Errors and Uncertainties in Radiation Dose Reconstruction for Epidemiology: Approaches and Challenges

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Outline

- Classical (measurement) and Berkson (grouping) errors
- Shared, unshared, and mixed shared-unshared uncertainties
- Autocorrelation of uncertainty within individuals
- Multiple dose history realizations
- Quantitative uncertainty analysis for external irradiation
- 2-stage Monte Carlo approach
- Creating distributions of “possibly true” doses
Berkson and Classical Errors and Uncertainties

• In 1950, Joseph Berkson, M.D. pointed out the differing effects of two kinds of errors on regression analysis

• Classical or measurement error is well understood in metrology

• A different kind of error, that made when assigning the same value to all members of a group, became known as a “Berkson error” or grouping error

• In health physics, we create Berkson errors when we use the same value or same assumptions for every member of a group
  – Assume same background count rates for different samples
  – Use Reference Man & ICRP dosimetry models for everyone
  – Assign the same radon progeny exposure to everyone in a mine
## Comparing and Contrasting

<table>
<thead>
<tr>
<th>Classical errors...</th>
<th>Berkson errors...</th>
</tr>
</thead>
<tbody>
<tr>
<td>• are independent of the measurand</td>
<td>• are independent of the observed, assigned, or reconstructed value</td>
</tr>
<tr>
<td>• result from imprecise measurement</td>
<td>• result from using a single value to represent a group</td>
</tr>
<tr>
<td>• result in the variance of the observed, assigned, or reconstructed values being larger than the variance of the measurands</td>
<td>• result in the variance of the measurands being larger than the variance of the observed, assigned, or reconstructed values</td>
</tr>
<tr>
<td>• cause “bias towards the null” in linear regression analysis</td>
<td>• if group averages are unbiased, cause no bias in linear regression analysis</td>
</tr>
</tbody>
</table>
Conclusions (3 Uncertainty Types)

• Berkson uncertainties affect the slope of a linear dose-response relationship differently from classical uncertainties
  1. Classical uncertainties cause bias towards the null
  2. Berkson uncertainties may lead to
     – little bias for linear models
     – significant bias for nonlinear models
  3. Berkson uncertainties with residual bias may result in bias towards or away from the null
Shared and Unshared Errors and Uncertainties

• Random, uncorrelated measurement errors “cancel” each other out when measurements are combined

• Systematic or correlated measurement errors do not cancel each other out when measurements are combined

• When an uncertain parameter applies to all measurements or model calculations, its use results in shared errors

• Examples of sources of shared errors
  – models
    • dosimetric phantom
    • biokinetic model
    • environmental transport model
  – model parameters
    • dosimeter calibration factor
    • solubility determination for an aerosol
Handling Shared Errors and Uncertainties

• When modeling doses to a population, *shared uncertainties* must be handled separately from *unshared uncertainties*

• One approach is to use 2-stage Monte Carlo modeling
  – Pioneered by the Hanford Environmental Dose Reconstruction (HEDR) project in the early 1990s
  – Now considered state-of-the-art for radiation epidemiology

• The *multiple dosimetry realizations* Monte Carlo procedure generates 100s or 1000s of sets of “possibly true doses”
  – First, values of shared uncertain parameters are randomly selected, using the same value for every person for whom the value is shared
  – Second, values of unshared uncertain parameters are randomly selected for individuals
Creating Realizations

1. Choose Next Realization Number $j$

2. Sample $S$ and $S$-portion of SU parameters for $j$

3. Choose Next Individual $m$

4. Sample $U$ and $U$-portion of SU parameters for Individual $m$

5. Generate Dose Value for Individual $m$ in Realization $j$

6. If $j = J$? No, go back to step 1. Yes, go to step 7.

7. If $m = M$? No, go back to step 4. Yes, Done.

(Proudly Operated by Battelle Since 1965)
A Single Dose Realization

2nd Stage: A Sample of Unshared and Individual Parameters \( \{I_{m,j}\} \)

Individual \( m = 1, 2, 3, \ldots, M \) …

Calculation Algorithm containing parameters of the \( j^{th} \) Dosimetry Environment

1st Stage: A Sample of Shared Parameters \( \{S_j\} \) …

A Dose Realization: \( \bar{D}_{m,j}() \)

\[ \bar{D}_{m,j}(\text{year, organ, rad type, source, data provenance}) \]

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unique Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>( M )</td>
<td>26,000</td>
</tr>
<tr>
<td>year</td>
<td>( \sim 60 )</td>
</tr>
<tr>
<td>organ</td>
<td>( \sim 25 )</td>
</tr>
<tr>
<td>rad type</td>
<td>6</td>
</tr>
<tr>
<td>source</td>
<td>( \sim 10 )</td>
</tr>
<tr>
<td>data provenance</td>
<td>&lt;10</td>
</tr>
<tr>
<td>Total</td>
<td>( 24 \times 10^9 )</td>
</tr>
</tbody>
</table>
A Series of $J$ Dose Realizations

$\vec{D}_{m,1}(\ldots)$

$\vec{D}_{m,2}(\ldots)$

$\vec{D}_{m,3}(\ldots)$

$\ldots$

$\vec{D}_{m,J}(\ldots)$
What Does the Dosimetry Product Look Like?

- Each realization will result in 1 table for each of type of radiation
- Each row will be labeled by
  - individual \( i \)
  - year \( y \)
- Each row will contain column entries for doses to organs \( o \)
- There are no entries for uncertainty, because uncertainty is implicit in the multiple realizations
Autocorrelation over Time
(Within-Individual Correlation)

• Suppose annual doses to tissues and organs for individuals are needed
  – epidemiology
  – compensation

• Doses from one year to the next may be correlated
  – if a person had an acute intake of a tenaciously-retained radionuclide
  – if a person had the same job or job title (for job exposure matrix dose reconstruction)

• Bias in dose from one year to the next may be correlated
  – if a person had posterior-anterior exposure but anterior-posterior exposure was assumed
  – if an individual was a smoker and nonsmoker was assumed
  – if an individual had a poor respirator fit each year
Conclusions

• Epidemiology and biostatistics have matured
• Uncertainties must be handled correctly
  – Berkson (grouping) and classical (measurement)
  – Shared, unshared, mixed
  – Correlations among parameters
  – Autocorrelation
• The current approach requires multiple realizations of possibly true doses
• Dosimetry scientists, biostatisticians, and epidemiologists all must change how they do business
• Uncertainties on the excess relative risk per gray \( (ERR/Gy) \) will be more realistic
• Disaggregating experimental uncertainty from population variability is the next challenge (Paper WAM-C7)
Acknowledgments

• This presentation builds on a decade and a half of work by Russian and US researchers too numerous to list
• This work is funded by the U.S. Department of Energy under the auspices of the US-Russian Federation Joint Coordinating Committee for Radiation Effects Research (JCCRER)
• http://www.hss.energy.gov/HealthSafety/IHS/ihp/jccrer.html
• More detail on uncertainty in dosimetry can be found at http://www.pnl.gov/bayesian/strom/strompub.htm