



Status of the Serpent criticality safety validation package

Serpent UGM 2017

Riku Tuominen and Ville Valtavirta, VTT

Outline

- Criticality Safety Evaluation
- What is subcritical enough?
- Goal of Criticality Safety Validation
- Validation package
- Criticality safety validation package at VTT
- Validation script
- Burnup validation
- Gamma validation

Criticality Safety Evaluation

- Need to ensure the subcriticality of a target system
- Calculate an upper value for k_{eff} of the target (k_{calc})
- Include statistical uncertainties of the calculation (Δk_{calc})
- Include uncertainties of the target system (Δk_{tgt}):
 - Material compositions and densities.
 - Fabrication tolerances (geometry)
- Check that the calculated k_{eff} plus the uncertainties stay below the upper safety limit (k_{USL})

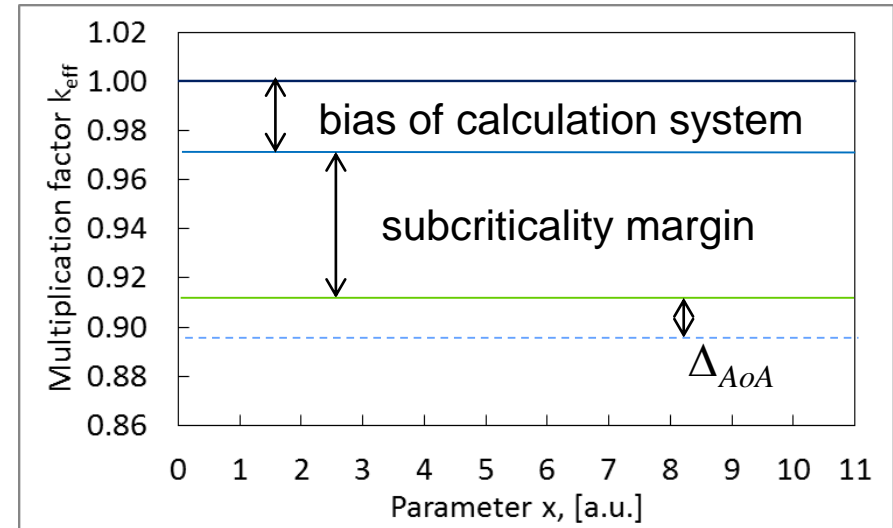
$$k_{\text{calc}} + \Delta k_{\text{calc}} + \Delta k_{\text{tgt}} \leq k_{\text{USL}}$$

k_{calc} : k_{eff} of the system under evaluation
 Δk_{calc} : statistical uncertainty of k_{calc} , usually 2σ
 Δk_{tgt} : uncertainty of k_{tgt} , usually 2σ
 k_{USL} : upper safety limit

What is subcritical enough?

$$k_{calc} + \Delta k_{calc} + \Delta k_{tgt} \leq k_{USL}$$

- Enough margin needed to cover:
 - Systematic difference (bias) due to calculation system Δk_{code}
 - Unknown uncertainties (administrative subcriticality margin Δk_{sm})
 - Extra margin due to extensions to the area of applicability, Δk_{AoA}

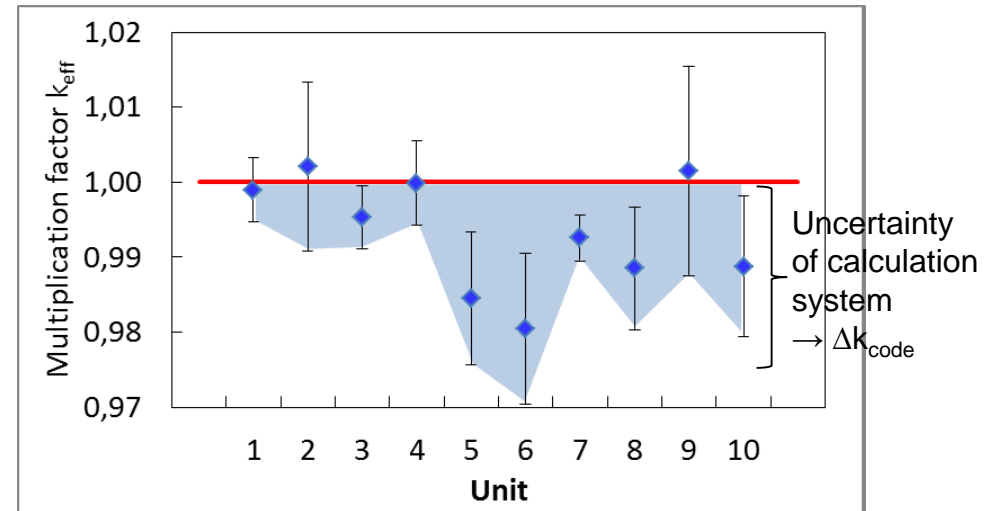


$$k_{USL} = 1 - \Delta k_{code} - \Delta k_{sm} - \Delta k_{AoA}$$

Δk_{code} is obtained through a validation process

Goal of Criticality Safety Validation

- Evaluating the systematic over- or underprediction of k_{eff} due to calculation system.
 - Code
 - Cross-section library
 - Platform
- Through simulation of systems known to be critical.
 - Systems need to be similar to the target system.
- Δk_{code} inferred from the differences between experimental and modelled values
- Together with Δk_{sm} and Δk_{AoA} forms the upper safety limit for the k_{eff}



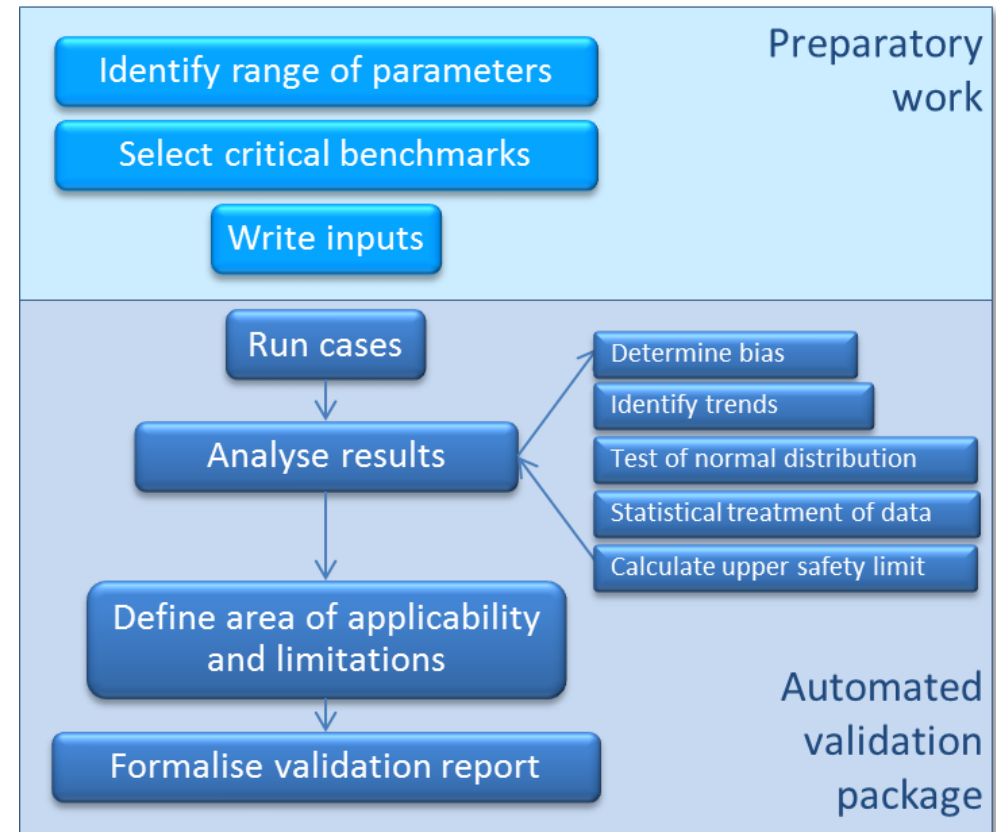
See: J.C. Dean and R.W. Tayloe, Jr. "Guide for Validation of Nuclear Criticality Safety Computational Methodology", NUREG/CR-6698 (2001)

$$k_{USL} = 1 - \Delta k_{\text{code}} - \Delta k_{\text{sm}} - \Delta k_{\text{AoA}}$$

Validation package

- Contains critical benchmarks
 - Critical or nearly critical systems
 - Area of applicability
- Modelling
- Analysis of the data
 - Trends
 - Statistical analysis
 - ➔ 150-200 cases
- Validation report

Automatic system that runs through the process

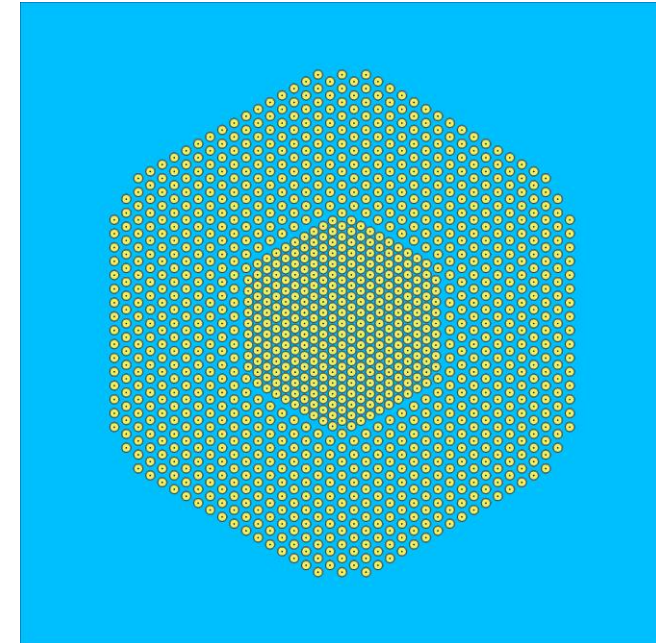


Criticality safety validation package at VTT (1/2)

- In development for Serpent since 2013 (and for MCNP since 2011)
- The package includes:
 - Inputs based on critical experiments presented in the International Handbook of Evaluated Criticality Safety Benchmark experiments¹⁾
 - Automated validation script
- Developed for criticality safety validation of Serpent for VTT's criticality safety analyses concerning fuel storage and transfer configuration
 - The package has been previously distributed to two Serpent user organizations
 - If you are interested in obtaining the package, contact us

Criticality safety validation package at VTT (2/2)

- Currently 481 Serpent inputs from 27 experimental series
 - From the LEU-COMP-THERM (Low enriched uranium in compound form in thermal arrangements) part of the Handbook
 - Several fuel enrichments, in nearly all experiments below 5 wt. %
 - Both hexagonal and square fuel assemblies
 - Light water moderated
 - Absorbers such as cadmium, borated stainless steel, Boral etc.
- Recently Serpent was validated for criticality safety calculations of wet storage of AES-2006 fuel assemblies (See: [Report](#))



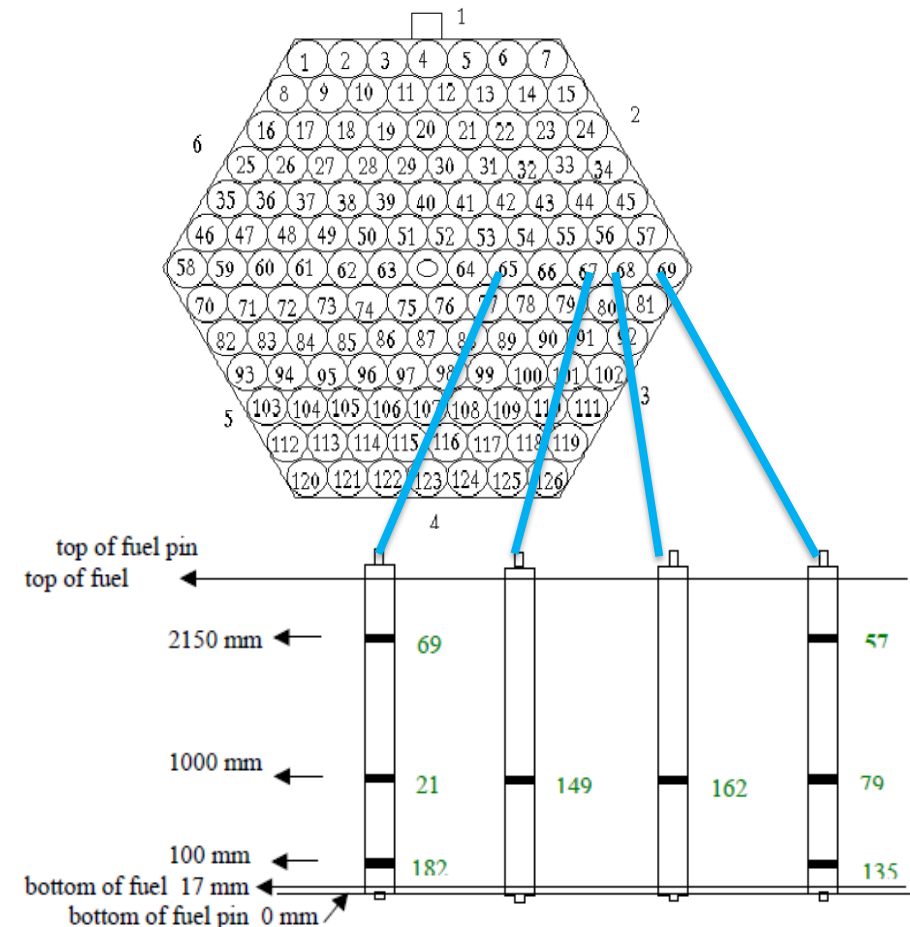
Validation script

- Written in Perl
- What it does
 - Runs the selected inputs using Serpent/MCNP
 - Collects the simulation results
 - Statistical analysis
 - Systematic bias of the calculation system, upper safety limit etc.
 - Trend analysis against pre-chosen parameters
 - Produces a simple latex report on the results
- Includes some additional features such as an option to change cross-section/thermal scattering library

Burnup validation

- Recently calculations on NEA BUC Phase IV benchmark
 - Experimental data from 8 locations representing pins of maximum, minimum and average burnup
 - Specific irradiation history for all sample points
 - 1109 irradiation days in 4 cycles, each of them between 98 and 325 days

Schematic arrangement of fuel rods in fuel assembly 135



Average BU (MWd/kgU):

36.4	37.6	39.3	42.2
------	------	------	------

Gamma validation

- Started in late 2016
- In very early phase
- Two experiments used for the photon transport validation of MCNP has been modelled
 - Kansas skyshine experiment
 - Hupmobile TLD experiment
- SINBAD database of shielding benchmarks was reviewed in order to identify experiments that can be used for further validation
 - Most of the experiments require coupled neutron/photon calculations

Thank you! Questions?



TECHNOLOGY «FOR» BUSINESS

