Overview of ORIGEN-ARP and its Application to VVER and RBMK

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Outline

- **Overview of ORIGEN-ARP**
- **Description of VVER and RBMK libraries**
- **Validation studies**
- **Summary**

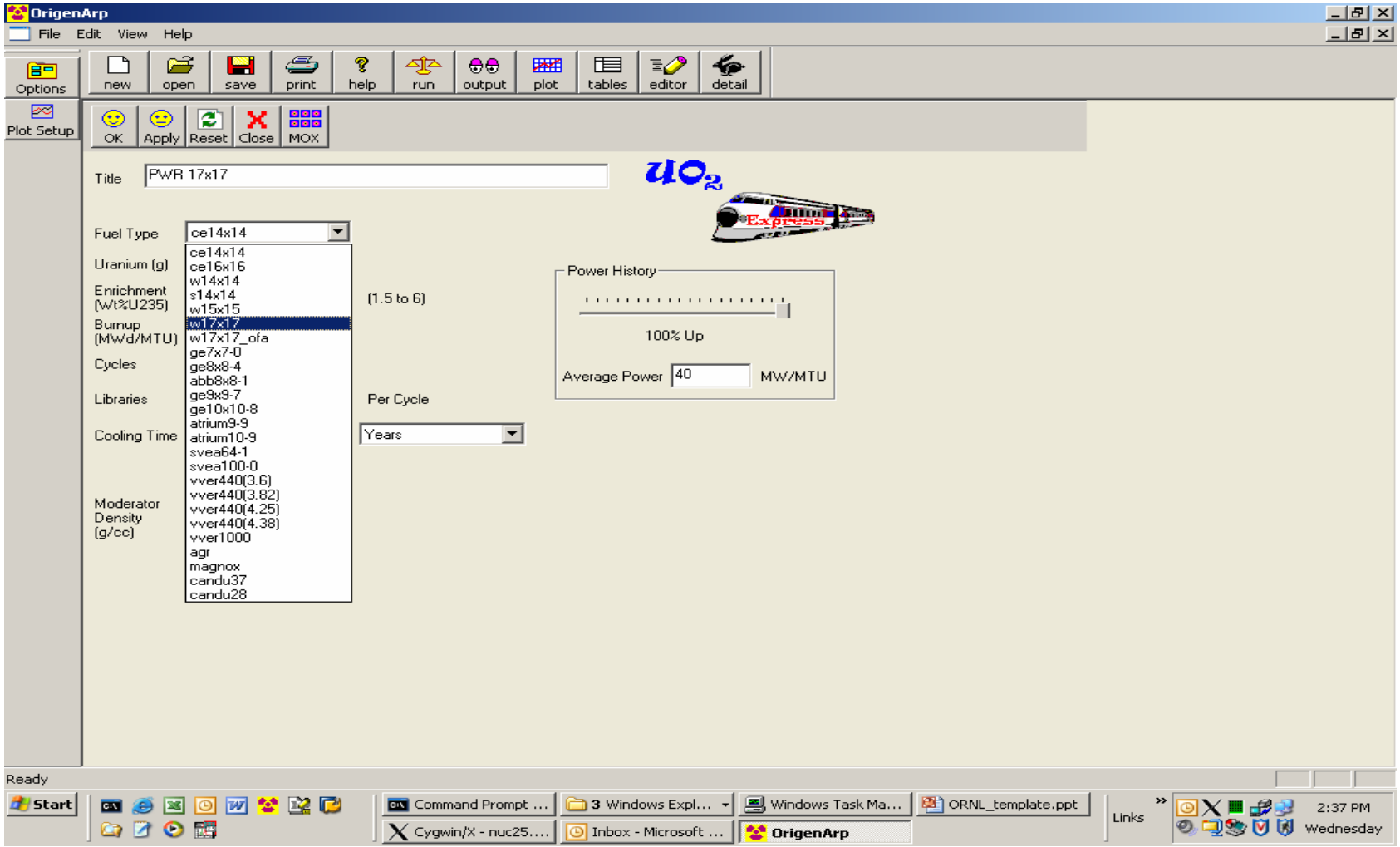
Overview of ORIGEN-ARP

- **Allows easy setup of ORIGEN-S depletion and decay cases**
- **Interactive Windows program with built-in help files**
- **Windows interface generates SCALE input file for execution on PC or workstation**
- **Executes code sequence within SCALE on PC**
- **Runs very fast – in a few seconds**
- **Used for analysis of fuel samples in this study**

Overview of ORIGEN-ARP (cont)

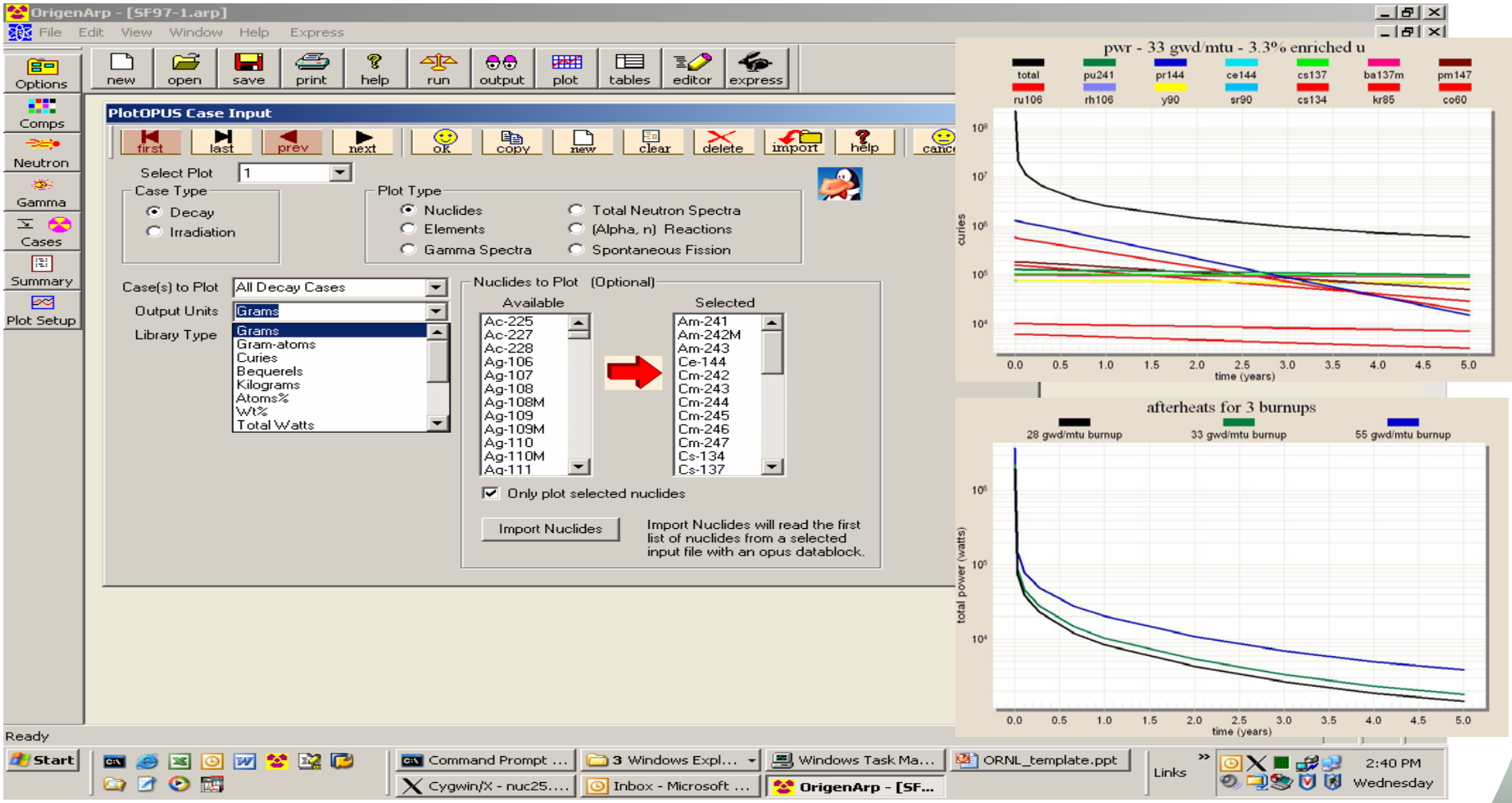
- **Structure - three main components**
  - **ARP code**
    - **interpolate on a set of pre-generated burnup-dependent cross sections to obtain cross sections for use with ORIGEN-S**
    - **for uranium-based fuel, interpolation parameters are: burnup, fuel enrichment, coolant density**
  - **ORIGEN-S code**
    - **perform isotopic depletion and decay simulations**
  - **OPUS/PlotOPUS codes**
    - **extract and plot the calculated results**

Overview of ORIGEN-ARP (cont)



ORIGEN-ARP graphical interface – Express option

Overview of ORIGEN-ARP (cont)



ORIGEN-ARP graphical interface – Plot menu

Overview of ORIGEN-ARP (cont)

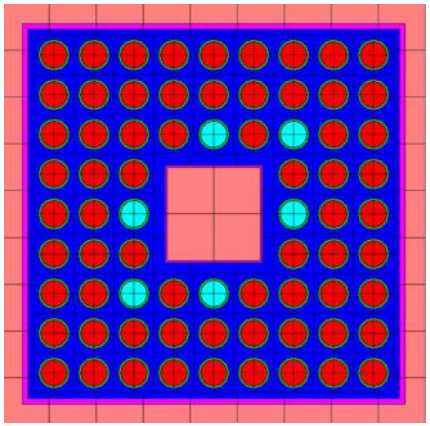
LWR libraries for ORIGEN-ARP in SCALE 5.1

- **PWR**
  - **14x14: Westinghouse, Westinghouse CE, Siemens**
  - **15x15: Westinghouse**
  - **16x16: Westinghouse CE**
  - **17x17: Westinghouse, Westinghouse OFA**
- **BWR**
  - **7x7: GE**
  - **8x8: GE, ABB, SVEA-64**
  - **9x9: GE, ATRIUM-9**
  - **10x10:GE, ATRIUM-10, SVEA-100**
- **VVER**

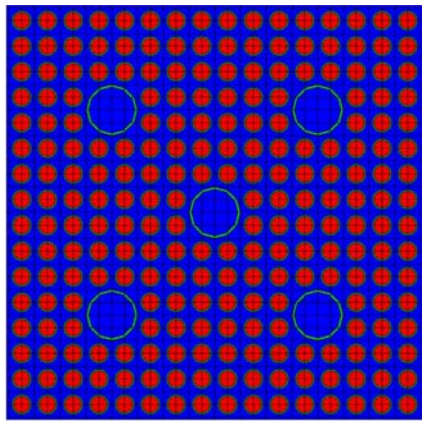
  VVER440

  VVER1000

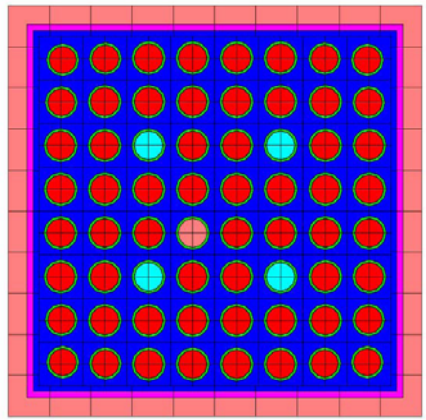
Overview of ORIGEN-ARP (cont)



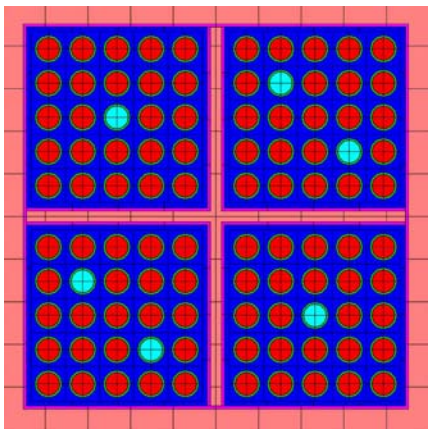
ATRIUM-9



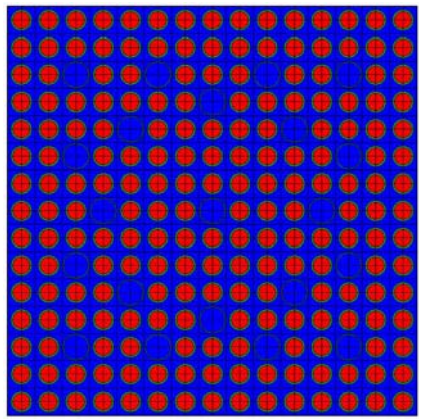
CE 14x14



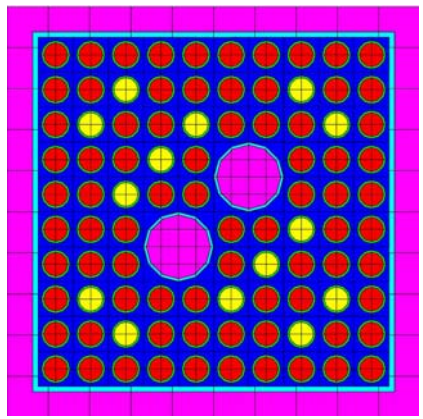
GE 8x8



SVEA-100



W 17x17



GE 10x10

Cross section library generation methods (TRITON)

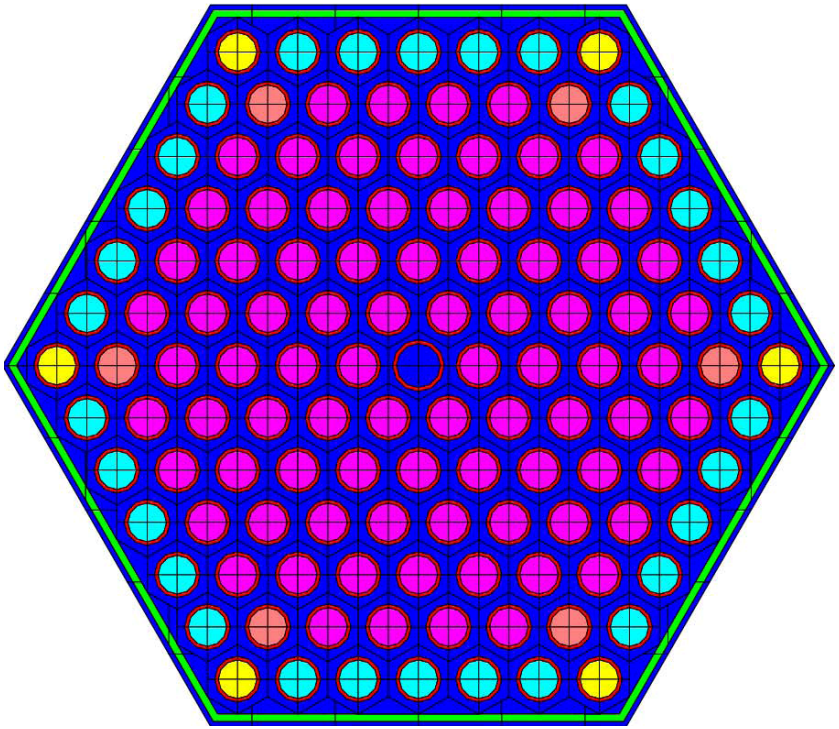
- **TRITON couples the 2-D arbitrary polygonal mesh transport code NEWT with the point depletion and decay code ORIGEN-S**
- **Additional 3-D depletion capabilities using KENO V.a and KENO VI Monte Carlo codes available in SCALE 5.1**
- **TRITON/NEWT sequence**
  - **generates burnup-dependent cross sectionsperforms pin-by-pin depletion of different materials**
  - **generates few-group cross-section data (including discontinuity factors) for use in subsequent nodal diffusion calculations**

Description of VVER libraries

Assembly design	Name of library	Enrichment profile	Enrichment (wt % ^{235}U)
VVER-440	vver440(3.6)	flat	1.6, 2.4, 3.6
VVER-440	vver440(3.82)	zoned	average 3.82
VVER-440	vver440(4.25)	zoned	average 4.25
VVER-440	vver440(4.38)	zoned	average 4.38
VVER-1000	vver1000	flat	1.5, 2.0, 3.0, 4.0, 5.0, 6.0

Burnup range: 0 – 70 GWd/MTU

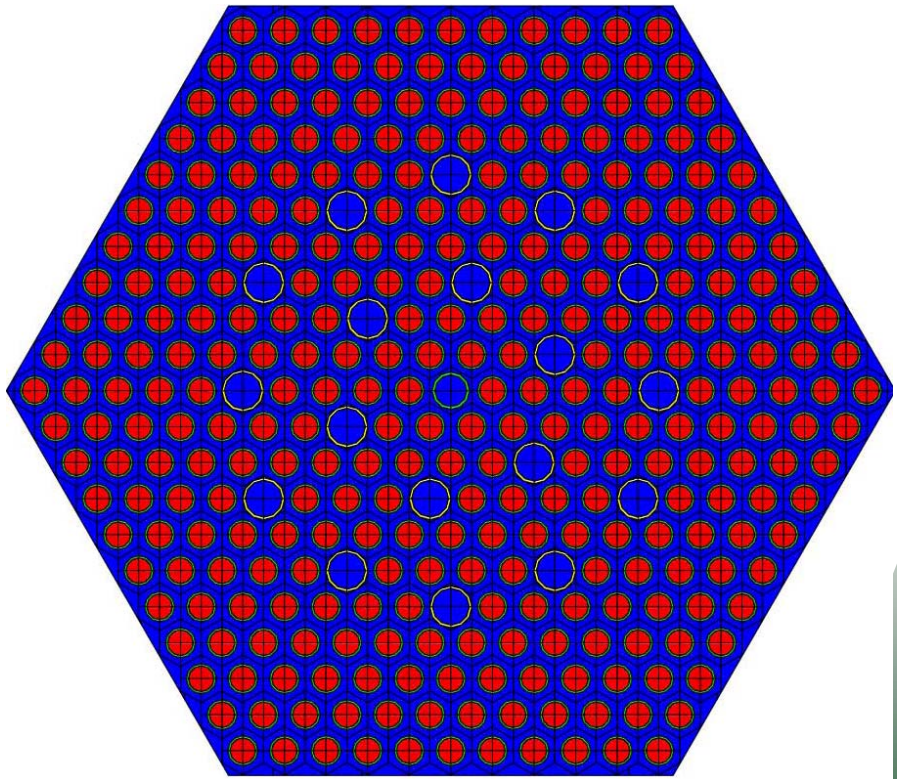
2-D TRITON models for VVER assemblies



VVER-440

(zoned enrichment)

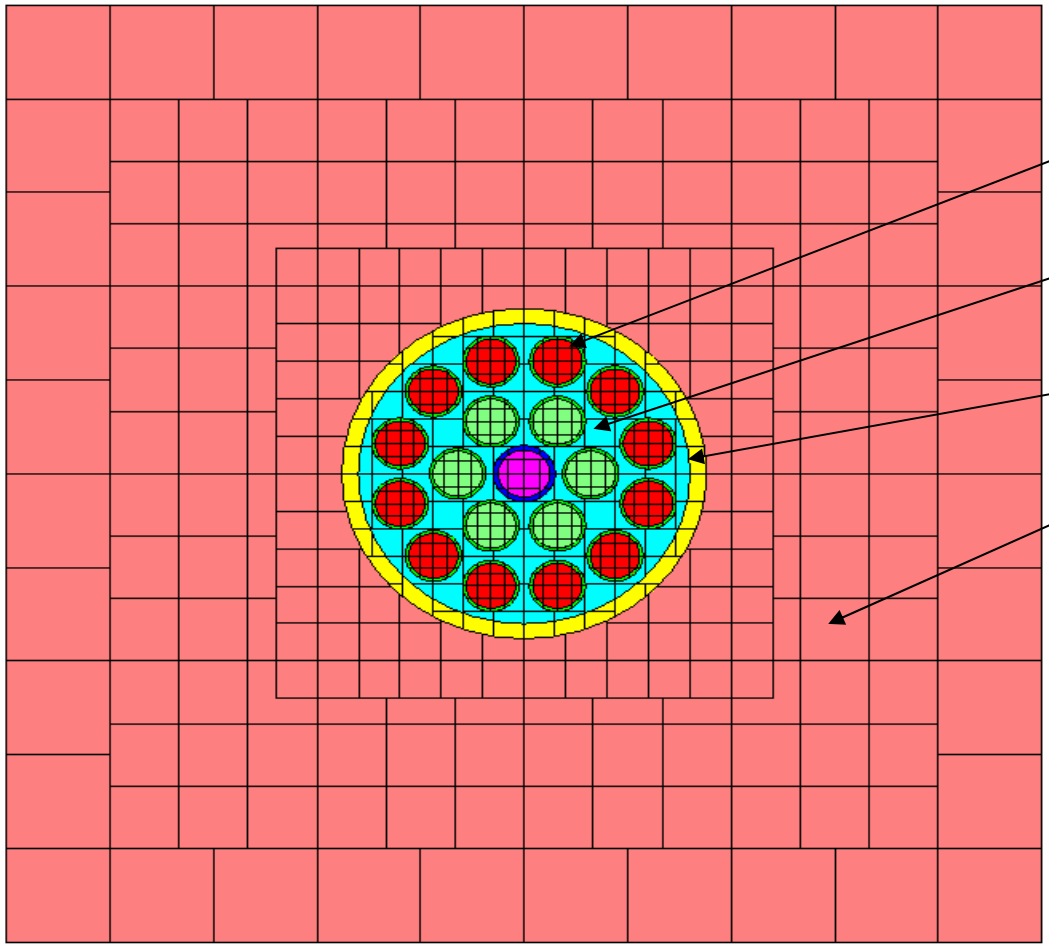
VVER-1000



Description of RBMK libraries

- **Libraries were generated based on design data representative of the Chernobyl Unit 4 reactor**
- **Work performed in support of an IAEA project**
- **Libraries were prepared for variable parameters:**
  - **enrichment: 1.8 to 2.2 wt % ^{235}U**
  - **coolant density: 0.15 to 0.80 g/cm^3**
  - **burnup: 0 to 25 GWd/MTU**
- **Libraries not included in SCALE 5.1 release**

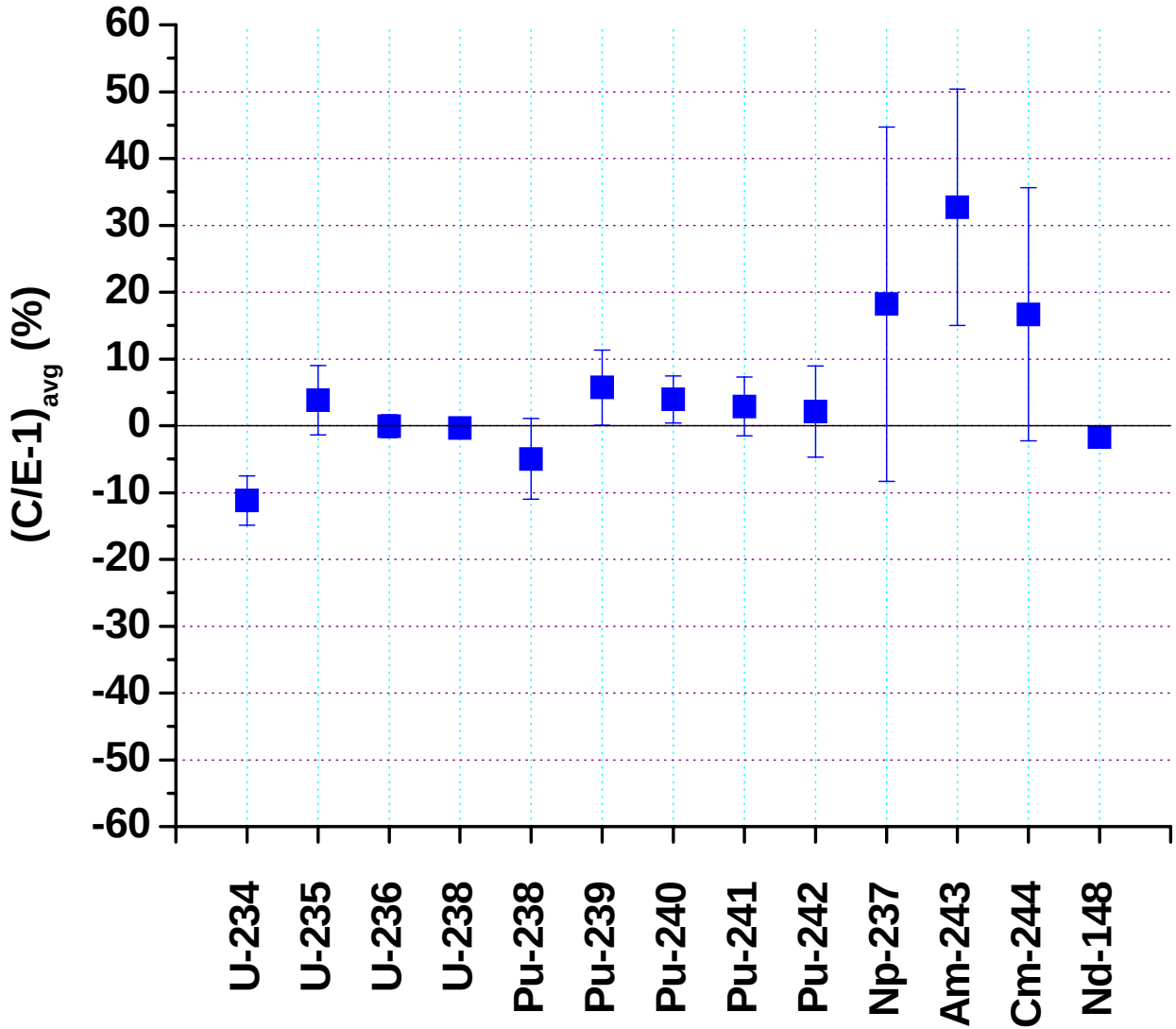
2-D TRITON model for RBMK assembly



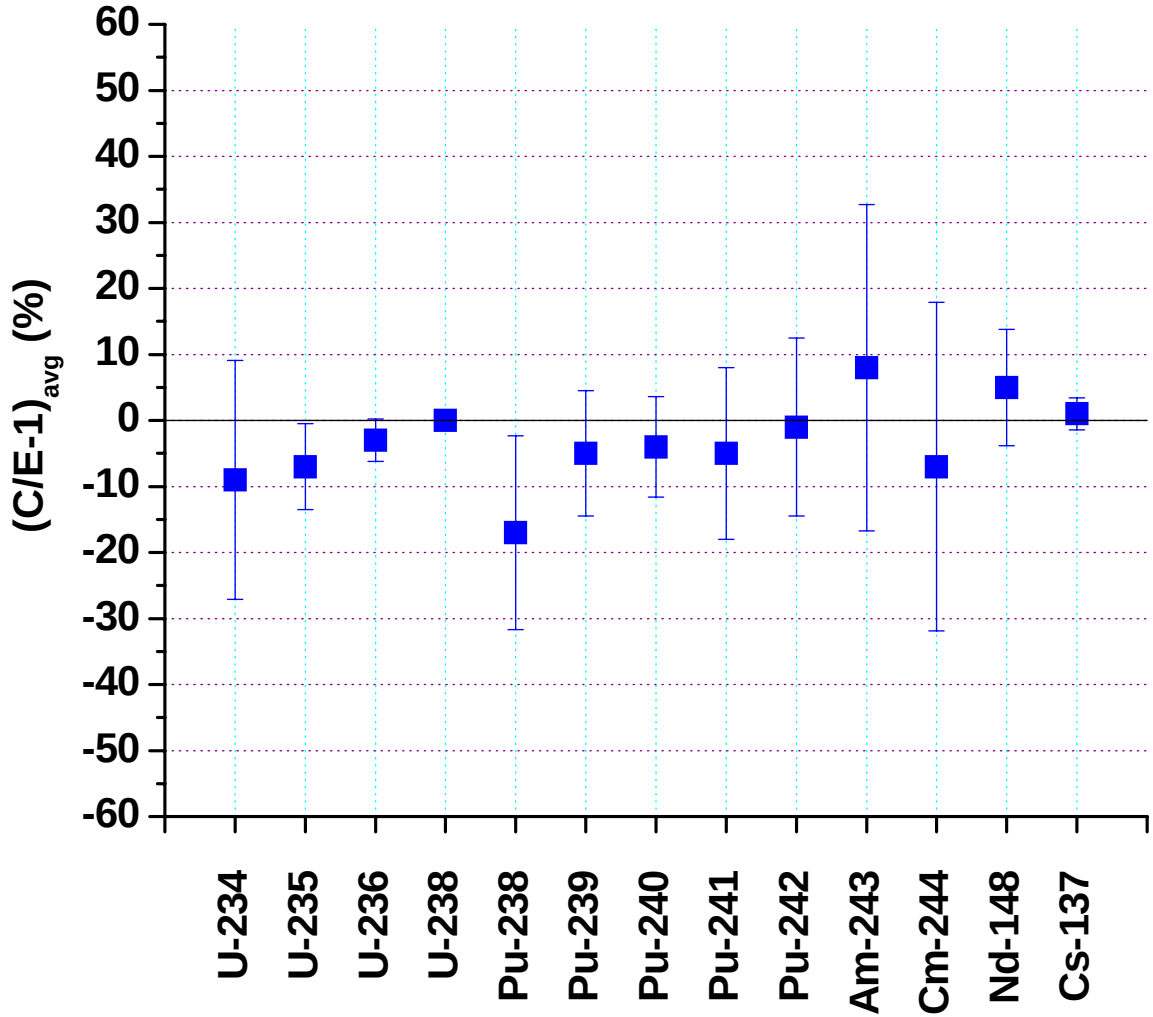
Validation studies – VVER libraries

- **Performed by comparison to isotopic assay experimental data from experiments performed at the Khlopin Radium Institute in Russia**
- **VVER-440 fuel**
  - **20 samples**
  - **enrichment : 3.6 wt % ^{235}U**
  - **burnup: 20 – 43 GWd/MTU**
  - **cooling time: 3 – 4 years**
- **VVER-1000 fuel**
  - **13 samples**
  - **enrichment : 4.4 wt % ^{235}U**
  - **burnup: 14 – 52 GWd/MTU**
  - **cooling time: 7 – 10 years**

Validation studies – VVER-440
(average of 20 samples)



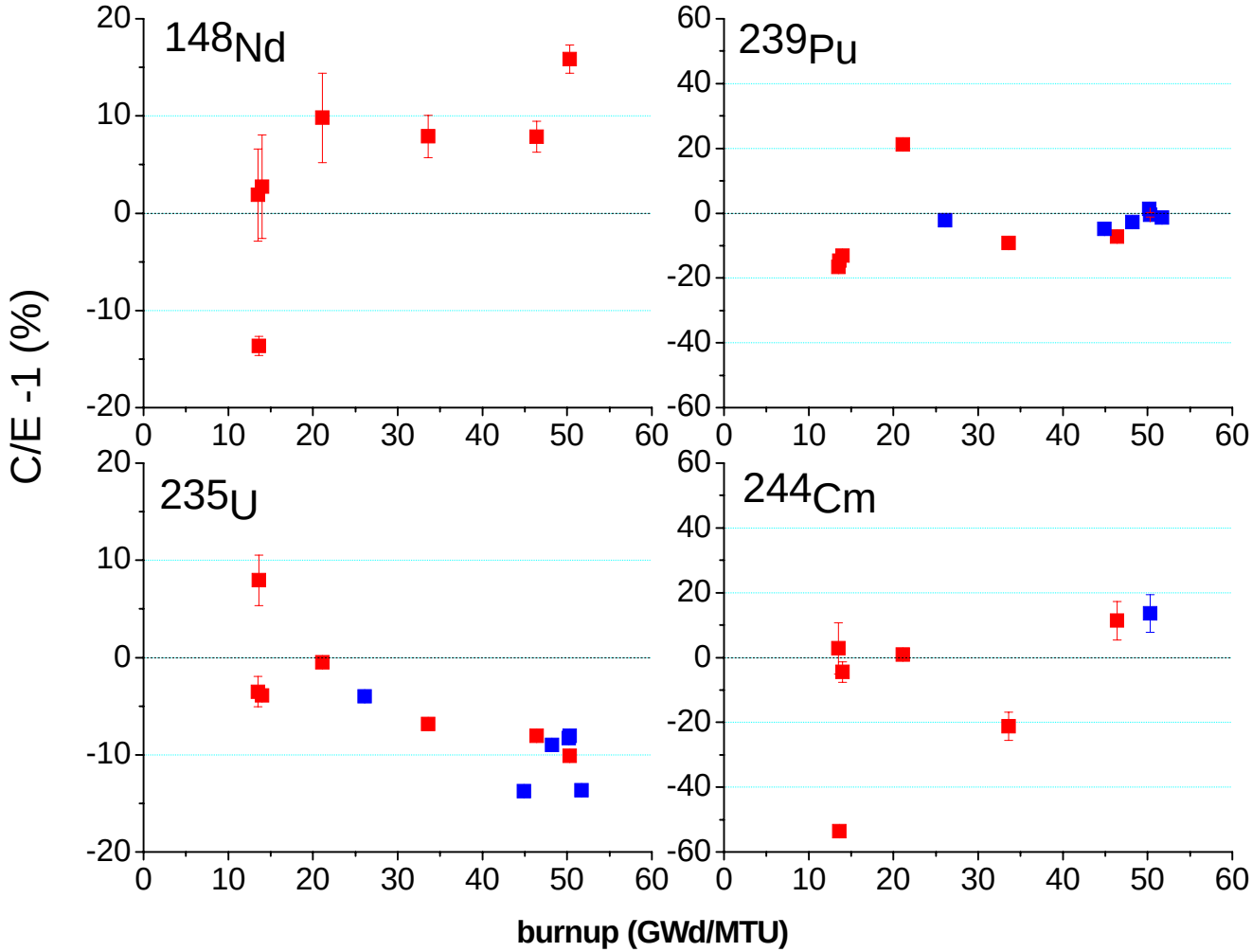
Validation studies – VVER-1000
(average of 13 samples)



Validation studies – VVER libraries

- **Validation results show good agreement between measured data and ORIGEN-ARP results**
- **Sources of uncertainty include:**
  - **Uncertainties in irradiation history data**
    - **irradiation details not available**
  - **Uncertainties in burnup**
    - **burnup indicator ^{148}Nd overpredicted 5% on average for VVER-1000 data**
    - **correlated to underprediction of major actinides**
  - **Uncertainties in measured data**
  - **Effect of pin location (peripheral vs. assembly average)**
    - **cross sections derived for average assembly**
    - **effect can be reduced, depending on the accuracy level desired, by generating cross-section libraries for specific fuel rod locations in an assembly**

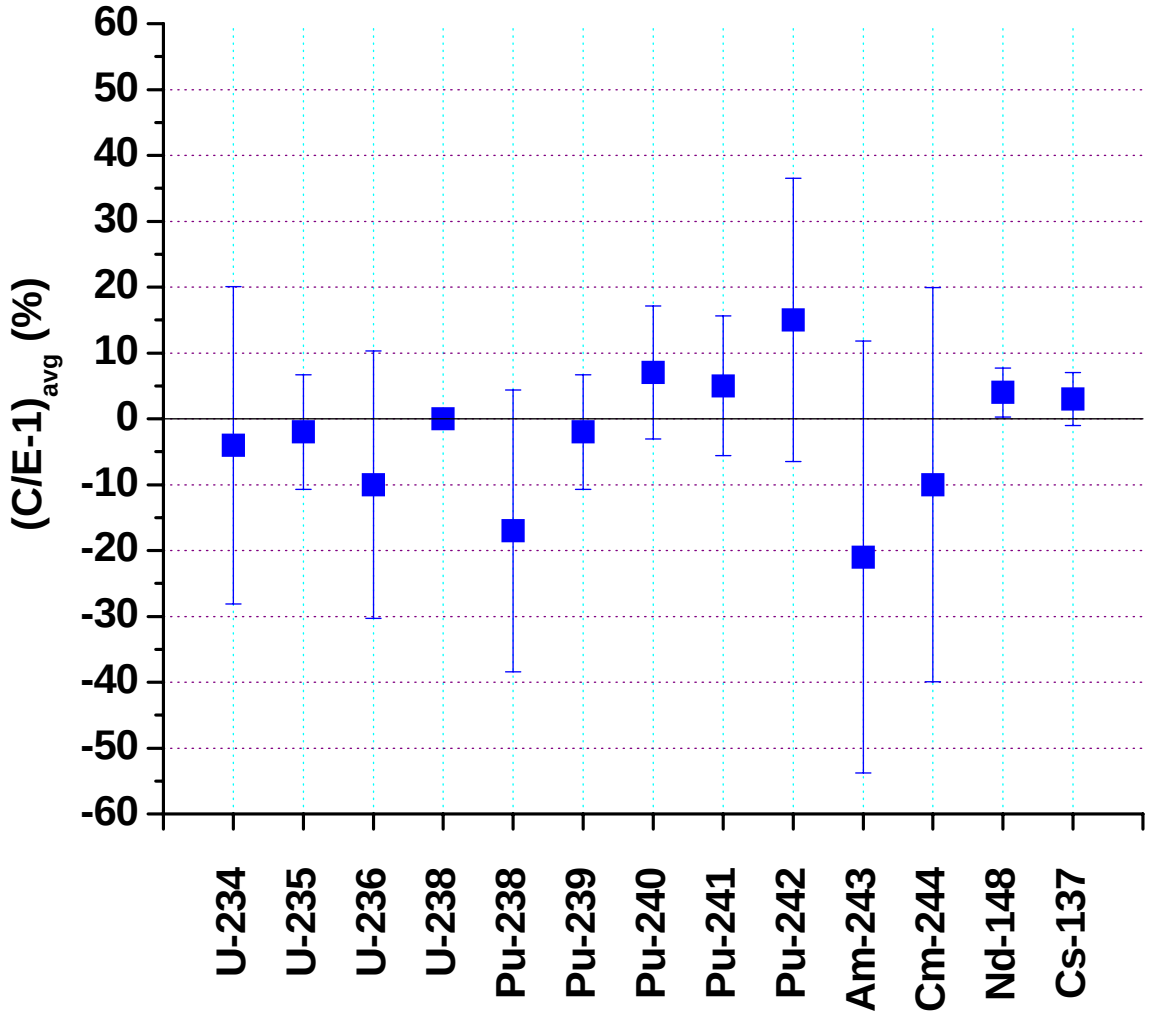
Validation studies – VVER-1000 effect of uncertainty in burnup



Validation studies – RBMK libraries

- **Performed by comparison to isotopic assay experimental data from experiments performed at the Khlopin Radium Institute**
  - **15 samples**
  - **enrichment : 1.80 – 2.09 wt % ^{235}U**
  - **burnup: 6 – 23 GWd/MTU**
  - **coolant densities not available (estimated)**
  - **detailed irradiation history data not available**

Validation studies – RBMK
(average of 15 samples)



Summary

- **VVER and RBMK cross section libraries for ORIGEN-ARP were generated using the depletion module TRITON/NEWT**
- **VVER 440 & 1000 libraries released in SCALE 5.1**
- **Validation of libraries was performed by comparison to measured isotopic assay data for spent fuel**
- **Validation results show good agreement between the measured data and ORIGEN-ARP results**

Thank you for your attention!

Questions?