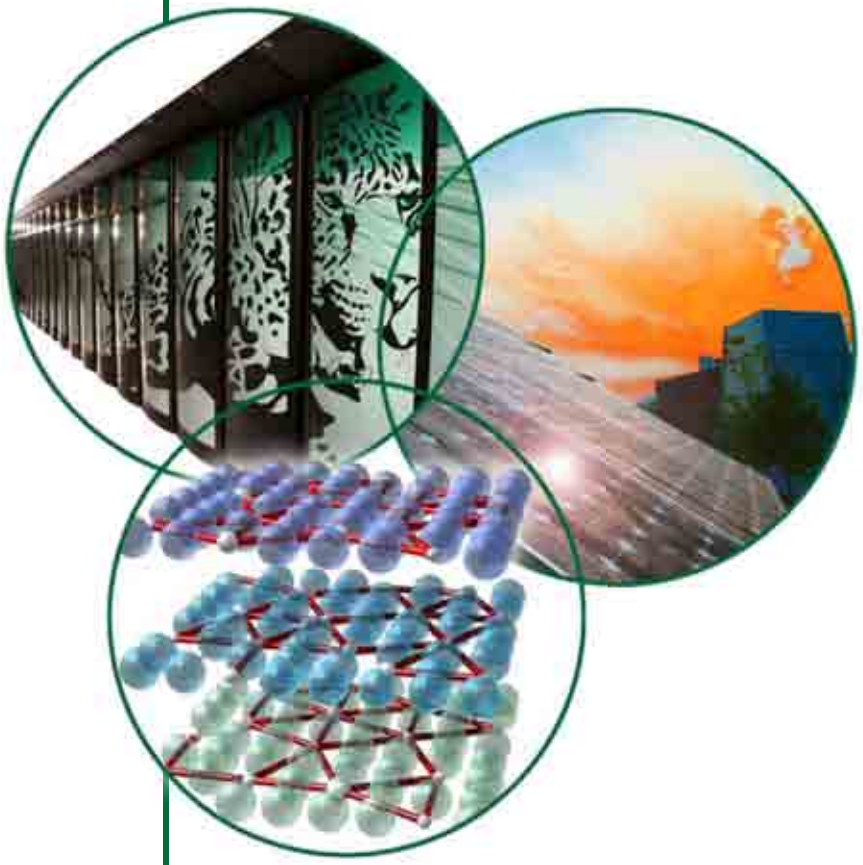
Overview of SCALE/TSUNAMI Use for Design of Criticality Experiments



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Do all CeDT experiments warrant sensitivity analysis?

Not necessarily

Depends primarily on type or purpose of the experiment

- Criticality experiments (new vs known configuration)
- Irradiation experiments (Silene, Godiva)
- Reactor experiments (7uP with “holes”)
- Other

Criticality experiment

- Done to directly determine or enable computational prediction of physical parameters associated with the critical state

“Criticality” experiments include

- “Critical” experiments where a condition of k_{eff} = unity is obtained
- Very high multiplication experiments (k_{eff} ~ 0.99x) where the uncertainty with extrapolation to critical conditions is negligible
- Subcritical experiments (k_{eff} ~ 0.5 to 0.9x, e.g., where the intent is to obtain a subcritical benchmark)

The relationship of criticality experiments and process applications has changed significantly during the last 30 years.

This change has been driven by changes in how criticality assessments (evaluations) are performed.

Changes in criticality assessments have resulted from a reduced level of risk acceptance.

Criticality assessment focus:

Historical – Focus on being sure the normal condition is subcritical with adequate safety margin, plus identifying abnormal conditions of concern for which risk must be managed.

Usually allowed direct use of experiments and handbooks to cover most or all normal and abnormal conditions documented in the assessment.

Criticality assessment focus:

Current – Focus on demonstrating that a (very) wide range of abnormal conditions is assuredly subcritical.

The variety (details) of abnormal conditions usually requires extensive use of computational methods to fill gaps not covered by experiments or experiment interpolations.

Observation:

For future criticality experiments, it may not be practical to directly cover the wide range of abnormal conditions that criticality safety practitioners may imagine.

Performance of experiments with high overall "similarity" to wide range of abnormal conditions may not be practical (but is needed for traditional validation methods for k_{USL}).

Observation (Continued):

Future criticality experiments should focus on supporting the veracity of nuclear data and application of more modern validation methods.

The experiments should more closely resemble physics benchmarks covering a wide range of neutron spectra, with less focus on directly simulating normal or abnormal process conditions.

Simple example of optimizing an experiment for testing of nuclear data: PU-SOL-THERM-020 Case 8

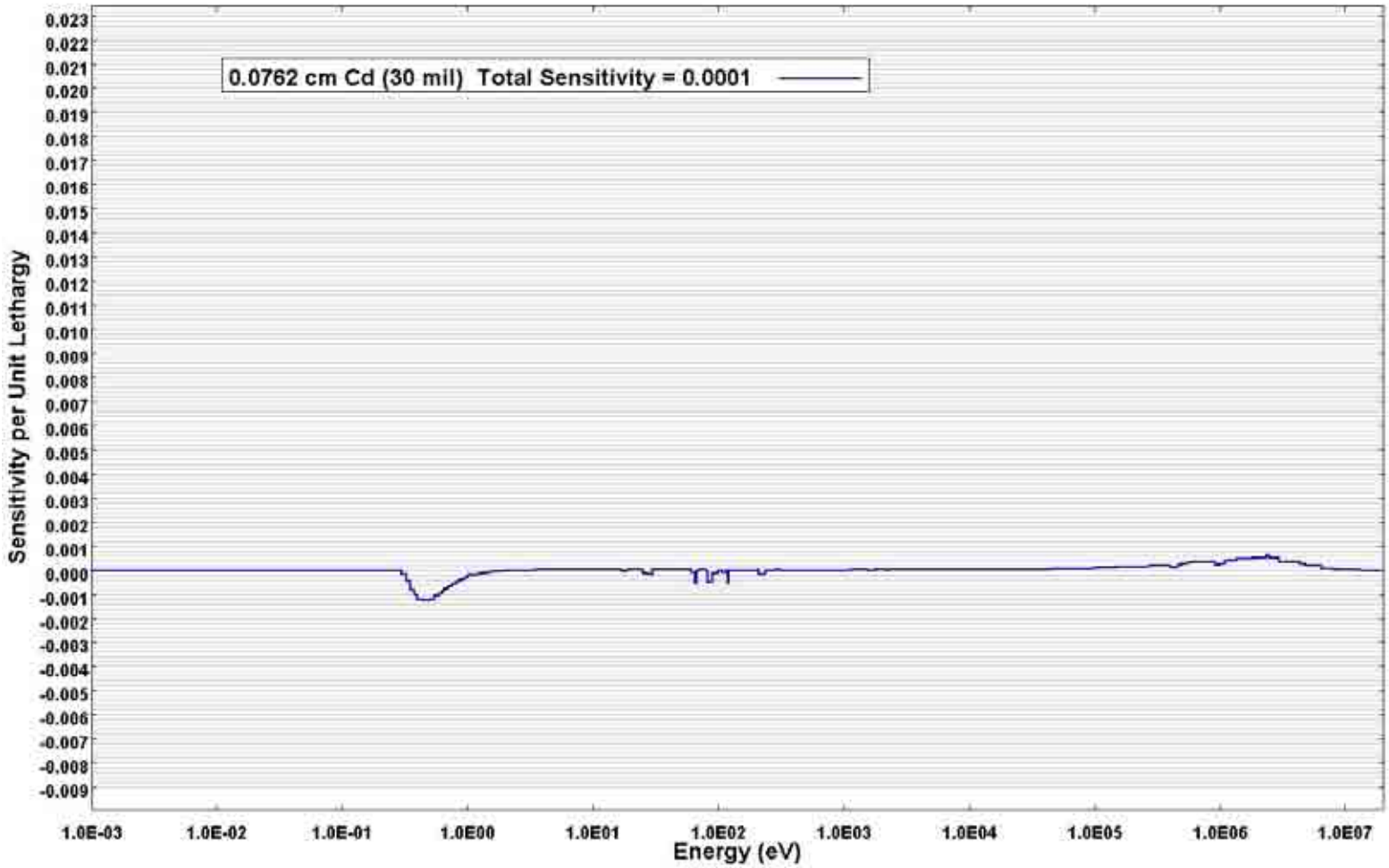
Benchmark model:

- Pu nitrate solution
- Thin-wall stainless steel tank, ideal spherical shape
- Cadmium metal layer surrounding tank, 30 mil thickness (0.030 inches or 0.762 mm)
- 300 mm thick water reflector

PU-SOL-THERM-020 Case 8 Computational Results (SCALE 6/KENO-V.a, V7-238 library):

- Benchmark model k_{eff} = 1.0000 $\pm$ 0.0059
- Computed k_{eff} = 0.9962 + 0.0001 (within 1 σ_{exp})
- If cadmium is replaced with void: k_{eff} = 1.0705 $\pm$ 0.0001
- Critical conditions are strongly influenced by the cadmium.
- If the cadmium atom density is reduced by 50%, then k_{eff} = 0.9965 + 0.0001.
- The cadmium thickness is optically "black" for thermal neutrons.

PU-SOL-THERM-020 Case 8 TSUNAMI Total Sensitivity for Cd



PU-SOL-THERM-020 Case 8 Observations

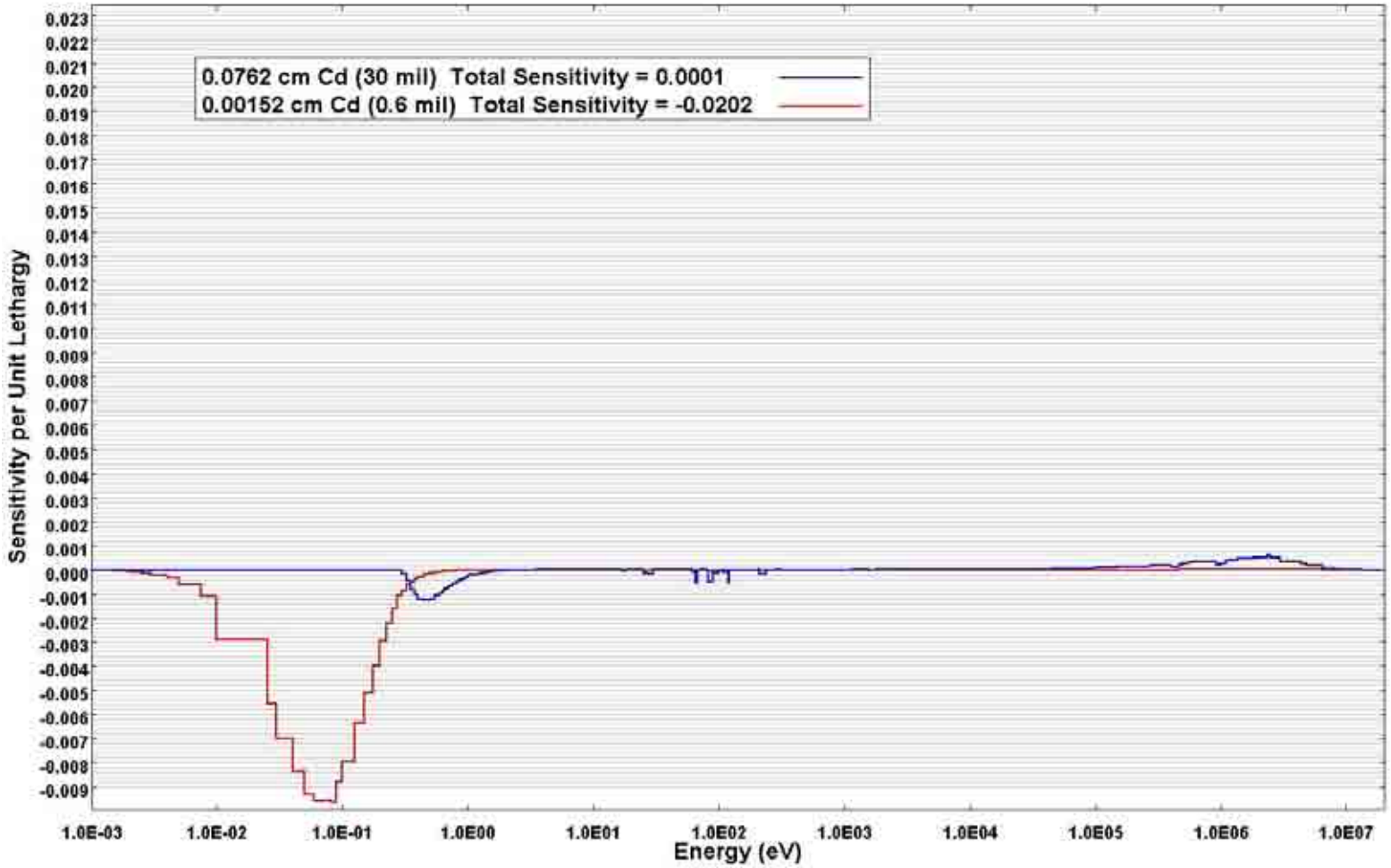
- The Cd thickness (areal density of Cd about the sphere) is optically “black” for thermal neutron transmission.
- The experiment is useless for supporting accuracy of thermal cross section data for Cd.
- The experiment has little or no utility for validation methods for Cd process applications.

PU-SOL-THERM-020 Case 8 Alternate Experiment for Testing of Cd Thermal Cross Sections

- Calculated sphere radii (for computed k_{eff} = 1.000) for Cd thickness ranging from 0 to 30 mil
- Performed TSUNAMI analysis for each case
- Determined thickness for which total Cd sensitivity (S) is maximized

$$S = (\delta k_{eff} / k_{eff})/(\delta\sigma/\sigma)$$

PU-SOL-THERM-020 Case 8 Alternate Thermal Experiment



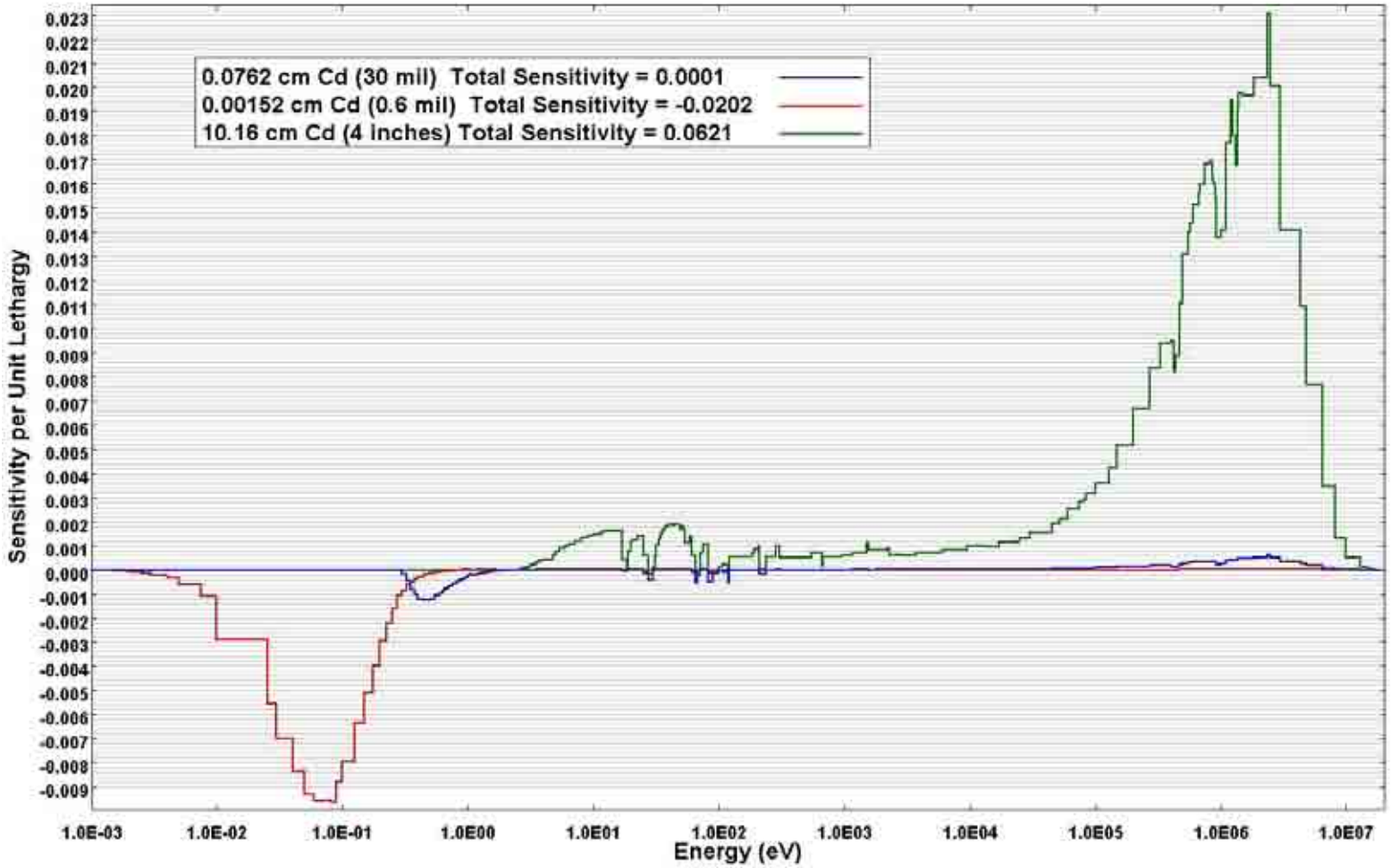
PU-SOL-THERM-020 Case 8

Could a similar experiment be designed to test Cd cross sections in an alternate energy region?

- Calculated sphere radii (for computed k_{eff} = 1.000) for Cd thickness ranging from 30 mil to several cm
- Peformed TSUNAMI analysis for each case
- Determined thickness for which total Cd sensitivity (S) is maximized

$$S = (\delta k_{eff} / k_{eff})/(\delta\sigma/\sigma)$$

PU-SOL-THERM-020 Case 8 Alternate Experiment for Fast Cross Sections



PU-SOL-THERM-020 Case 8 Final Observations

- Higher thermal sensitivity could be obtained for a different geometry (e.g., lattice of several Cd plates with intervening fissile material)
- Epithermal sensitivity could be maximized with some Cd thickness between fast-optimum and thermal-optimum.
- A series of similar experiment (same overall geometry and fissile materials with a range of Cd thicknesses), Cd cross sections throughout the entire energy range could be investigated.
- Computational biases primarily due to Cd nuclear data could be determined.

Optimizing an Experiment for Similarity to a Process Application: Lessons Learned

- CeDT TSUNAMI application (classified) performed in 2009
- Application: 3x3x3 array of fissile metal units w "test material" of interest, units air-spaced and within a cuboidal reflector of thick concrete

Optimizing Experiment Similarity: Lessons Learned (Continued)

- A proposed experiment design was determined consisting of alternating plates of fissile metal, concrete simulant, and Plexiglas
- Thicknesses of layers was optimized so that the sensitivities of all major isotopes in the application were a very close match to the application
- Variation of layer thicknesses extended the proposed experiment series to cover a range of process applications more and less thermal than the application

Optimizing Experiment Similarity: Lessons Learned (Continued) The Lessons:

- CeDT communications are very important. The actual desire was for experiments that tested cross sections of the test material, but the test material sensitivity in the application was small. High similarity of experiments and applications was not a primary objective.

Optimizing Experiment Similarity: Lessons Learned (Continued)
The Lessons:

- Using TSUNAMI tools, experiments with high similarities to applications may be determined that require (1) much less fissile and non-fissile materials than the application and (2) a much simpler material configuration.
- For historical experiment designs, experiments for the application would have likely required a split-table apparatus for the large experiment mass.
- Use of TSUNAMI for design of similarity experiments may reduce the material or machine requirements, and allow achievement of lesser benchmark uncertainties.