How to Design a Critical Experiment aka "CED-1 and CED-2"

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Why a Presentation on "How to ...."?

- The DOE NCSP Integral Experiment (IE) Program Element is now back **"on-line" and "operational."**
- Plans for the experimental program are very impressive.
  - There are **>100 Integral Experiment Requests (IERs)** in the pipeline!!!
  - Not all IERs will survive to become experiments, but clearly the IE program will be designing and performing a steady stream of experiments as the program moves forward.
- Success of these experiments depends on many factors – not the least of which is their proper design.
  - A careful, even perfect, execution of a poorly designed experiment is unlikely to be of value.
- This presentation will share some very basic ideas so that all of us might have some understanding of the design of a critical experiment.

Limited Scope of this Talk

- **Integral Experiment Requests (IERs) may include one or more measurements of one of more types of experiments, such as:**
  - k_{eff} (Critical and/or Sub-Critical Configurations)
  - Deep Transport – (Shielding, CAAS, etc)
  - Reaction Rates – (Spectral Indices, Spatial Profiles, Dosimetry, etc)
  - Spectrum – (Neutron, Gamma)
  - Reactivity Worths – (Small-sample, Doppler Temperature Coefficients, Material Replacement, Control Rods, Void or Insertion, etc)
  - Kinetic Parameters – (β_{eff}, Delayed Neutron Fractions, a_i's and λ_i's, etc)

Limited Scope of this Talk (Cont'd)

- **Present discussion will appear to address only criticality measurement for a variety of reasons, including:**
  - Limitation of time,
  - Limitations of the speaker,
  - Criticality is the most fundamental measurement, and perhaps most importantly,
  - Design for the other measurements is generally an "add-on" for the criticality case we are discussing.

For example, measurement of spectral indices requires description of the "critical" configuration, plus specification of the reaction rates to be measured, the measurement locations, the fission chambers or foils, deposit or foil compositions, etc.

Or measurement of replacement worths requires description of the "critical" configuration, plus specification of the material to be replaced, the locations, sample masses, sample compositions, etc.

Types of Critical Experiments

- There are two basic types of Critical Experiments:
- **Physics Benchmarks**
  - Clean simple compositions
  - Clean simple geometry
  - e.g., Godiva, Jezebel, ZPR-9/34 (the U/Fe Benchmark), ORNL spheres, TRX lattices

- **Engineering Mockup Criticals (EMC)**
  - ZPR-9/27 (FTR-EMC)
  - ZPPR-21 (Criticality Safety Mockup of Crucible for Pyro-Processing of Spent Fuel)

Note: One of the first steps of the Design Process is to decide which of these two basic types of experiments is requested (i.e., which of these types of experiments will meet the requestor's needs).

Requirements for a Conceptual Design (CED-1)

The CED-1 report **must** contain the following four items:

1. Brief Description of the Purpose of the Experiment and the Measurement Approach
2. Brief Description of the Experiment
   a. Materials
      i. Dimensions
      ii. Masses
      iii. Compositions
3. Model of the Experiment
   a. Geometry and Environment of Experiment
4. Predicted Values of the Experiment
   a. Eigenvalue, k_{eff} (and Material Worth, $\Delta k_{eff,}$ if relevant)
   b. Neutron Energy Spectrum
   c. Neutron Balance (by Isotope, Region)
   d. Experiment Sensitivities

Requirements for a Final Design (CED-2)

The CED-2 report **must** contain the following four items:

1. Brief Description of the Purpose of the Experiment and the Measurement Approach
2. Brief Description of the Experiment
   a. Materials
      i. Dimensions
      ii. Masses
      iii. Compositions
3. Model of the Experiment
   a. Geometry and Environment of Experiment
4. Predicted Values of the Experiment
   a. Eigenvalue, k_{eff} (and Material Worth, $\Delta k_{eff,}$ if relevant)
   b. Neutron Energy Spectrum
   c. Neutron Balance (by Isotope, Region)
   d. Experiment Sensitivities

Pop Quiz

QUESTION: What very important information was not mentioned on the two preceding (CED-1 and CED-2) slides?

ANSWER: Uncertainties, uncertainties, uncertainties.

Uncertainty analysis was not listed as a **separate** task or requirement because consideration of uncertainties should be an **integral part** of **all experiment design** – that includes all facets of the CED-1 and CED-2 tasks.

Bottom Line: If you have measured (experimental) values, but no estimate of the uncertainties in these values, then these experimental data cannot be used for validation.

How to Meet CED-1 and CED-2 Requirements

Notice the close parallel between:

the Requirements for a Conceptual Design (CED-1),
the Requirements for a Final Design (CED-2), and
the Requirements for an ICSBEP Benchmark Document.

Section 1. Description of Experiment

Section 2. Evaluation of Experiment

Section 3. Description of Model

Section 4. Calculated Results

It should not be surprising that the same elements necessary to produce a quality benchmark document are identical to the necessary elements of a critical experiment design.

How to Meet CED-1 and CED-2 Requirements (Cont'd)

- Understand the goal of the experiment
- Collect full description of
  - Measurement technique (and uncertainties)
  - Materials
    - Dimensions, Masses and Compositions (and uncertainties)
  - Geometry (and uncertainties)
- Create Model of Experiment
- Calculate (Predict) Experimental values (and uncertainties)

It is natural to consider the predicted value as the most important feature (because it is), but

Estimation of the uncertainty components and their sum is equally important and considerably more difficult.

How to Meet CED-1 and CED-2 Requirements (Cont'd)

Likely the predicted values will be obtained with Continuous Energy Monte Carlo calculations.

Although the uncertainty components could also be obtained with these methods, it is often preferable to use higher-order deterministic methods (provided acceptable cross sections are available).

Preliminary design, analyses, and reporting of an experiment is performed exactly as if it were to be the final experiment design. That is, it is modeled with the expectation that it will be built exactly as modeled. In most cases, this preliminary design will become the final design, and only in exceptional cases will something change in the interim which will modify the model for the final experiment design. Of course, the model of the actual experiment (and a benchmark model of the experiment) will depend on final parameters (such as separation distance, core height, reflector thickness, etc) available after the experiment is performed.

Concluding Remark

These very basic thoughts regarding design of a critical experiment have focused on performing and reporting the experiment design and have not mentioned the Critical Experiment Design Team.

But it should be obvious that most of the requirements will come from the requestor; most of the inputs will be provided by the experimenter; most of the calculations will be provided by the analytical methods member; most of the due diligence to obtain all information necessary to produce a benchmark quality experiment and report will be supported by the ICSBEP member, and all of the review, questions, suggestions, etc. to design and execute an experiment which meets the requestor's needs will be **the collective effort of the full C_EdT team**.