Application of the next generation of the OSCAR code system to the ETRR-2 multi-cycle depletion benchmark

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Introduction

- IAEA CRP T12029 focuses on benchmarking computational tools against experimental data on fuel burnup and material activation for utilization, operation and safety analysis of reseach reactors (from 2015 - 2018).
- Verification and validation of computational reactor physics codes.
- General overview of the OSCAR code system.
- Next generation high-fidelity scheme/tools implemented in the OSCAR code system.
- The scheme is applied to the ETRR-2 multi-cycle depletion benchmark (which is part of the CRP).

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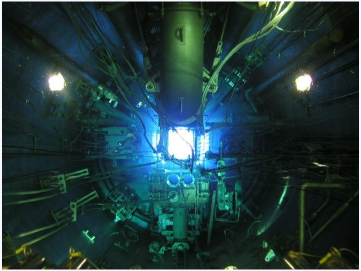
Facility Overview: ETRR-2 Research Reactor in Egypt

- Open pool type.
- Nominal power: 22 MW.
- Max. thermal neutron flux (10^{14}).
- Fuelled with low-enriched (19.7 %) U_3O_8 fuel elements.
- Cooled and moderated with light water.
- Reflected by beryllium elements.
- 6 control blades.



http://tc.iaea.org/tcweb/regionalsites/africa/features/gallery/galleryitem/default.asp?galleryid=554

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Experimental Description

- Control rod calibration experiments:
  - Start-up cores with critical bank positions.
  - Core SU-29-2SO was chosen as a basic core configuration (Rod 5 calibration against rods 3 & 6).
  - Experimental data was taken from a previous IAEA CRP 1496.
- Fuel burnup experiments:
  - First four operating cycles were considered for multi-cycle depletion analysis.
  - The discharge burnup of three fuel elements were measured using gamma spectroscopy.
  - Experimental data made available in the current IAEA CRP T12029.

Experimental Description

TABLE. First Four Operating Cycles

Cycle Name	Full Power Days	Downtime (Years)
Cycle 1	7.30	2.6
Cycle 2	16.00	0.9
Cycle 3	13.75	2.8
Cycle 4	13.64	

TABLE. Measured Fuel Elements

Name	Initial ^{235}U Mass (g)	Number of Cycles in Core
FE022	148.22	1
FE014	148.22	2
FE020	209.02	4

Experimental Description

Benchmark specifications are unclear on how the measured burnup was calculated and therefore the following assumptions were made:

- Measured burnup is an average for the entire assembly, and
- Burnup percentage is defined as:

$$\text{Burnup } \% = \frac{\text{Total number of fissioned atoms}}{\text{Initial fissile atoms}} \times 100 \quad (1)$$

with the number of fissioned atoms estimated using,

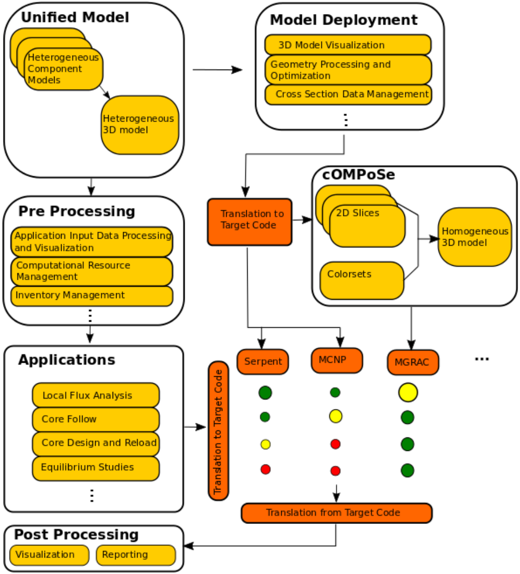
$$\text{Total number of fissioned atoms} \approx \sum_{c=1}^{T} \frac{N_{c,1} - N_{c,0}}{\gamma}, \quad (2)$$

with T the total number of cycles the target assembly has in the core, $N_{c,0}, N_{c,1}$ the number of ^{137}Cs atoms at the beginning and end of cycle c respectively, and γ the yield of ^{137}Cs per fission.

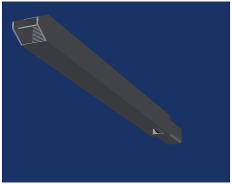
Codes Description

- Serpent (Monte Carlo):
  - Modified v2.1.23.
  - Modifications include some basic operational support functionalities- control bank movements during irradiation sequence, critical bank searches etc.
  - ENDF/B-VII.0 based cross section libraries.
- HEADE (2D lattice code):
  - Collision probablity method.
  - WIMS-E libraries based on JEFF2.2 evaluation.
  - code used to prepare fuel cross sections for the core diffusion solver.
- MGRAC (3D Nodal Diffusion Solver):
  - Multi-Group Analytic Nodal Method.
  - Homogenized cross sections prepared by Serpent and HEADE.
  - Microscopic depletion model.

Calculational Approach: The OSCAR-5 Code System



Model Description: ETRR-2 Assembly Library



(a) Fuel Assembly

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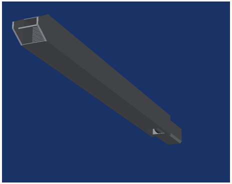

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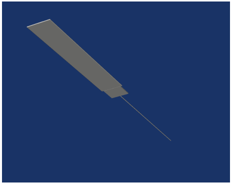

(b) Control Blade

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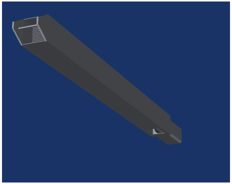

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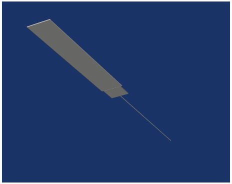

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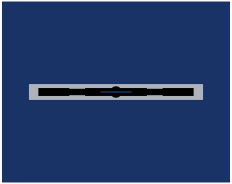

(c) Control Guide

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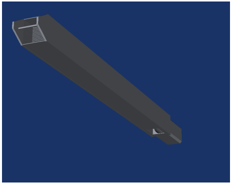

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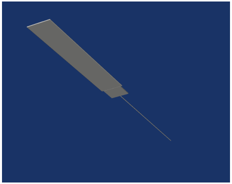

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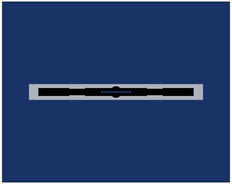

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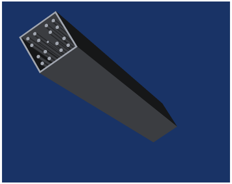

(d) Cobalt Irradiation Facility

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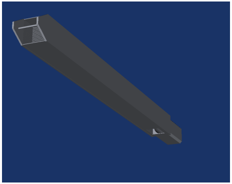

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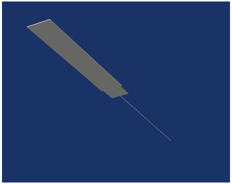

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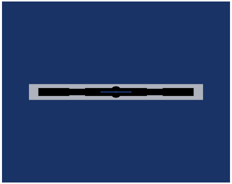

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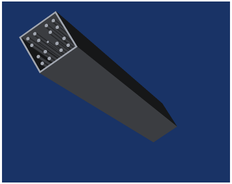

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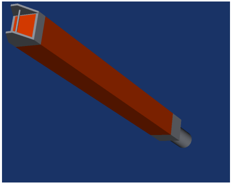
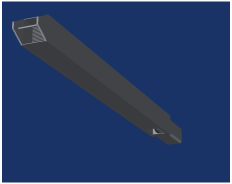


(e) Beryllium Element

Model Description: ETRR-2 Assembly Library



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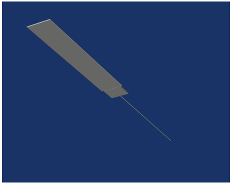

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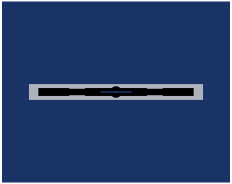

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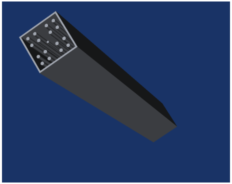

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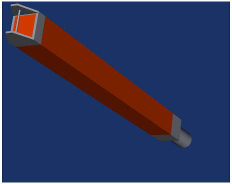
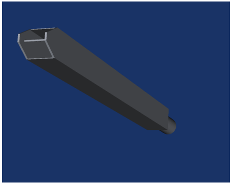


(e) Beryllium Element



(f) Irradiation Box

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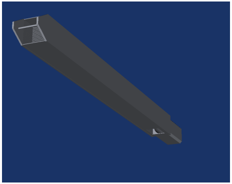
Model Description: ETRR-2 Assembly Library



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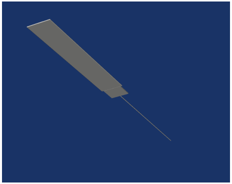

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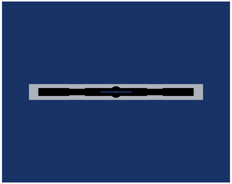

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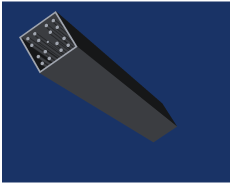

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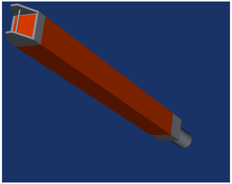

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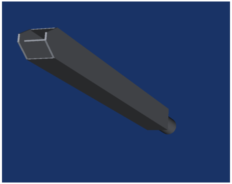

(f) Irradiation Box

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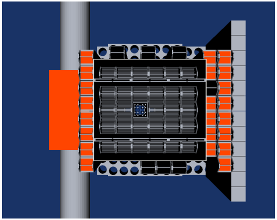
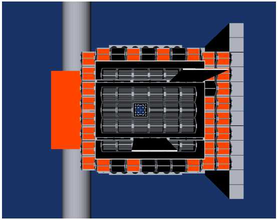
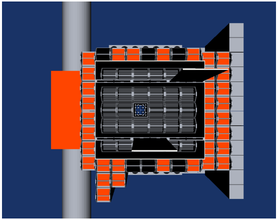
Model Description: Core Configurations



(a) Core SU-29-2SO

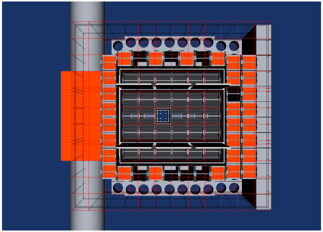


(b) Cycle 1

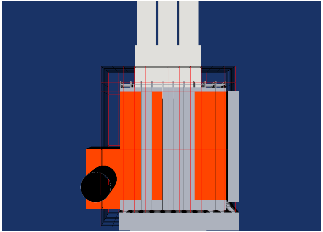


(c) Cycle 2,3 and 4

Model Description: Overlay Nodal Mesh for MGRAC



(a) Radial View



(b) Axial View

- Radial meshes were chosen in such a way that the main core pitch is preserved.
- Axially divided into six regions/cuts (two active cuts, two bottom and top reflector cuts).
- Nodal parameters (node average cross sections and leakages) were generated on each node in the mesh using Serpent and HEADE for fuel cross sections.

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Model Testing: 3D Errors Induced in the Model

TABLE. 3D ERROR ESTIMATION OF MGRAC MODEL

	Reference k_{eff}	MGRAC Offset (pcm)	Max Power Error
All Rods Out	1.07865	-700	4.20 %
All Rods 50 % Extracted	1.00662	57	4.00 %
All Rods In	0.91106	-647	3.85 %

- Maximum assembly power error is in the order of 4 %.
- Axial leakages are not preserved in the 3D model.
- From the results, an offset of about 600 pcm was deduced between Serpent and MGRAC model.

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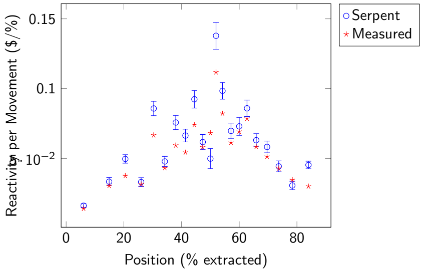
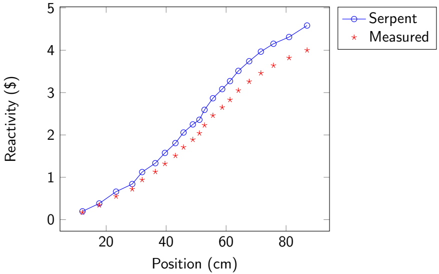
Control Rod Calibration Results



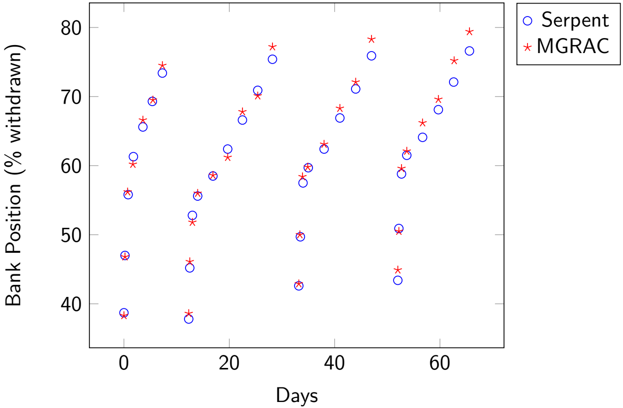
Rod 5 Differential Worth Curve



Rod 5 Integral Worth Curve

- Our model slightly over-estimates the measured values in most cases.
- Serpent results also seemed to be overly sensitive to reactivity changes (towards the core center).
- Deviation between our model and the measured values is also clearly seen from the integral rod worth curve.

Cycle Simulation: Critical Bank Positions During Irradiation Period



Fuel Burnup Results

TABLE. BURNUP OF THE THREE SPENT FUEL ELEMENTS

Name	Measured Burnup %	Burnup (%)	
		Serpent	MGRAC
FE022	3.26	3.71	3.82
FE014	10.07	11.77	11.98
FE020	20.92	20.11	20.52

- Both models are reasonably in good agreement with the measured burnup % derived from the experimental measurements.
- MGRAC slightly predicted higher burnup for the three selected assemblies.

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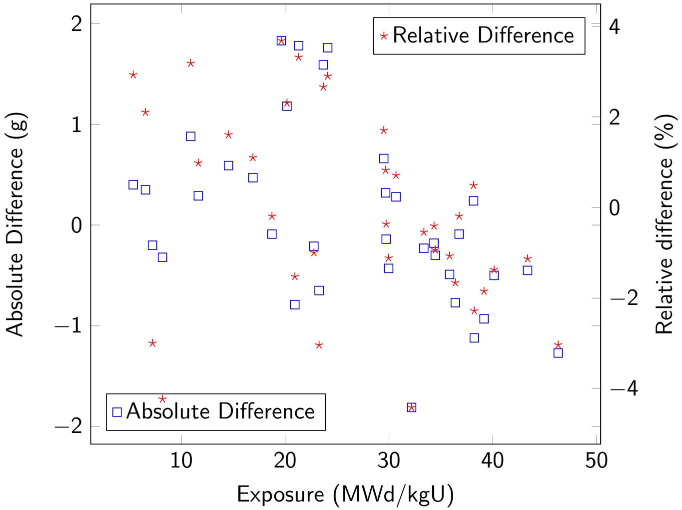
Difference in Discharge ^{235}U Mass between Serpent and MGRAC



Concluding Remarks and Recommendations

- This work forms part of our contribution to a current IAEA CRP T12029 which focuses on benchmarking computational tools against experimental data on fuel burnup and material activation for research reactors.
- CRP was considered to be a good candidate to test the applicability of the high-fidelity scheme in modelling research reactors.
- A detailed heterogeneous code-independent model was created for the ETRR-2 research reactor.
- Analysis was performed on rod calibration experiments as well as depletion of the first four operational cycles with Serpent and MGRAC.
- The overall performance of the models was reasonably good, showing good agreement with experimental reactivity and burnup measurements.
- For future work, models are to be refined, especially for fuel cross section generation as well as modelling additional rod calibration experiments.

Thank You

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