ACR TECHNOLOGY BASE: REACTOR PHYSICS

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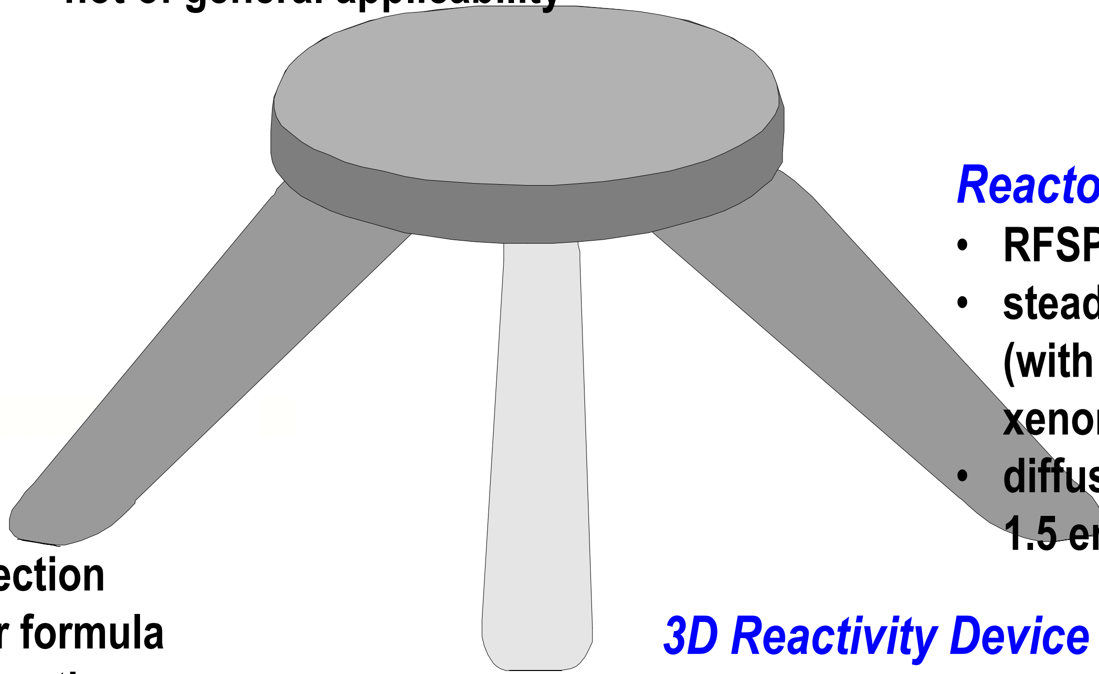
Outline

- Analysis basis
  - original, current
- ZED-2 reactor physics measurements
- Validation of the reactor physics toolset
  - for CANDU
  - for ACR

Original CANDU Physics Analysis Basis

- generally good accuracy
- many parameters tuned to give agreement with measurements
- not of general applicability



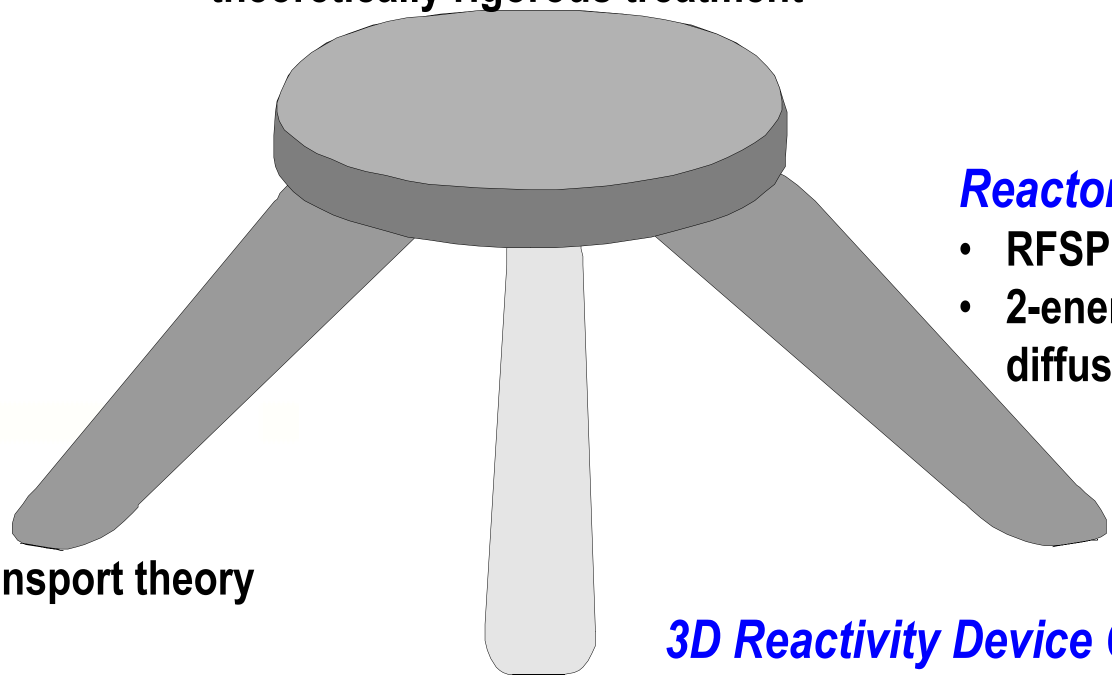
Lattice Code
- POWDERPUFS-V
- “Westcott” cross-section convention, 4-factor formula
- cell-average cross sections

Reactor Code
- RFSP
- steady state, kinetics (with T/H coupling), xenon transients
- diffusion theory in 1.5 energy groups

3D Reactivity Device Code
- MULTICELL
- “incremental cross sections” added to cell-average cross sections for reactivity devices

Current CANDU Physics Analysis Basis

- good accuracy and of general applicability
- part of the "Industry Standard Toolset" (IST)
- theoretically rigorous treatment



Reactor Code
- RFSP
- 2-energy group diffusion theory

Lattice Code
- WIMS
- multi-group, 2-D transport theory

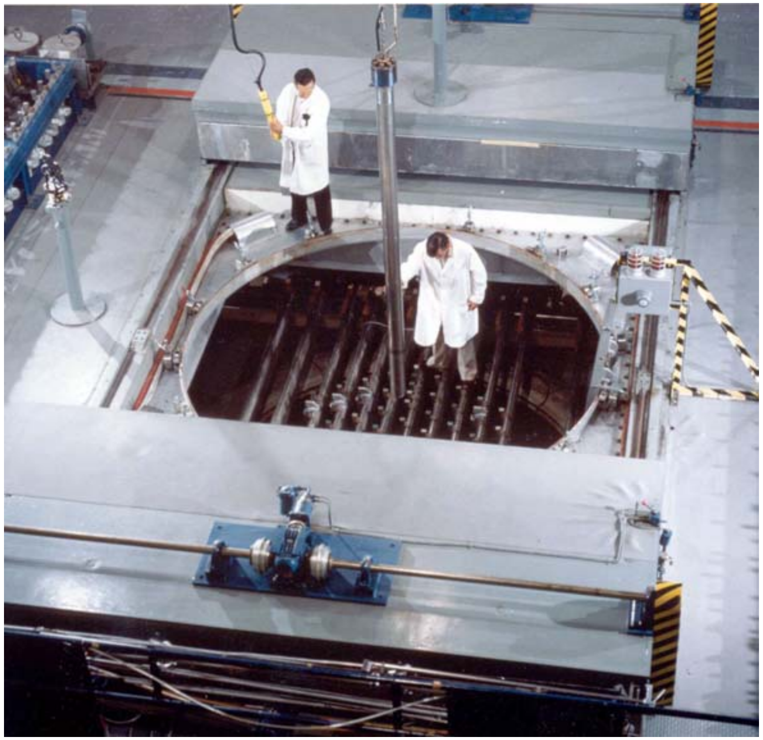
3D Reactivity Device Code
- DRAGON
- multi-group, 3D transport theory

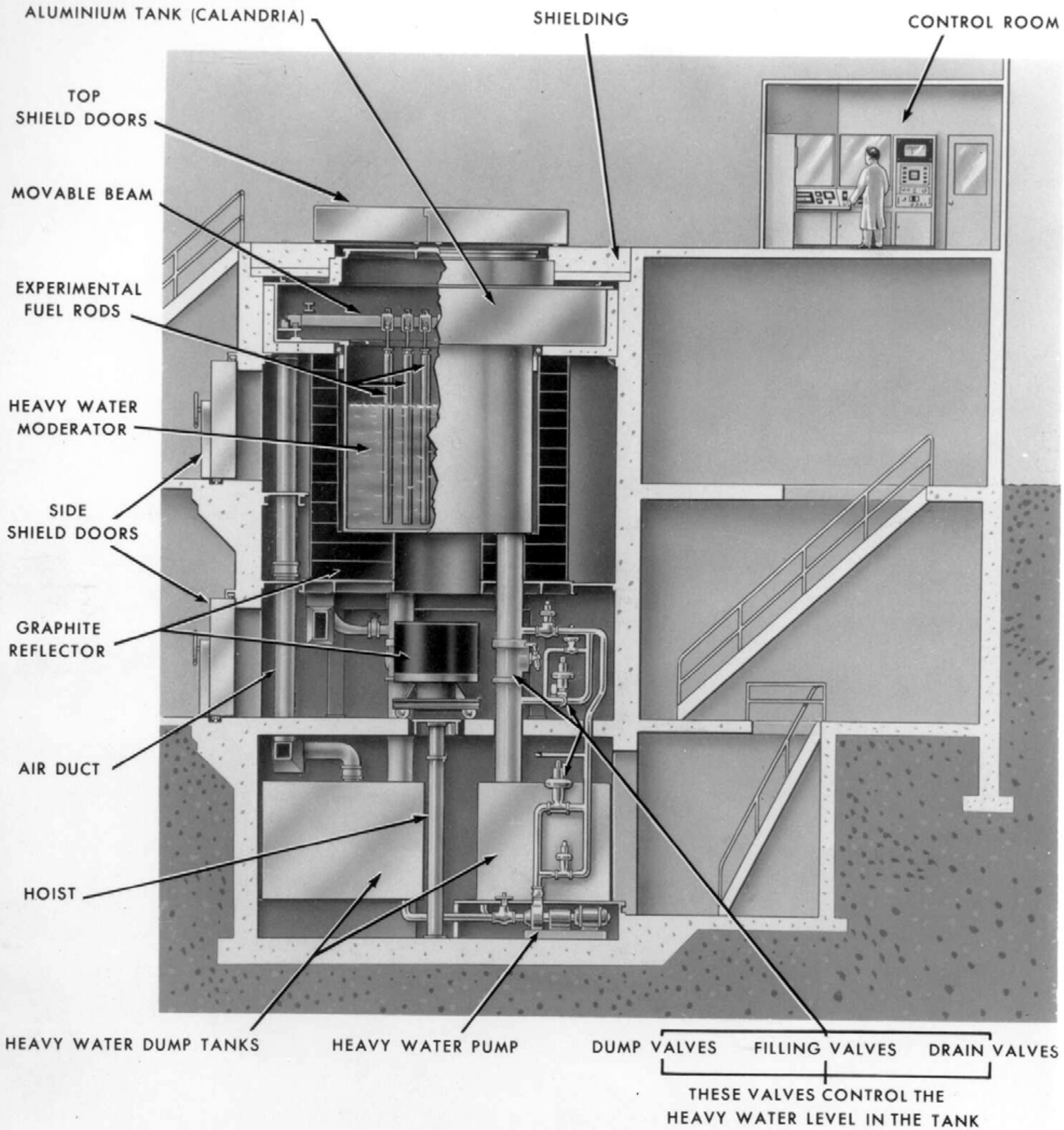
MCNP

- **Monte-Carlo code MCNP increasingly used in design and validation as benchmarking tool**

ZED-2 Reactor

- Tank-type critical facility, 3.3 m (11 ft) in diameter & depth
  – runs at a few watts
- Flexible facility
  – allows testing of a variety of fuels, different pitches, different coolants: D_2O, H_2O, air (voided)
- D_2O moderated
- Typical lattice arrangement is hexagonal, with 55 channels, each containing 5 bundles
- 7 “hot sites” can be located in center
  – 10 MPa (1450 psi), up to 300 ºC (570 ºF)
- Shielding insufficient for measurements on irradiated fuel





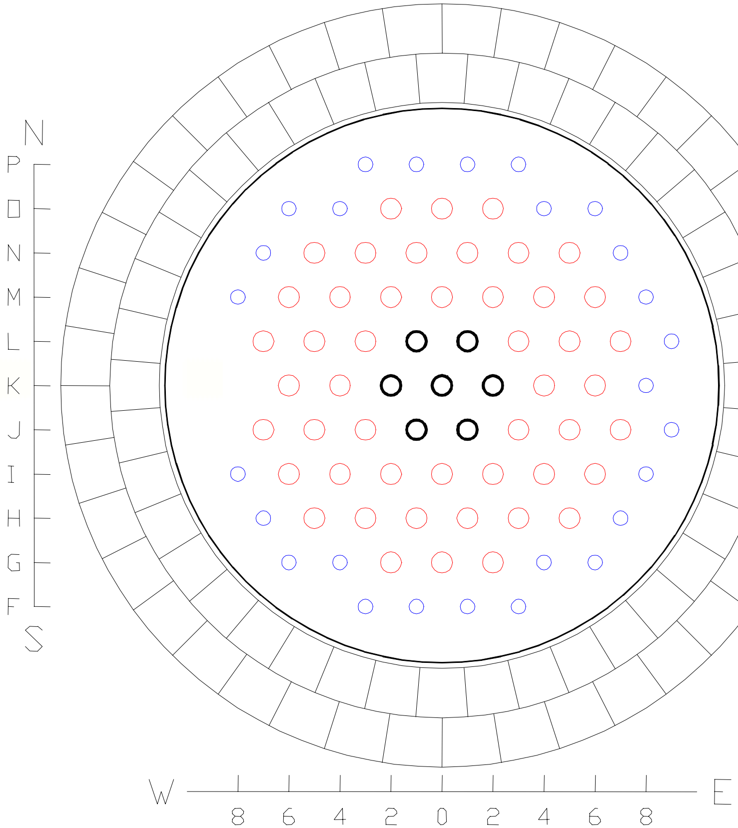
ZED-2 REACTOR

ZED-2 Measurements

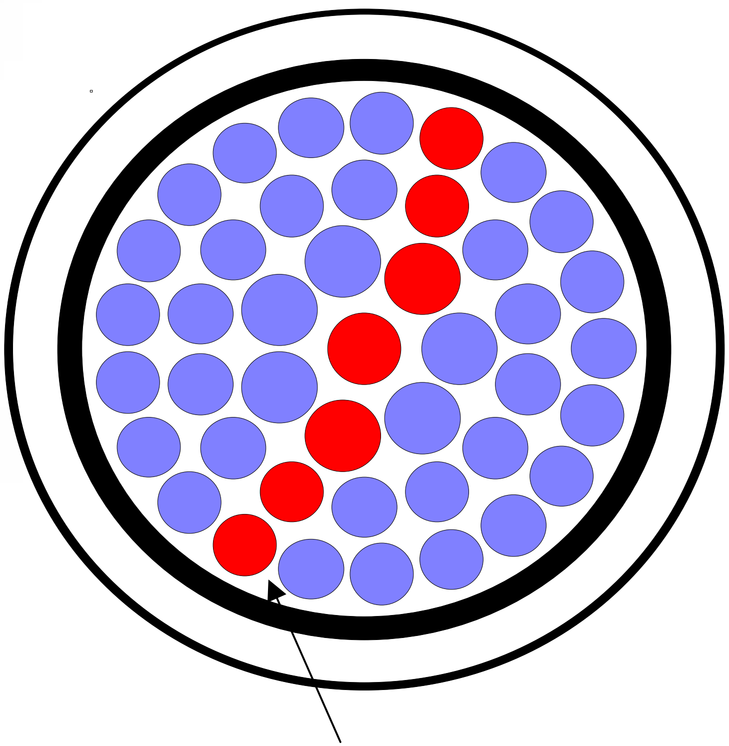
- Buckling (reactivity)
  - full core flux maps & substitution experiments
  - reactivity coefficients
    - void reactivity; fuel temperature; coolant temperature & purity; moderator temperature, purity, and poison
- Worth of reactivity devices (shutoff rod, adjuster rod)
- Reactor period measurements (for neutron kinetics)
- Reaction rates in foils
  - U-235, Pu-239, Dy-164, Cu-63, Mn-55, Au-197 In-115, Lu-176
  - reaction-rate ratios are sensitive indicators of the energy spectrum
    - Pu-239/U-235 fission, Lu-176/Mn-55 capture, Au-197/Cu-63 capture
- Thermal flux through lattice cell (Cu-63)

Typical Set-up for Substitution Experiment

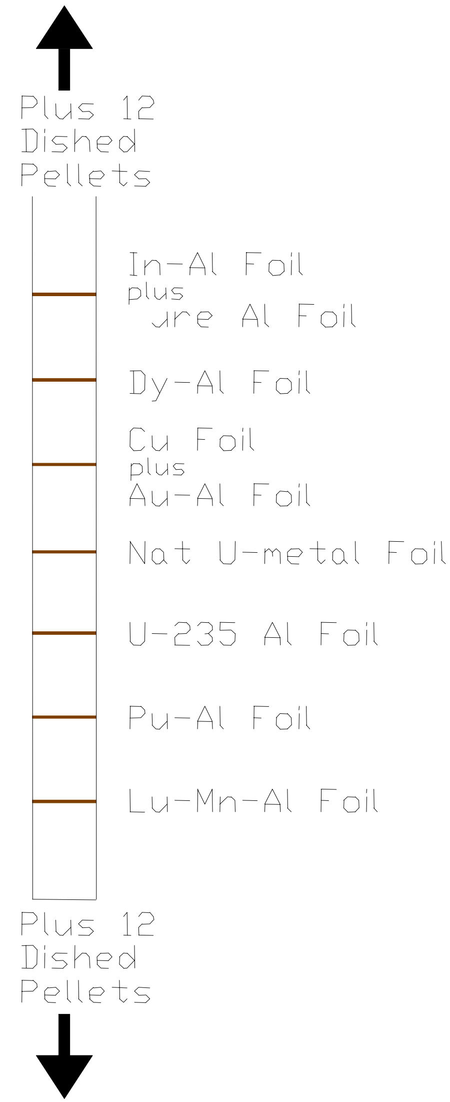
- Booster Channel
- Driver Channel
- MOX Channels



Activation Foils in a CANFLEX Bundle



7 demountable elements in
central bundle containing foils

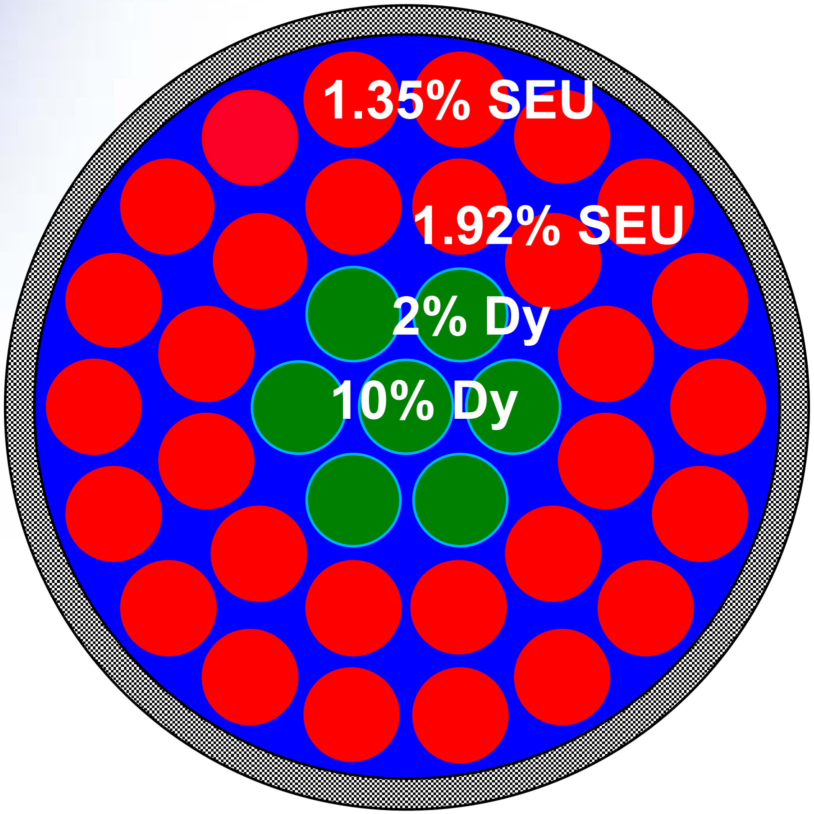



10 11 12 13 14 15 16 17 18

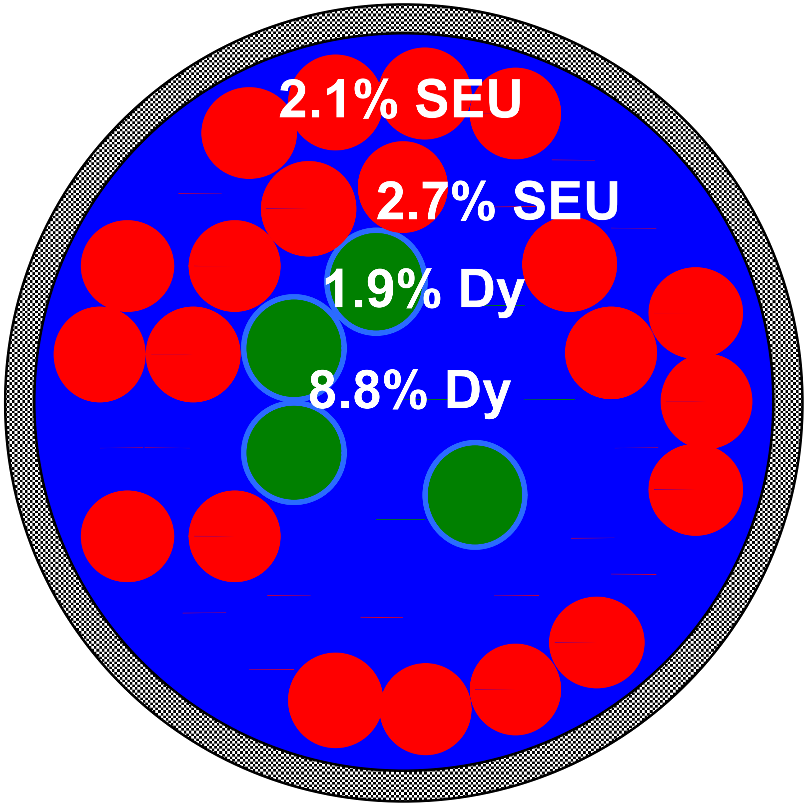
Fuels Measured in ZED-2

- Geometries
  - 28-element, 37-element, 43-element CANFLEX
- Compositions
  - fresh NU
  - simulated “mid-burnup” NU fuel
    - 0.4 wt% U-235, 0.3 wt% Pu (75% fissile), 0.05 wt% Dy
  - “low void reactivity fuel” (LVRF)
    - 37-element; 7-rod substitution measurements
    - CANFLEX high burnup LVRF; single rod (5 bundle) substitution measurements
      - similar to ACR fuel

LVRF Bundles Tested in ZED-2



37-element LVRF



CANFLEX LVRF

Other Reactor Physics Measurements

- NRU
  - isotopic depletion and burnup from experimental bundles irradiated in NRU: NU, SEU, LVRF, Dy-doped elements

- CANDU power reactors
  - physics tests during commissioning
  - in-core flux detector measurements during operation
  - thermal-power measurements in some channels
  - burnup of discharged bundles
  - kinetic behavior (slow and fast transients, shutdown-system tests)
  - realistic in terms of scaling, but
    - always “integral” measurements (rather than separate effects)
    - larger measurement uncertainties than in ZED-2
    - not completely known boundary conditions

Validation of Reactor Physics Toolset

- Followed standard methodology (described in workshop)
- Validation involved
  - comparison against ZED-2 measurements
  - comparison against power reactor measurements
  - extrapolation / scaling using MCNP
- Validation identified bias and uncertainty for key parameters
  - for example, WIMS over-predicts void reactivity (ie, is conservative) in operating CANDU reactors with a bias of between +1.6 to +2.0 mk, with an uncertainty of +/- 1 mk
  - CNSC and industry commissioned Independent Expert Panel (IEP) to review industry conclusions wrt void reactivity, fuel temperature reactivity coefficient, & delayed neutron data
    - draft report by IEP released in Aug 2002 was in the end generally in agreement with numbers used by Industry
    - final report expected in October

ACR Physics

- **Key differences affecting physics**
  - fuel type
    - 2% SEU with Dy in central element
  - lattice
    - H_2O cooled, tight lattice pitch
  - fuel channel
    - larger gap between pressure tube and calandria tube
  - core geometry
    - reflector has greater importance

ACR Physics Analysis Basis

- Current physics toolset will be used
  - WIMS, DRAGON, RFSP
- Currently confirming suitability of toolset
  - number of energy groups in full-core diffusion calculations
  - suitability of diffusion theory throughout core
  - estimated accuracy in key parameters
  - nuclear data library
- Assessment includes inter-code comparisons with MCNP and multigroup diffusion code DONJON

Validation of Physics Codes for ACR

- ZED-2 experiments
  - buckling measurements
    - full core and substitution
    - reactivity coefficients
  - reaction rate measurements
- Measurements from NRU irradiations
  - isotopic depletion and burnup from prototype ACR fuel irradiated in NRU
- Extrapolation / scaling with help of MCNP

Summary

- Reactor physics toolset recently upgraded to more rigorous methods
  - currently confirming suitability of toolset for ACR
- Validation of reactor physics toolset based on decades of measurements in ZED-2
  - ZED-2 measurements will provide validation data for ACR physics
- CANDU analysis and measurement methodologies well established
  - independent international expert review of our methods

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