

# 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**

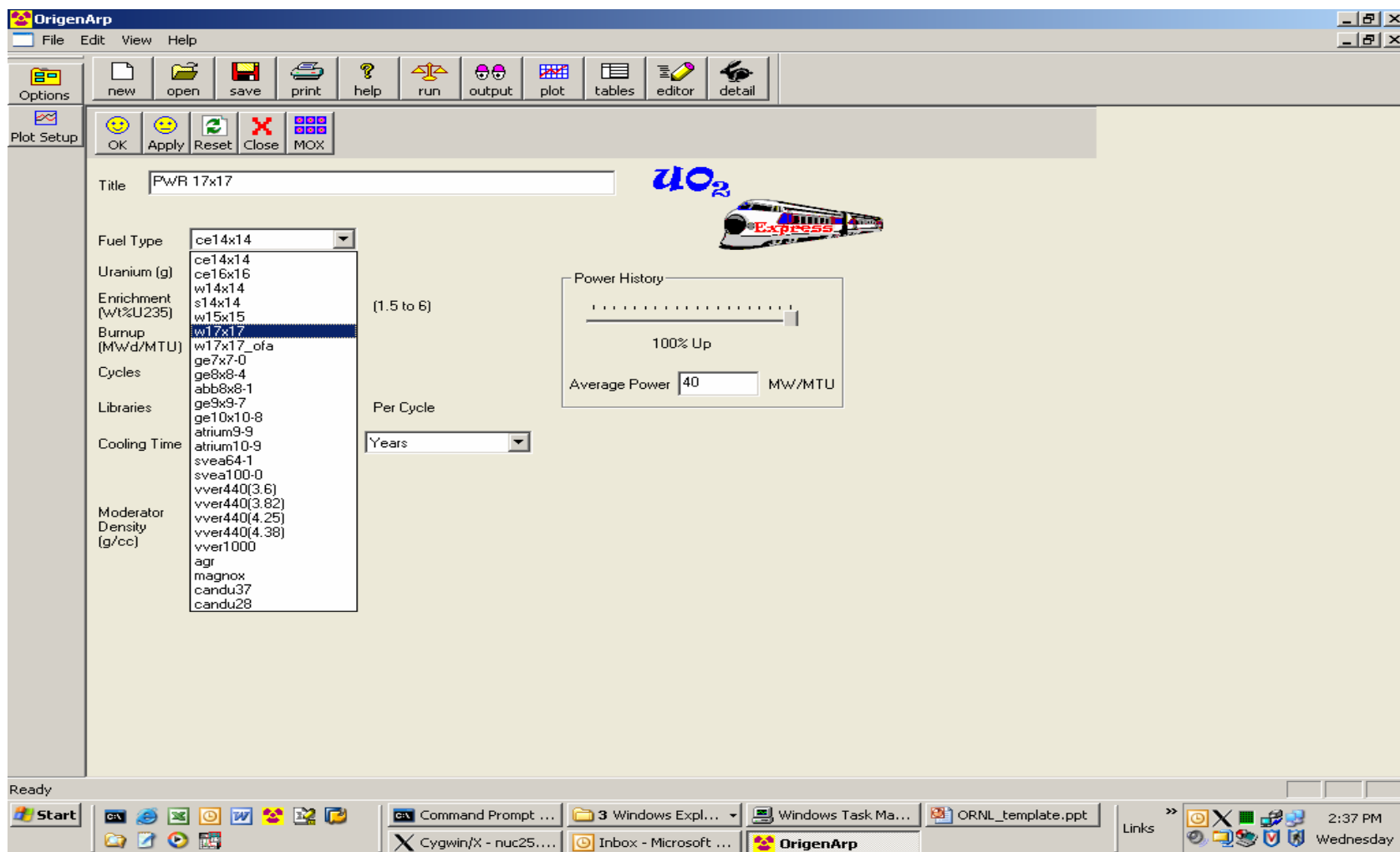
# Overview of ORIGEN-ARP

- **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)

The screenshot displays the ORIGEN-ARP software interface. The main window is titled "OrigenArp - [SF97-1.arp]". The menu bar includes File, Edit, View, Window, Help, and Express. The toolbar contains icons for new, open, save, print, help, run, output, plot, tables, editor, and express. The left sidebar shows navigation options: Options, Comps, Neutron, Gamma, Cases, Summary, and Plot Setup.

The "PlotOPUS Case Input" dialog is open, showing the following settings:

- Select Plot: 1
- Case Type:  Decay,  Irradiation
- Plot Type:  Nuclides,  Total Neutron Spectra,  Elements,  (Alpha, n) Reactions,  Gamma Spectra,  Spontaneous Fission
- Case(s) to Plot: All Decay Cases
- Output Units: Grams
- Library Type: Grams
- Nuclides to Plot (Optional): Available list includes Ac-225, Ac-227, Ac-228, Ag-106, Ag-107, Ag-108, Ag-108M, Ag-109, Ag-109M, Ag-110, Ag-110M, Ag-111. Selected list includes Am-241, Am-242M, Am-243, Ce-144, Cm-242, Cm-243, Cm-244, Cm-245, Cm-246, Cm-247, Cs-134, Cs-137. A red arrow points from the Available list to the Selected list.
- Only plot selected nuclides
- Import Nuclides button: Import Nuclides will read the first list of nuclides from a selected input file with an opus datablock.

Two plots are shown on the right:

- Plot 1:** "pwr - 33 gwd/mtu - 3.3% enriched u". The y-axis is "curies" (log scale, 10<sup>0</sup> to 10<sup>10</sup>) and the x-axis is "time (years)" (0.0 to 5.0). The plot shows the decay of various nuclides over time. A legend at the top lists nuclides: total, pu241, pr144, ce144, cs137, ba137m, pm147, ru106, rh106, y90, sr90, cs134, kr85, co60.
- Plot 2:** "afterheats for 3 burnups". The y-axis is "total power (watts)" (log scale, 10<sup>4</sup> to 10<sup>6</sup>) and the x-axis is "time (years)" (0.0 to 5.0). The plot shows the decay of total power for three different burnup scenarios: 28 gwd/mtu burnup (black line), 33 gwd/mtu burnup (green line), and 55 gwd/mtu burnup (blue line).

The Windows taskbar at the bottom shows the Start button, several open applications (Command Prompt, Windows Explorer, Windows Task Manager, ORNL\_template.ppt, Cygwin/X - nuc25..., Inbox - Microsoft...), and the system tray with the time 2:40 PM on Wednesday.

## 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

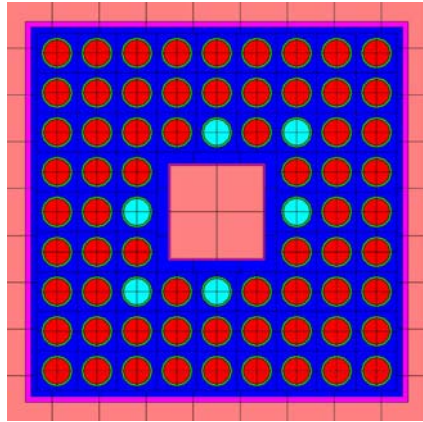
### ■ BWR

- 7x7: GE
- 8x8: GE, ABB, SVEA-64
- 9x9: GE, ATRIUM-9
- 10x10: GE, ATRIUM-10, SVEA-100

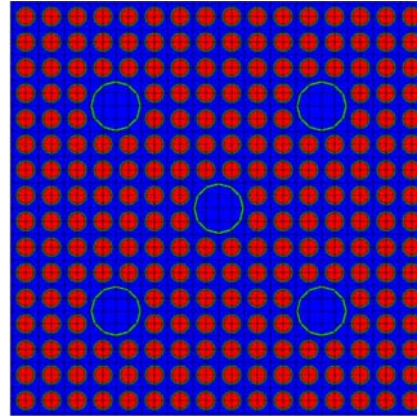
### ■ VVER

VVER440  
VVER1000

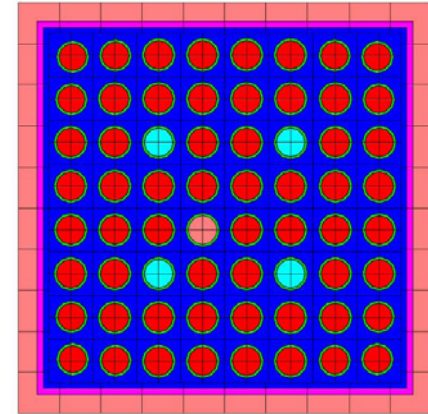
# Overview of ORIGEN-ARP (cont)



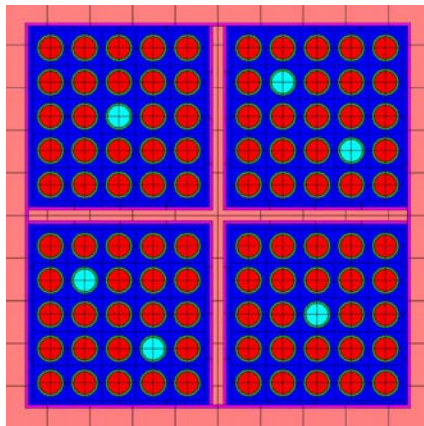
**ATRIUM-9**



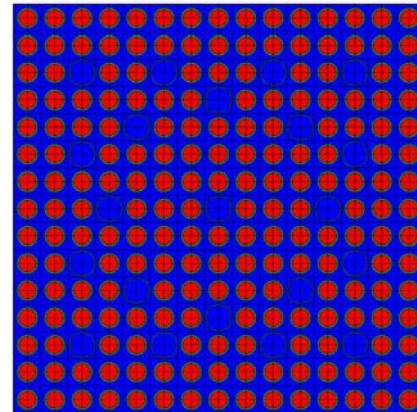
**CE 14x14**



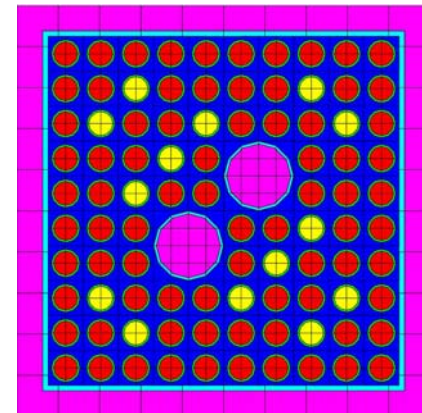
**GE 8x8**



**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**

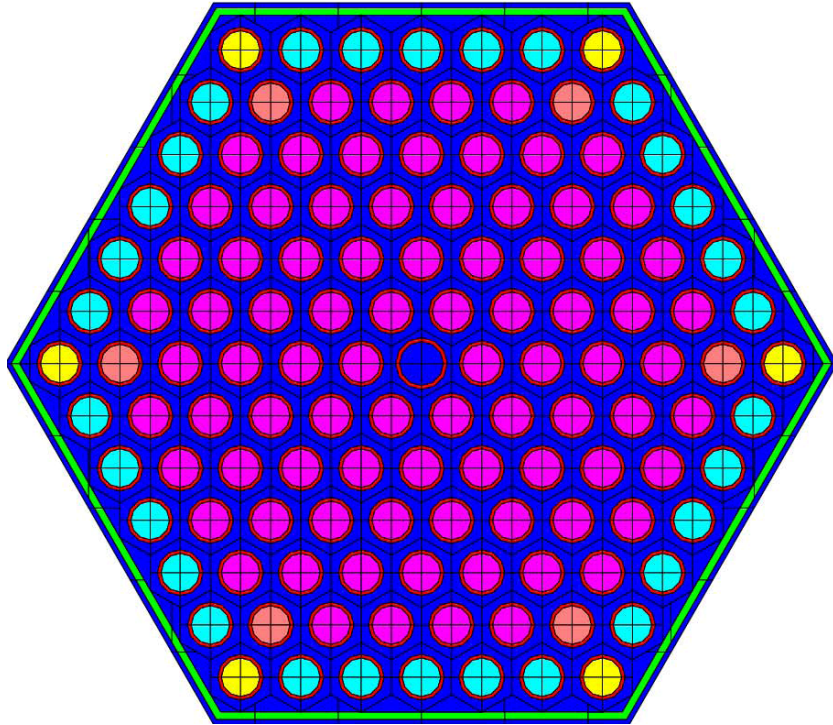


# Description of VVER libraries

<b>Assembly design</b>	<b>Name of library</b>	<b>Enrichment profile</b>	<b>Enrichment (wt % <sup>235</sup>U)</b>
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**

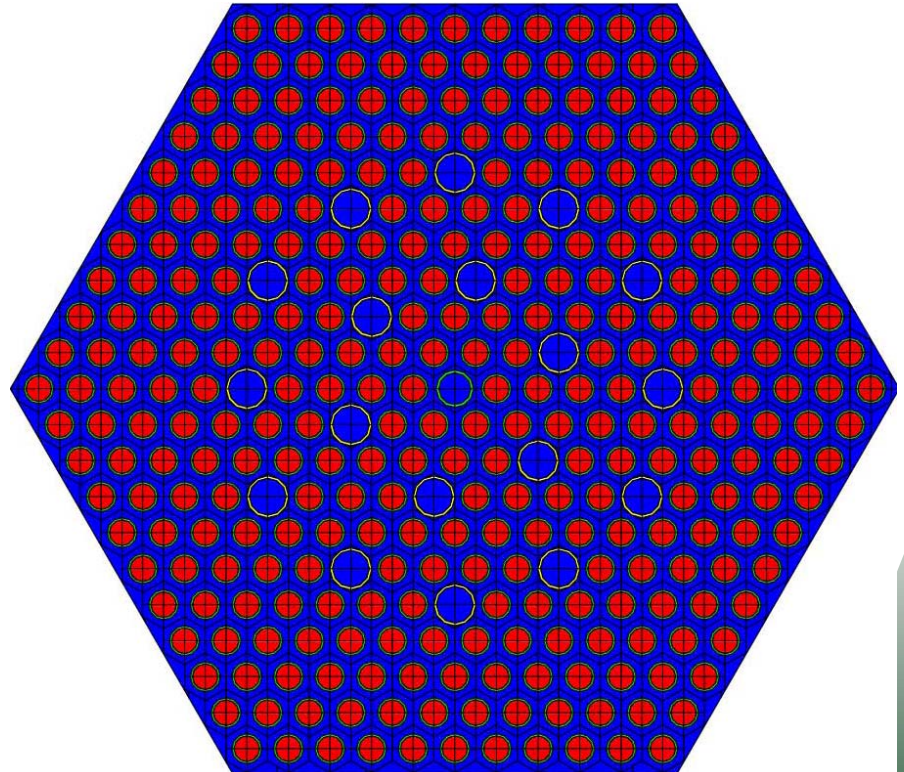
# 2-D TRITON models for VVER assemblies



**VVER-440**

(zoned enrichment)

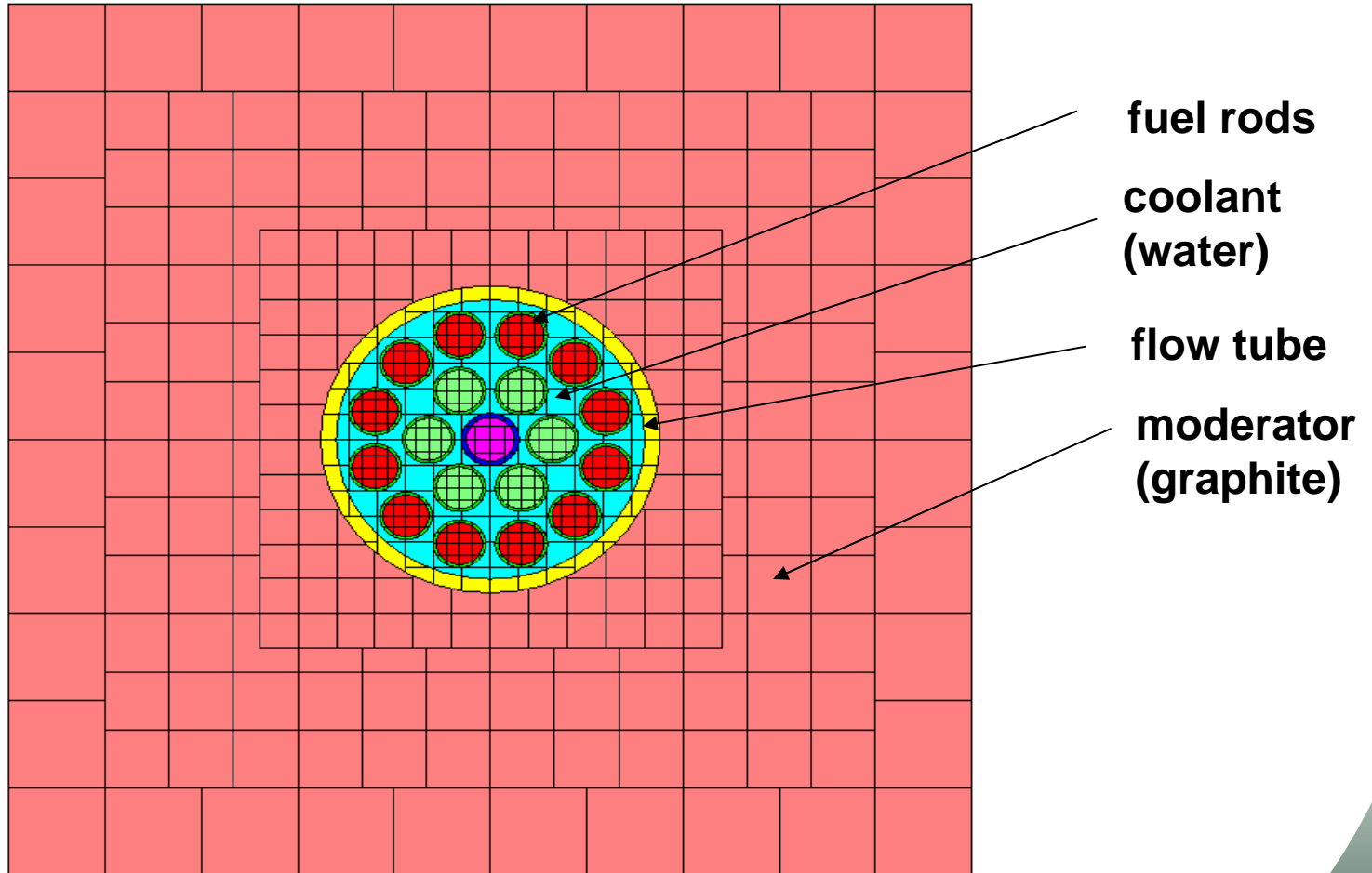
**VVER-1000**



# 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 %  $^{235}\text{U}$**
  - **coolant density: 0.15 to 0.80 g/cm<sup>3</sup>**
  - **burnup: 0 to 25 GWd/MTU**
- **Libraries not included in SCALE 5.1 release**

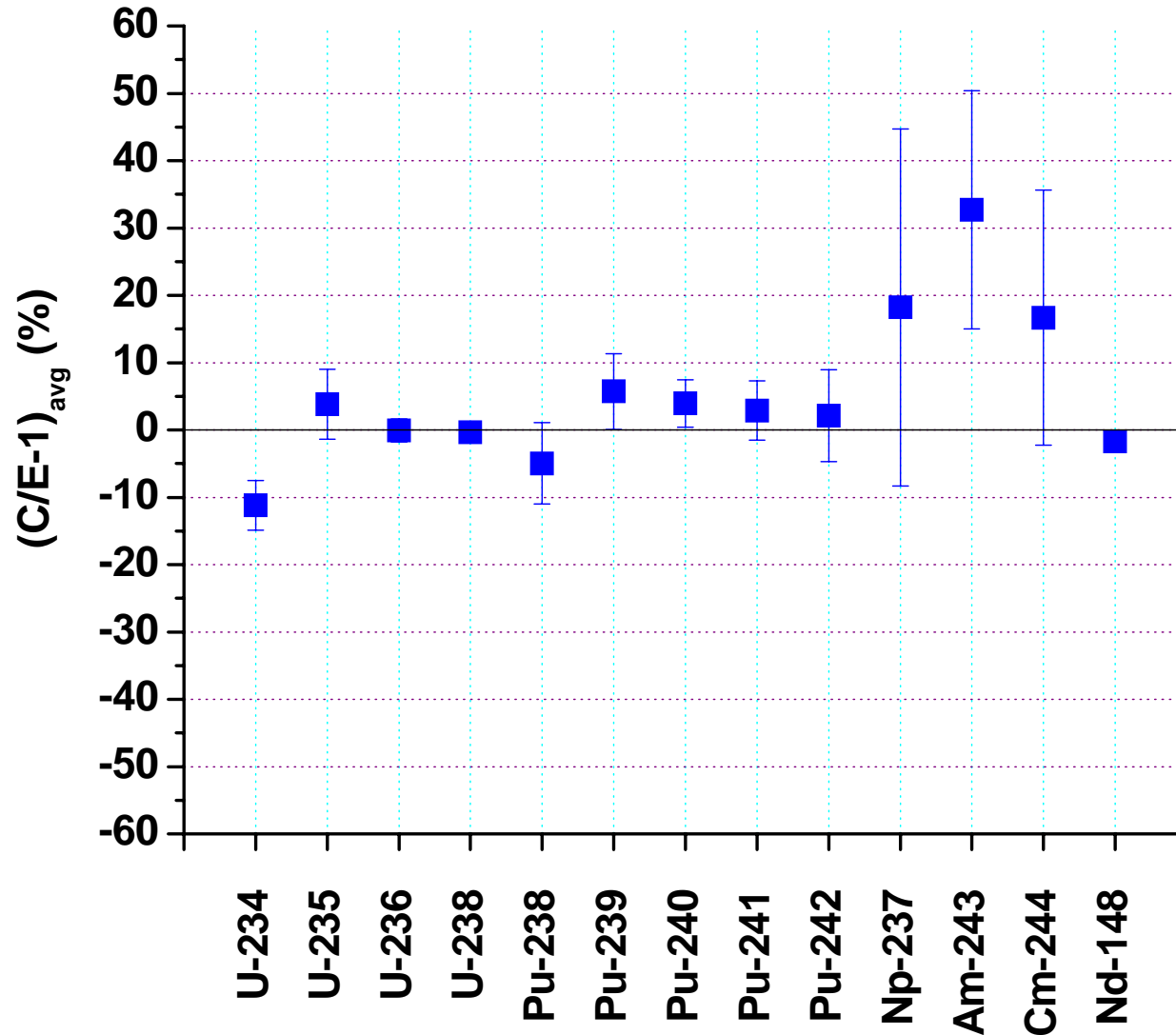
# 2-D TRITON model for RBMK assembly



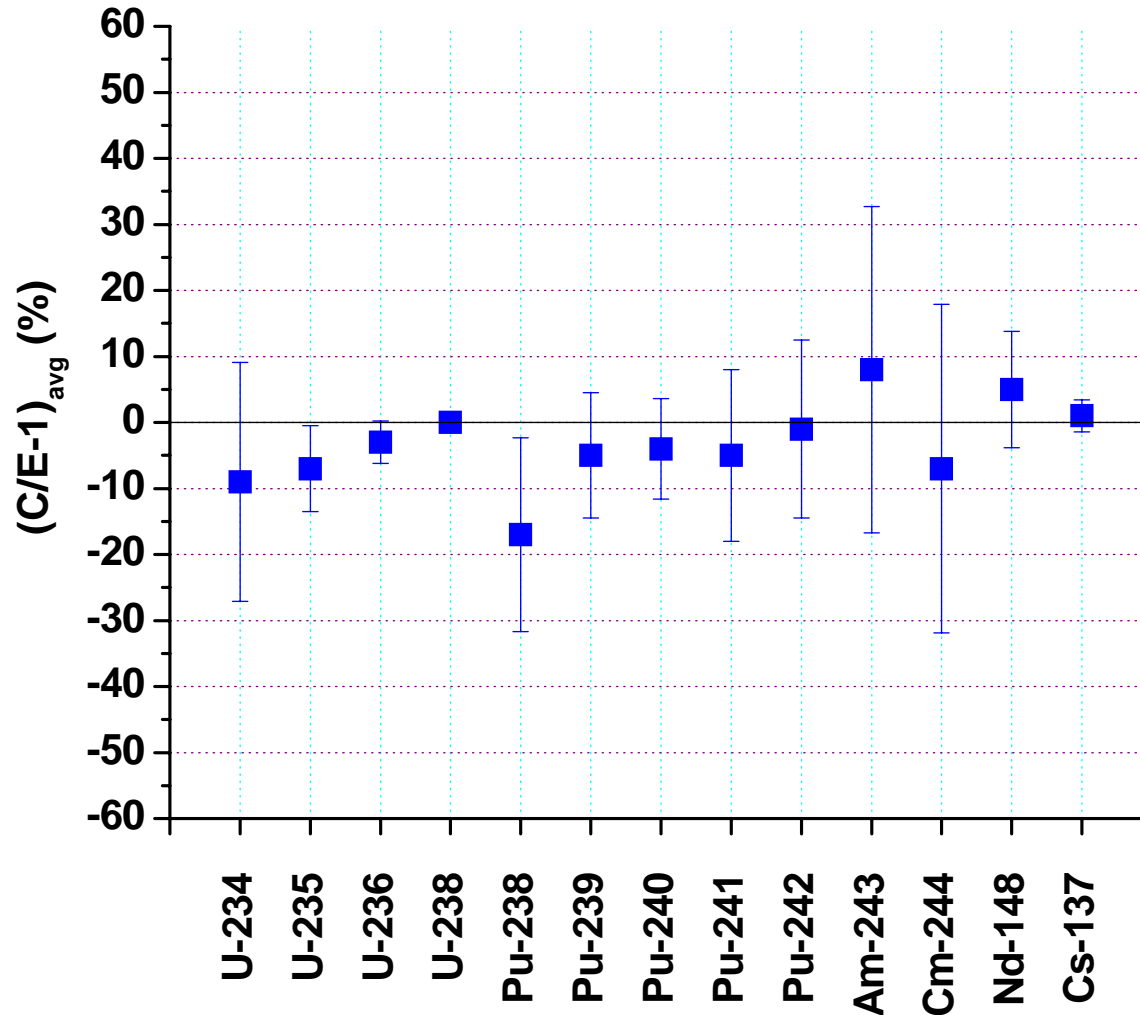
# Validation studies – VVER libraries

- **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 %  $^{235}\text{U}$**
  - **burnup: 20 – 43 GWd/MTU**
  - **cooling time: 3 – 4 years**
  
- **VVER-1000 fuel**
  - **13 samples**
  - **enrichment : 4.4 wt %  $^{235}\text{U}$**
  - **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)

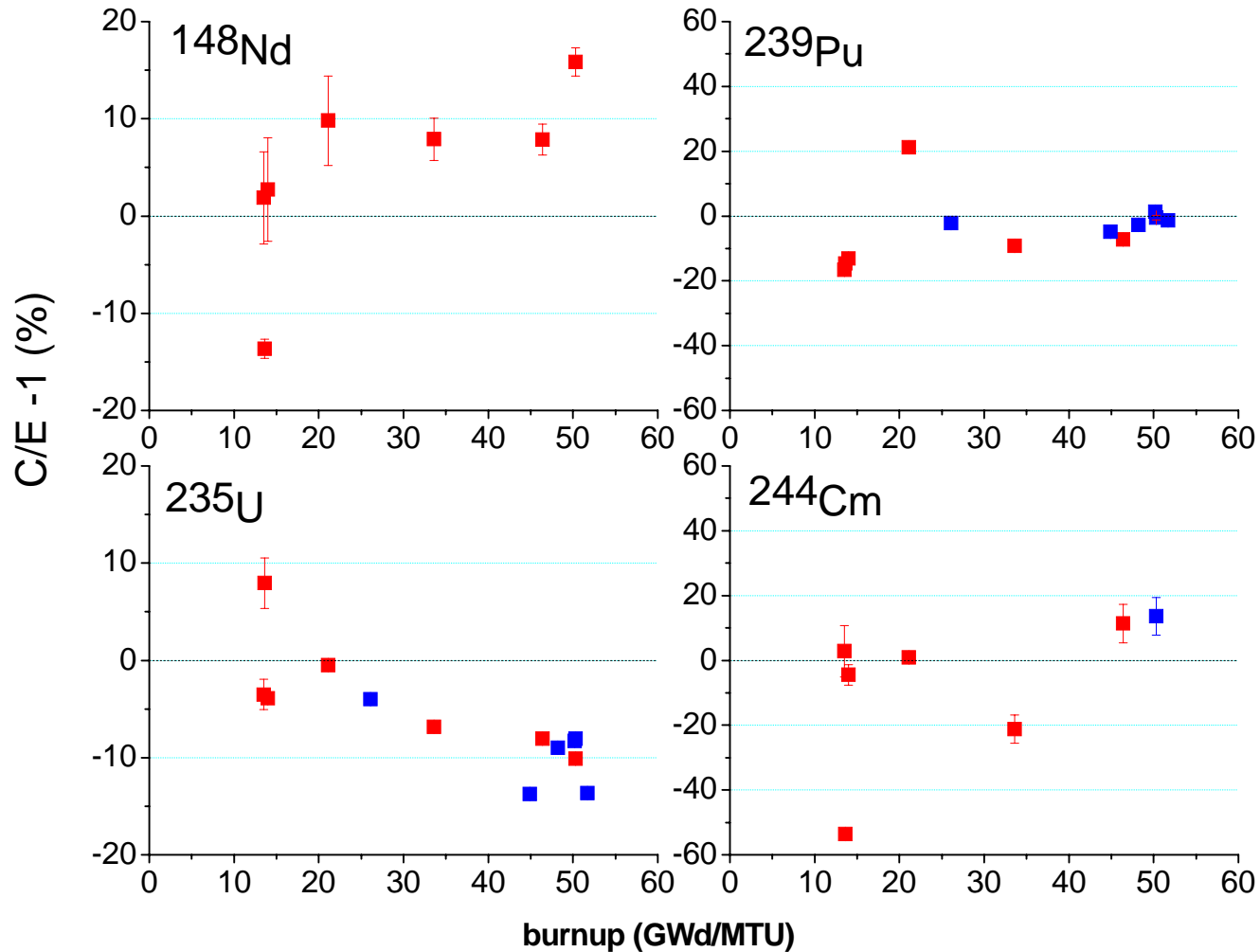




# Validation studies – VVER libraries

- **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  $^{148}\text{Nd}$  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

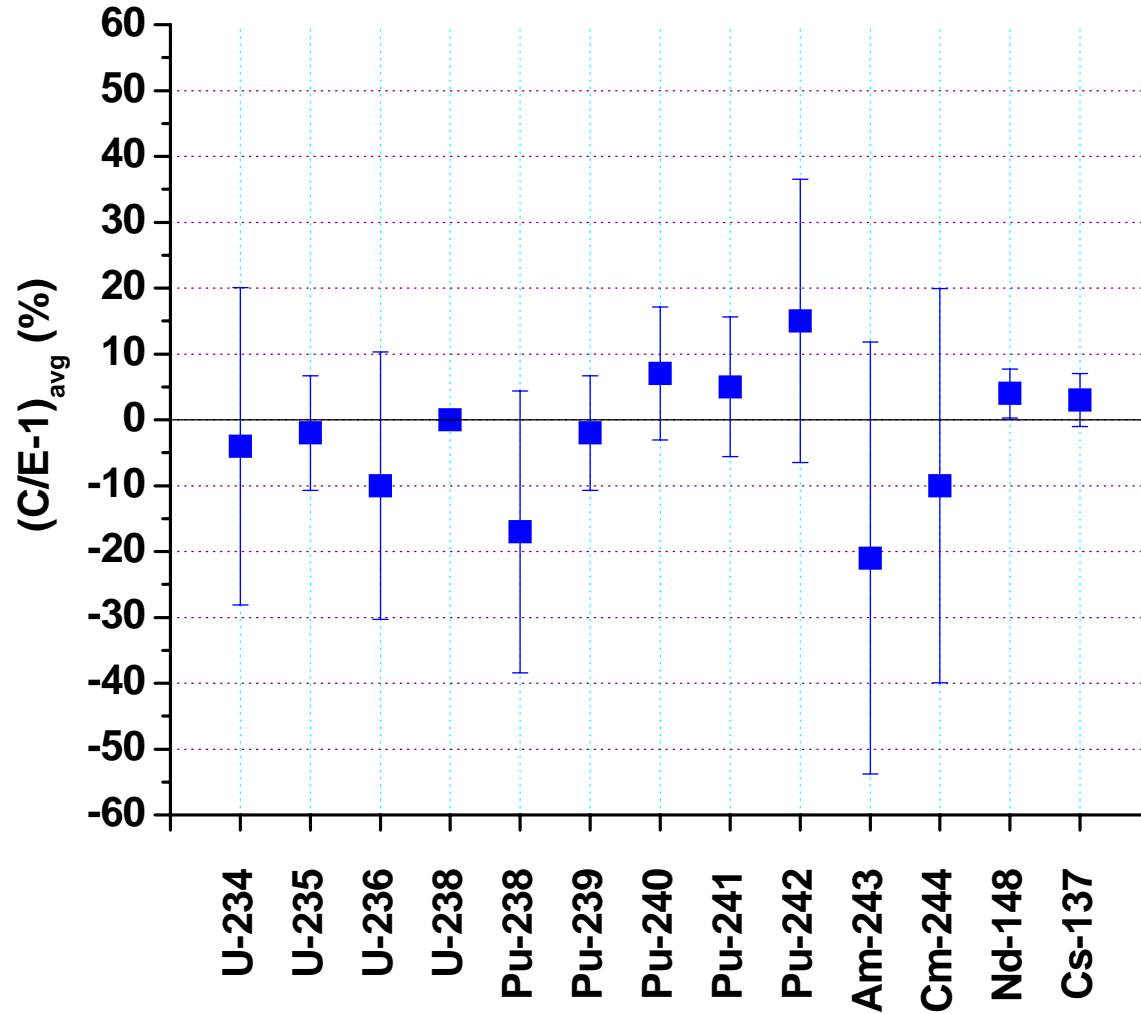


# Validation studies – RBMK libraries

- **Performed by comparison to isotopic assay experimental data from experiments performed at the Khlopin Radium Institute**
  - 15 samples
  - enrichment : 1.80 – 2.09 wt %  $^{235}\text{U}$
  - 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?**