Preliminary Assessment of Physics Toolset for ACR Applications

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Presented to US NRC

December 5, 2002

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Presentation Outline

- **Physics Codes and Data Libraries**
- **Preliminary assessments to ascertain adequacy of physics toolset**
  - Requirements imposed by ACR lattice design
  - Requirements imposed by ACR core design
  - **Preliminary ZED-2 measurements**
  - **Lattice-cell model study and inter-code comparisons**
  - **Full core modeling considerations**
- **Summary**

Major Physics Codes

- **WIMS-AECL**
  - NDAS ENDFB/VI 89-group library, with patch for Dy burnup
  - Fully qualified for CANDU physics analysis
- **DRAGON-IST**
  - Use same ENDFB/VI 89-group library
  - For supercell calculations only
    - Device incremental x-section
    - Bundle end-flux peaking
  - Fully qualified for CANDU physics analysis
- **RFSP-IST** 2-group diffusion method
  - Fully qualified for CANDU physics analysis

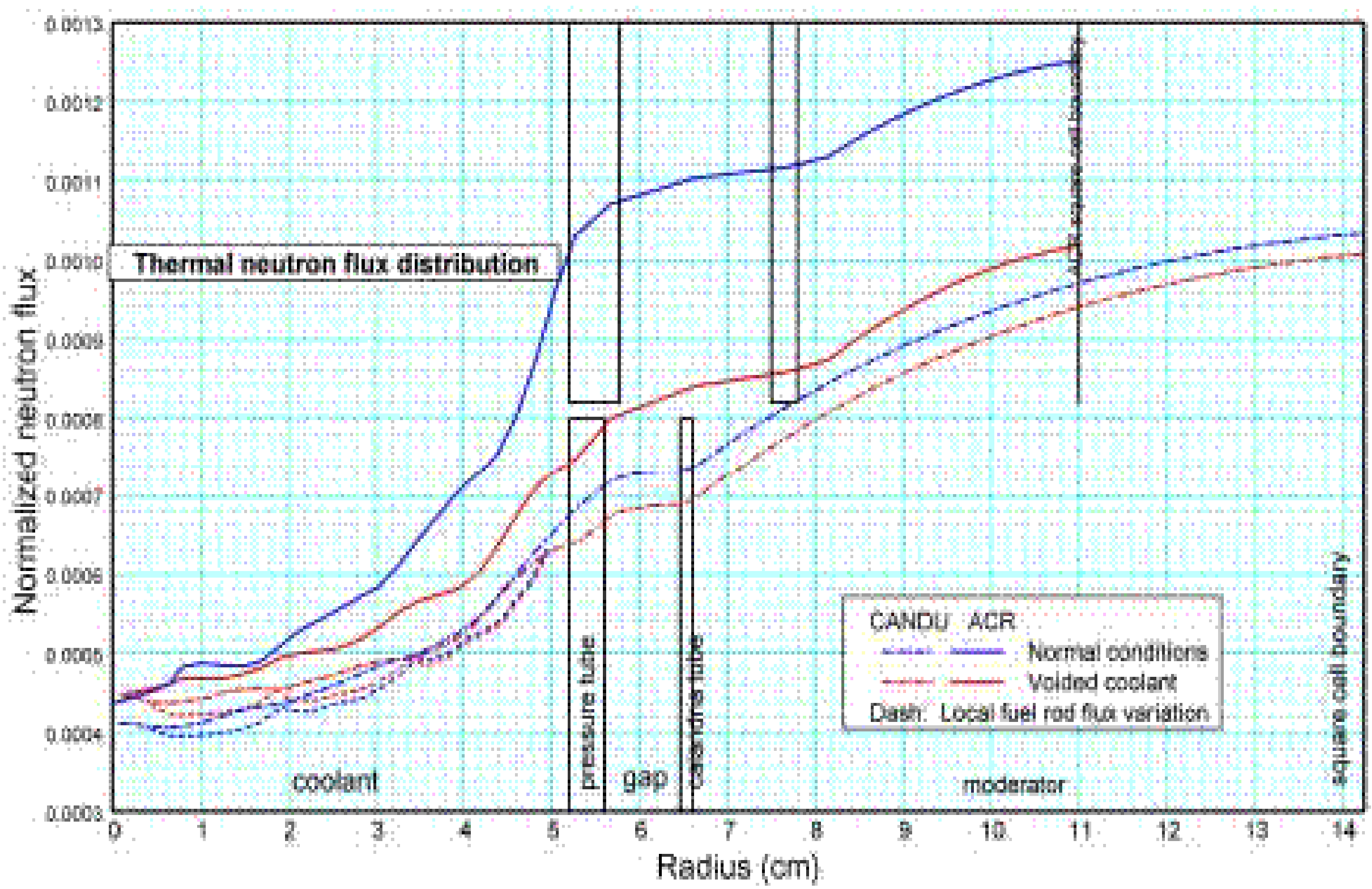
Other Physics Tools

- **MCNP-4C**
  - AECL Library ENDF65MT
  - Extensively used for benchmarking the major physics codes
- **DONJON**
  - Multi-group diffusion code from U of Montreal
  - Use WIMS-AECL (or DRAGON) lattice-cell properties

Neutronic Characteristics arising from lattice design - with implications on lattice-cell model

- Negative coolant void reactivity
- Dy burnout and impact on CVR
- Reduced moderation – harder energy spectrum
- Much shorter mean free path in coolant
- Steeper flux depression across bundle, and across fuel elements
- Neutron streaming in gap between CT/PT (and voided coolant sub-channels)
- Stronger coupling to neighboring lattices
- Much higher fuel burnup

Thermal Flux Profiles
– Cooled and Voided Lattice



Requirements on ACR Lattice Code and Model

- CVR Prediction must be accurate
- Accurate Dy burnout modeling
- Fine meshes, particularly in coolant and fuel regions
- Appropriate coolant volume associated with each fuel element for correct resonance treatment (spectral type specification)
- Optimal energy spectrum discretization (energy group specification)
- Suitable Outer cell-boundary condition
- Suitable leakage treatment in 2-D cell calculations
- Optimal burnup and transport calculation steps cover extended burnup range
- Acceptable run time for production calculations

ACR Core Design Features

- with implications on supercell and core models

- Flat global flux shape across the core
- Small core size, relatively higher importance of leakage out of core
- Flux rise in peripheral core and reflector region upon loss of coolant, further enhanced negative coolant void reactivity
- Higher neutron utilization in SEU fuel
- Lower absorber worth and moderator poison worth
- Nine pairs of zone control elements inserting from top and bottom
- Twenty SOR, 6 LIZZ nozzles in reflector region
- Non-circular control elements and SOR

Full-Core and Supercell Model Considerations

- Adequacy of 2-group calculations
- Convergence of spatial flux calculations – sensitivity to core mesh structure
- Adequacy of diffusion theory
- Directional diffusion coefficients (axial and radial)
- Small time steps in dynamic transients calculations
- Device modeling considerations
  - Flux spectrum at interstitial locations
  - Running-Track shape device modeling approximation
  - Size of supercell model and boundary conditions
  - Fuel burnup of neighboring bundles

Adequacy of Physics Toolset
- Preliminary Assessments

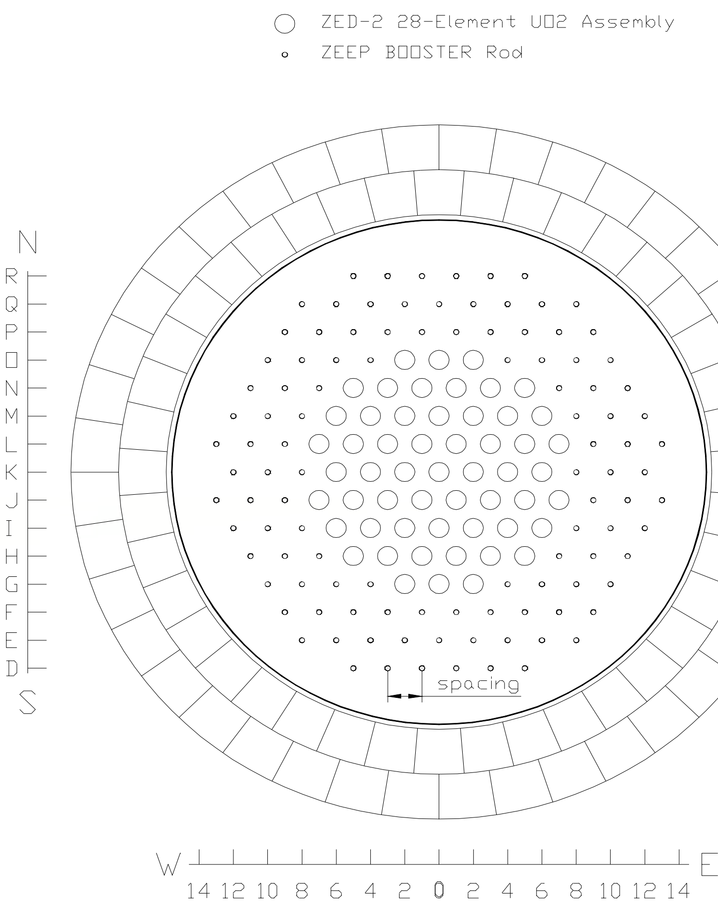
- ZED-2 measurements
  - Comparisons with WIMS-AECL
  - Comparisons with preliminary MCNP calculations
- Lattice-cell modeling and inter-code comparisons
  - WIMS versus MCNP
- Core Modelling
  - RFSP vs DONJON (2-group)
  - DONJON N-group

ZED-2 Measurements
- with relevance to ACR Lattice

- **Lattice arrangement for flux-map measurements**
  - 55 rods with 28-element NU fuel, outer driver with 108 ZEEP rods
  - H_2O coolant
  - Tight hex pitches in the range of 20 – 23 cm
- **Flux maps measurements**
  - H_2O cooled and air cooled
  - Three lattice pitches 22.86 cm (9"), 21.59 cm (8.5") and 20 cm
  - Provided data on CVR variation with lattice pitch
  - Cu activation data fitted to cosine and Bessel function

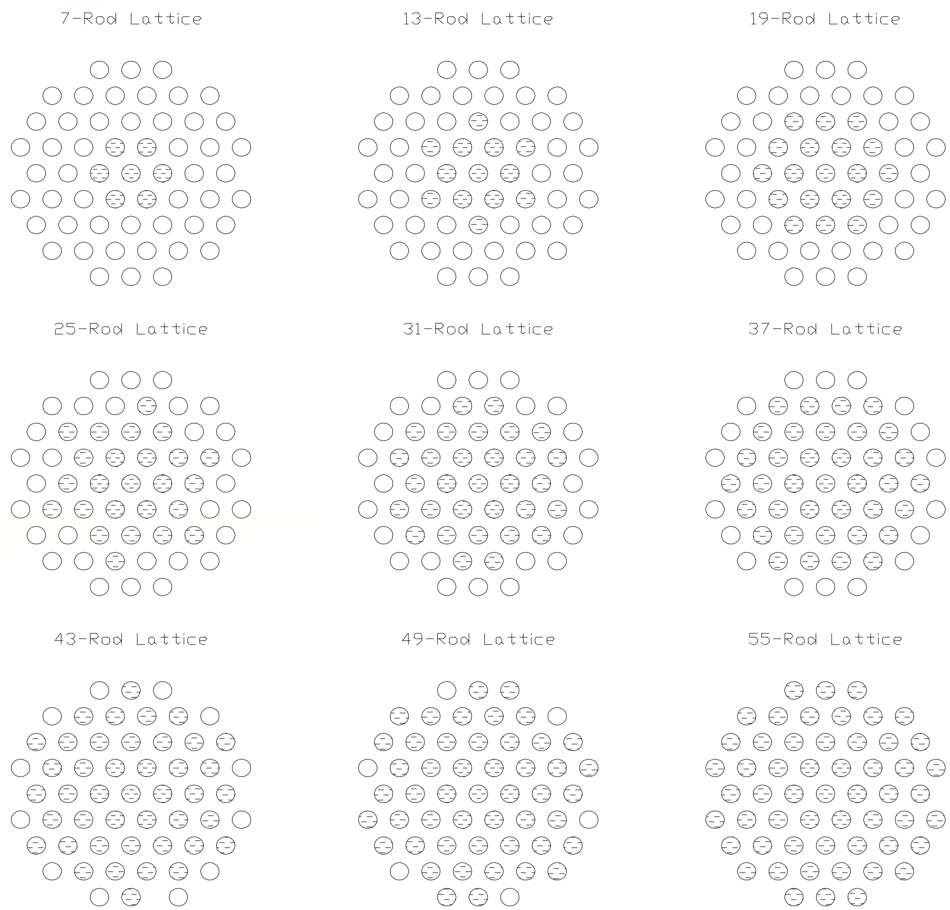
    $A(z,r) = A_o * \text{Cos a } (z-z_o) * J_o (?r)$
- **Substitution measurements**
  - 21.59 cm pitch and 20 cm pitch lattices
  - Voided core reference , substituted 1, 3, 5, 7 , … to full H_2O cooled lattice
  - Full flux map with 7-rod substitution

ZED-2 Lattice for Full-Core Flex Map

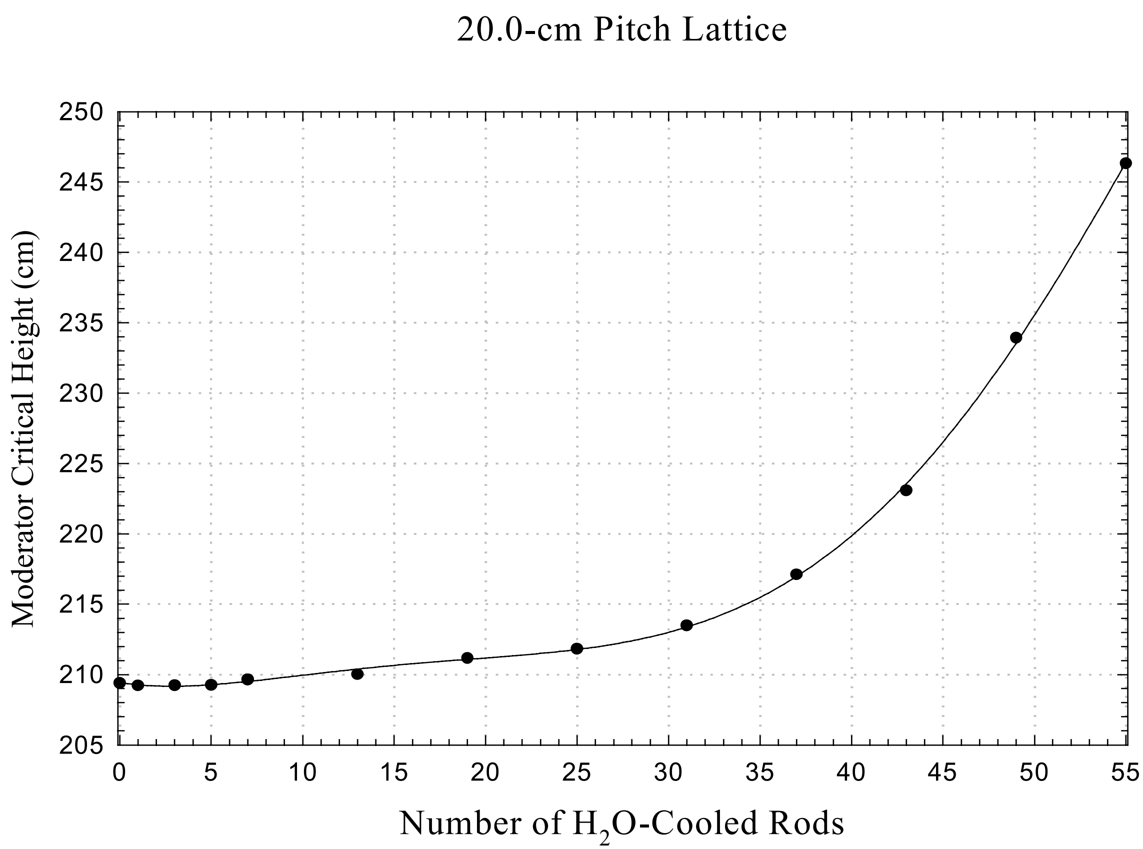


Drawing is to scale

Substitution Measurement Lattice



Critical Height variation with Number of Substitution Rods – 20 cm Pitch Lattice



WIMS-AECL Lattice-Cell Model Study

- Frozen WIMS version and data library
- WIMS relies on simplifications / approximations of real physical situations
- Benchmark against MCNP for both cooled and voided lattice
- Assessment of individual elements of computation model and numerical method
- Goal: Reduce individual element CVR errors to 0.1 mk if possible
  - Apply high accuracy numerical approximations
  - Use most adequate physical model
  - Avoid heuristic approaches
  - Run time is a constraint

WIMS Modelling Features Investigated

- **Spatial approximations**
  - Outer cell boundary model
  - Extent of coolant spectral region
  - Annulus sub-divisions for coolant and moderator regions
  - Fuel rod subdivisions
  - Extent of 2-D numerical integration for collision probabilities
- **Cross-Sections and Few-Group Structure**
  - ENDF/B-VI library
  - Combinations of resonance-shielded or unshielded zirconium data, and U238 and U238NF data
  - 89-Group vs condensed number of groups
- **Burnup Time Steps**

Most accurate WIMS Model

- Most accurate model has been established
- Other error sources
  - Cylindrical cell boundary
  - Deficiencies in resonance treatment
  - Inaccuracies in data library
    - Unshielded Dy cross-section data
    - Old Pu-239 / U-235 data
    - Room temperature data for fission products
    - Flux spectrum used in X-section average not specific to ACR
    - Zr data independent of temperature
  - Cancellation of errors
- Upgrade of both code and data library in progress

Core Modelling Study

- RFSP / DONJON Diffusion Solution Method

- RFSP-IST currently formulated in 2 energy-group
- DONJON has multi-group capability – not an IST code
- RFSP vs DONJON (2-group)
- Accuracy of 2-group calculations
  - DONJON 2-group compared with N-group (N up to 10, with some checks extending up to 32 groups)
  - Variations in key core parameters
    - K-eff
    - CVR
    - Power distribution
    - ZCR device worth

Preliminary Conclusions
- Accuracy of 2-Group Core Calculations

- **Variations of integral quantities with increasing energy groups are reasonably small**
  - Core reactivity over-estimate by about 2.5 mk
  - CVR
    - Relatively insensitive to number of groups (within ±0.5 mk)
    - 2-group "error" within uncertainties arising from WIMS input model
  - ZCR Worth
    - 2-group under-estimates worth (fully in to fully out) by ~0.5 mk
- **Larger uncertainties in distributed parameters (e.g. channel powers)**
  - 2-group under-estimates maximum CP roughly 3%
  - 2-group under-estimates CP increases upon voiding
  - Currently under further investigation

Summary

- **Basic Toolset consists of WIMS-AECL, DRAGON-IST and RFSP-IST**
- **Analysis of Relevant ZED-2 measurement data**
  - WIMS predicts CVR variation with lattice pitch with constant bias
- **Extensive comparisons of WIMS and MCNP lattice-cell calculations**
- **Assessment of adequacy of two-group core calculations and uncertainties**
- **Suitability and performance of Toolset judged to be satisfactory – biases and uncertainties need to be more precisely quantified**
- **Full-fledge Toolset Qualification Plan discussed in next presentation**