Validation of WIMS-IST

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Validation of WIMS-IST

- What is WIMS-IST?
- Reactor physics phenomena
- Experimental data
- Method of comparing WIMS-IST and experiment
- WIMS-IST input model
- Comparison of WIMS-IST and experiment for different phenomena
- Summary of results

What is WIMS-IST?

- IST – Industry Standard Toolset
- 2-dimensional collision probability solution of the neutron transport equation for a CANDU lattice cell.
- Calculates critical bucklings, k-effective, and cell-average parameters to use in subsequent calculations.
- WIMS-AECL Release 2-5d, used with the ENDF/B-VI-based NDAS library Version 1a.

Reactor physics phenomena

- 16 phenomena, 11 simulated by WIMS-IST
- Associated with reactivity changes due to
  - Fuel, coolant, or moderator temperature changes
  - Coolant or moderator density changes
  - Moderator purity or poison-concentration change
  - Coolant purity change
  - Lattice geometry change

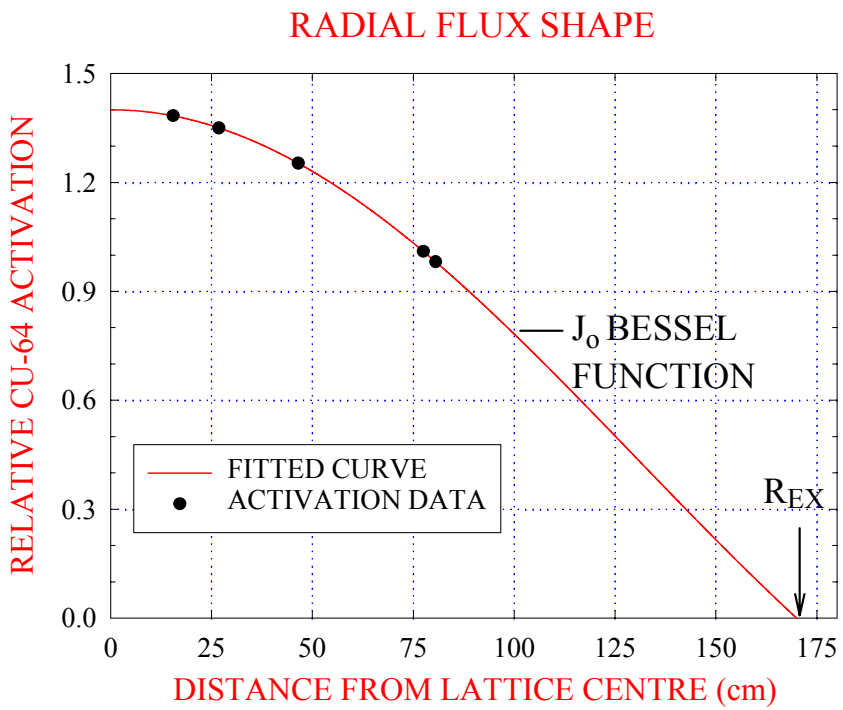
  and
  - Flux and power distribution
  - Fuel-isotopic-composition change

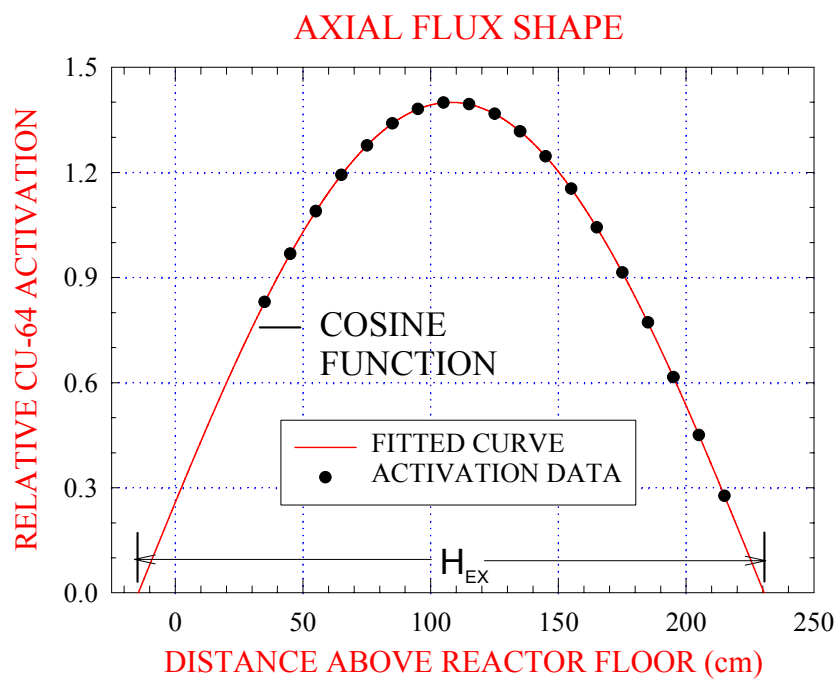
Experimental data

- For flux distribution and fuel-isotopic-composition change, compare calculated fluxes and fuel-isotopic compositions directly to experimental quantities

- For reactivity effects, critical buckling is the important parameter
- Obtained from flux-mapped or substitution experiments

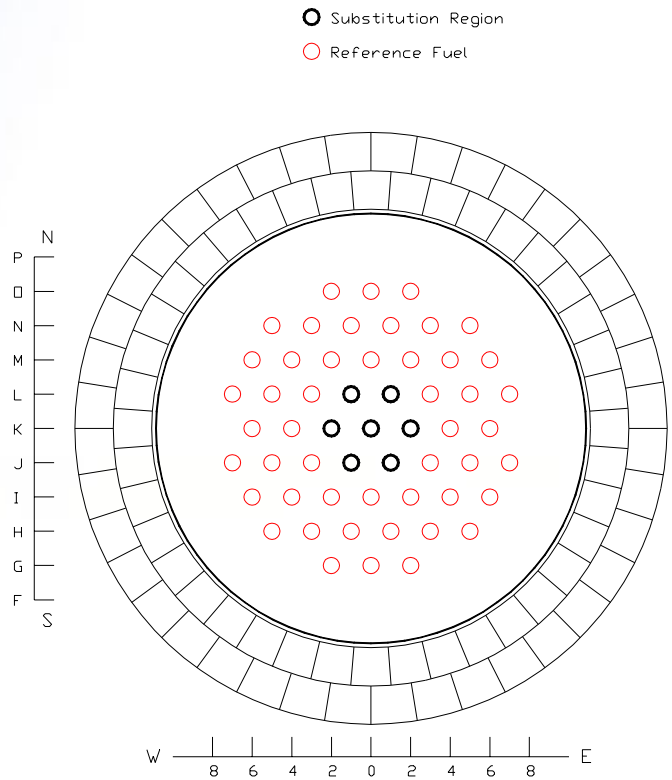
DETERMINING BUCKLING BY FLUX MAP

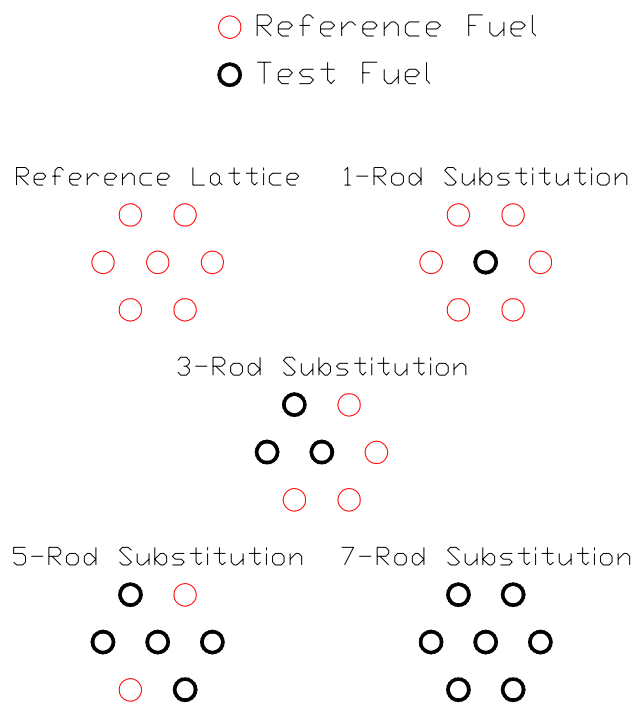




$$\text{Buckling} = (2.405/R_{EX})^2 + (\pi/H_{EX})^2$$

SETUP FOR THE ROOM-TEMPERATURE SUBSTITUTION EXPERIMENTS





Method of comparing WIMS-IST and experiment for reactivity effects

- Direct buckling method
  - Compare calculated and measured buckling coefficients of reactivity to get bias and uncertainty.
- K-eff method
  - Calculate k-eff with WIMS-IST and the measured critical bucklings at different values of the parameter of interest.
  - The deviation from a constant value is a measure of the bias and the scatter is a measure of the uncertainty.

- Both methods are essentially the same

WIMS-IST input model

- Compromise between accuracy and required resources
- For normal design and fuel management calculations
- Combination of 1- and 2-dimensional collision probability methods
- 33 energy groups
- Shielded Zr cross-sections
- End regions
- Reasonable spatial mesh

Coolant-Density-Change Induced Reactivity

- Void effect – voiding coolant causes a positive reactivity effect
- Leads to power pulse during a loss-of-coolant accident
- Uncertainties in void effect cause uncertainties in power pulse
- Void effect studied extensively

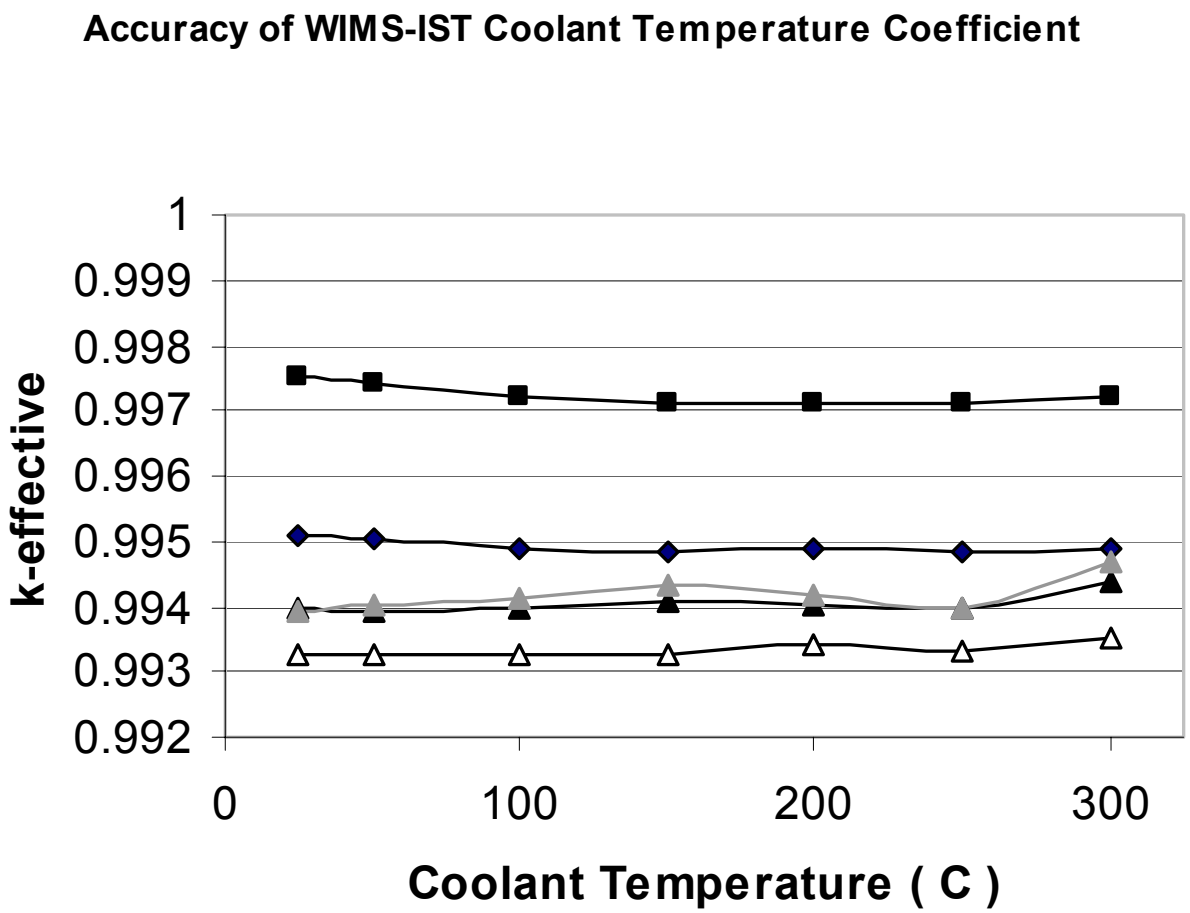
Overestimate of Void Reactivity by WIMS-IST

Fuel 22 °C, 99.75 wt% Heavy Water, 31-cm Hexagonal Pitch	Void Reactivity Discrepancy (mk)
28-element FNU (flux mapped)	0.57 ± 0.4
28-element FNU (AECL calibration)	0.78
28-element FNU (OPG method)	0.73
37-element FNU (AECL calibration)	1.89 ± 0.64 [2]
37-element FNU (OPG method)	1.90 ±0.45
37-element MOX (AECL calibration)	1.68 ± 0.75 [2]
37-element MOX (OPG method)	1.29 ±0.78
43-element CANFLEX FNU (AECL calibration)	1.83

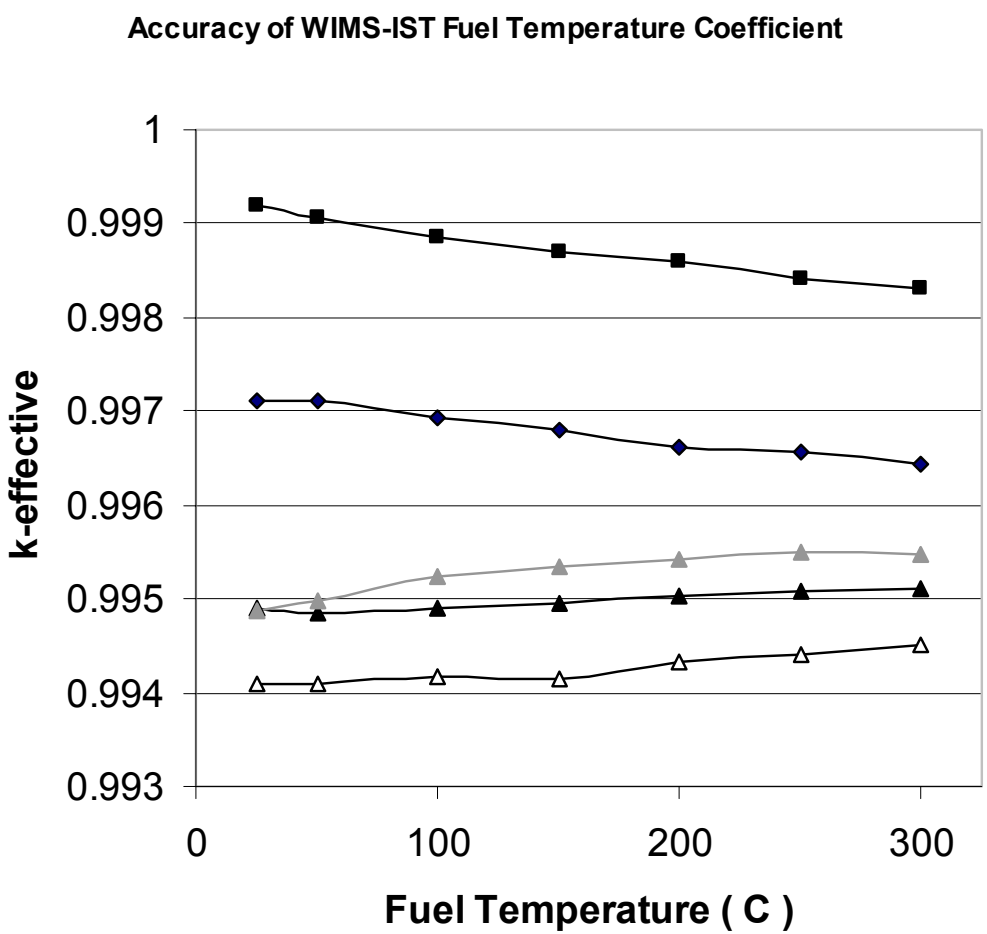
Fuel- and Coolant-temperature-change Induced Reactivity Experiments

- 37-element FNU fuel bundles
- 37-element MOX fuel bundles
  - 19-element boosters, room temperature extrapolation
  - 19-element boosters, measured temperature-dependant extrapolation
  - ZEEP rod boosters, room temperature extrapolation
- 43-element CANFLEX natural UO_2 fuel bundles
- Coolant temperature: zero bias, uncertainty ±4%
- Fuel temperature: zero bias, uncertainty ±10%
  - Overestimate for FNU
  - Underestimate for MOX

Coolant-temperature-change Induced Reactivity



Fuel-temperature-change Induced Reactivity



Moderator-density- and moderator-temperature-change induced reactivity

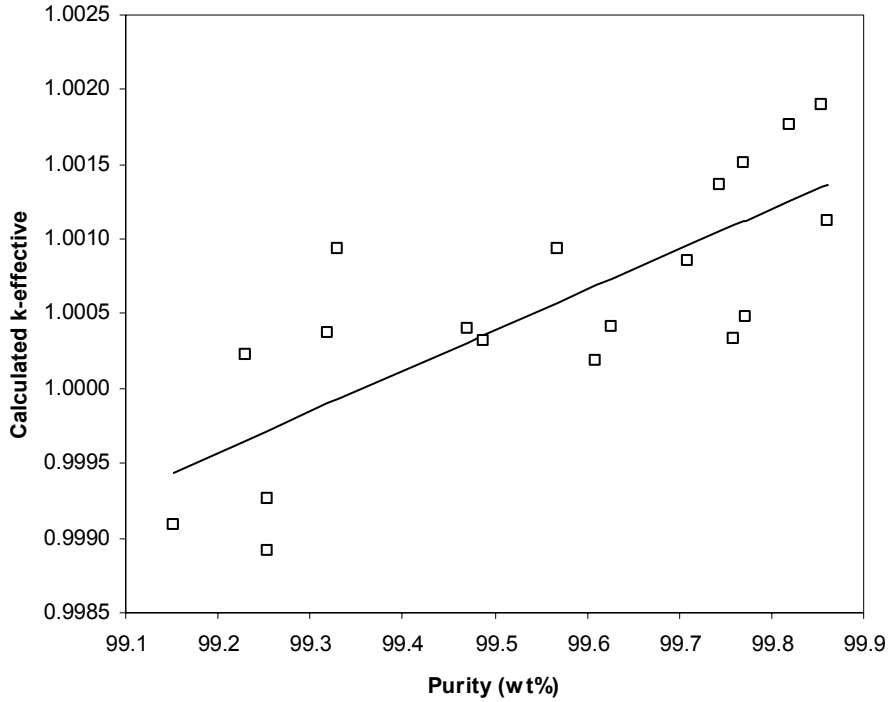
- Flux-mapped 19-element fuel
- 11 to 82°C (uniform reactor temperature)
- Comparing buckling coefficients leads to zero bias with uncertainty of ±2.6%

Difference between Moderator-Poison (Boron) Buckling Coefficients

Experiment	Coolant	Relative Difference in Coefficient
28-element air-cooled FNU	Air	-1.3%
37-element FNU	Air	1.7%
	D_2O	0.0%
37-element MOX	Air	-2.6%
	D_2O	-3.0%

Moderator-purity-change induced reactivity

- 28-element UO_2 fuel
- Moderator purity reactivity coefficient overestimated by 8% with uncertainty of ±3%



Coolant-purity-change induced reactivity

- 37-element FNU and MOX substitution experiments
- 31-cm hexagonal lattice pitch
- 3 purities from 99.76 to 95.1 wt% D_2O
- FNU bias and uncertainty 8%±11%
- MOX bias and uncertainty –10%±8%
- Overall assign a bias and uncertainty of 0±12%

Lattice geometry distortion effects

- Only channel sag
- Change in lattice pitch
- 19-element and 28-element UO_2 fuels
- Hexagonal pitches from 24 to 40 cm
- No bias with varying lattice pitch

Flux distribution within bundle

- 8 zero-power experiments with foils or other flux indicators
- 28, 31, 36, 37 and 43-element fuel
- Pitch mostly 31-cm hexagonal although 2 measurements with pitches of 24-cm hexagonal
- Number of different foil materials
- Flux depression through a fuel bundle calculated to an accuracy of about 1%

Fuel-isotopic-composition change

- 19-element NPD bundle – half elements from each ring
- 28-element Pickering-A bundle – outer element
- 37-element Bruce-A bundle half elements from each ring

- No or small bias and an uncertainty of ±2%

Bias and uncertainty using element data (all bundles)

Atom Ratio	Average C/M	Standard Deviation C/M	Bias	Uncertainty
$^{235}U/U$	1.005	0.016	0.5%	±2%
$^{236}U/U$	0.961	0.040	-4%	±4%
$^{238}U/U$	1.000	0.000	0	0
$^{239}Pu/Pu$	0.996	0.004	-0.4%	±0.4%
$^{240}Pu/Pu$	1.006	0.008	0.6%	±0.8%
$^{241}Pu/Pu$	1.037	0.023	4%	±2%
$^{242}Pu/Pu$	1.001	0.024	0.1%	±2%
Pu/U	1.017	0.021	2%	±2%

Summary of bias and uncertainty

Description of Phenomenon	Bias	Uncertainty
Coolant void reactivity	Overestimate +1.9 mk (37-element FNU)	±0.8 mk
Coolant-temperature coefficient	No bias	±4%
Moderator-density and moderator-temperature coefficient	No bias	±3%
Moderator-poison coefficient	No bias	±2%
Moderator-purity coefficient	Overestimate +8%	±3%
Fuel-temperature coefficient	Overestimate for FNU Underestimate for simulated mid-burnup fuel	±10%
Fuel isotopic change	No or small bias for actinides	±2%
Flux-power distributions	No bias in bundle flux shape	±1% in bundle flux shape
Lattice distortion reactivity	No bias in lattice cell with varying pitch	_____
Coolant-purity coefficient	No bias	±12%

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