Preliminary Assessment of Physics Toolset for ACR Applications

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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
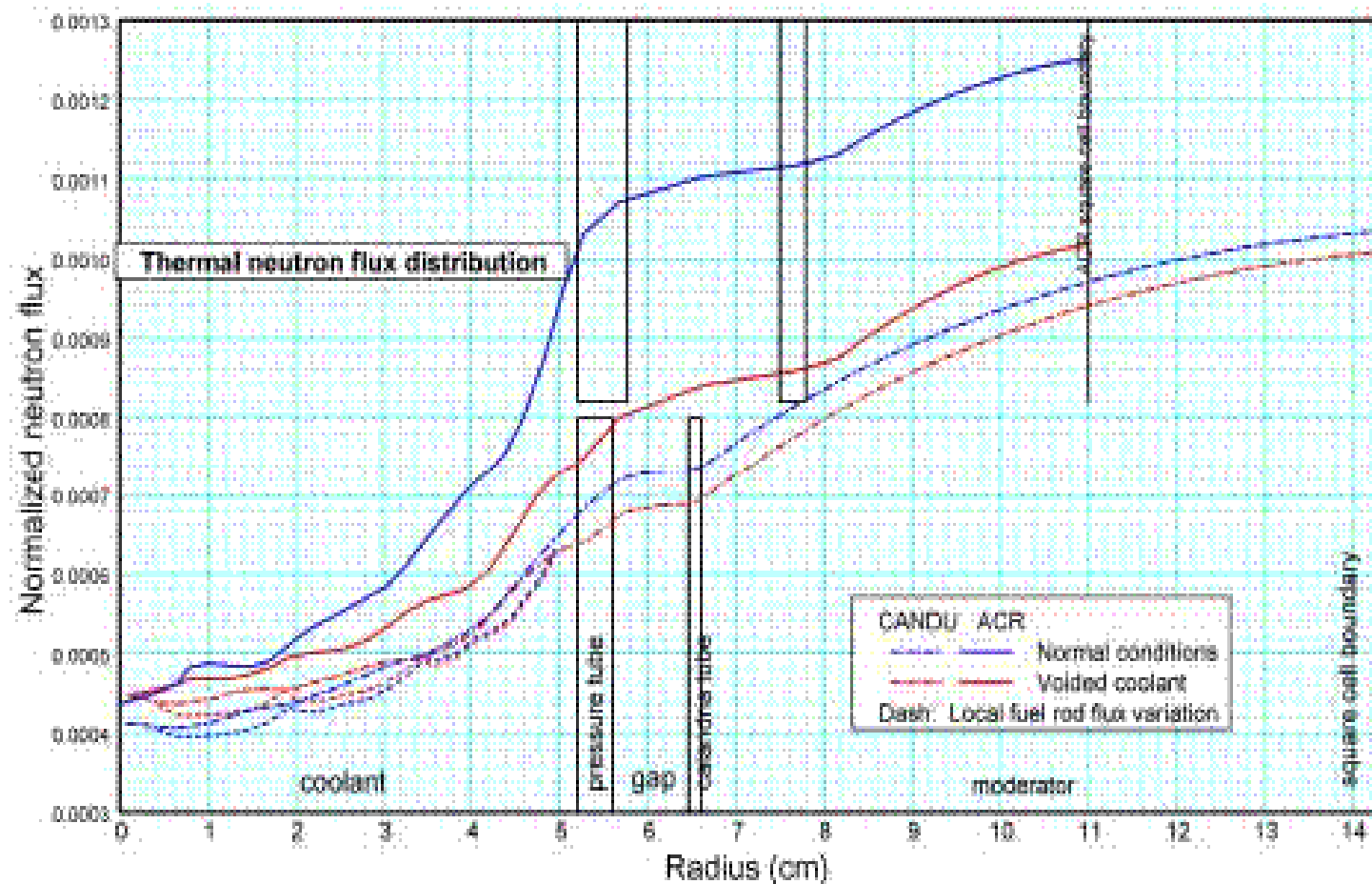
Requirements on ACR Lattice Code and Model

- 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
    $$A(z,r) = A_o * Cos\ a\ (z\text{-}z_o) * J_o\ (\ ?r)$$
- **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
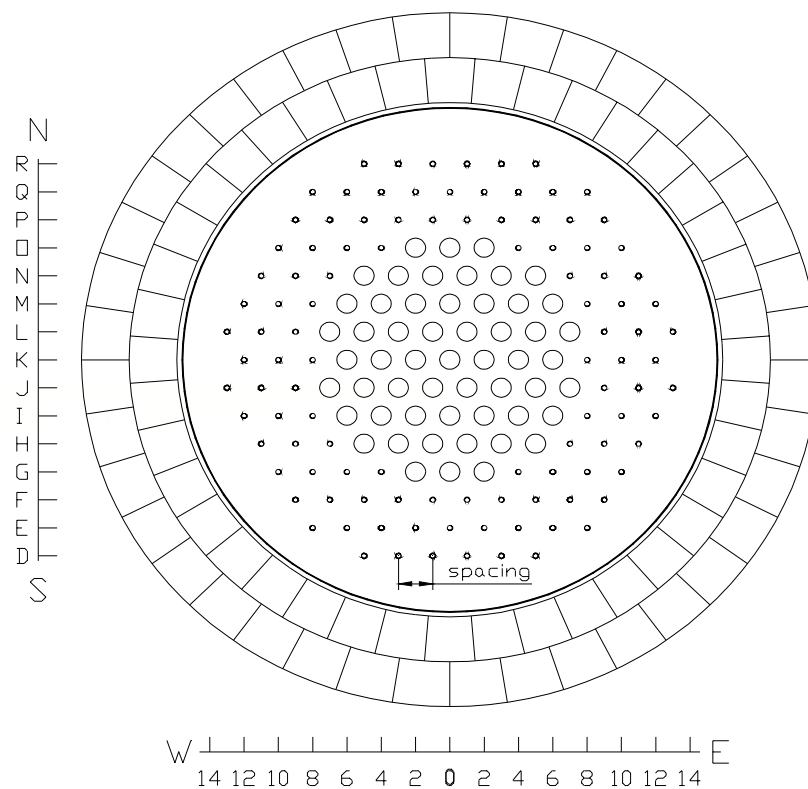
Drawing is to scale

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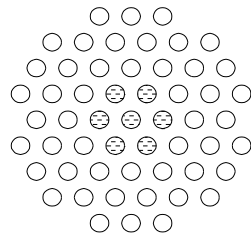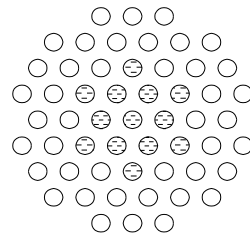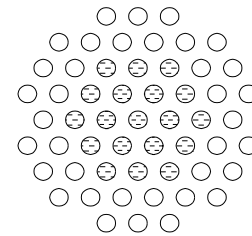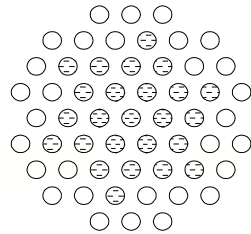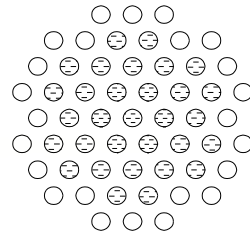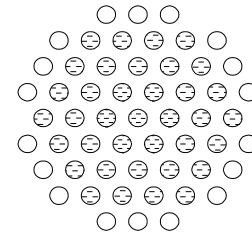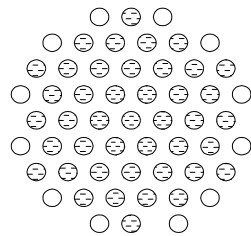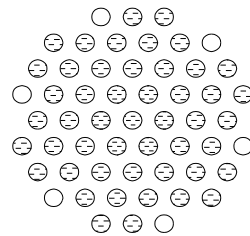
Critical Height variation with Number of Substitution Rods – 20 cm Pitch Lattice

20.0-cm Pitch Lattice

WIMS-AECL Lattice-Cell Model Study

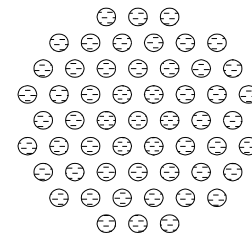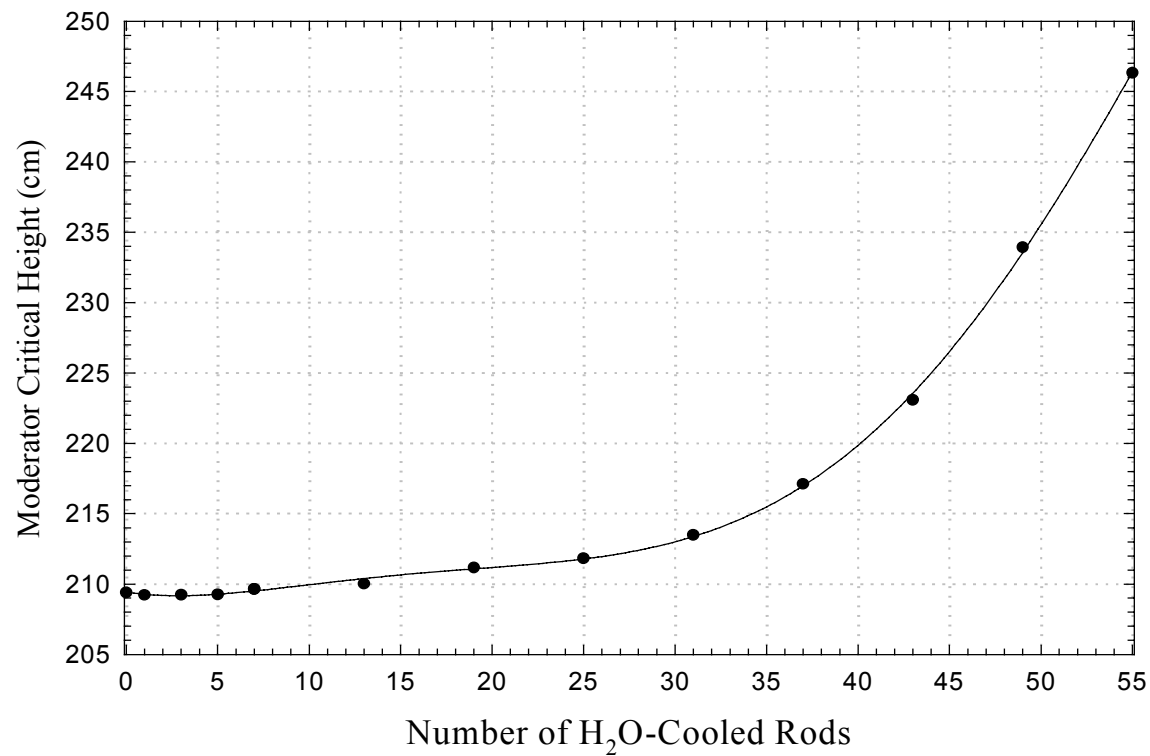- Frozen WIMS version and data library
- WIMS relies on simplifications / approximations of real physical situations
- Benchmark against MCNP for both cooled and voided lattice
- Assessment of individual elements of computation model and numerical method
- Goal: Reduce individual element CVR errors to 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**