Sensitivity/Uncertainty Analysis for Nuclear Criticality Safety Validation

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Outline

1. Sensitivity coefficients
2. Covariance data
3. Similarity assessment
4. Validation

Sensitivity Coefficients

- Predict the expected change in a response (k) due to a change in some input parameter (Σ)
  - These responses can be k_{eff} (or ratios of reaction rates)
  - These input parameters are typically nuclear data
    - Cross sections, multiplicity (nubar: $\bar{\nu}$), fission spectrum (chi: χ)
- The coefficients are dimensionless ratios
  - What would happen to the system k_{eff} if some piece of data were changed by some amount?
  - The coefficient is calculated *without* making the change

$$S_{k,\Sigma} = \frac{\delta k / k}{\delta \Sigma / \Sigma}$$

TSUNAMI Sensitivity Methods

1. **TSUNAMI-1D**
   Deterministic, Multigroup
2. **TSUNAMI-2D**
   Deterministic, Multigroup
3. **TSUNAMI-3D**
   - **Multigroup TSUNAMI-3D**
     Monte Carlo, Multigroup
   - **Iterated Fission Probability (IFP) Method**
     Monte Carlo, Continuous-Energy
   - **CLUTCH Method**
     Monte Carlo, Continuous-Energy

- TSUNAMI offers several options for sensitivity calculations based on system complexity, desired level of accuracy, and runtime.

Data-induced uncertainty in k_{eff}

- Covariance data represent an estimate of the uncertainty in nuclear data and an estimate of correlations between energy groups, reactions, and/or nuclides
  - Relative uncertainties are tabulated in SCALE covariance libraries
  - Less standardized evaluation process than best estimate data
- Uncertainty in the system k_{eff} is propagated from the nuclear data uncertainty using the sensitivity coefficients:

$$\sigma_{k_{eff}}\left(\frac{\%\Delta k}{k}\right) = \sigma_{\Sigma}\left(\frac{\%\Delta\Sigma}{\Sigma}\right) \times S\left(\frac{\Delta k/k}{\Delta\Sigma/\Sigma}\right)$$

Similarity assessment

- The integral index *c(k)* or c_k describes the amount of shared nuclear data-induced uncertainty between two systems

$$S_{R_1,\Sigma_x} \cdot Cov_{\Sigma_x,\Sigma_y} \cdot S^T_{R_2,\Sigma_y} = \sigma^2_{R_1,R_2} \quad \rightarrow \quad c_k = \frac{\sigma^2_{R_1,R_2}}{\sigma_{R_1}\sigma_{R_2}}$$

$$\left(\frac{\delta R/R}{\delta\Sigma/\Sigma}\right) \qquad (\Delta\Sigma/\Sigma)^2 \qquad \left(\frac{\delta R/R}{\delta\Sigma/\Sigma}\right) \qquad (\Delta R/R)^2$$

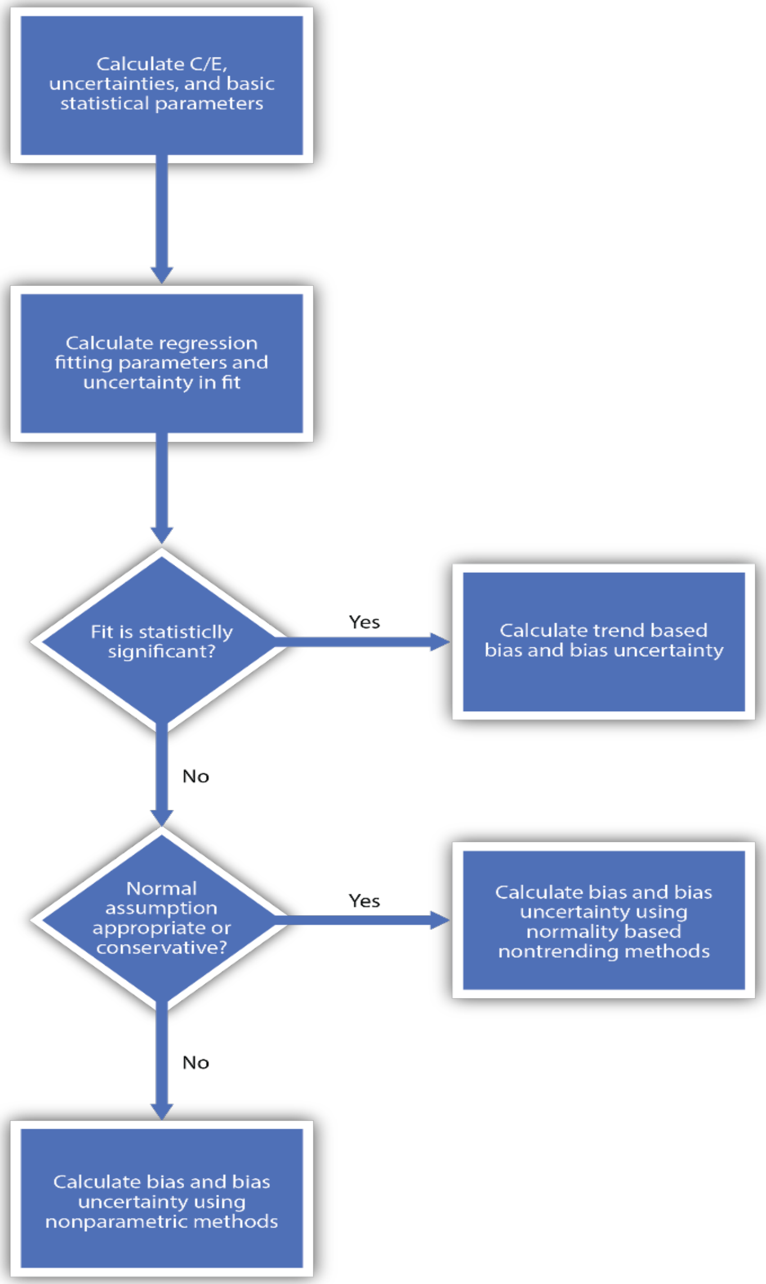
- TSUNAMI-IP calculates c_k values between target applications and benchmark experiments

Fundamental theorem of TSUNAMI validation

- The majority of the code bias in modern transport codes comes from nuclear data errors
- The nuclear data errors are bounded by their covariance data
  – Nuclear covariance data can be viewed as "bias potential"
- Systems that use the same energy-dependent nuclear data will manifest the same bias
- These benchmarks are most representative of safety applications and should be used in validation

Validation

- Given set of benchmarks:
  - Select physically meaningful trending parameter(s)
  - Develop trend(s)
  - Test for statistical significance of trend(s)
  - **If significant, use bias and bias uncertainty with value from application**
  - If no trend, test for normality
  - **If normal, use parametric lower tolerance limit**
  - **Otherwise use nonparametric lower tolerance limit**



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Questions?