Relative Risk and Uranium Recovery

Presented To:
National Mining Association (NMA) / Nuclear Regulatory Commission (NRC)
Uranium Recovery Workshop
Denver – April 29, 2008

Presented By:
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Outline of Presentation

- Radiation Doses from Natural Background
- Regulation of Radiation Dose from Mining and Milling
- Risks from Ionizing Radiation
- Radiation Doses from Mining and Milling
  - Workers
  - Members of the public
- Context
Background Levels of Radiation

Natural Background
82%

Other (17%)
- Medical X-Ray 10.3%
- Nuclear Medicine 3.8%
- Consumer Products 2.7%
- Miscellaneous 0.2%

After BEIR VII
Terrestrial Gamma-Ray Exposure at 1m Above Ground

Source of data: U.S. Geological Survey Digital Data Series DDS-9, 1993
Generalized Geologic Radon Potential of the United States

by the U.S. Geological Survey

Geologic Radon Potential
(Predicted Average Screening Measurement)
- LOW (<2 pCi/L)
- MODERATE/FAVORABLE (2-8 pCi/L)
- MEDIUM (8-15 pCi/L)
- HIGH (>15 pCi/L)

State
Continental United States and Hawaii
Sources of Radiation Exposure to the U.S. Population

- Radon: 200 mrem (Natural)
- Internal: 39 mrem (Natural)
- Medical X-rays: 14 mrem (ManMade)
- Terrestrial: 28 mrem (Natural)
- Cosmic: 27 mrem (Natural)
- Nuclear Medicine: 10 mrem (ManMade)
- Consumer Products: 3 mrem (ManMade)

### Natural Background Radiation in the U.S. (mrem/yr)

<table>
<thead>
<tr>
<th>Source</th>
<th>Mean</th>
<th>Variability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cosmic</td>
<td>27</td>
<td>20 - 60</td>
</tr>
<tr>
<td>Gamma</td>
<td>28</td>
<td>10 - 80</td>
</tr>
<tr>
<td>Internal</td>
<td>40</td>
<td>30 - 100</td>
</tr>
<tr>
<td>Inhaled</td>
<td>200</td>
<td>20 - 80</td>
</tr>
<tr>
<td>Total</td>
<td>300</td>
<td>100 - 1000</td>
</tr>
</tbody>
</table>

Sources: NCRP 94, NUREG-1496
Relative Magnitude of Individual Doses

Effective dose (mSv)

SOURCE: Fred Mettler, NCRP  2007
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Radiation Dose Limits

- **International**
  - International Commission on Radiological Protection (ICRP)

- **United States**
  - Nuclear Regulatory Commission (NRC)
  - Environmental Protection Agency (EPA)
  - Mine Safety Health Administration (MSHA)
ICRP Recommendations

- Latest recommended dose limits (2007) unchanged from 1990 ICRP 60 limits
- Limits in terms of “effective dose” (mSv)
  - sum of organ doses weighted according to contribution of that organ to total health detriment resulting from whole body irradiation
- All occupational exposures considered - inhalation, ingestion, and external
- Considered equivalent to TEDE (total effective dose equivalent) in US
ICRP Dose Limits

- **Workers**
  - 100 mSv in 5 years
    - In practice 20 mSv/year averaged over 5 years
  - Maximum of 50 mSv in any single year not to exceed 100 mSv in 5 years

- **Public**
  - 1 mSv/year

- **Overriding Principals**
  - Justification (benefit > harm)
  - ALARA (optimization)

Note: 1 mSv = 100 mrem
10 CFR Part 20
- Occupational: 5 rem
- Public: 0.1 rem

Appendix B to Part 20 gives:
- Annual Limit on Intake (ALI) and Derived Air Concentration (DAC) values (Table 1)
- Effluent Concentrations (Table 2)

Total Effective Dose Equivalent (TEDE):
- The sum of the deep-dose equivalent (for external exposures) and the committed effective dose equivalent (for internal exposures).
ALI’s are the annual intakes of a given radionuclide by "Reference Man" which would result in either:
- A committed effective dose equivalent of 5 rem (stochastic ALI)
- A committed dose equivalent of 50 rem to an organ or tissue (non-stochastic ALI).

DAC’s are derived limits based on ALI’s used to control exposure
- DAC’s are radionuclide concentrations which, if inhaled or ingested continuously over the course of a year, would produce a TEDE of 0.05 rem (50 mrem or 0.5 mSv).
## U.S. NRC - 3

<table>
<thead>
<tr>
<th>Class</th>
<th>Occupational Values</th>
<th>Effluent Concentrations</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Oral Ingestion ALI (µCi)</td>
<td>Inhalation</td>
</tr>
<tr>
<td></td>
<td>ALI (µCi)</td>
<td>DAC (µCi/ml)</td>
</tr>
<tr>
<td>Rn-222</td>
<td>With daughters removed</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>With daughters present</td>
<td>-</td>
</tr>
</tbody>
</table>
A licensee with uranium fuel cycle operations shall comply with EPA's 40 CFR part 190 (Subpart B).

Operations covered by this subpart shall be conducted in such a manner as to provide reasonable assurance that:

- “The annual dose equivalent does not exceed 25 millirems to the whole body, 75 millirems to the thyroid, and 25 millirems to any other organ of any member of the public as the result of exposures to planned discharges of radioactive materials, radon and its daughters excepted, to the general environment from uranium fuel cycle operations and to radiation from these operations.”
MSHA

- 5 rem external and,
- 4 WLM radon decay products

... But

Applied Independently and Not a Sum Rule
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Health Effects of Ionizing Radiation

- International and National Authorities rely on the work of scientific committees such as:
  - United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR);
  - Biological Effects of Ionizing Radiation (BEIR) Committees;
  - National Council on Radiation Protection and Measurements (NCRP), and others

for their scientific evaluation on the health effects of exposure to ionizing radiation
General Assembly, public & scientific community

UNSCEAR
- Levels, effects, risks
- Scientific independence

Data

Findings

ICRP
- Protection
- Philosophy
- Principles & units

Recommendations

FAO, IAEA, ILO, WHO, UNEP
- Protection
- Standards

Levels

Development

Implementation

Member States

Scientific Literature, UN Member States, organizations & NGOs
UNSCERAR

- Established by UN General Assembly resolution in 1955
- Scientists from 21 UN Member States
- Other States & organizations provide relevant data
- Holds annual sessions
- Assess as scientific information on levels and effects of ionizing radiation
- Disseminates findings to UN Assembly, UN agencies, scientific community & public
Most Recent UNSCEAR Reports
(available at unscear.org)
Dose Effect Models

- Linear
- Linear Quadratic
- Horsmesis

Below Epidemiology

100-200 mSv

DOSE
Trends In Relative Risk With Dose (and 90% CI) For Leukaemia

SOURCE: AFTER UNSCEAR, 2001
Trends In Relative Risk With Dose (and 90% CI) For All Malignant Neoplasms Other Than Leukaemia and Lung Cancer

SOURCE: AFTER UNSCEAR, 2001
Relative Risk Leukaemia Mortality and Incidence

SOURCE: AFTER UNSCEAR, 2001
Key Observations from UNSCEAR 2006 and BEIR VII

- Cancer risk estimates have not changed much since 1990
- In general, a significant radiation effect is only detectable at doses above (about) 100 mSv
Non-Cancer Effects (cardiovascular disease)

- Traditionally, effects of radiation on diseases other than cancer regarded as “non-stochastic”, i.e., a threshold is assumed to exist
- Annex focuses on recent follow-up of non-cancer endpoints in Japanese atomic bomb survivors (LSS) cohort and high-dose radiation therapy, in particular cardiovascular disease
- No clear evidence of risk at radiation doses below about 1 Gy
Dose-Response Curves for Non-Cancer Mortality (LSS 1968-1997)

After UNSCEAR 2007
Epidemiological Studies of Radiation and Cancer

Estimates of the Site-Specific Solid Cancer ERR with 90% Confidence Intervals and One-Sided P-Values for Testing the Hypothesis of No Dose Response

All estimates and P-values are based on a model in which the effects of age at exposure and of attained age were fixed at the estimates for all solid cancers as a group. The light dotted vertical line at 0 corresponds to no excess risk, while the dark solid vertical line indicates the sex-averaged risk for all solid cancers.

After UNSCEAR 2006
ICRP Risk Coefficients

- Latest cancer risk coefficients essentially unchanged from ICRP60 values (about 5% per Sv)
- Risk of heritable effects reduced 6 to 8 fold (risk now summed over two generations only – extending over a very large number of generations not now considered reasonable)
- LNT assumed for radiation protection purposes
## ICRP Risk Coefficients (% per Sv)

<table>
<thead>
<tr>
<th>Exposed Population</th>
<th>Cancer</th>
<th>Heritable Effects</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2007</td>
<td>ICRP 60</td>
<td>2007</td>
</tr>
<tr>
<td>Whole</td>
<td>5.5</td>
<td>6.0</td>
<td>0.2</td>
</tr>
<tr>
<td>Adult</td>
<td>4.1</td>
<td>4.8</td>
<td>0.1</td>
</tr>
</tbody>
</table>
Time Since Exposure

*SOURCE: After Howe et al, 2005
Smoking is Main Cause of Lung Cancer

Darby et al (2005) in a study of 13 European residential case control studies looked at combined effect of smoking and residential radon on the absolute risk of lung cancer and found that for lifetime (75 y) of exposure to 100 Bq m\(^{-3}\) and using the same relative risk factor of 0.16 per 100 Bq m\(^{-3}\):

- 0.47% risk from radon to never smokers
- 11.6% risk from radon to smokers
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Radiological Effects of Uranium Mining and Milling

- Uranium Mine and Mill Workers
  - No recent data for conventional mines in US and therefore illustrate with data from Canada
- People who live nearby to a uranium mine or mill
Average Annual Radiation Dose to Underground Miners at Uranium Mines in Canada
Average Annual Radiation Dose to Mill Workers at Uranium Mines in Canada

![Chart showing average annual radiation dose to mill workers at uranium mines in Canada from 1995 to 2004.](chart)

- **X-axis:** Year (1995 to 2004)
- **Y-axis:** Dose in mSv

The chart illustrates the trend in average annual radiation dose to mill workers at uranium mines in Canada from 1995 through 2004.
Average Annual Radiation Dose to Surface Personnel at Uranium Mines in Canada

![Graph showing average annual radiation dose to surface personnel at uranium mines in Canada from 1995 to 2004. The x-axis represents the years, and the y-axis represents the dose in mSv. The graph compares the average dose and the dose from radon.](image-url)
## Total Doses to Mill Workers
(All doses given in mrem per year)

<table>
<thead>
<tr>
<th>Source</th>
<th>Total Dose (TEDE)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uranium Milling GEIS (NUREG 0706)</td>
<td>380 mrem</td>
<td>Data for 17 U.S. uranium mills circa 1975</td>
</tr>
<tr>
<td>Canada 1997 to 2004</td>
<td>186 mrem</td>
<td>Data for 3 uranium mills in Canada</td>
</tr>
<tr>
<td>US Natural Background</td>
<td>296 mrem</td>
<td>US average (NCRP 1987)</td>
</tr>
</tbody>
</table>
## Dose to People Living Nearby

<table>
<thead>
<tr>
<th>Source</th>
<th>Annual Dose (TEDE, mrem per year)</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional Mine and Mill</td>
<td>50 mrem</td>
<td>NUREG 0706 and Chambers et. al, 1989</td>
</tr>
<tr>
<td>ISR</td>
<td>0.52 mrem</td>
<td>Average of airborne releases for 3 nearest residences, NUREG 1508</td>
</tr>
<tr>
<td>Surface Workers</td>
<td>47 mrem</td>
<td>Canadian Data</td>
</tr>
<tr>
<td>US Natural Background</td>
<td>296 mrem</td>
<td>U.S. average (NCRP 1987)</td>
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Doses

- from natural background
  - 300 (200 – 800) mrem per year

- from mining and milling
  - Workers (500-1000) mrem
  - Public (50 -100) mrem
Baseline Risks
(NVSS 2005)

- Male - all causes
  - All Ages: $8.5 \times 10^{-3}$
  - 25-34: $1.4 \times 10^{-3}$
  - 55-64: $11.8 \times 10^{-3}$

- Male - Neoplasms
  - All Ages: $2.0 \times 10^{-3}$
  - 25-34: $0.06 \times 10^{-3}$
  - 55-64: $4.0 \times 10^{-3}$

- Male Accidents
  - All Ages: $0.49 \times 10^{-3}$
  - 25-34: $0.48 \times 10^{-3}$
  - 55-64: $0.45 \times 10^{-3}$
Risks from Radiation

- **Lifetime risk per**
  - 1 mrem \(5 \times 10^{-7} \text{ (0.0005 } 10^{-3})\)
  - 100 mrem \(5 \times 10^{-5} \text{ (0.05 } 10^{-3})\)
  - 1000 mrem \(5 \times 10^{-4} \text{ (0.5 } 10^{-3})\)

- **Annual risk of accidental death**
  - 0.49 \(10^{-3}\)

- **Consider Risk of Lung Cancer**
Lung Cancer Rankings by State: 2004, Male, Lung and Bronchus
Age-standardized Death Rates in 2004

<table>
<thead>
<tr>
<th>Males: 2004 Age Standardized Death Rates per 100,000 for Cancer</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td>Total</td>
</tr>
<tr>
<td>Lung and Bronchus*</td>
</tr>
<tr>
<td>Leukemias</td>
</tr>
</tbody>
</table>

Source: http://apps.nccd.cdc.gov/uscs on 24 April 2008

Notes:
a) Four corner area statistically significantly lower than U.S. Average
   • other factors (smoking prevalence, industrial pollution) may differ.
b) Four corner area lower than U.S. average, but not statistically significant.
Study of Colorado Populations Near U Mining/Milling Operations

- Boice et al (Rad. Res. 2007) examined mortality rates (1950-2000) around historical mining areas (early 1900s-1980s)
- No statistically significant increases for any cause of death except LCs in males (associated with historical occupational exposures); no increase in females
- No evidence that residents experienced increased risk of death due to environmental exposures from uranium mining and milling