Best Estimate and Uncertainty Analysis (BEAU) Methodology

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BEAU Definition

- BEAU = Best Estimate Analysis with Uncertainty
- A probabilistic approach to nuclear safety analysis using Monte Carlo methods

Current Approach

- LOE = Limit of Operating Envelope, currently used in the Canadian Nuclear Industry

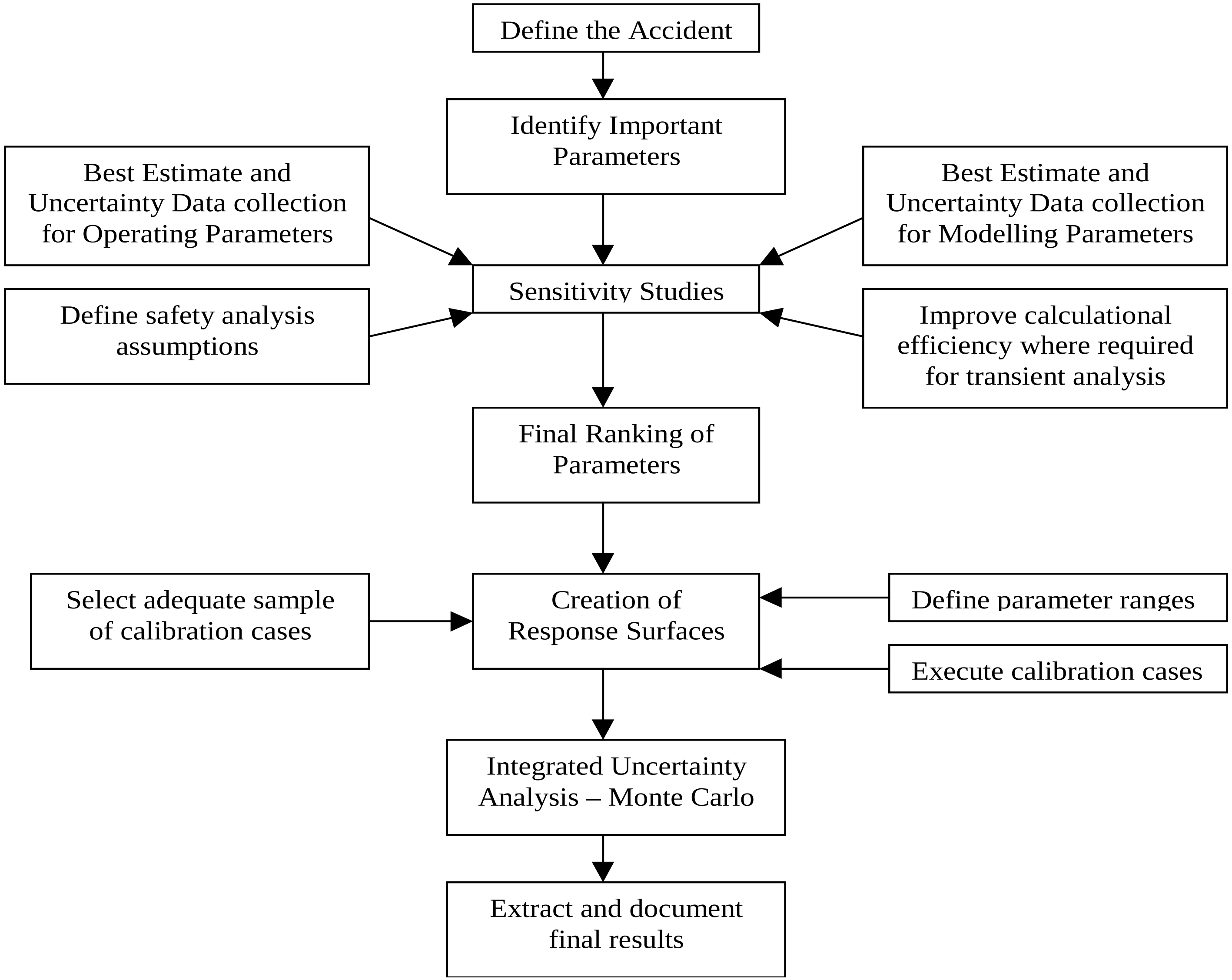
- LOE concept is to simultaneously set important operational parameters to bounding values that yield the worst accident consequences and leave modelling parameters at best estimate values.

- Over-conservatism

  => prediction of small safety margins

  => reduction of power levels, design modifications, change to operating limits

BEAU Flow Diagram



Define the Accident

- Full consideration to all important technical information and plant behaviours needs to be documented specifically where it will impact safety.

- LOCA Example:
  - Documentation supporting plant and system behaviour during a LOCA (e.g.. Depressurization of the HTS, temperature excursions)
  - Safety issues and related parameters associated with the main physical phenomena during the LOCA
  - Summary of previous LOCA analysis findings
  - Defining behaviours of interest for a LOCA (i.e. peak temperatures for fuel centerline and sheath, maximum fuel string expansion, and maximum pressure tube strain)

Identify and Rank Key Parameters

- Identify parameters that would potentially affect the outcome of the analysis and then estimate their importance, or “rank”, them accordingly

- This part of the process acts as a qualitative filter to go from thousands of parameters to a manageable list

Sensitivity Analysis

- To quantify the sensitivity of a parameter to the behaviours of interest in a LOCA scenario
- Historical data is statistically analyzed to produce best estimate and uncertainty values for each parameter
- **Base Case** = a transient analysis in which each parameter value is set to its best estimate value to be used as a benchmark to which “sensitivity studies” are compared
- A sensitivity study is a transient analysis in which a variation of one parameter will allow for quantification of it’s effect on an analysis outcome

Final Ranking of Parameters

- Comparison of the sensitivity study transient and the base case transient yield a set of values (differences) between the two cases for each behaviour of interest (max. fuel sheath temperature, max. fuel centerline temp. etc.)
- This value is normalized and then a final “rank” can be assigned to each parameter
- Ranking will determine how a parameter will be treated

Response Surfaces

- A response surface serves as a surrogate to a transient analysis code
- Using a random subset of values for parameters a series of transient analysis simulations are run, calibration cases
- A second order polynomial (or a “response surface”) for each behaviour of interest can be fitted to the results of the calibration cases,

$$M = \beta_0 + \sum_{i=1}^{k} \beta_i P_i + \sum_{j=1}^{k} \sum_{i \geq j}^{k} \beta_{ij} P_i P_j$$

M is a particular behaviour of interest (e.g., maximum fuel centreline temperature)
P are the key input parameters (e.g., initial bundle power, channel power, etc.)
k is the number of key input parameters
B are the response surface coefficients

Integrated Uncertainty Analysis

- Monte Carlo method

- Input required is
  - second order polynomial response surface functions
  - distribution functions of the input parameters which appear as terms within the polynomials

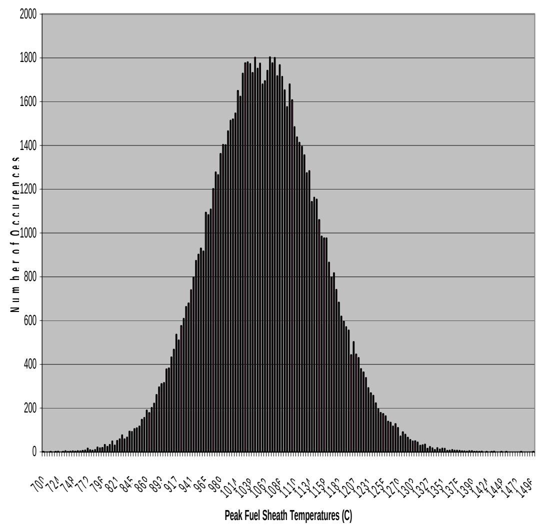
- Random number generation, according to probability functions for each parameter, allow the varying of parameters for tens of thousands of simulations.

- Polynomials allow fast answers to transient simulations

Results

- Resulting histogram for each behaviour of interest
- The mean, 50th percentile and 95th percentile values can be extracted from these results
- Improved safety margin over LOE results can lead to relaxation of operating limits and room for future discovery issues

Behaviour of Interest	LOE	BEAU
Peak Fuel Centerline Temperature (C)	2300	1980
Peak Fuel Sheath Temperature (C)	1453	1066
Max. Fuel Sheath Relative Axial Expansion (mm)	34.1	20.7
Max. Pressure Tube Strain (%)	16.3 (contact)	9.94



Further Work and Discussion

- Investigating the validity of the response surfaces
- Improving calculational efficiency
- Development of a Compliance Model
- Regulatory Acceptance