Division of Fuel Management — U.S. Nuclear Regulatory Commission

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Protecting People and the Environment

Code Validation - A Critical Step for Ensuring Criticality Safety

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Outline

- Criticality safety
- Computer code validation
- Frequently Asked Questions

Criticality Safety

- Criticality accidents do happen
  - Fatal radiation exposures
  - Contamination to facility and environment
  - Costly remediations
  - Impacts on public confidence on safety of nuclear facilities
- Must assure criticality safety by design
  - Facility design
  - Operating procedures
  - Regulatory requirements: 10 CFR (NRC, DOE), 49 CFR (DOT), IAEA Regulations (SSR-6).

Criticality safety (cont.)

- Neutron multiplication factor: k_{eff}
  - The eigenvalue of the neutron transport equation or diffusion equation
  - Solving the neutron transport equation or diffusion equation
- Cross section

Criticality Safety (cont.)

- Neutron multiplication factor: K_{eff}
  - A derived value
  - Can not be measured
  - Must be known ahead of time for criticality safety in system designs
- Determination of K_{eff}
  - Mockup experiments
  - Cannot do experiments for true accident conditions
  - Solving neutron transport equation

Criticality Safety (cont.)

- Mockup
  - Traditional way to determine k_{eff}
  - Still need to calculate k_{eff} by extrapolation
  - Cannot simulate accident conditions
  - Costly
- Determine system k_{eff}
  - Hand calculation: $k_{eff} = 1 – S/N$
  - S: external source,
  - N: Neutron population

Criticality safety (cont.) — Calculation Methods

- Hand calculation
  - Solve only simple problems with less accuracy
- Computer code
  - Implementation of the algorithms
  - Same as hand calculations
  - With more accurate representation of the problem
- Can simulate accident conditions
- Cross section

Computer Code Validation

- Verification
  - Verify the correct implementation of the algorithm
  - Done by the software developers
- Validation of calculations is to:
  - Determine if the code is appropriate for a specific application
  - To determine the bias and errors associated with the calculations

Computer Code Validation (cont.)

- Code validation: Critical to assuring correct and accurate answers
  - Different solution methods
  - Different implementations
  - Representation of the system
  - Different approximations
  - Different conversion criteria
  - Run on different computers (CPU and compiler)
- Guidance: ANS 8.1, 8.15, 8.17, NUREG, IEEE

Computer Code Validation (cont.)

- Standards for Validation of Calculations
  - ANSI/ANS 8.1: Nuclear Criticality Safety in Operations with Fissionable Materials Outside Reactors
  - ANSI/ANS 8.7: Nuclear Criticality Safety in the Storage of Fissile Materials
  - ANSI/ANS 8.17: Criticality Safety Criteria for the Handling, Storage, and Transportation of LWR Fuel Outside Reactors
  - ANSI/ANS 8.24: Validation of Neutron Transport Methods for Nuclear Criticality Safety Calculations
- NRC Guidance
  - NUREG/CR-6361: For LWR fuel storage and transportation
  - NUREG/CR-6698: For general fissile system

Computer Code Validation (cont.) —Select Critical Experiments

- Similarity to the system (Area of Applicability)
  - —Material composition, i.e., U, UO_2, MOX, Pu
  - —Enrichment (U-235 only)
  - —Geometry, i.e., solution, rod, plate, cluster, assembly
  - —H/X ratio, Reflector
- Critical experiments
  - – International Handbook of Evaluated Criticality Safety Benchmark Experiments
  - – Other resources, ORNL, LANL, Westinghouse, GE

Computer Code Validation (cont.) —Expected Results

- Bias and Bias Uncertainty
- Trend against major factors
  - Enrichment, geometry, H/X ration, EALF, etc
- Number of critical experiments
  - Around 100 is recommended
  - Minimal 30 based on textbook
  - Minimal 25 experiments (NUREG/CR-6361)
  - Perform normality distribution analysis if fewer than 25 and apply further uncertainty

Computer Code Validation (cont.) —Available Tools

- Trend analysis tool:
  - USLSTATS - A straightforward tool
  - User specific tool, least square curve fitting
- Critical experiment selection tool:
  - TSUNAMI (SCALE code suite)
  - Whisper (MCNP code suite)
  - Useful tools for selecting more fit critical experiments and may give a better bias.
  - User should still need to check the properness of the selected experiments.

Computer Code Validation (Extra) —Burnup Credit

- Two steps:
  - Depletion code
  - Criticality safety analysis code
- Guidance
  - Interim Staff Guidance Number 8, Revision 3 (now part of NUREG-2215/NUREG-2216 (SRP)
  - NUREG/CR-6811
  - NUREG/CR-6801, NUREG/CR-6800
  - NUREG/CR-7108, NUREG/CR-7109, NUREG/CR-7205

Frequently Asked Questions

- Similarity to the system (Area of Applicability)
  - Thermal, mid-energy or fast system
  - Material composition, i.e., U, UO_2, MOX, Pu
  - Enrichment (U-235 only)
  - Geometry, i.e., rod, plate, cluster, assembly
  - H/X ratio, Reflector type
- Number of critical experiments
  - Suffient
  - Distributions (normality test)

Frequently Asked Questions (cont.)

- Trending analysis
  - Trending against major parameters
  - Upper subcriticality limit
- Bias and bias uncertainty
  - All biases and bias uncertainties accounted for
  - The total bias calculated correctly

Questions?