) Mental health, counseling of those in evacuation zone
- (4) Pregnant women and nursing mothers

KOSHU EISEI JOHO (Public Health Information) 41(6):18-21, Sep 2011
Fukushima Daini NPP
Sept 13, 2011

Domo - Arigato
Thank you


Bibliography - 3


Bibliography Fukushima - 1


Bibliography Fukushima – 4


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