Application of ORIGEN for Spent Fuel Analysis, Safety, and Nuclear Safeguards

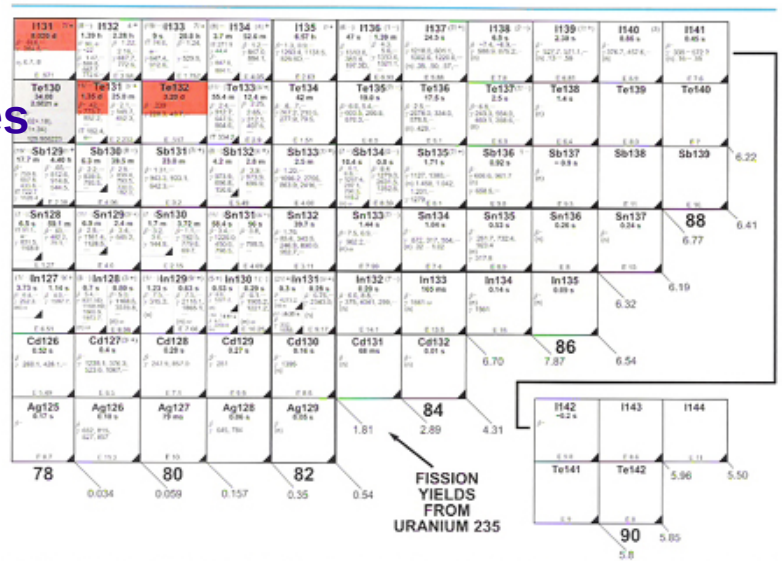
Nuclear Systems Analysis, Design, and Safety

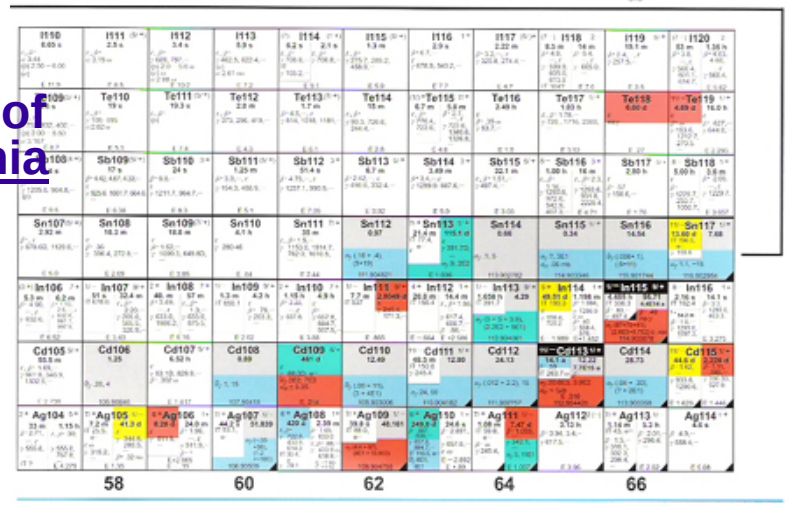
Ian C. Gauld
NSTD – Reactor Analysis Group

OAK RIDGE NATIONAL LABORATORY
U. S. DEPARTMENT OF ENERGY

Overview of ORIGEN-S

- ORIGEN-S is the Oak Ridge Isotope Generation code developed for SCALE code system
- Irradiation and decay simulation code
- Explicit simulation of 1484 unique nuclides (1946 nuclides in database)
  - 129 actinides
  - 1119 fission products
  - 698 structural activation materials
  - Other physics codes typically track a minimum subset of isotopes that are important for reactivity
- Decay heat
- Radiation sources (neutron/gamma)
- One of few codes available with comprehensive isotopic characterization of fuel over time scale of seconds to millennia
  - Accident analysis
  - Storage, handling, and transportation
  - Disposal or reprocessing
  - Repository analysis (dose assessment)





Development - Safety and Licensing

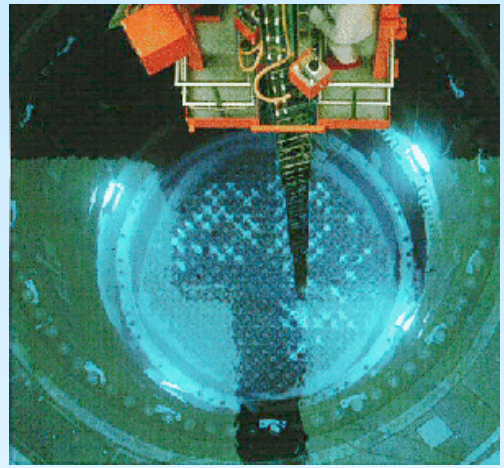
- **ORIGEN-S developed within framework of SCALE code system**
- **Developed at Oak Ridge National Laboratory for the Nuclear Regulatory Commission (NRC) beginning in 1976**
- **Maintained/enhanced under co-sponsorship of NRC and Department of Energy (DOE) since 1987**
- **A multi-purpose computational system for analyses of nuclear facilities and packages**

Applications

- Spent fuel inventories and radiation sources
- Decay heat (transportation & repository)
- Fuel cycle analysis (GNEP)
- Repository and waste management analysis
- New fuel design
- Minor actinide transmutation
- Medical source applications
- Activation studies (decommissioning)
- Postulated accident and consequence analysis (decay heat, elemental compositions and activities)
- Spent fuel safeguards
- Environmental sampling and nuclear non-proliferation

Material processing and fabrication

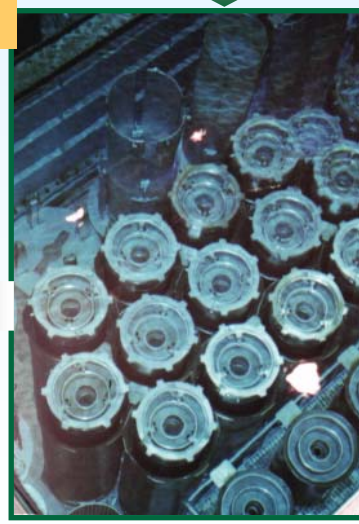
Commercial and research reactors



SCALE is modular code system used throughout the world for reactor and fuel cycle applications

Disposal

Transport



Storage

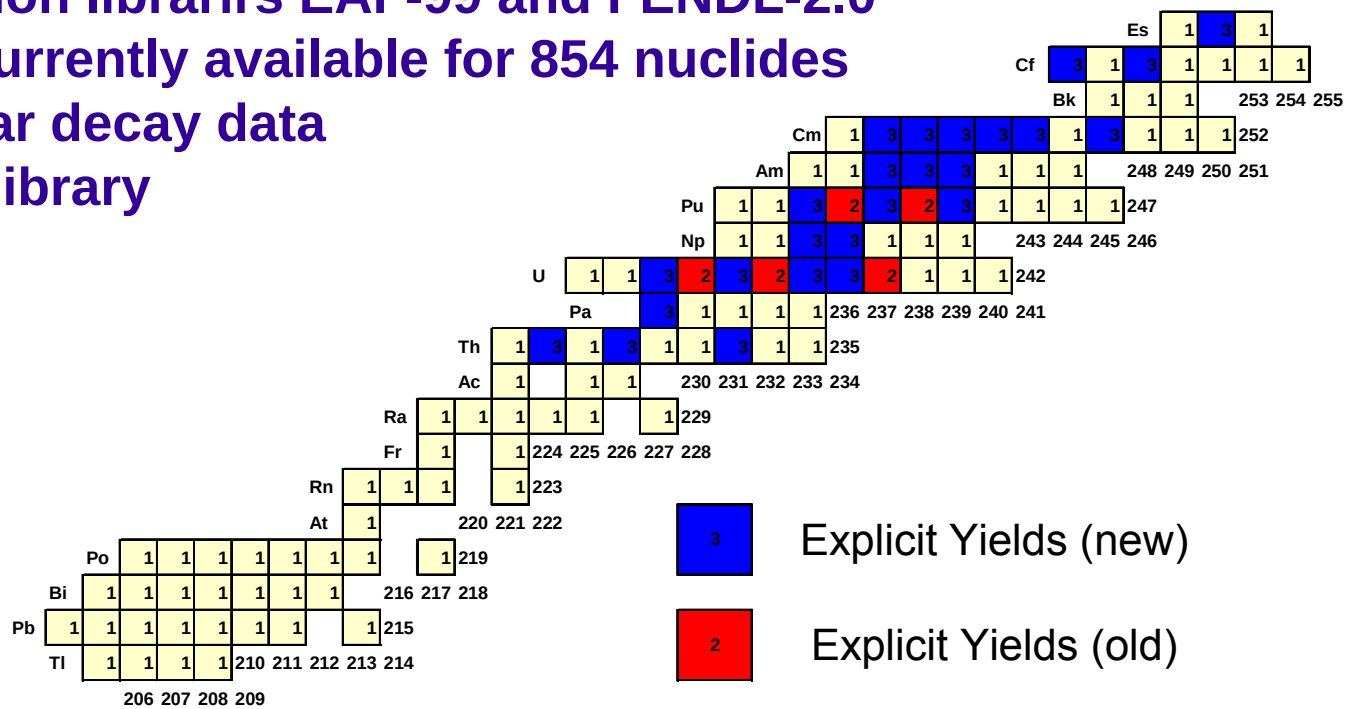
Reprocessing

Nuclear Data Libraries

- **ORIGEN is used to solve large systems of coupled differential equations**
  - Radioactive decay
  - Neutron reactions (n,g), (n,2n), (n,3n), (n,p), (n,a), (n,f)
  - Fission products from fission
- **Accuracy of the code is determined by the accuracy of the nuclear data**
  - Decay half lives and branching fractions
  - Cross sections
  - Fission product yields
  - Gamma ray production data
  - Neutron production data
    - Alpha decay energies
    - Stopping powers
    - Alpha,n yield cross sections
    - SF spectral parameters
    - Delayed neutron spectra

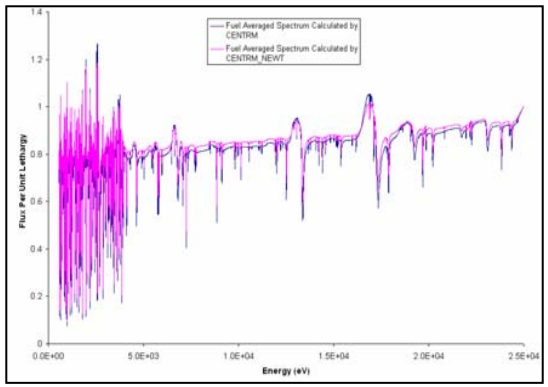
Improved Nuclear Data

- **1946 isotopes in data library**
  - 698 naturally-occurring isotopes and decay progeny, structural materials and activation products
  - 1119 fission products (21 ternary yields)
  - 129 actinides
- **ENDF/B-VI Fission yields for 30 actinides: ^{227,228,232}Th, ^{231}Pa, $^{232-238}$U, $^{238-242}$Pu, ^{241,242m,243}Am, ^{237,238}Np, $^{242-246,248}$Cm, ^{249,252}Cf, ^{254}Es**
- **ENDF/B-VI neutron reaction cross sections, supplemented with data from activation librarirs EAF-99 and FENDL-2.0**
- **Cross sections currently available for 854 nuclides**
- **ENDF/B-VI nuclear decay data**
- **Updated photon library**



Rigorous Methods for Cross Section Generation

- **CENTRM: 1-D continuous energy resonance processing**
- **ORIGEN-S: detailed isotopic compositions**
- **NEWT: 2-D flexible mesh geometry discrete ordinates transport**



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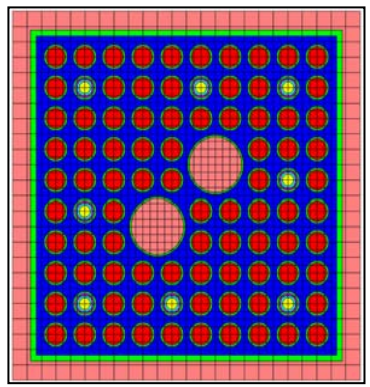

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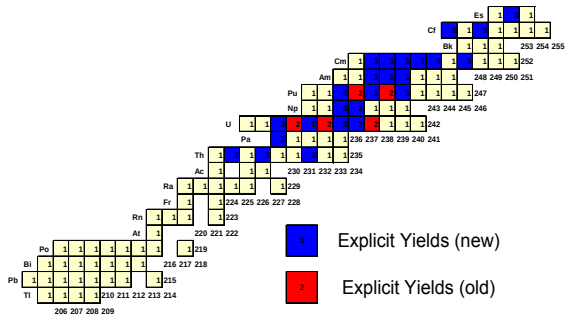
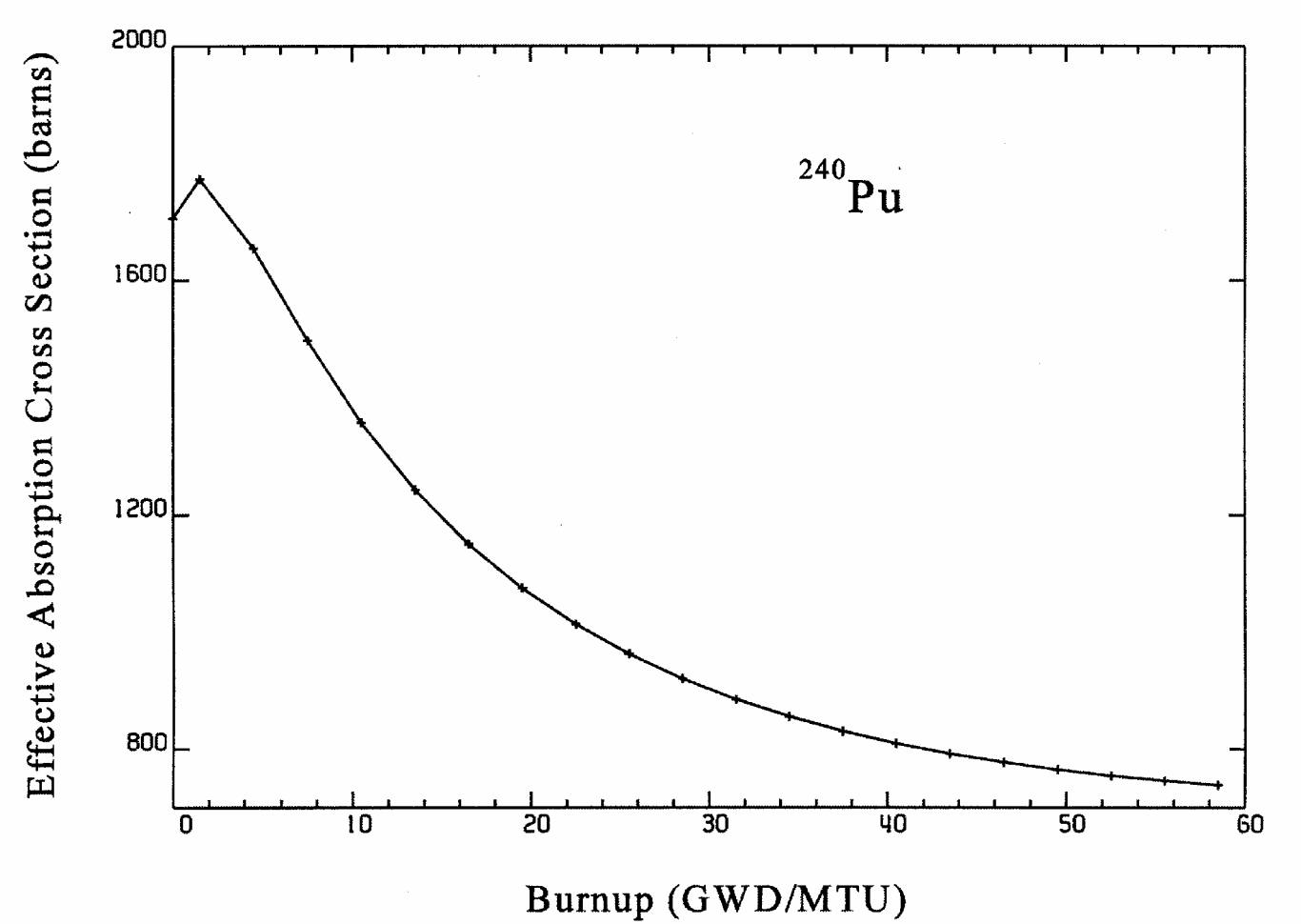


CENTRM (Energy Detail)

NEWT (Spatial/Angular Detail)

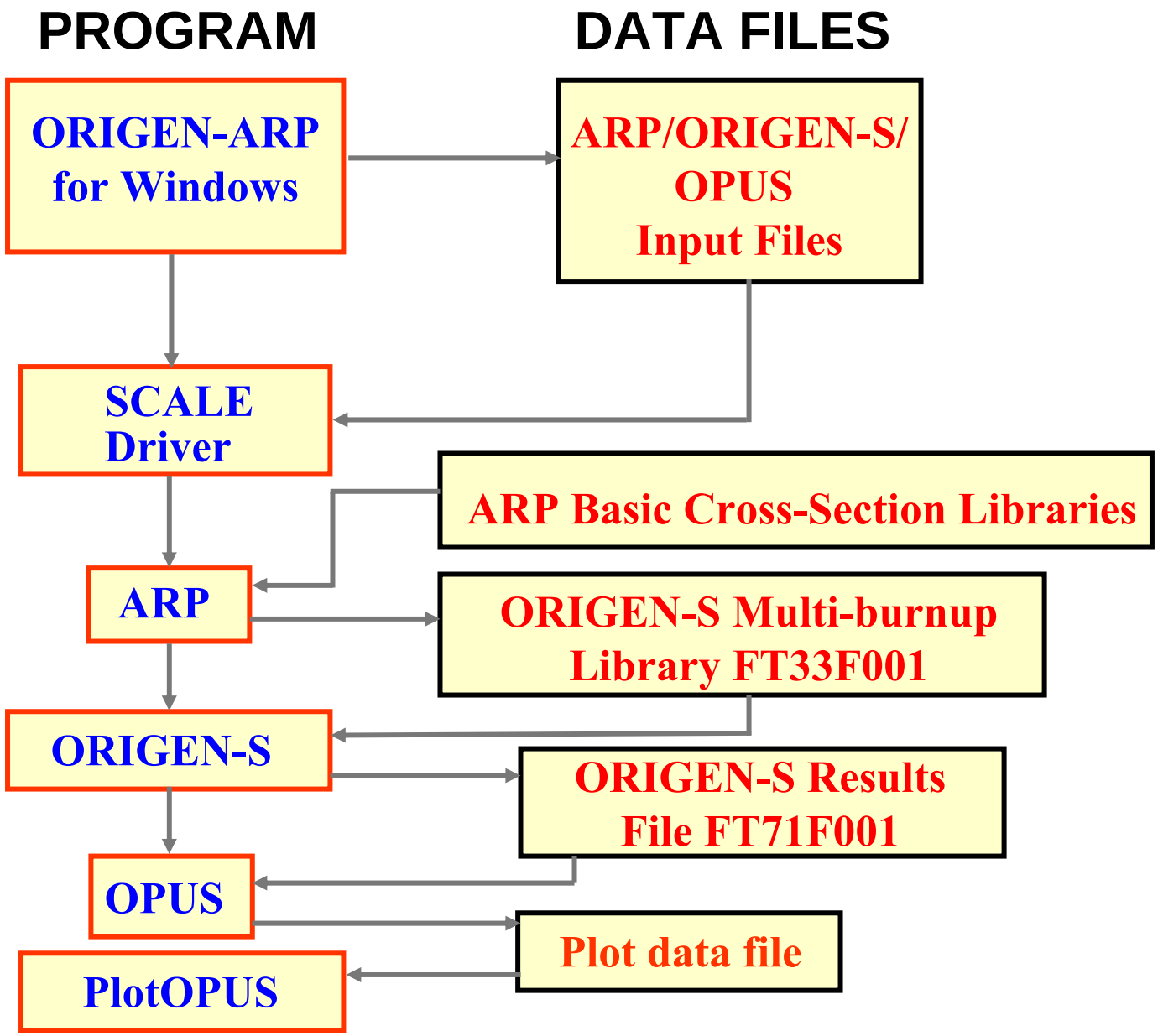
ORIGEN-S (Isotopic Detail, 1600 nuclides)

^{240}Pu Absorption Cross Section vs Burnup



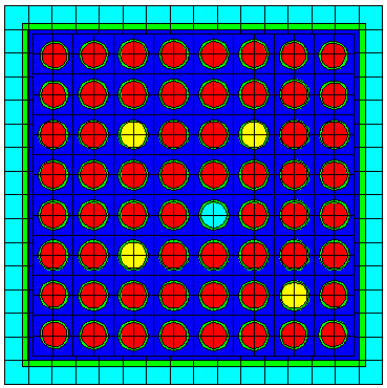
ORIGEN-ARP Features

- **Graphical Windows interface allows easy setup of burnup *and decay cases* using ORIGEN-S**
- **Interactive on-line help**
- **Windows interface generates input files for ARP, ORIGEN-S, and OPUS on PC or workstation**
- **Executes calculations within SCALE on PC**
- **Runs very fast – in a few seconds**
- **Maintains accuracy of rigorous reactor physics calculations**

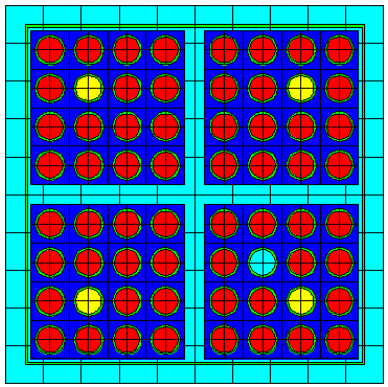

PROGRAM
DATA FILES
ORIGEN-ARP for Windows
ARP/ORIGEN-S/ OPUS Input Files
SCALE Driver
ARP Basic Cross-Section Libraries
ARP
ORIGEN-S Multi-burnup Library FT33F001
ORIGEN-S
ORIGEN-S Results File FT71F001
OPUS
Plot data file
PlotOPUS

Commercial reactor libraries created for use with ORIGEN-S

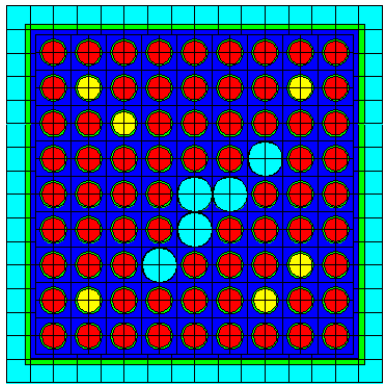
8x8-1



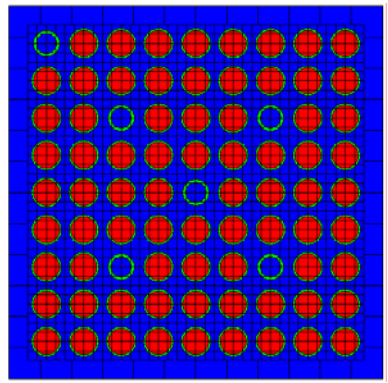
SVEA 64



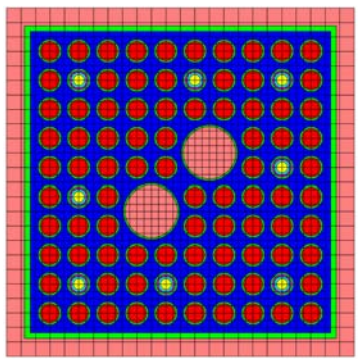
9x9-5



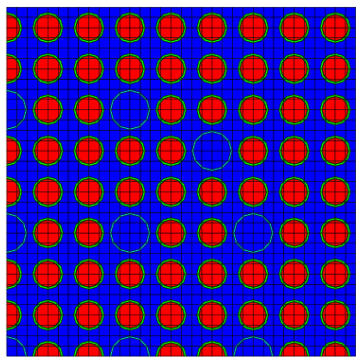
9x9-6



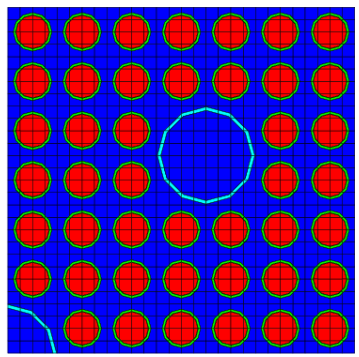
GE 10x10



W 17x17 (1/4)



CE 14x14 (1/4)



Summary of Validation Studies

How well do we do?

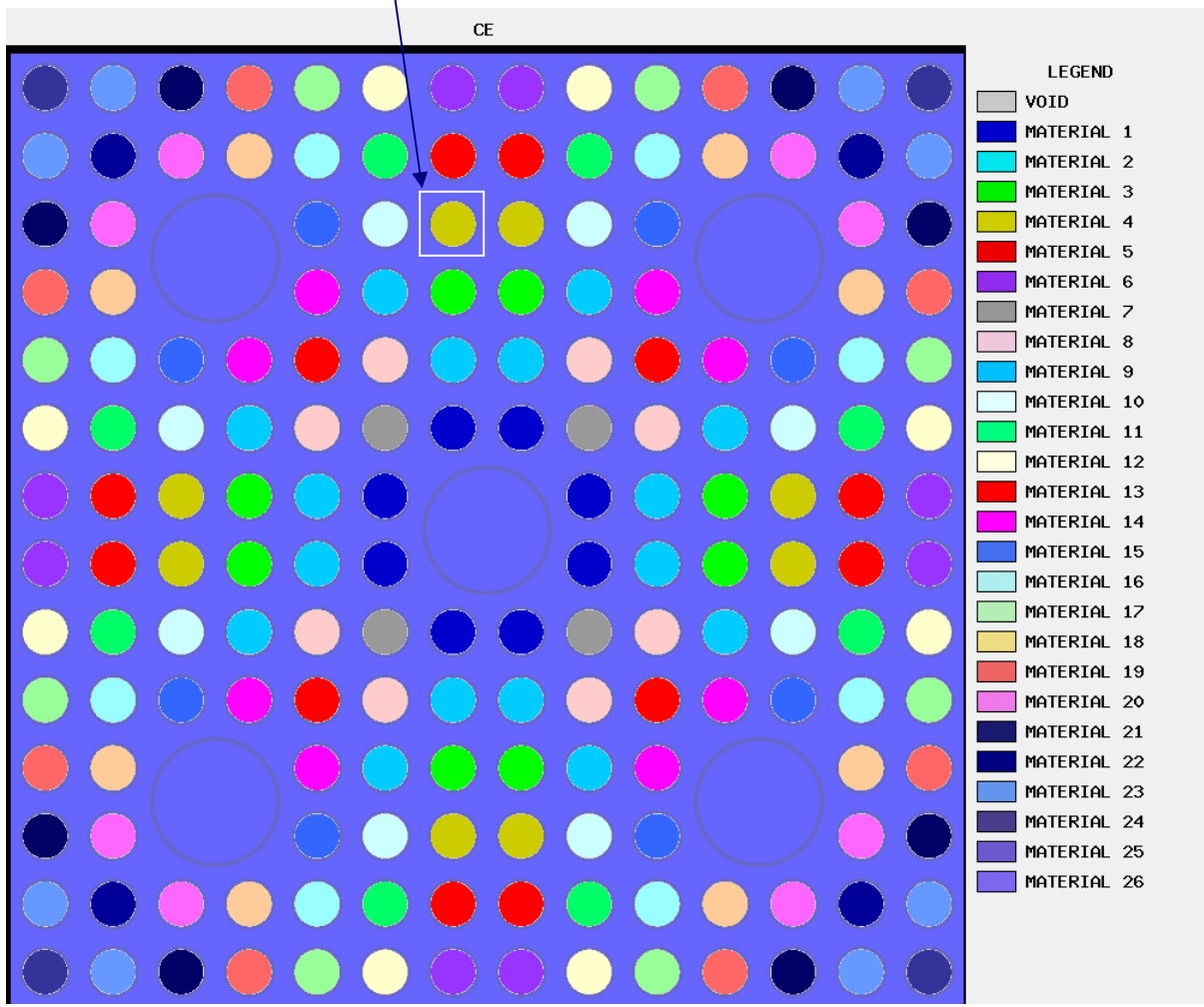
- **Destructive isotopic assay (56 PWR samples, 32 BWR samples)**
  - High burnup LEU and MOX data evaluated
- **Decay heat measurements**
  - U.S. data from GE-Morris and Hanford operations (116 fuel assemblies)
  - Swedish CLAB facility
- **Short time decay heat measurements (1 – 10^5 s)**
- **Dose rate measurements (GE-Morris)**
- **Gamma spectra (burst fission)**
- **Neutron spectra (SF and alpha,n sources)**

Calvert Cliffs Assembly D047, Rod MKP109 (44.34 GWd/MTU)

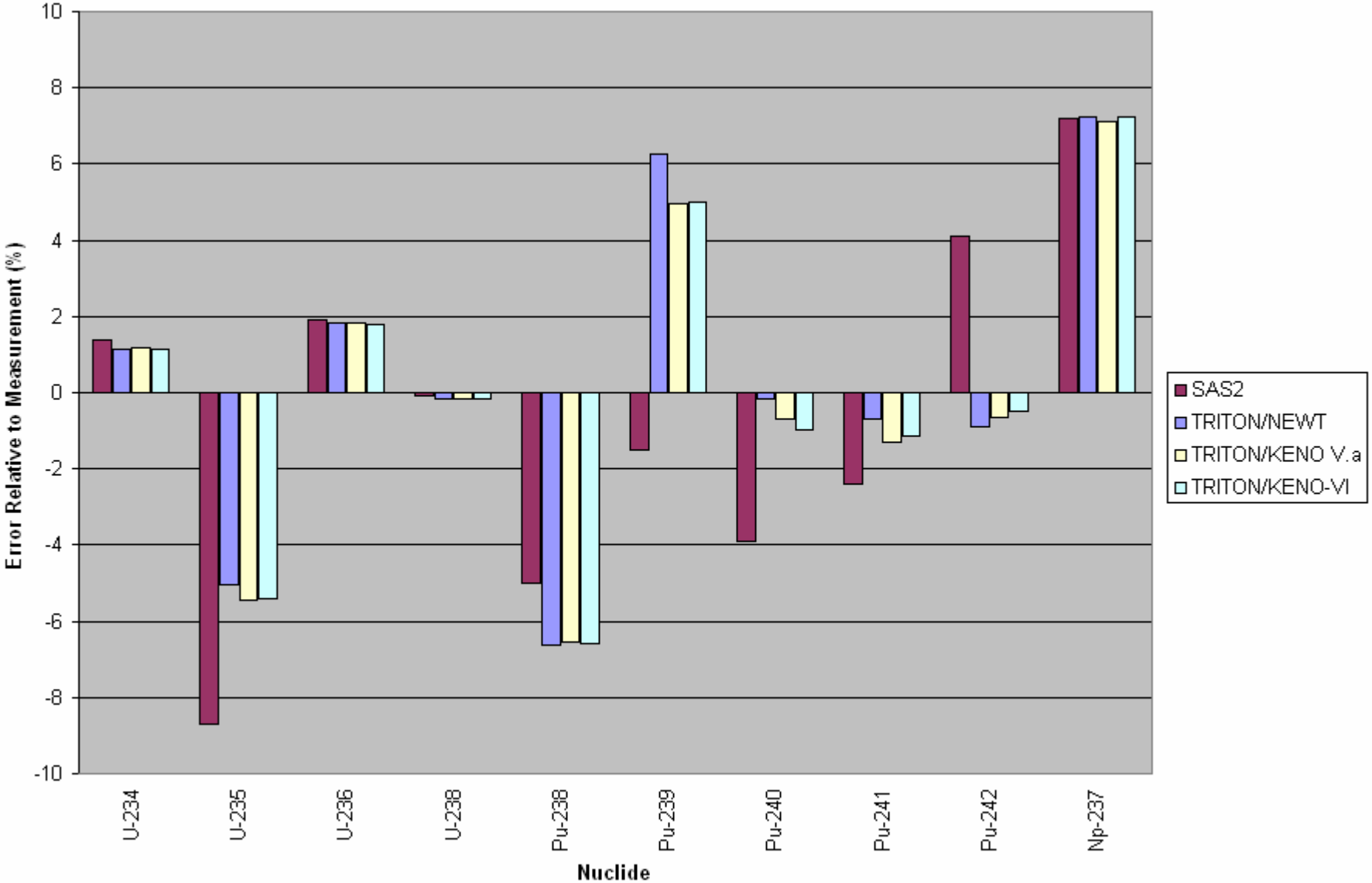
Rod MKP109

CE 14x14 PWR Assembly

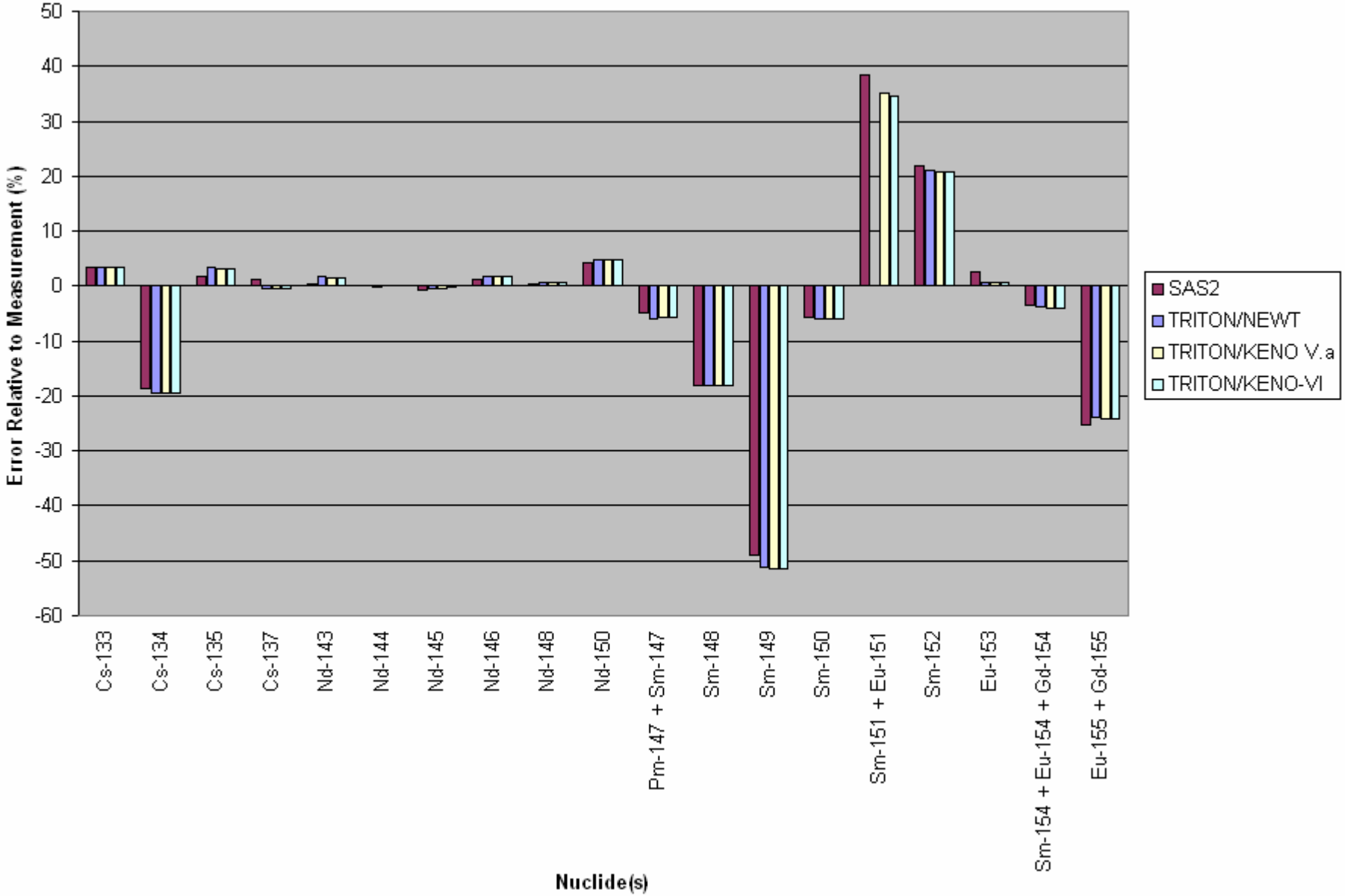
¼ assembly symmetric model



Calvert Cliffs Rod MKP109 (44.34 GWd/MTU) Actinide Results



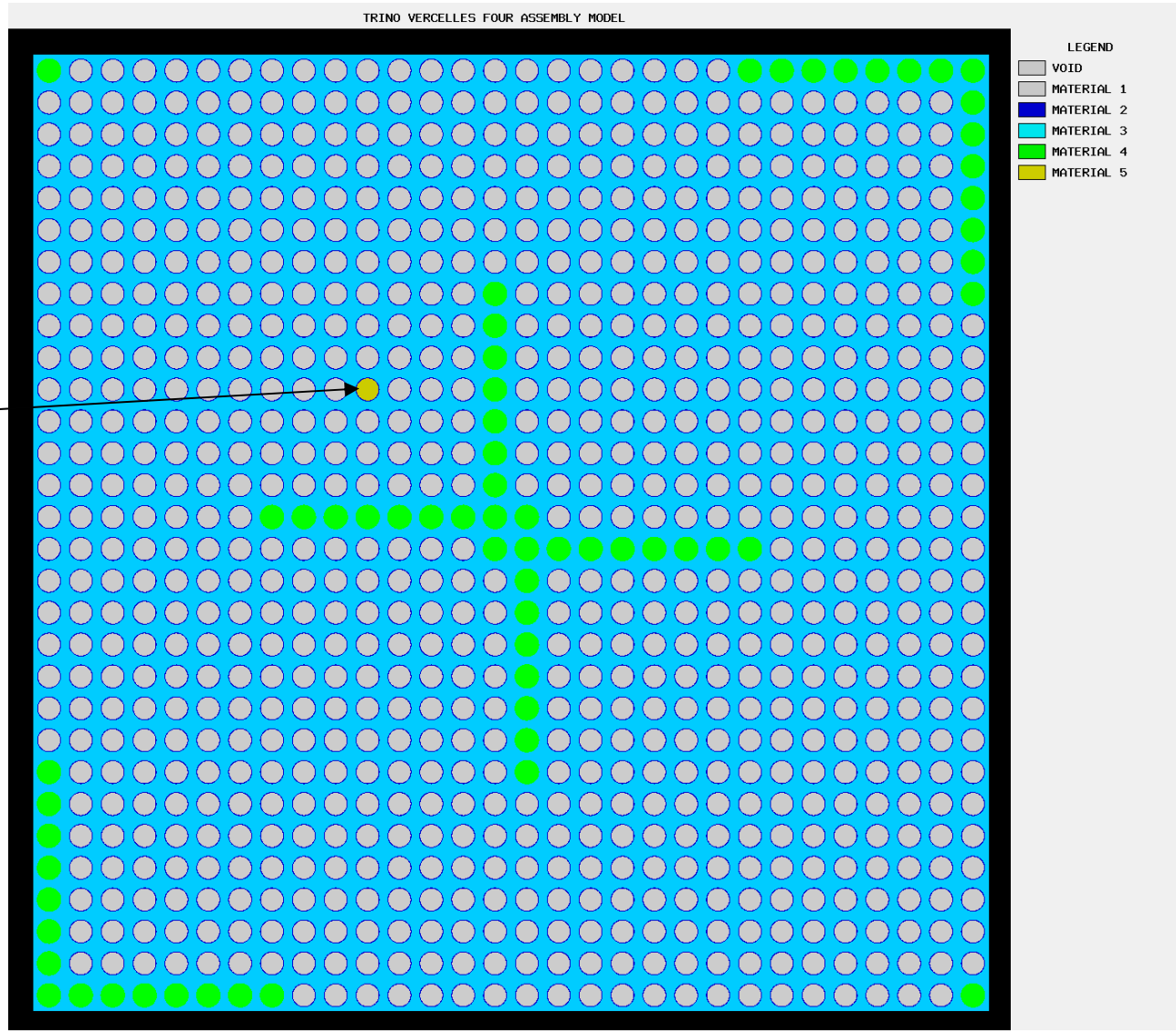
Calvert Cliffs Rod MKP109 (44.34 GWd/MTU) Fission Product Results



Trino Vercelles assembly 509-069 Rod E11 (12.859 GWd/MTU)

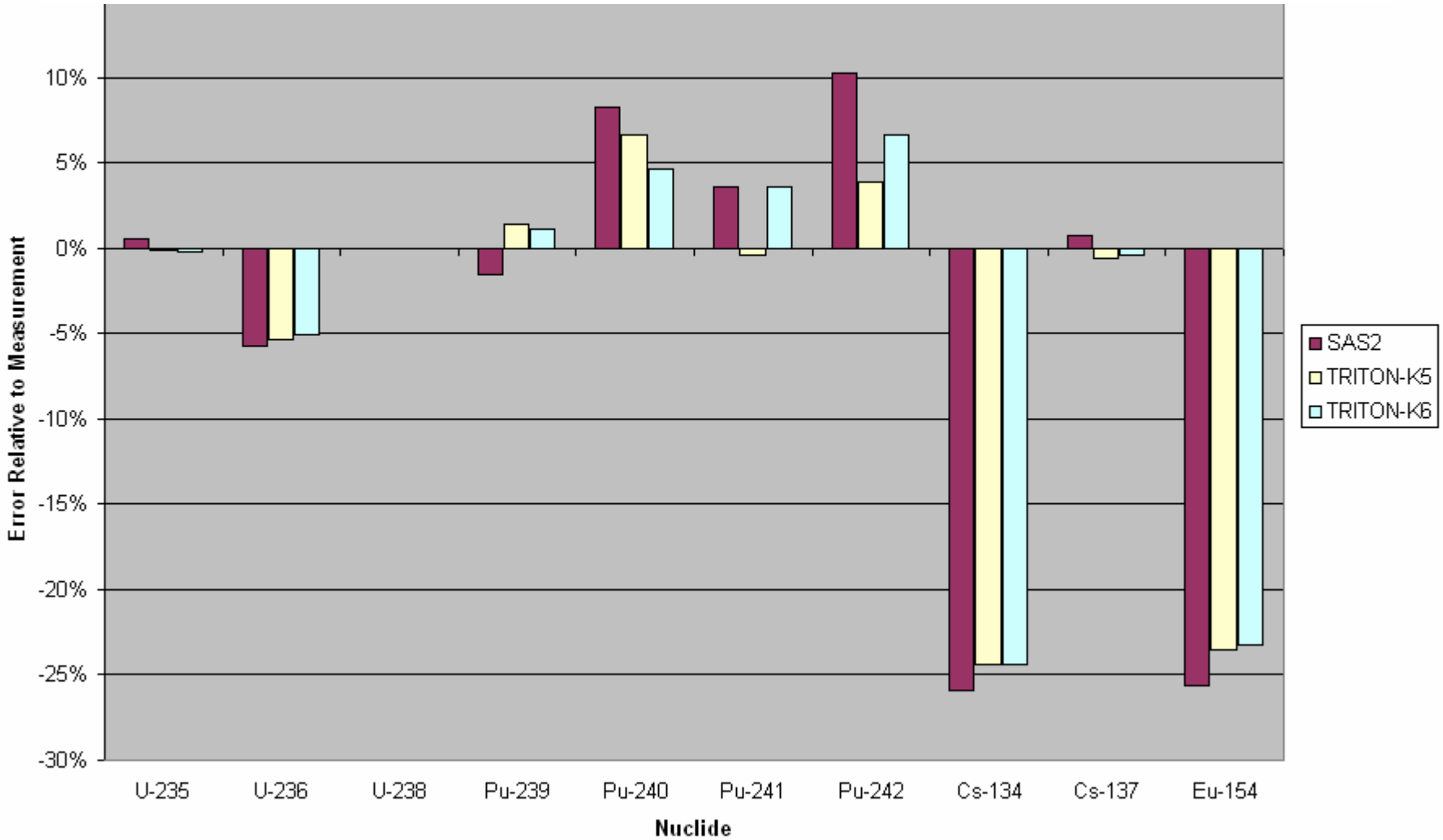
Early 15x15 PWR design with cruciform control rod positions

Fuel rod E11



4 assembly model with periodic boundary conditions

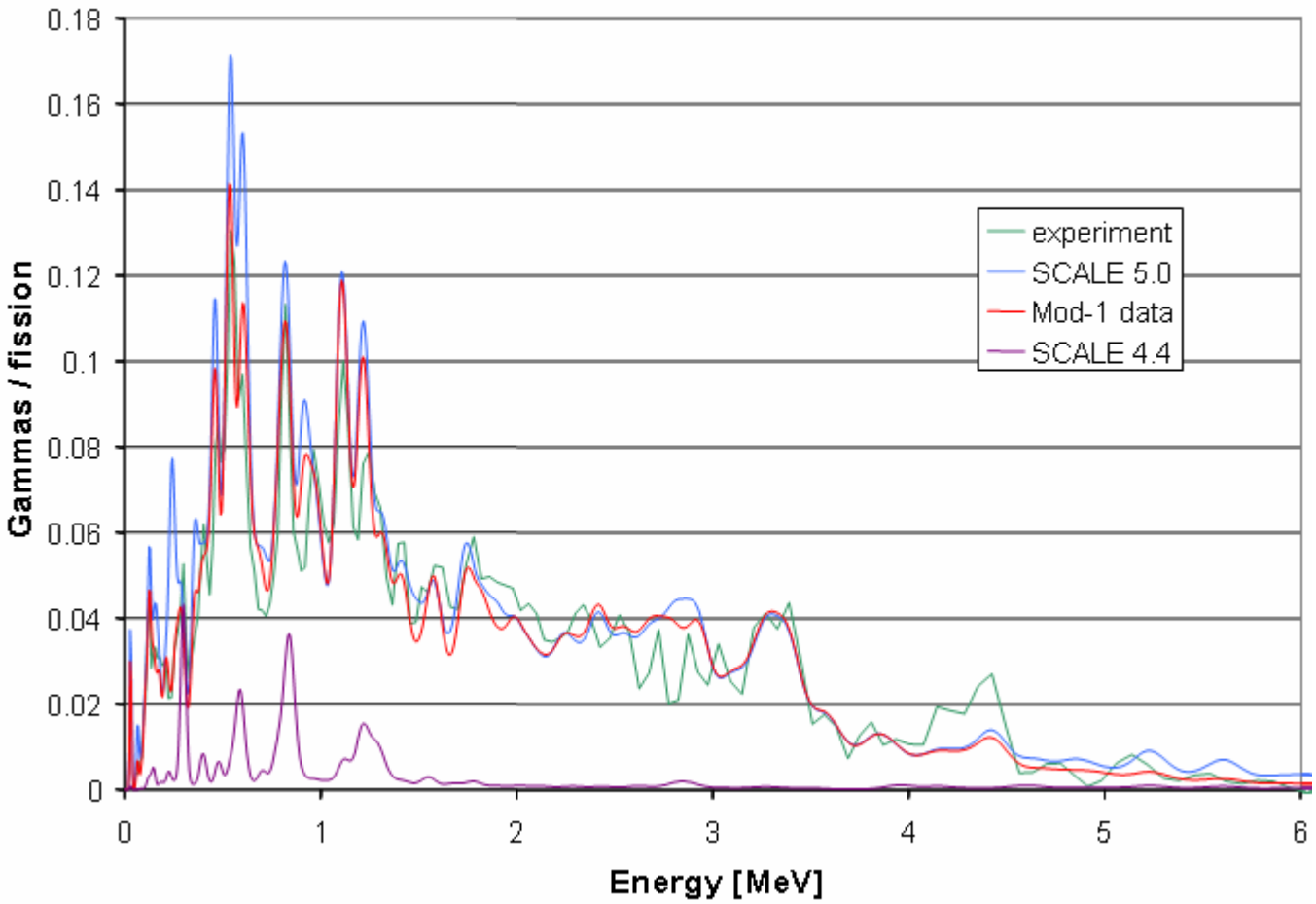
Trino Vercelles Assembly 509-069 Rod E11 (12.859 GWd/MTU)



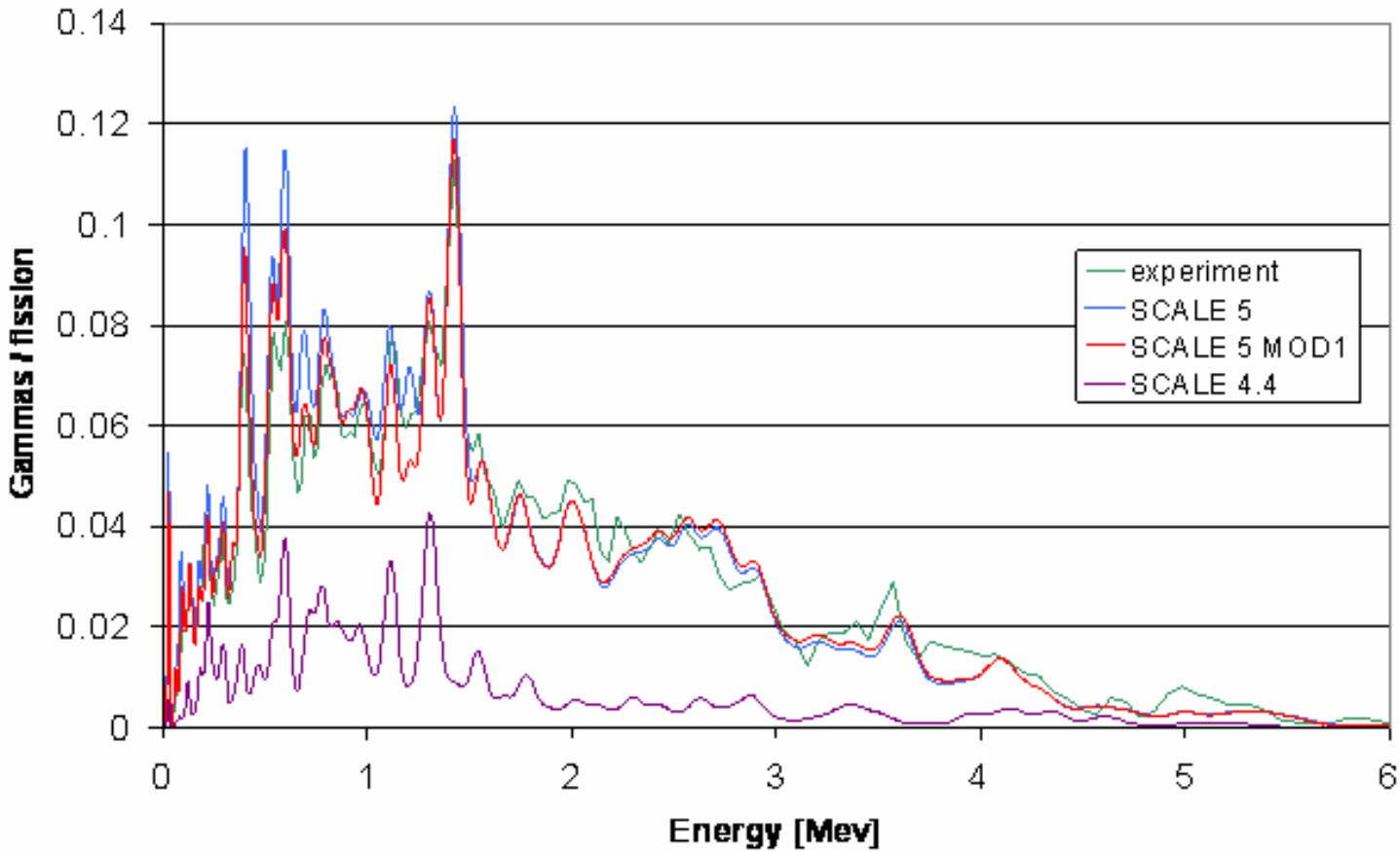
Gamma Library validation

- **ORNL burst fission measurements**
- **^{235}U, ^{239}Pu, and ^{241}Pu fissions**
- **Extends validation to extremely short decay times important to postulated accident analysis**

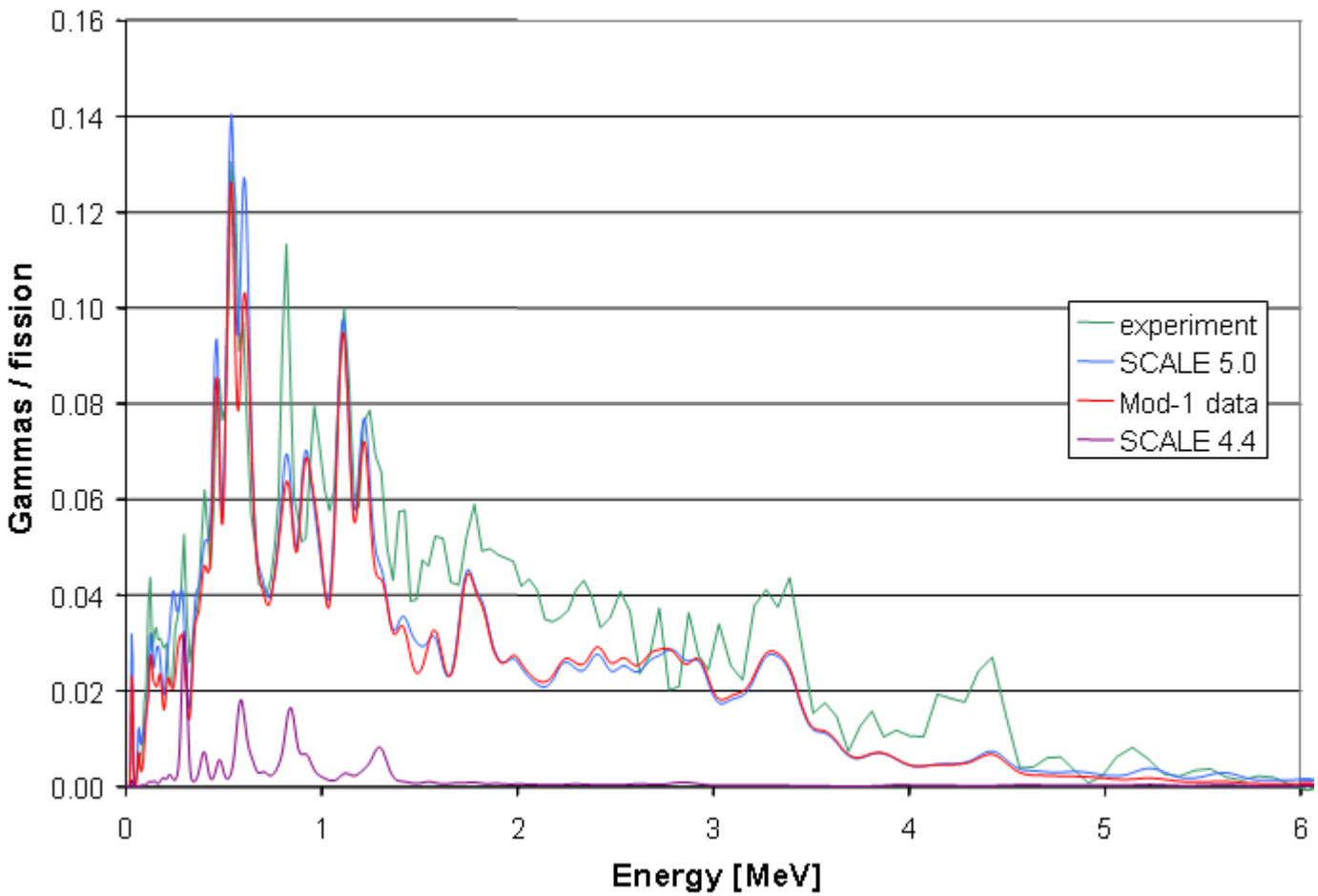
Gamma Spectra 1.7 s after ^{235}U fission



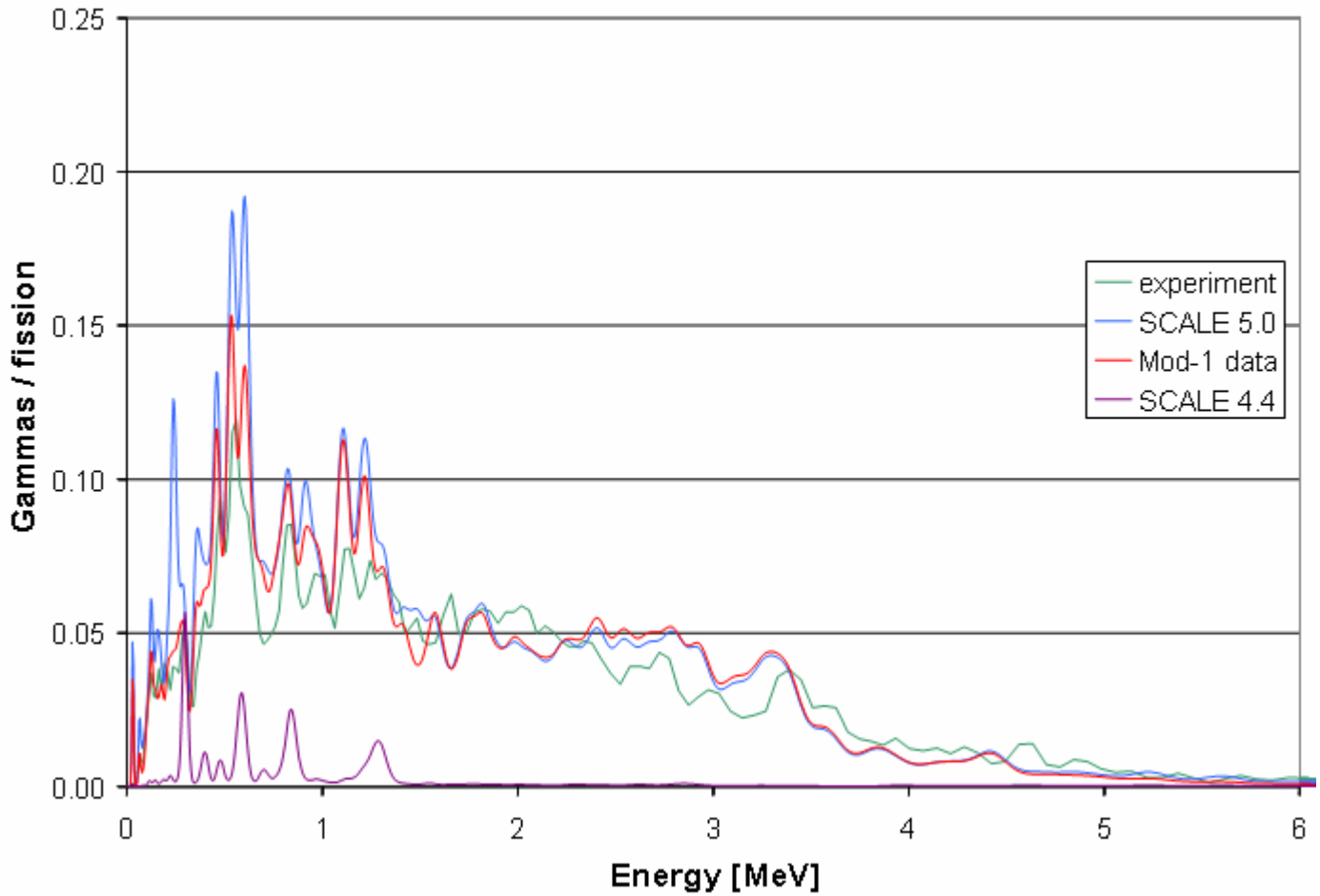
Gamma spectra 35 s after ^{235}U fission



Gamma Spectra 1.7 s after ^{239}Pu fission



Gamma Spectra 1.7 s after ^{241}Pu fission

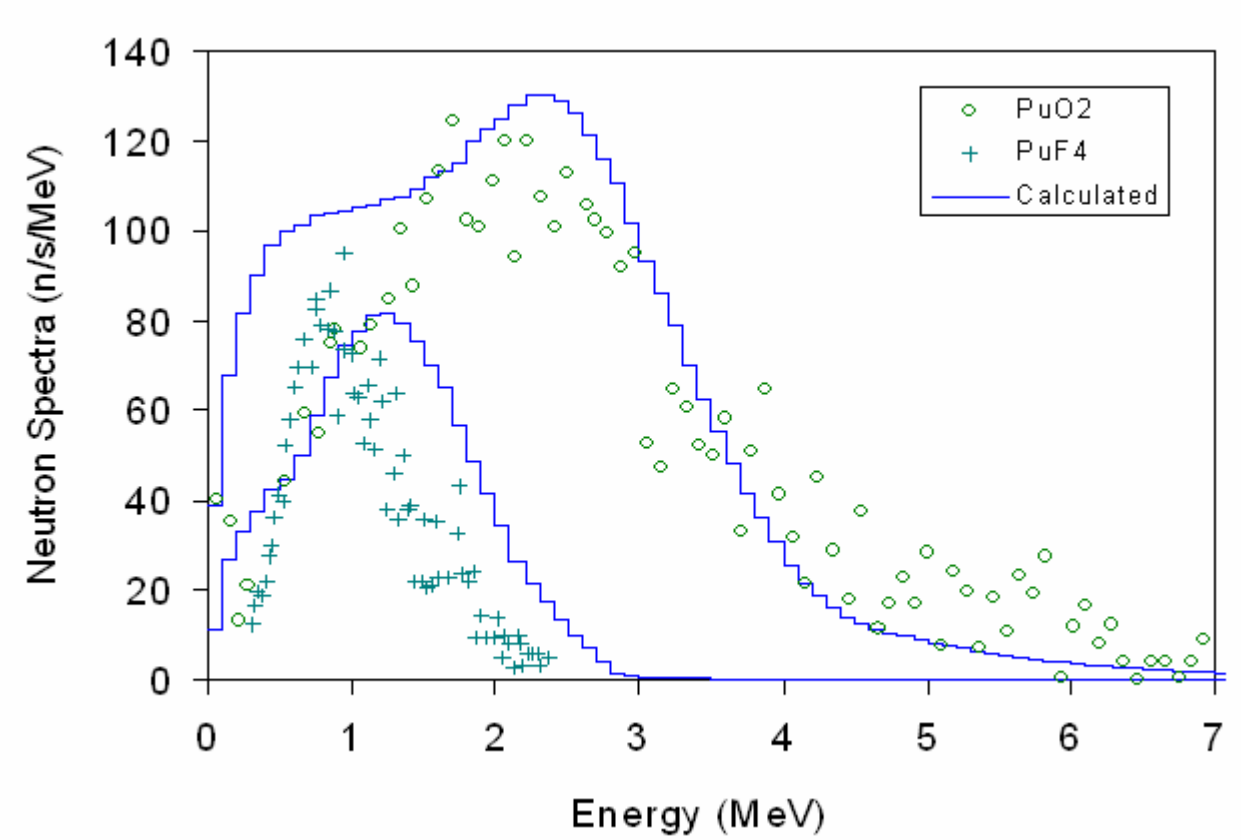


Neutron Source Validation Studies

Measurements on:

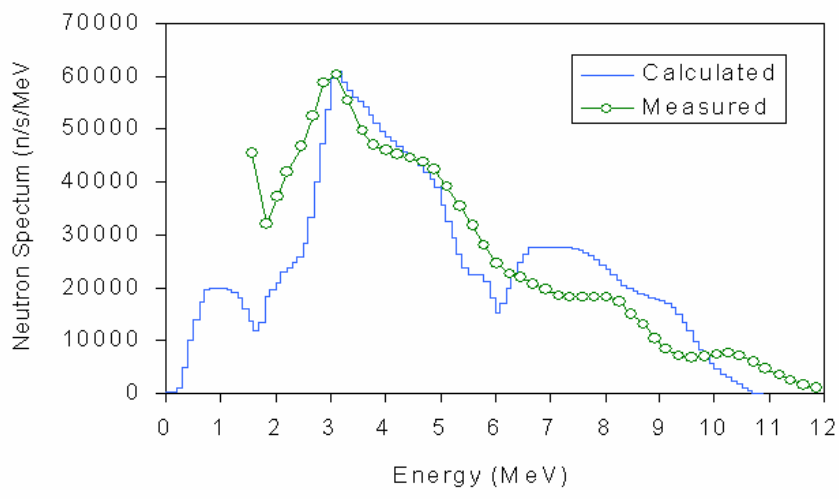
- **CmO_2 and Cm_2O_3**
- **$^{238}PuO_2$ borosilicate glass (SRL)**
- **$^{238}PuO_2$ in boron**
- **$^{238}PuF_4$ in LiF**
- **Pu-Be**
- **Reprocessed high-exposure Pu (BNWL)**
  - PuO_2 and PuF_4
- **Delayed neutron measurements (Texas A&M University)**

Reprocessed Pu Compound Spectra

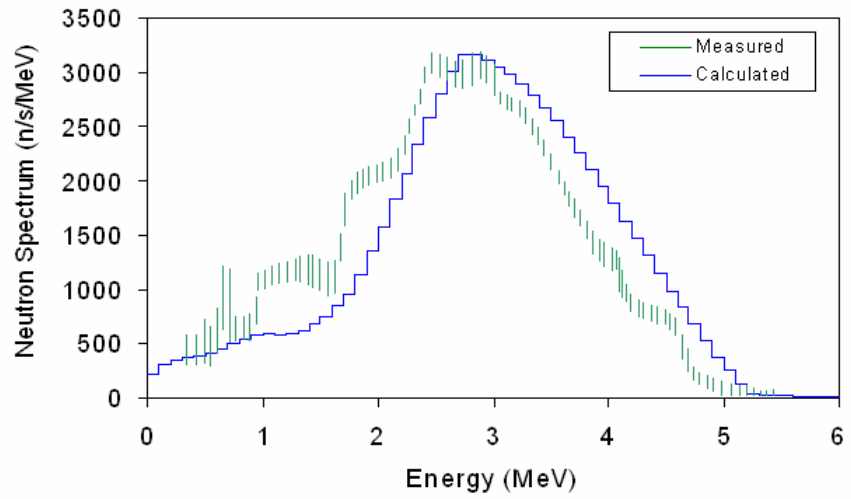


Pu mixtures spectra

Pu-Be Spectrum



$^{238}PuO_2$ + B Spectrum

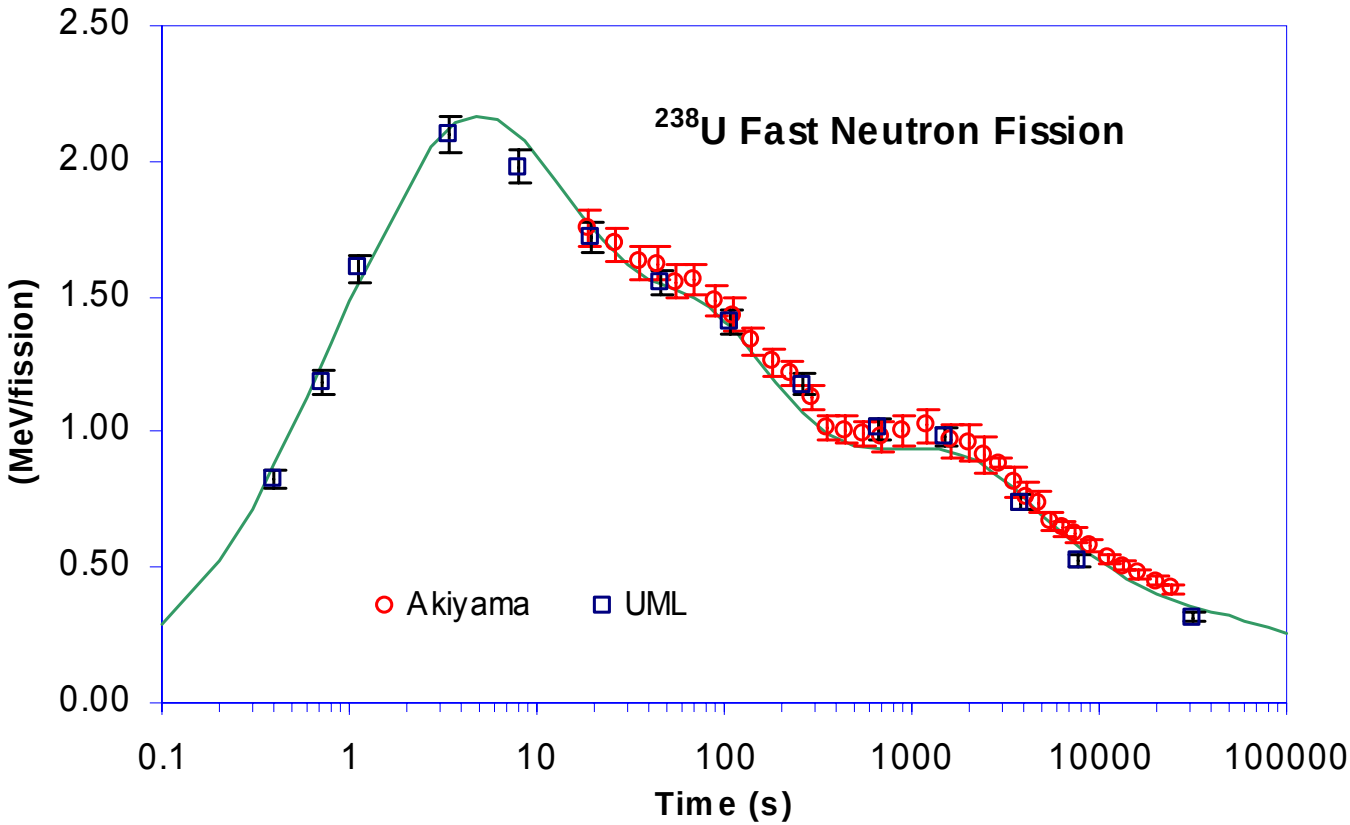


Fission Energy Release Data Sets

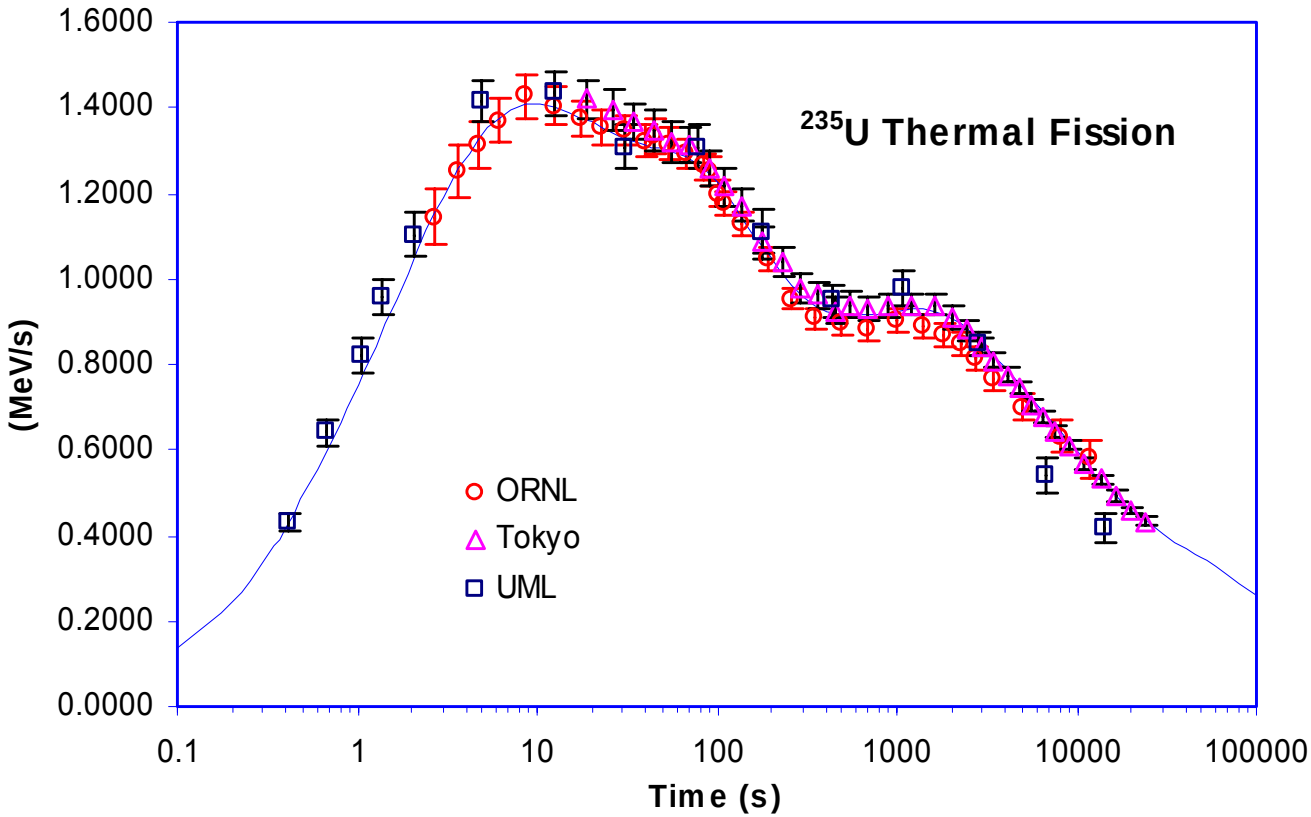
Data set	*Isotopes*	*Method*	*Author(s)*	*Institute*	*Pub. Year (circa)*
1	^{235}U, ^{239}Pu, ^{241}Pu	γ, β spec.*	Dickens et al	Oak Ridge National Laboratory	1980, 1981
2	^{235}U	Calorimeter	Baumung	Karlsruhe	1981
3	^{233}U, ^{235}U, ^{238}U, ^{39}Pu, ^{232}Th	γ, β spec.	Akiyama et al	Tokyo University	1982
4	^{235}U	γ, β spec.	Johansson	Uppsala University	1987
5	^{235}U, ^{238}U, ^{239}Pu	γ, β spec.	Schier and Couchell et al	University of Mass., Lowell	1997

*** Spectroscopic method**
**** indicate that Akiyama are all fast fission measurements**

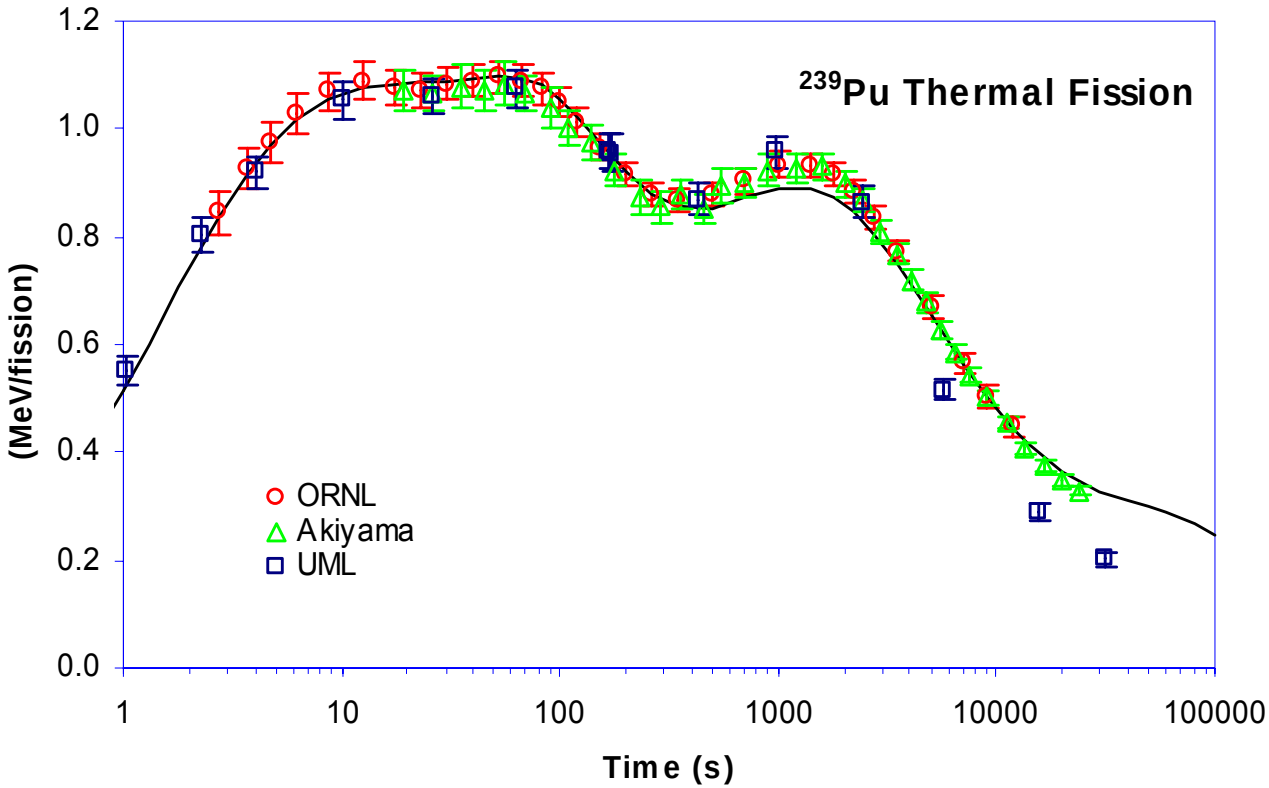
^{238}U Fission Pulse



^{235}U Fission Pulse



^{239}Pu Fission Pulse

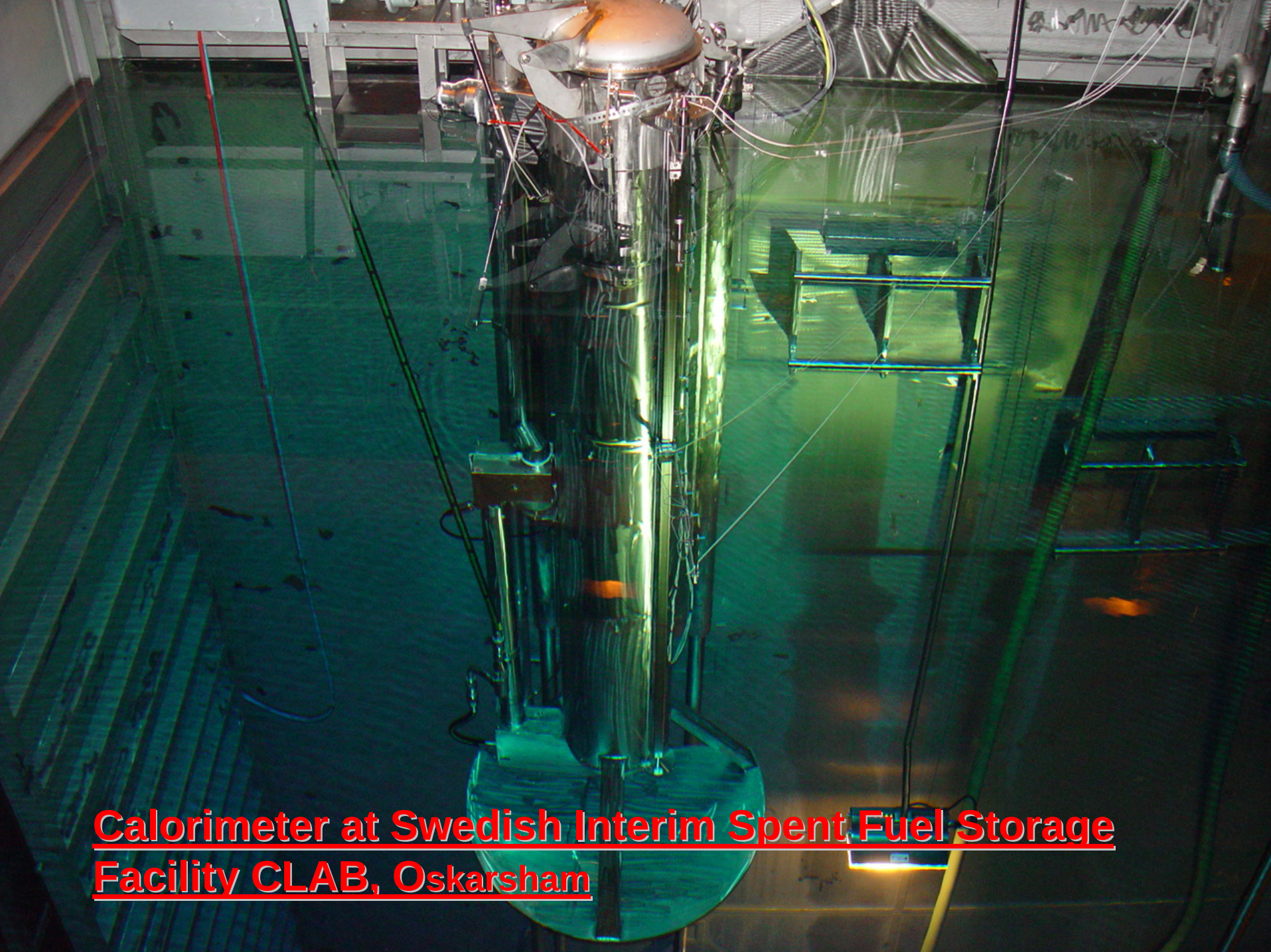


Fuel Assembly Decay Heat Validation

- **U.S. Program measurements (116 assemblies)**
  - **GE-Morris**
  - **HEDL**
- **SKB – Swedish Nuclear Fuel and Waste Management Co. (86 assemblies)**
  - **Swedish spent fuel stored at Swedish Central Interim Spent Fuel Storage Facility (CLAB)**
  - **Plant mix includes BWRs and PWRs**
  - **Diverse fuel assembly designs**
  - **Extended range of burnups and decay times**

Swedish Assembly Designs

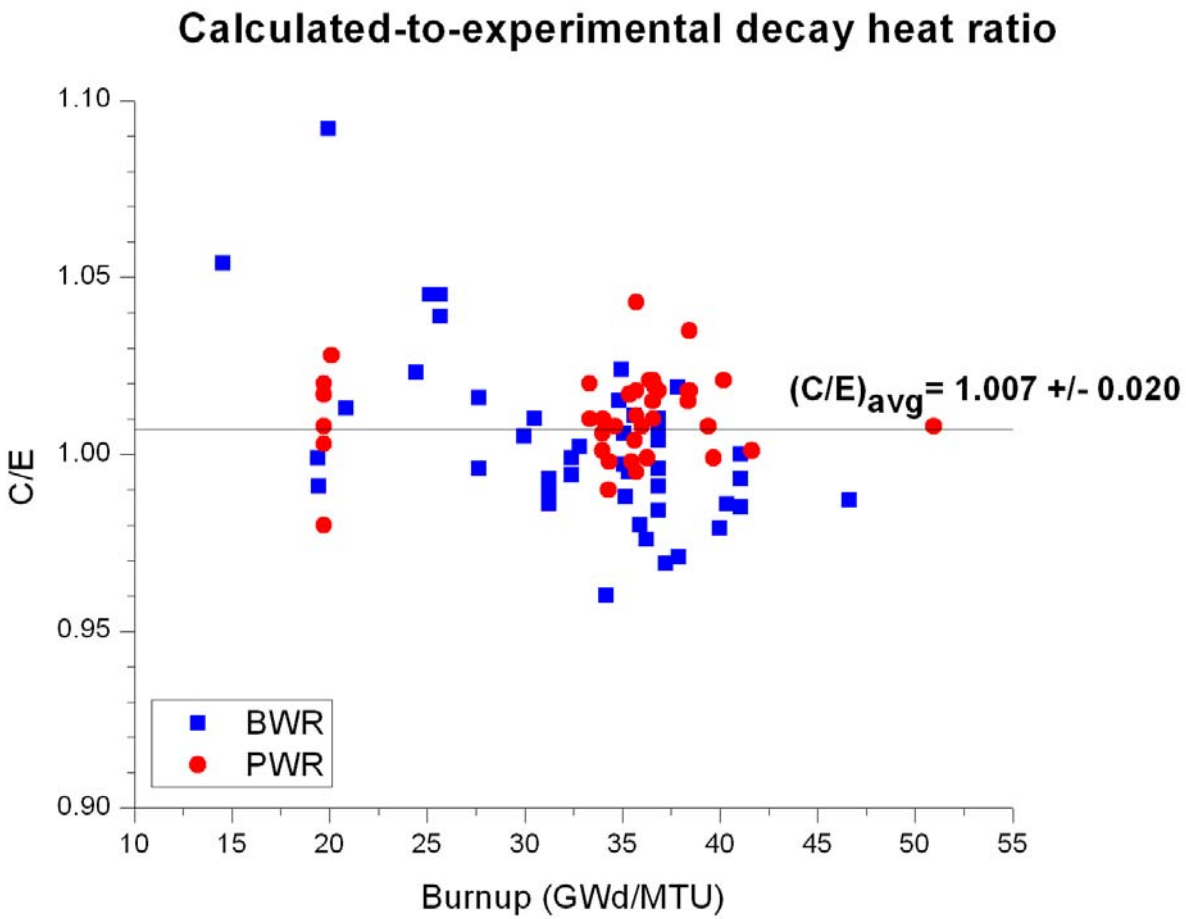
- **BWR Assembly Types**
  - ABB 8x8 (36)
  - Kraftwerk 8x8 (4)
  - SVEA-64 8x8 (4)
  - SVEA-100 10x10 (4)
- **PWR Assembly Types**
  - WE 15x15 (20)
  - WE 17x17 (16)



Calorimeter at Swedish Interim Spent Fuel Storage Facility CLAB, Oskarsham

ORIGEN-S Results for Swedish Fuels

(C/E = Calculation/Experiment Watts)

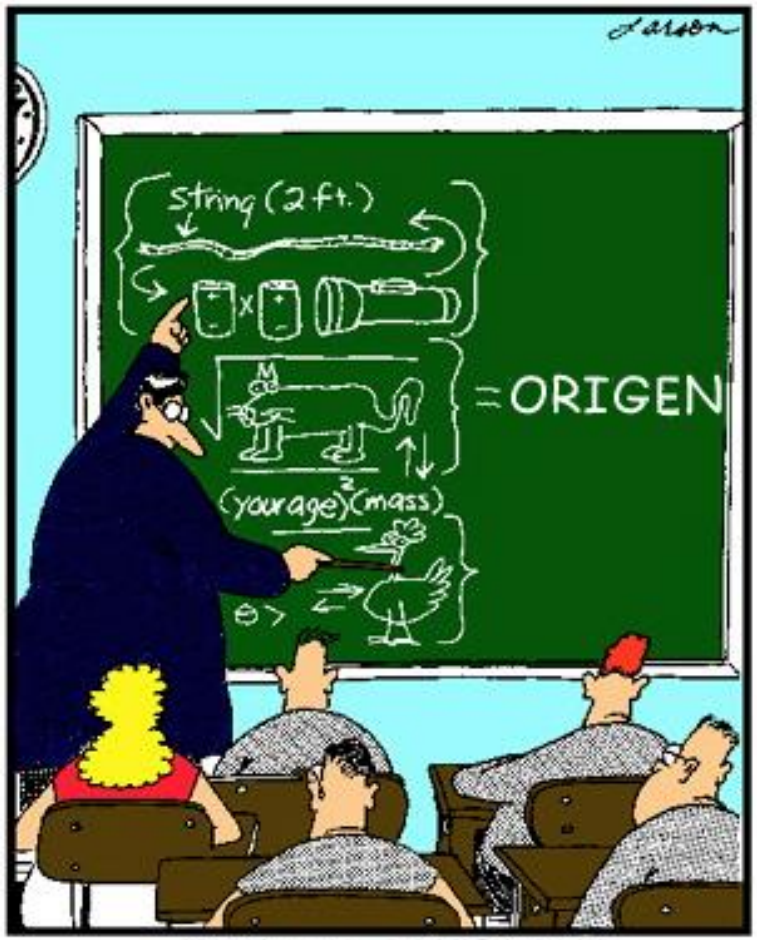


Swedish Fuels at CLAB Facility

- Higher burnup fuel
- High measurement accuracy
- Validation data reduces level of computational uncertainty
- Directly applicable to supporting regulatory guidance on decay heat

Summary

- **Nuclear fuel simulations are required for a wide range of spent fuel applications**
- **ORIGEN-S has the data to support applications over the time of seconds to millions of years**
- **most extensive validation database of any code available**
- **ORIGEN-ARP and the graphical Windows interface makes performing complex calculations easy, fast, and accurate for novice user and expert alike**



ORIGEN Explained

Questions?