BEIR VII AND ITS IMPLICATIONS ON RISK – FACTS VERSUS MYTHS

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Why are we concerned with Radiation Risks?

Using LNT & BEIR VII report, estimated radiation-related incident cancers

Estimated that 29,000 future cancers could be related to CT scans performed in the U.S. in 2007.....and would translate into about 14,500 cancer deaths.

Arch Intern Med. 2009;169(22):2078-2086
CT Scan Radiation May Lead to 29,000 Cancers, Researchers Warn
Popular Diagnostic Scans May Be Overused, Some Worry

(Reuters) - Radiation from CT scans done in 2007 will cause 29,000 cancers and kill nearly 15,000 Americans, researchers said on Monday.

By Julie Steehuysen
CHICAGO | Mon Dec 14, 2009 4:30pm EST
Where does the estimate of 29,000 cancers come from?

Based on Table 12D from BEIR VII, + risk estimates for 56,900,000 patients
TABLE 12D-1 Lifetime Attributable Risk of Cancer Incidence

<table>
<thead>
<tr>
<th>Age at Exposure (years)</th>
<th>0</th>
<th>5</th>
<th>10</th>
<th>15</th>
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<td>43</td>
<td>36</td>
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<td>1076</td>
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<tr>
<td>All cancers</td>
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<td>3377</td>
<td>2611</td>
<td>2064</td>
<td>1646</td>
<td>1065</td>
<td>886</td>
</tr>
</tbody>
</table>

**NOTE:** Number of cases per 100,000 persons exposed to a single dose of 0.1 Gy.
What is the BEIR VII Report

An estimate of cancer risk from low doses of ionizing radiation!

- Input data:
  - Environmental studies
  - Occupational studies
  - Medical studies
  - Atomic bomb studies

- Model: LNT model (no allowance for dose-rate effects)

- Risk models:
  - ERR (excess relative risk)
  - EAR (excess absolute risk)
  - LAR (lifetime attributable risk)

- Subjective opinion of committee!
Sources of data

- Environmental Radiation Studies
- Occupational Radiation Studies
- Medical Radiation Studies
- Atomic bomb survivor Studies
Sources of data used in BEIR VII
Environmental Radiation Studies

Populations living near nuclear facilities
“..no increased risk…with radiation exposure”

Populations exposed to atomic bomb testing
“..some studies (4 out of 10) show some effect”

Chernobyl
High incidence of thyroid cancer
“..no evidence of an increase in any solid cancer type to date”

Natural background (China / India)
“..did not find higher disease rates in geographical areas with high background levels..”
Cancer Mortality in High Background Radiation Area of Yangjiang, China, 1979-1995

- Estimated cancer risk associated with the low level radiation exposure of 6.4 mSv / year
- 20-year study in 125,079 subjects
- Excess Relative Risk
  \[ \text{ERR/Sv} = -0.10 \ (-0.67 \text{ to } 0.69) \]
- Conclusion: the mortality of all cancers in Yangjiang was generally lower than that in control group, but not significant statistically.

(Tao et al, Zhonghua Yi Xue Za Zhi, 1999; 79: 487-492)
Radon Levels

Lung Cancer

Generated from EPA web site (https://www.epa.gov/radon/find-information-about-local-radon-zones-and-state-contact-information#radonmap)

Generated from NCI mortality map (http://ratecalc.cancer.gov/ratecalc/)
Sources of data

• Environmental Radiation Studies
• Occupational Radiation Studies
• Medical Radiation Studies
• Atomic bomb survivor Studies
Occupational Radiation Studies on Workers in the Nuclear Power Industry

“....in most cases, rates for all causes and all cancer mortality in the workers were substantially lower than the reference populations.”

Findings explained as “healthy worker effect”
(U.S. Academy of Science, BEIR VII, 2007)

Significant limitation of most occupational studies is absence of an appropriate control group!
Sources of data

• Environmental Radiation Studies
• Occupational Radiation Studies
• Medical Radiation Studies
• Atomic bomb survivor Studies
Medical Radiation Studies

Sources of data used in BEIR VII

Focus on therapeutic studies

“...most of the information comes from studies of populations with medium to high doses”

Lung Cancer – 9 studies, 40,000 subjects
average dose ~ 1 Gy

Breast cancer – 11 studies, 20,000 subjects
average dose ~ 300 mGy
Mortality from Breast Cancer after Fluoroscopy in Patients being treated for Tuberculosis

31,710 women treated between 1930 - 1952
40-year follow-up
Age range 10-40 years

“Risk was statistically significant for all those who received more than 100 mSv of radiation”

Mortality from Breast Cancer after Fluoroscopy in Patients being treated for Tuberculosis

31,710 women treated between 1930 - 1952
40-year follow-up
Age range 10-40 years
Sources of data used in BEIR VII

- Environmental Radiation Studies
- Occupational Radiation Studies
- Medical Radiation Studies
- Atomic bomb survivor Studies
Atomic bomb survivor Studies

- 120,000 survivors
  - 93,000 present at time of bombings
  - 27,000 from locale, but absent at time of the bombing (Not In City group)

- Monitored over 70 years & includes both sexes and all ages of exposure – mean dose = 200 mSv

- Dose range
  - 37,000 0-5 mSv
  - 32,000 5-100 mSv
  - 17,000 100 mSv – 2000 mSv

This is the primary source of data for LNT risk models
Atomic bomb survivor Studies

Data from Table 4, Preston et al, 2007

# solid cancers adjusted to per 100,000 people

(Radiation Effects Research Foundation)
Atomic bomb survivor Studies

Data from Table 4, Preston et al, 2007

# solid cancers adjusted to per 100,000 people

Preston et al, Rad Res 2007;168: 1-64. (Radiation Effects Research Foundation)
Atomic bomb survivor Studies

Ozasa et al, 2013, Doss et al 2012
Low Dose Risk Estimates require “Impracticably Large” sample requirements

- Does the radiation from mammography (about 1 mSv) cause breast cancer?
  - Cohort study: about 100 million (20-year follow-up)!
  - Case-control: about 1 million cases (4:1 ratio)
Sample size required to detect a significant increase in cancer mortality, assuming lifetime follow-up

Effect of Low Doses - 3 Theories

Linear No Threshold (LNT) Model
Threshold Model
Hormesis Model
Linear No-Threshold Hypothesis

LNT & Radiation

• 1930’s: developed by Herman Mueller to explain mutagenesis in fruit flies

• 1950: Mueller persuaded BEIR committee in 1950 to use his LNT hypothesis to explain carcinogenesis

LNT assumes that

- any amount of radiation exposure, no matter how small, can increase the chance of cancer.
- probability of cancer from radiation exposure increases with cumulative lifetime dose.
LNT Hypothesis

For example: Using the LNT model the following are equivalent in terms of their effect

1 person jumps off a 100-foot cliff

100 people jump off a 1-foot cliff

1 person jumps off a 1-foot cliff 100 times
Lung Cancer Mortality vs. Dose Rate

According to LNT they should be the same!

Dose delivered instantaneously

Dose delivered over 3 years
(avg. dose / session = 11 mSv)

Howe GR, Rad Res 1995; 142: 255-304
Risk Models used in LNT

Excess Relative Risk (ERR) model

The ERR is the rate of disease in an exposed population divided by the rate of disease in an unexposed population, minus 1.0.

(This is a useful model if the population under investigation is similar to the population on which the model was based.)

Excess Absolute Risk (EAR) model

The EAR is the rate of disease in an exposed population minus the rate of disease in an unexposed population.

(This model is more suited if there are significant differences (ethnicity, diet, etc) between the population under investigation and that on which the model was based.)
same data – 2 different risk models

comparison of lifetime risk of cancer using ERR and EAR

[Graph showing comparison of lifetime risk of cancer for different body parts (Stomach, Breast, Prostate) using ERR and EAR models for males and females.]
Risk Models used in LNT

Excess Relative Risk (ERR) vs. Excess Absolute Risk (EAR)

Which model is correct?

For each organ, final risk model
\[ = x \cdot \text{ERR} + (1-x) \cdot \text{EAR} \]
where \( x \) is determined by committee!
Risk Models

Cancer incidence from ionizing radiation

- Based almost exclusively on atomic bomb survivor studies
- Uses a combination of ERR and EAR
- Uses different combinations for different organs
- Includes additional assumptions about modifying factors such as latency
- Risk models (developed from Japanese population, wartime conditions) then applied to cancer rates for U.S. population
...range of plausible values for LAR is labeled a “subjective confidence interval” to emphasize its dependence on opinions in addition to direct numerical observation (BEIR VII, page 278)

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<table>
<thead>
<tr>
<th>Cancer Site</th>
<th>Males</th>
<th>Females</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>LAR Based on Relative Risk Transport&lt;sup&gt;a&lt;/sup&gt;</td>
<td>LAR Based on Absolute Risk Transport&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Stomach</td>
<td>25</td>
<td>280</td>
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<tr>
<td>Colon</td>
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<td>350</td>
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<td>Sum of site-specific estimates</td>
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<tr>
<td>All solid cancer model&lt;sup&gt;f&lt;/sup&gt;</td>
<td>1550</td>
<td>1250</td>
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</tbody>
</table>

**NOTE:** Number of cases per 100,000 persons of mixed ages exposed to 0.1 Gy.
Risk estimates are “subjective” and partly based on the opinion of members of the BEIR VII committee.

Risk estimates at low doses are extrapolated from high doses and are not supported by current low-dose studies.
The following organizations have clearly stated that the use of the LNT Hypothesis to compute the effects of small doses on large populations is inappropriate:

- International Commission on Radiological Protection
- American Association of Physicists in Medicine
- Health Physics Society
- Academie Nationale de Medecine, France
- National Council on Radiation Protection & Measurement
- United Nations Scientific Committee on Effects of Atomic Radiation
“The Scientific committee does **NOT recommend** multiplying very low doses by large numbers of individuals to estimate numbers of radiation-induced health effects within a population exposed to incremental doses at levels equivalent to or lower than natural background levels”

**Background Radiation:** 2 – 10 mSv / year worldwide
ANS / HPS Program: Oct 1st-3rd 2018
Pasco, WA

- 3-day program on applicability of radiation response models to low dose protection standards
- 200-300 participants divided into 3 primary camps
  - LNT (~10%)
  - Threshold (~70%)
  - Hormesis (~20%)
- Regulatory bodies
  - ICRP
  - UNSCEAR
  - NCRP / IAEA / NRC / EPA
The number of deaths indirectly related to the earthquake in Fukushima Prefecture was >1700.

Deaths were due to the physical / mental stresses related to the evacuation.
ICRP Recommendations

Encourage & support low-dose and low-dose-rate research

Improve messaging about risks at very low doses

Promote reasonableness in optimization of protection, avoiding over-conservatism, in:

- Standards
- Regulations
- Practice (including regulatory practice)
UNSCEAR Recommendations:

For legislators to exclude from the law low-dose exposure situations that are unamenable to be controlled.

For regulators to exempt from regulations low-dose exposure situations that do not warrant control.