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

Classical errors…	**Berkson errors…**
• are independent of the measurand	• are independent of the observed, assigned, or reconstructed value
• result from imprecise measurement	• result from using a single value to represent a group
• result in the variance of the observed, assigned, or reconstructed values being larger than the variance of the measurands	• result in the variance of the measurands being larger than the variance of the observed, assigned, or reconstructed values
• cause "***bias towards the null***" in *linear* regression analysis	• if group averages are unbiased, cause ***no bias*** in *linear* regression analysis

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

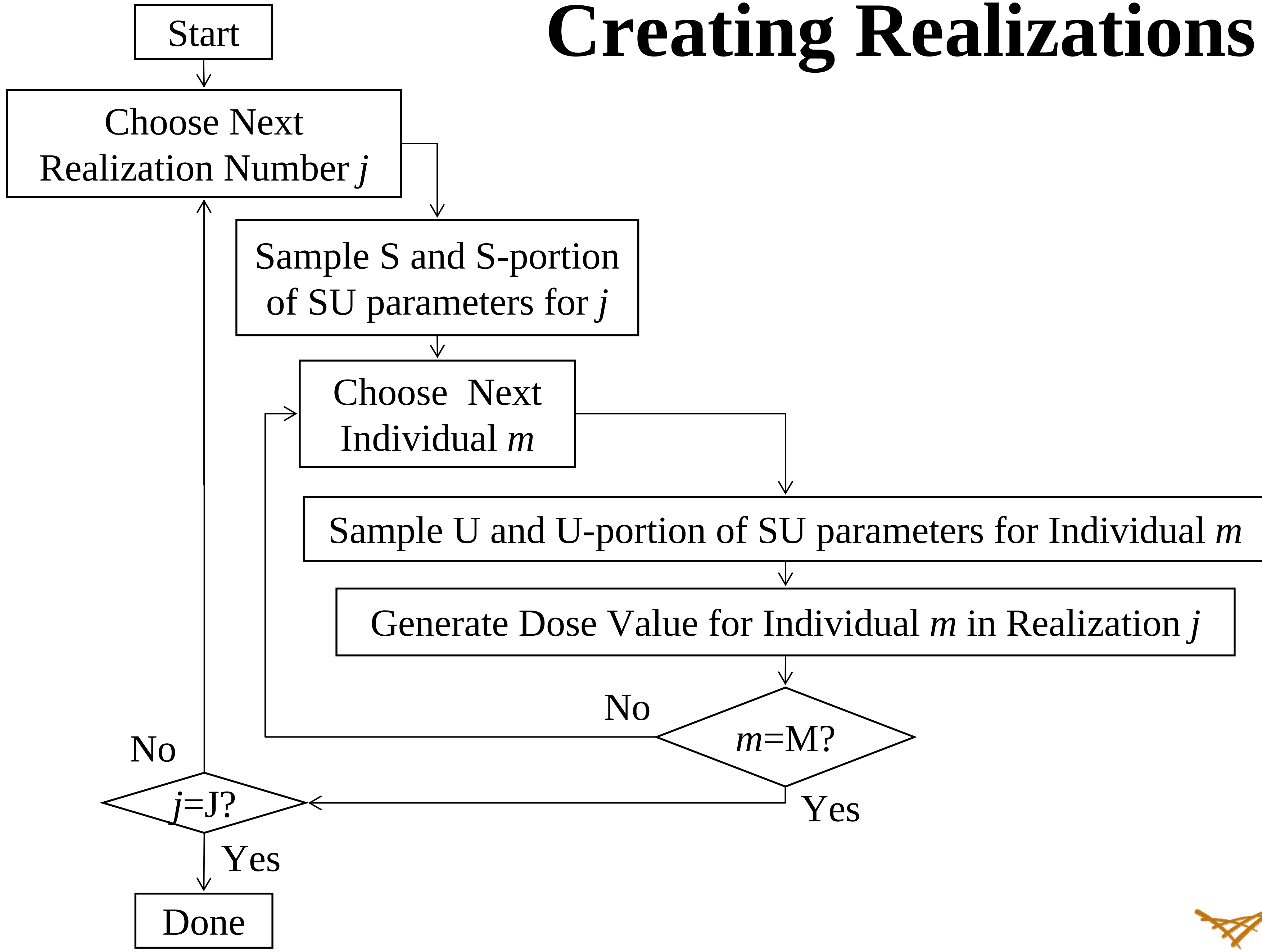
Shared and Unshared Errors and Uncertainties

- 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

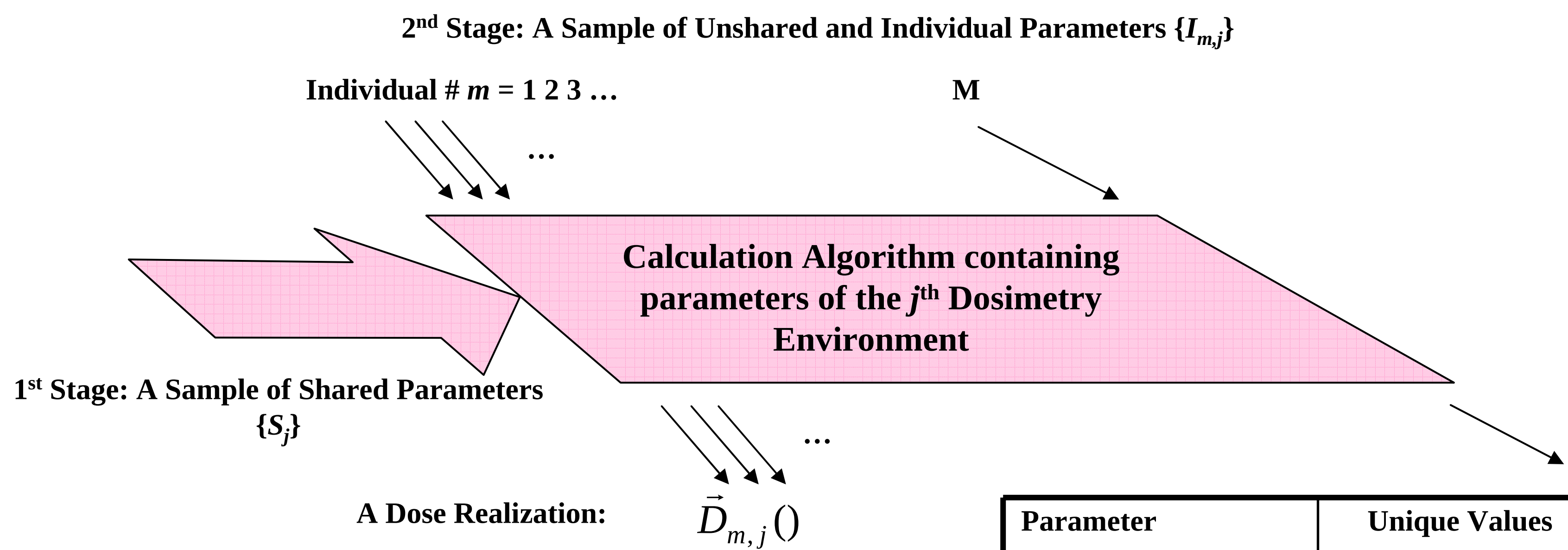
Handling Shared Errors and Uncertainties

- 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



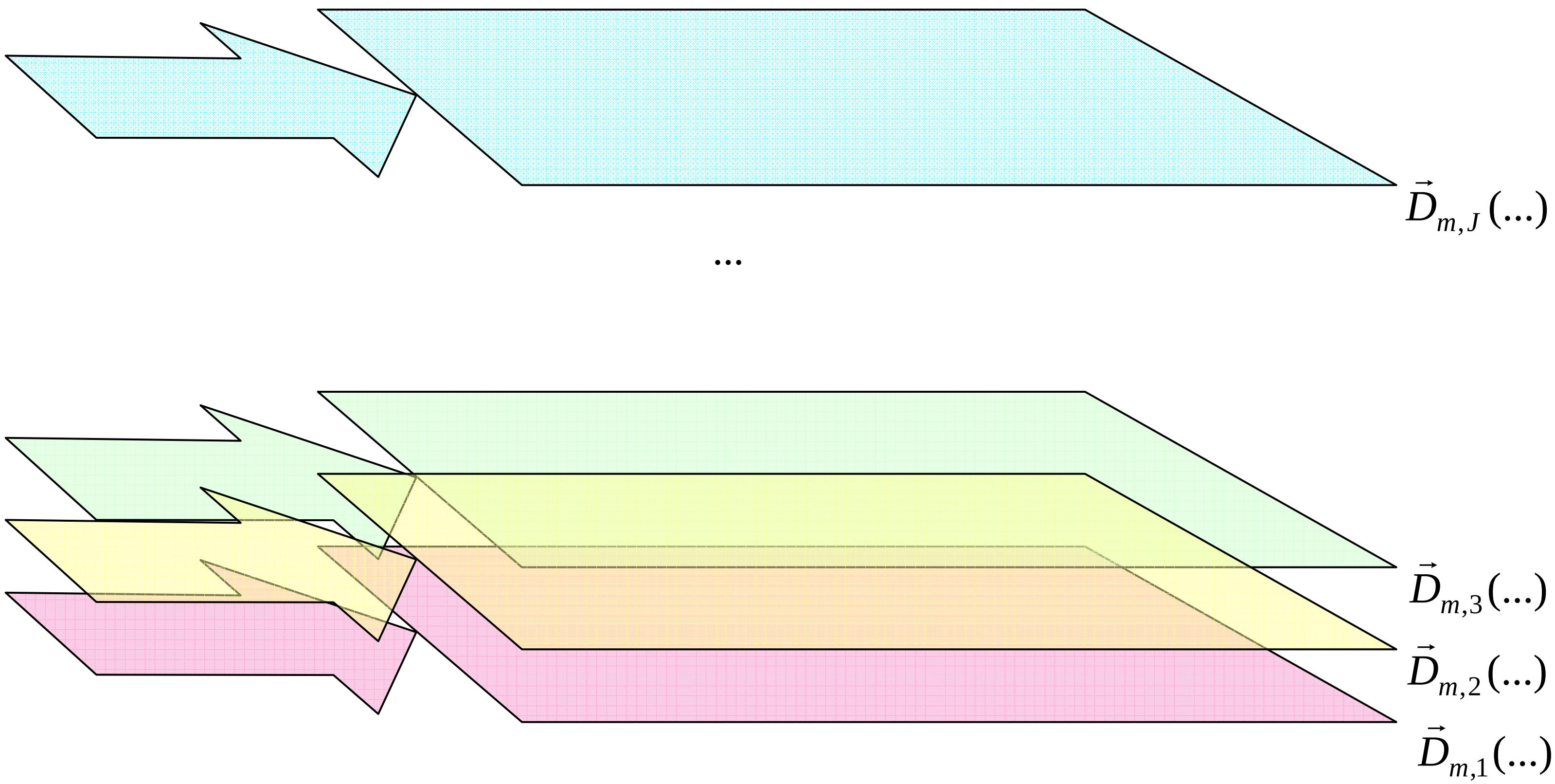
A Single Dose Realization



$$\vec{D}_{m,j}(\,year, organ, rad\ type, source, data\ \ provenance\,)$$

Parameter	**Unique Values**
M	**26,000**
year	**~60**
organ	**~25**
rad type	**6**
source	**~10**
data provenance	**<10**
Total	**24×10^9**

A Series of *J* Dose Realizations



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

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- 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