DEVELOPMENT OF THE MNR OSCAR-5 CORE FOLLOW AND RELOAD CALCULATIONAL MODEL FOR OPERATIONAL SUPPORT

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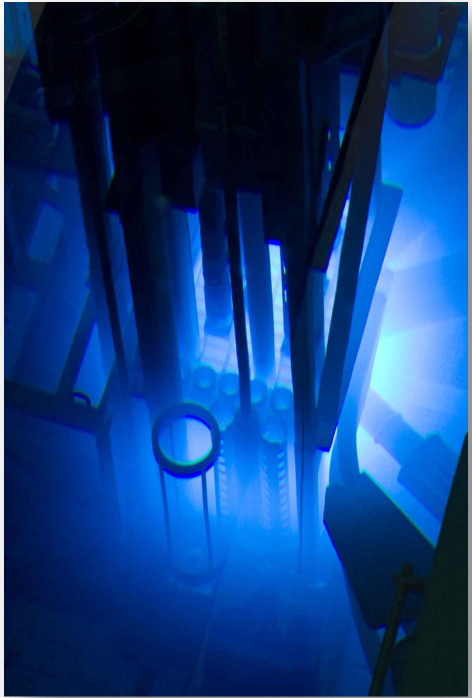
Presentation Outline

- Introduction
- MNR Overview
- The OSCAR-5 System
- Model Development
- Performance
- Future Applications
- Concluding Remarks

Introduction



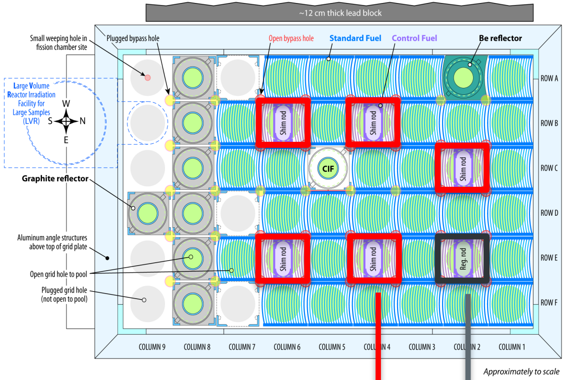
- The McMaster Nuclear Reactor (MNR)

  Part of Nuclear Operations & Facilities at McMaster University
  - Medium-power open-pool MTR-type reactor
  - Canada's biggest neutron source
  - Licensed to 5 MW thermal power
  - Growing user base / planned operation expansions

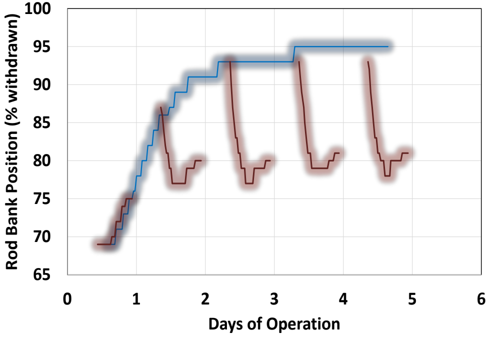
- Project to enhance analysis toolset and in-house analysis capabilities

  Objectives: (Fuel Management)
  - Provide additional analysis support
  - Improve integration with analysis toolset

MNR Overview



Typical MNR Core Configuration

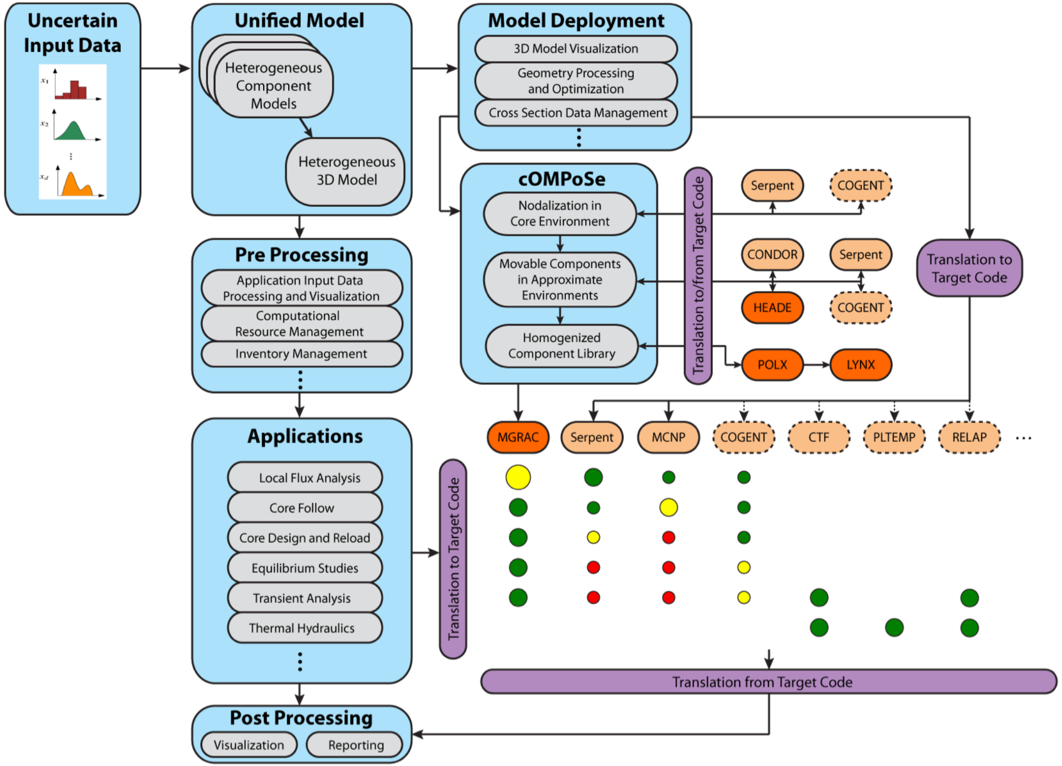


Low worth regulating rod

- **Fuel Management**
  - Refuel on burnup basis
  - No fixed refuelling pattern
  - Simple model
    - measurement-based system using calculational factors
  - Average assembly burnup
    - input into reload planning
- **Pre-project analysis scope**
  - Enveloping approach
  - Operating limits & licensing
  - Cycle specific (Validation)
  - Outsource thermal-hydraulics

OSCAR-5 REACTOR ANALYSIS PLATFORM

https://sites.google.com/view/oscar5



- RAPYDS component
- Plug-in interface
- Code within OSCAR5
- External Code

- Unified Model (single, code-independent)
- Python driver system (RAPYDS)
- Nodal Model (cOMPoSe)
- Error Tracking (deterministic model)
- Right tool for the job (fit for purpose)
- Reporting & Model Management

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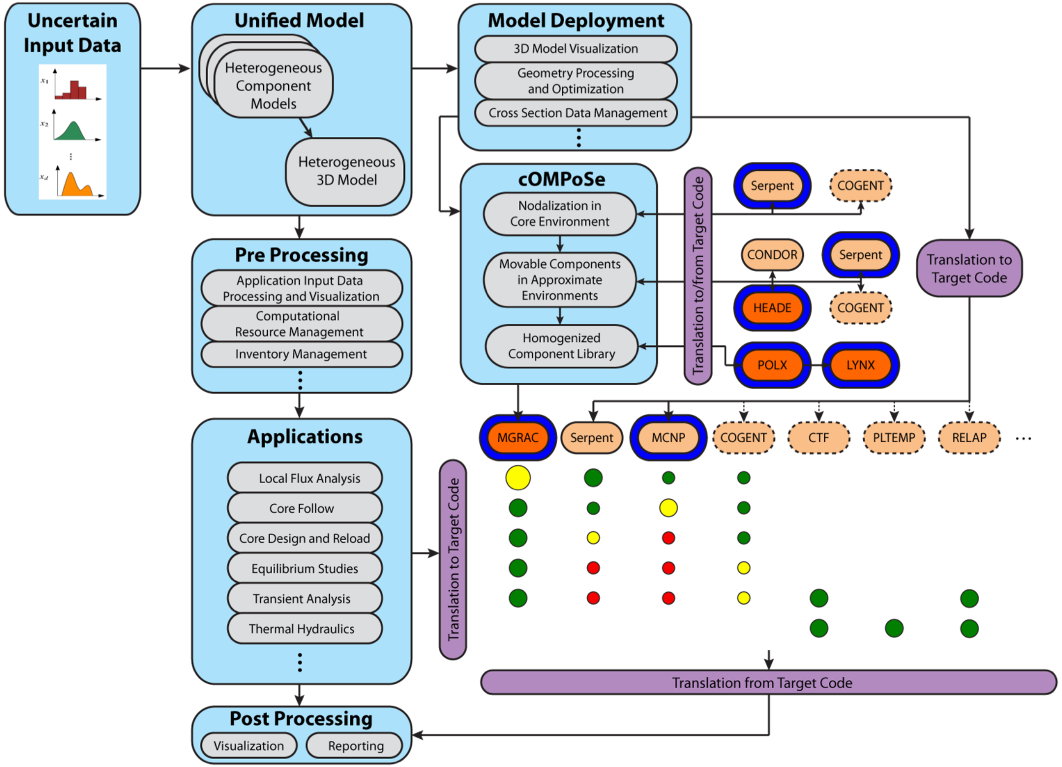
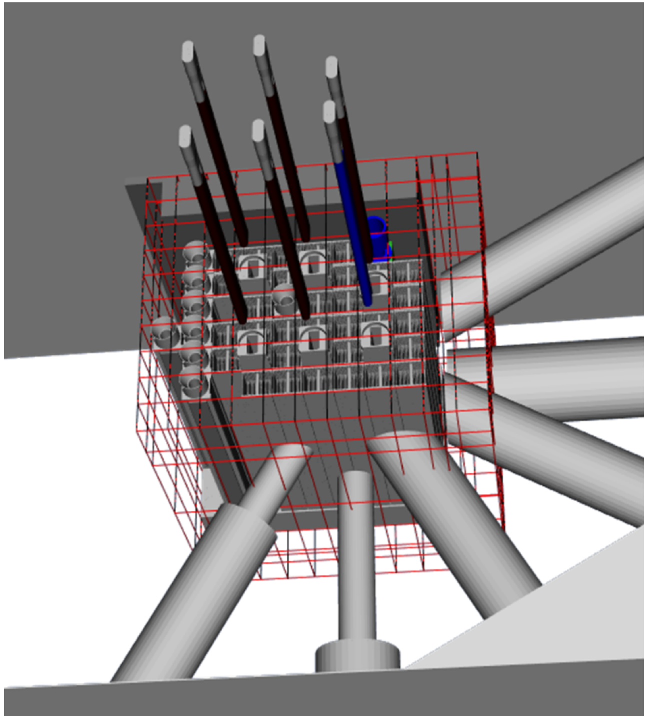


Codes used in this study

- MGRAC
  - Nodal diffusion code
  - Multi-group Analytic Nodal Method
  - Use of general equivalence theory
  - Performs depletion (microscopic model)
  - Support codes: HEADE, POLX, LINX
- SERPENT
  - Monte Carlo criticality and burnup code
  - cell-level and full-core calculations for determining group constants
  - standalone simulation
- MCNP
  - general purpose Monte Carlo code
  - advanced tally features
  - Preferred tool for local flux estimates

Model Development - Model Build



OSCAR-5 model of MNR (including homogeneous meshing structure)

- Specification (unified space)
  - Constructive Solid Geometry
- Heterogeneous Model
  - Directly deployable to MC codes, Serpent, MCNP
- Homogeneous Model (cOMPoSe sub-system)
  - Deployable to 3D nodal diffusion solver, MGRAC
  - Six-group (6)
  - Homogenization grid on scale of node per assembly
  - Six-layer (6) axial nodal mesh (2 active layers)
  - Eight-zone (8) axial burnup mesh
  - Albedo boundary conditions
  - Homogenization models
  - Full-core 2D slice for non-loadable components, Serpent
  - 3 x 3 mini-core for control fuel, Serpent
  - Infinite lattice for standard fuel, HEADE

Model Development - Nodal Model Evaluation

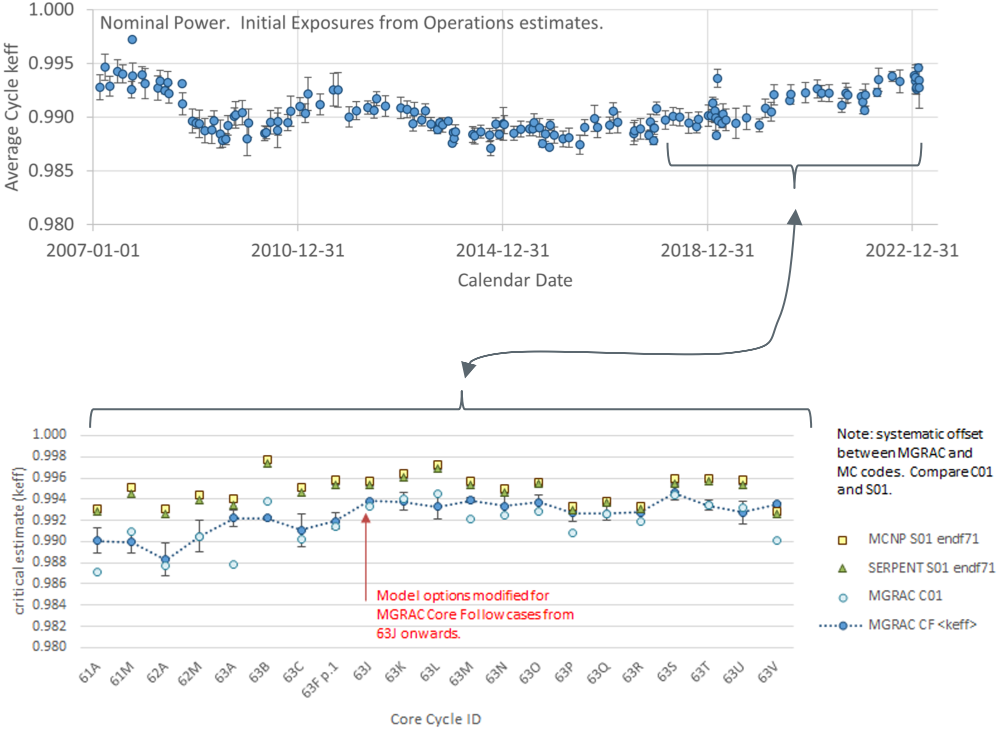
OSCAR-5 error checking metrics for the MNR nodal model build

Model Description	k-eff/ Δk-eff (Error)	Maximum Assembly Power Error (%)
2D Slice (Top Cut)		
Serpent ARO	1.22110	-
MGRAC ARO – Equivalence	8 pcm	0.48 (1F)
MGRAC ARO – SFA Replacement	605 pcm	1.94 (7C)
MGRAC ARO – CFA Replacement	-82 pcm	0.90 (2E)
MGRAC ARO – All FA Replacements	516 pcm	1.94 (7C)
2D Slice (Bottom Cut)		
Serpent ARO	1.21908	-
MGRAC ARO – Equivalence	44 pcm	0.76 (1C)
MGRAC ARO – SFA Replacement	658 pcm	1.86 (7E)
MGRAC ARO – CFA Replacement	-54 pcm	1.04 (2E)
MGRAC ARO – All FA Replacements	560 pcm	2.03 (2E)
3D Tests		
Serpent ARO	1.13369	-
MGRAC ARO	-374 pcm	2.86 (2E)
Serpent ARI	1.03066	-
MGRAC ARI	-258 pcm	2.38 (2C)
Serpent 3D – Rods at Mid-Core	1.08090	-
MGRAC 3D – Rods at Mid-Core	-245 pcm	2.28 (2C)

ARO = All rods out; ARI = All rods in
SFA/CFA/FA = Standard/Control/Fuel Assembly

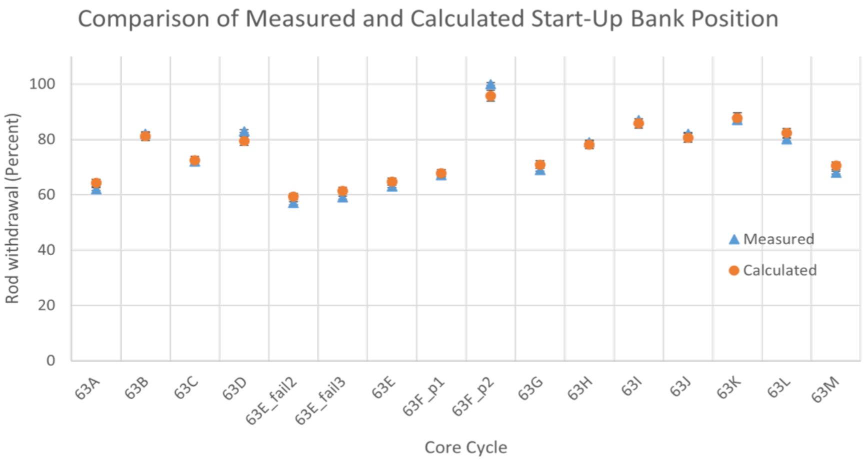
- **Procedure** (during nodal model build)
  - Convergence of 2D cut model
  - Discontinuity factor checks
  - Equivalence of nodal cut model
  - Replacement effect of using loadable models
  - 3D test of stacking of 2D cuts
- **MNR model performance**
  - Insight into areas for model improvement
  - -250 to -375 pcm offset expected on core model
  - Maximum nodal power error is < 3%
  - 3D tests on fresh core translate to burnt core

Model Performance – Core Follow



- MGRAC (nodal model)
- Multi-Cycle 2007-2023
  - 16 years / 195 reloads / 160 cycles
  - Core turnover 6-7 years
- Average Critical Estimate
  - 0.99047 ± 0.00197
- Assessment
  - Offset: reasonable
  - Behaviour: Stable
  - Some offset expected from nodal model build (error monitoring)
  - Remaining offset is common to MC code deployment

Model Performance - Reload



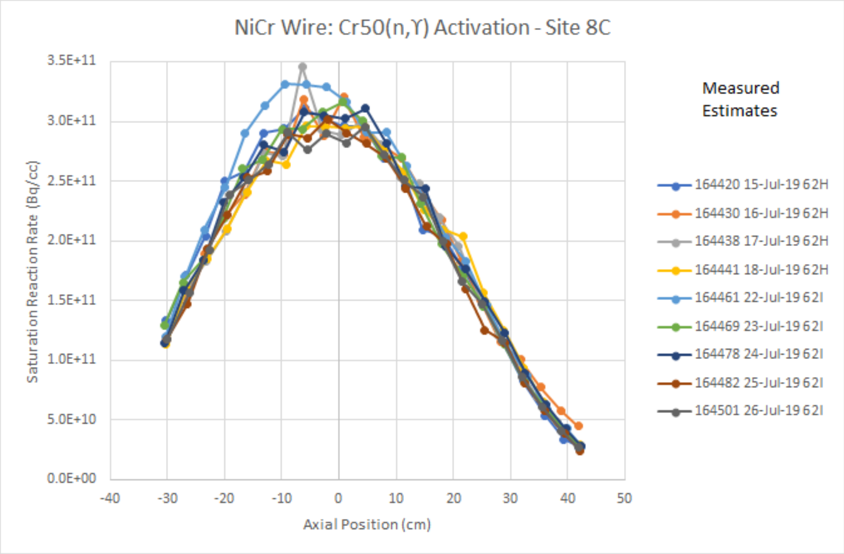
- Start-up bank estimates:
  - Target k-eff from multi-cycle Core Follow
  - Good agreement over the range of typical start-up bank positions

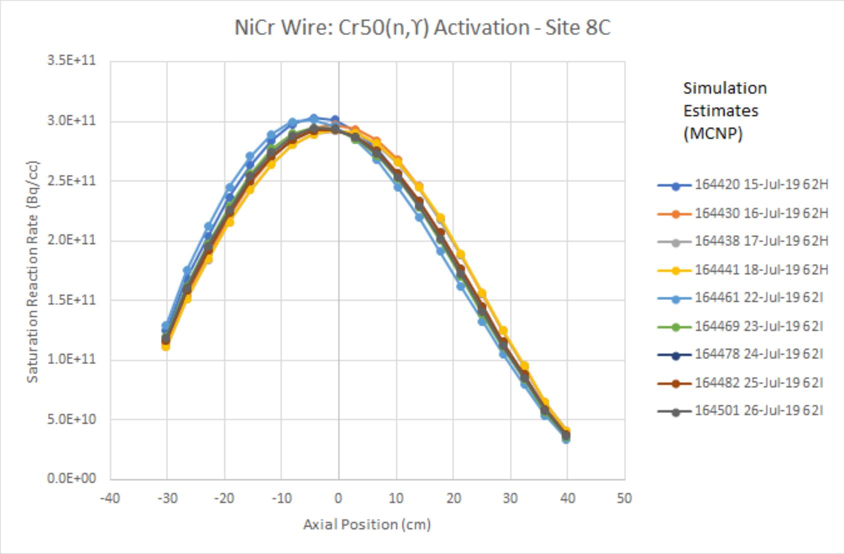
- MNR Reload Calculations:
  - Performed with MGRAC (nodal model)
  - Automation becomes useful due to complicated combination of calculations

Example of MNR Reload Calculation Parameters (design)

Parameter	Candidate 1	Candidate 2	Candidate 3
BOC Core U-235 Mass	5730 gram	5795 gram	5912 gram
Reload Worth	-25 pcm	187 pcm	938 pcm
SU Bank (Extracted)	77.9%	76.4%	69.1%
Xenon Worth	724 pcm	822 pcm	953 pcm
Excess Reactivity	1573 pcm	1772 pcm	2480 pcm
Excess Reactivity (Xe Free)	2297 pcm	2595 pcm	3433 pcm
Shim Test	-1889 pcm	-1720 pcm	-996 pcm
Shim Test (Xe Free)	-1165 pcm	-897 pcm	-0.43 pcm
Shim Bank Worth	10055 pcm	10076 pcm	9997 pcm
Regulating Rod Worth	302 pcm	313 pcm	306 pcm
Max Plate Power (SFA)	12.85 kW	13.95 kW	13.73 kW
Max Plate Power (CFA)	7.30 kW	7.33 kW	7.34 kW

Model Performance – Flux Wire Comparisons





- Measurement (2019 flux wire campaign)
  - Multi-site / multi-cycle
  - NiCr wire activation
- MNR OSCAR-5 Model (MCNP deployment)
  - Thermal reaction Cr50(n,g), good agreement
  - (not shown) Fast reaction Ni58(n,p), ± 15-20%

Future Development & Application

- With functional maturity on core follow and reload the MNR OSCAR-5 model now provides a foundation for other applications and expansions

- Areas of interest for model improvement & application include:
  1. Investigation of critical estimate offset
  2. Improvement in nodal model via refined fuel models
  3. Application: support for expansion of MNR operations
  4. Application: addition of multi-physics to core follow and reload applications using thermal-hydraulic codes: OTHA, PLTEMP
  5. Application: safety margin assessment using OSCAR-5 sampler mode for uncertainty propagation & coupled physics/TH analysis
  6. Application: core optimization via associated OSCAR-5 mode
  7. Application: modelling of safety cases via RELAP and MGRAC spatial kinetics

Concluding Remarks

- Objective & Vision:
  - enhance level of calculation support at MNR
  - create an integrated, expandable, and flexible analysis toolset
- Development Platform: OSCAR-5 calculation system
  - provides a state-of-the-art workflow framework for Research Reactor analysis
  - Key Aspects:
    - Construction of unified, code-independent reactor model
    - Deployment to a variety of codes, including MC and nodal solvers
    - Error monitoring during and following development of homogenized nodal model
    - Integrated model management and documentation system
- Outcomes & Benefits:
  - Successful model development (Core Follow, Reload applications)
  - Good quantification of model performance
  - Foundation for further enhancements, model application, collaboration platform
  - Involvement in IAEA CRP (Coupled Analysis & Treatment of Uncertainties)

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