

LLNL's Nuclear Criticality Safety and Reactor Physics Experimental Training Assemblies and Activities

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LLNL Has Two Experimental Assemblies for Nuclear Criticality and Reactor Physics Training

- Training Assembly for Criticality Safety (TACS)
 - Assembly using former critical experiment HEU shells
 - Training conducted at LLNL until 2012, then transferred to Nevada National Security Site
 - Training for Nuclear Criticality Safety (NCS) Engineers
- Inherently Safe Subcritical Assembly (ISSA)
 - Assembly with surplus HEU research reactor fuel from Los Alamos National Laboratory
 - Training begun in 2012 at LLNL
 - Wider training focus than TACS, including reactor physics concepts

LLNL HEU Shells: An Abridged History

- 1950's and 1960's- Livermore Critical and Subcritical Experiments
 - Nimbus Shells- Set of HEU (93.2% Enriched) Nesting Shells
- 1979- Criticality Safety Group establishes hands-on training for LLNL Fissile Material Handlers
- 1990- Training discontinued for handlers at LLNL
- 2006- US Department of Energy NCS Program Manager requests LLNL to start-up hands-on NCS training while LANL Critical Experiments Facility moves to Nevada

Training Assembly for Criticality Safety (TACS)

- Eight Nimbus HEU Shells
- Vertical lift machine with lower, moveable platform driven by a hand crank
- 1-D, spherical assembly
- Driven by neutron source
- Subcritical assembly with a peak multiplication of 10

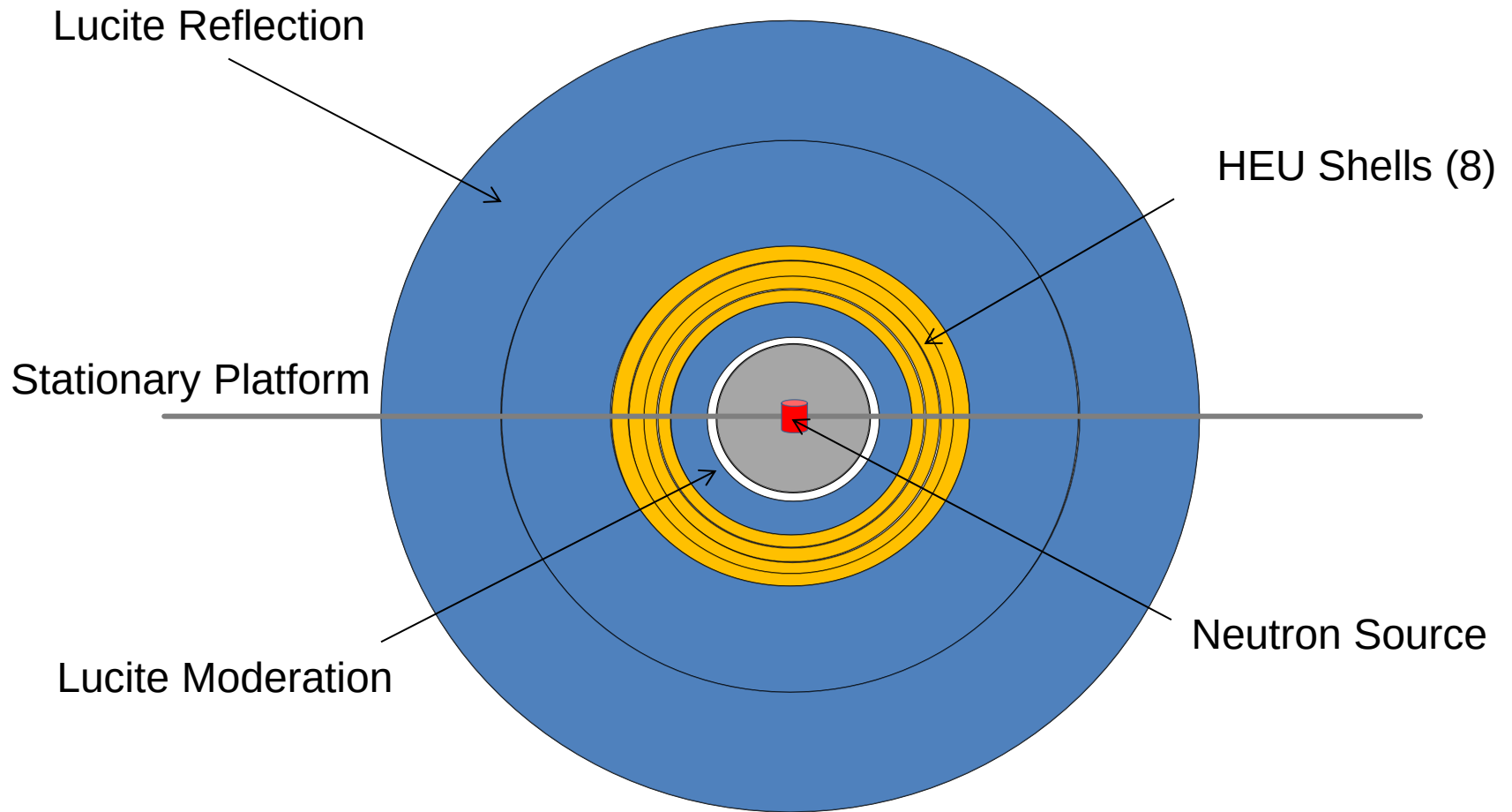


Uranium Shells



Eight nickel-clad HEU (93.15%) shells that nest together to create a 23 kg sphere with a central cavity.

TACS Details



Experimental Method: Two Experiments

Experiment 1: Conduct experiment with neutron source and depleted Uranium (D38) shells and use ^3He neutron detectors to take count rate, C_o .

Experiment 2: Conduct experiment exactly the same as Experiment 1, including same detector placement, but instead of D38 use HEU shells. Measure count rate, C .

Use data collected from experiments to determine *observed* M

$$M_{obs} = \frac{C}{C_o}$$

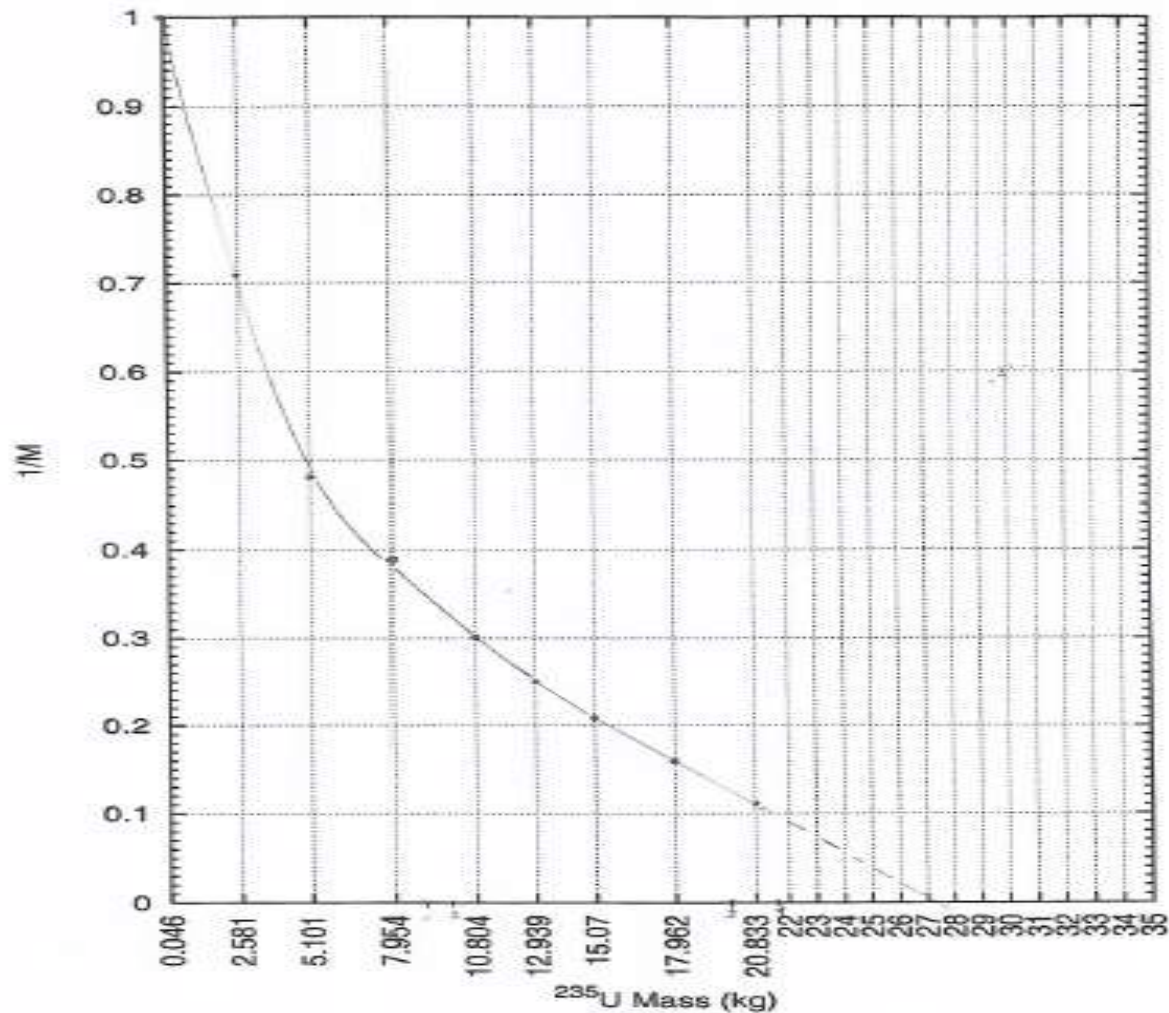


Experimental Method: Approach to Critical

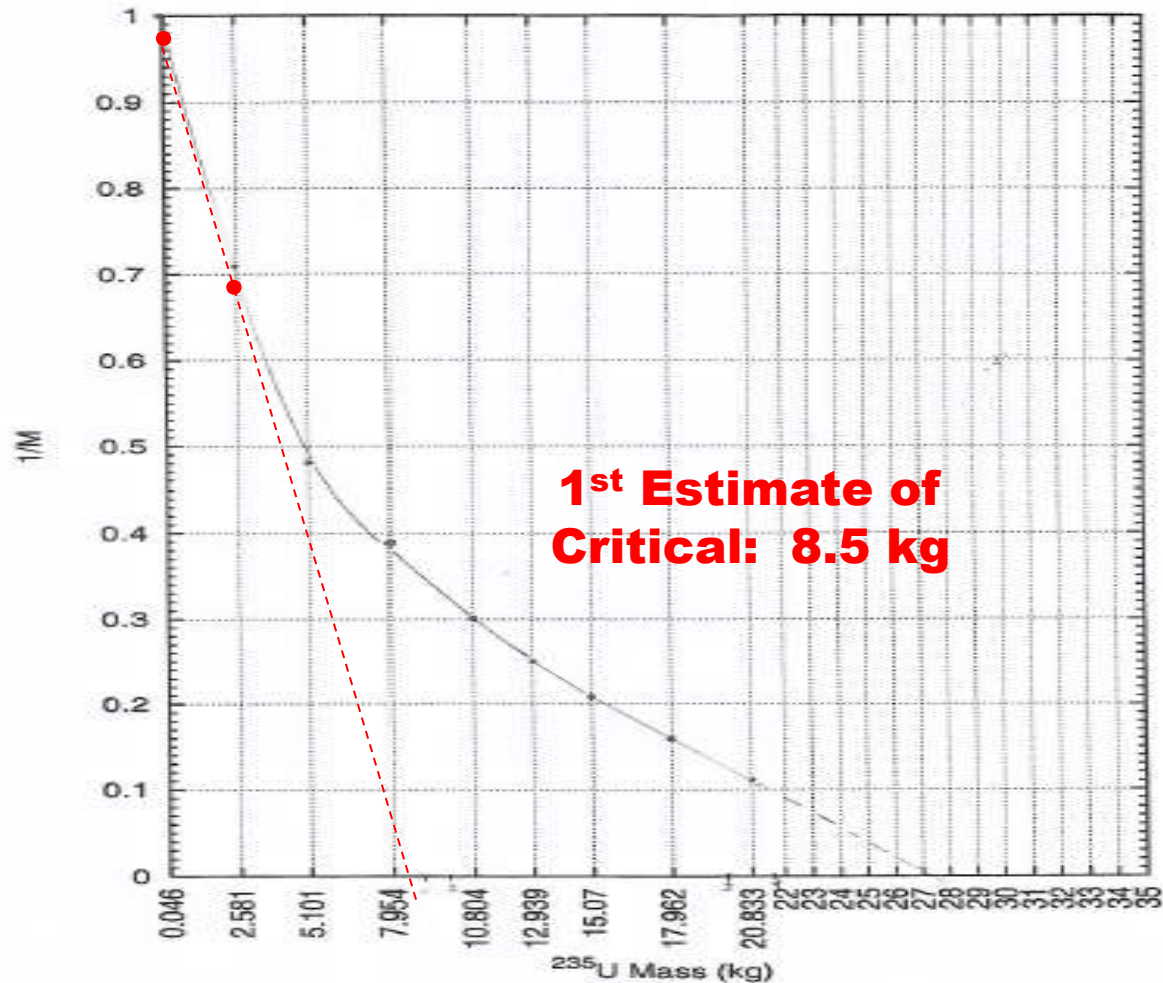
- Approach to Critical by Mass

- Step 1: Assemble TACS with D38 shells, determine neutron count rate, C_0
- Step 2: Add a known subcritical amount of mass (exchange one shell), determine neutron count rate, C_1 . Determine $M_{\text{obs1}} (=C_1/C_0)$. Plot $1/M$ versus mass.
- Step 3: Add a known subcritical amount of mass (exchange second shell), determine neutron count rate, C_2 . Determine $M_{\text{obs2}} (=C_2/C_0)$. Plot $1/M$ versus mass.
- Step 4....

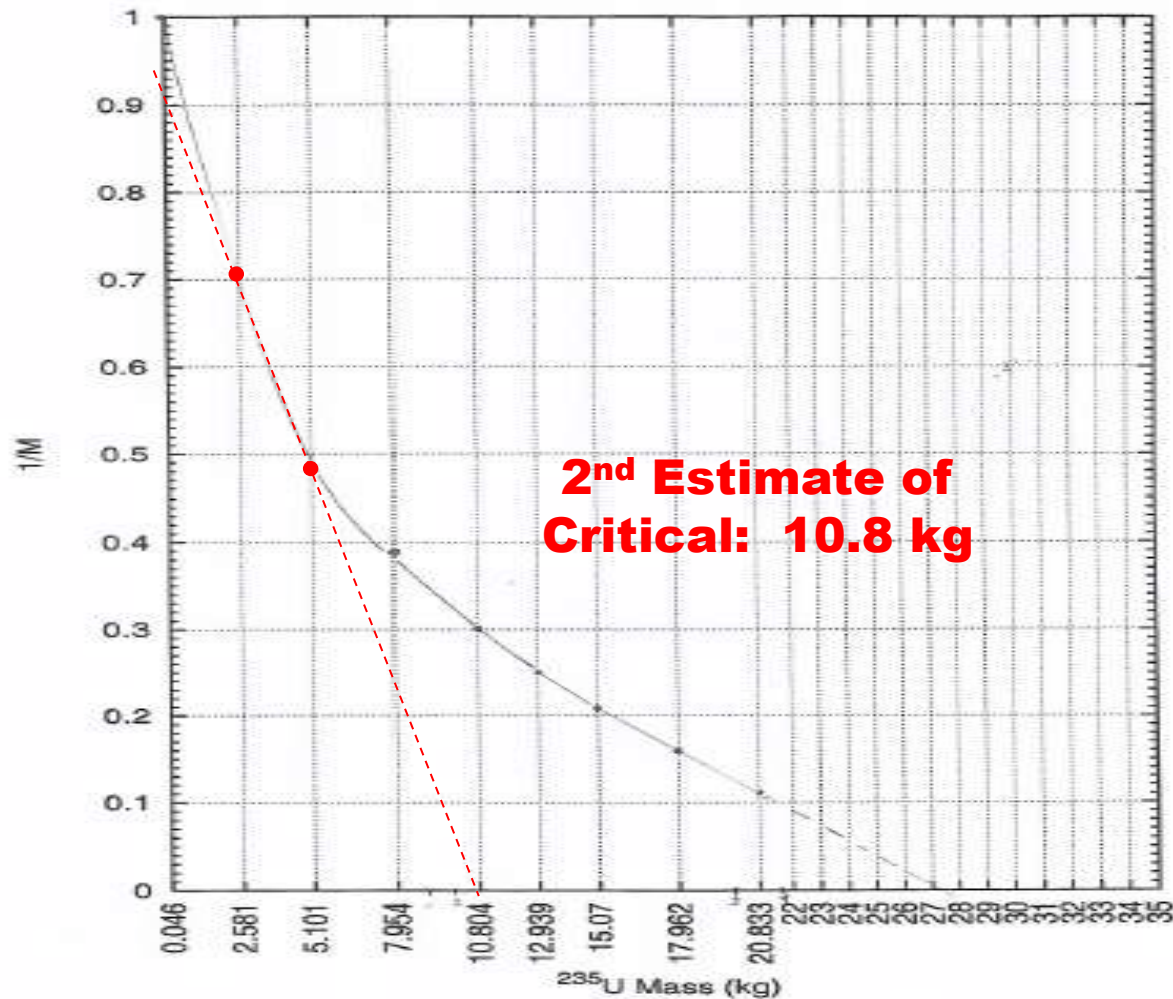
Class Data: Approach to Critical by Mass



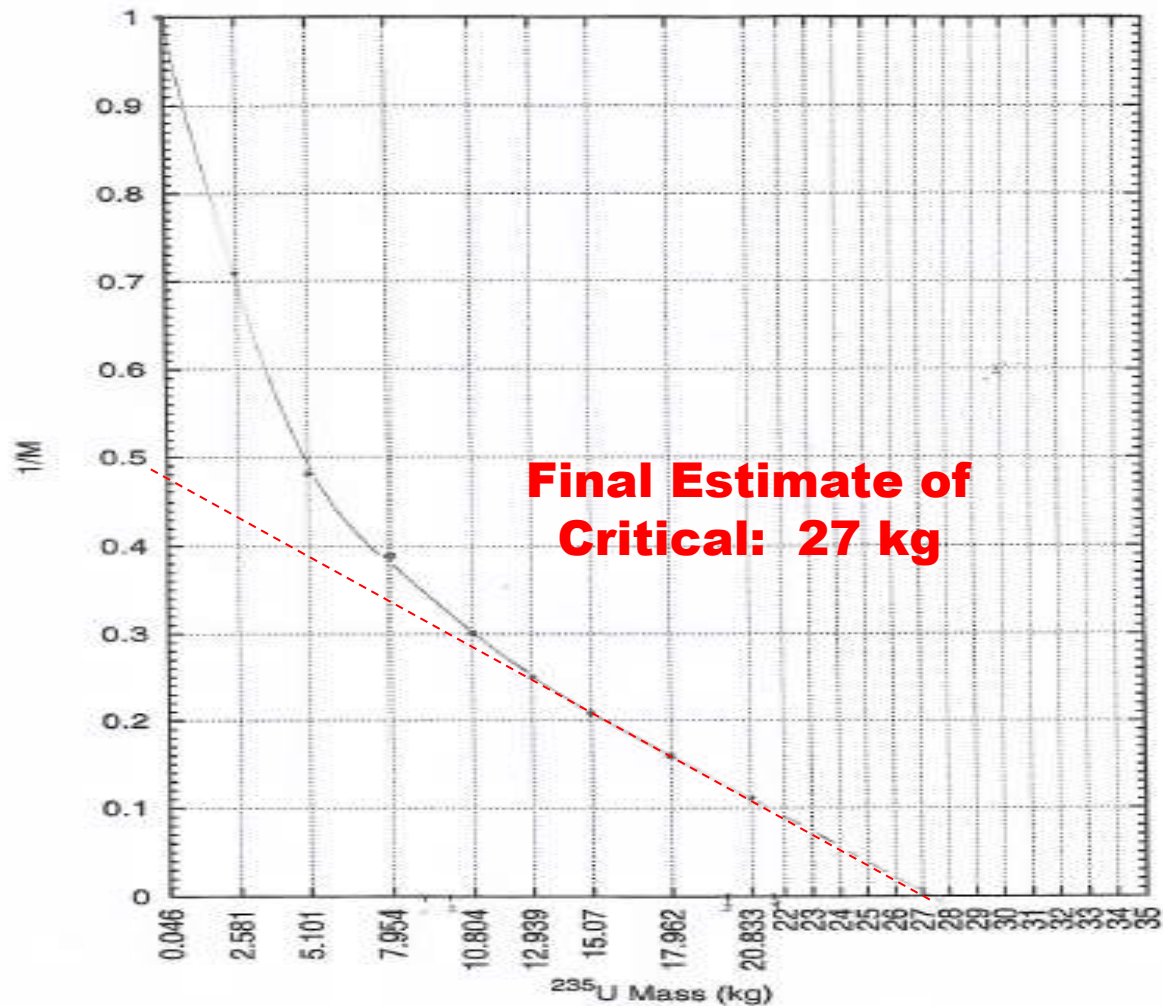
Class Data: Approach to Critical by Mass



Class Data: Approach to Critical by Mass



Class Data: Approach to Critical by Mass



Experiments Completed During TACS Training

- Approach to Critical by Fissile Mass
- Approach to Critical by Lucite Moderation
- Approach to Critical by Lucite Reflection
- Approach to Critical by Separation Distance
- Effect of Reflection by Operator Hands
 - Results reported in 2011 ICNC Paper for Criticality Safety Professionals
- Effect of Neutron Poisons



De-Inventory required Security Category I/II Materials such as the TACS to be removed from LLNL and transferred to other sites

- TACS contains Security Category I materials
- TACS transferred to more secure facility in Nevada, USA in 2012
- TACS remains a key asset for
 - National criticality safety training
 - LLNL detector development
- LLNL needed a TACS replacement for
 - Laboratory training
 - Detector development
 - Easy access at LLNL site



Conceptual Design

- Conceptual design criteria

- Inherent safety
- Simplicity
- Low cost
- Non-nuclear
- Accessibility

- What inspired us?

- SPERT-D arrays
- Delphi
- JSA



SPERT-D Array at ORNL c. 1964

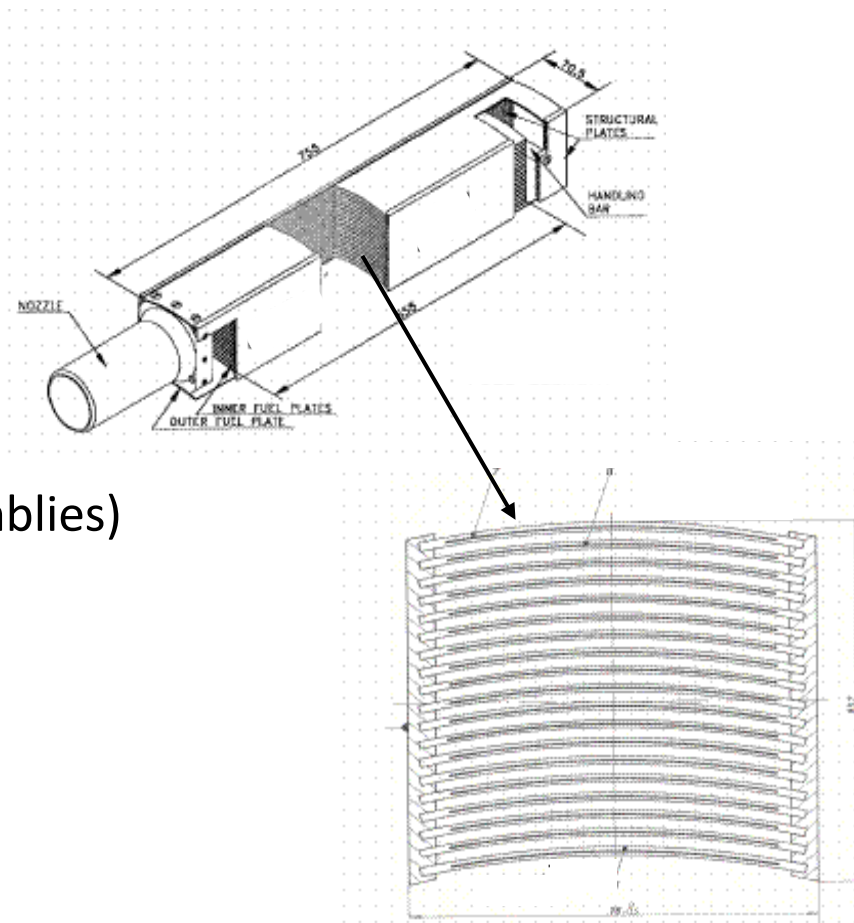


Jordan Subcritical Assembly (JSA)

A simple lattice in water. Is it possible to do? Can we afford to do it?

Omega West Reactor (OWR) surplus fuel available through the DOE Office of Fissile Material Disposition

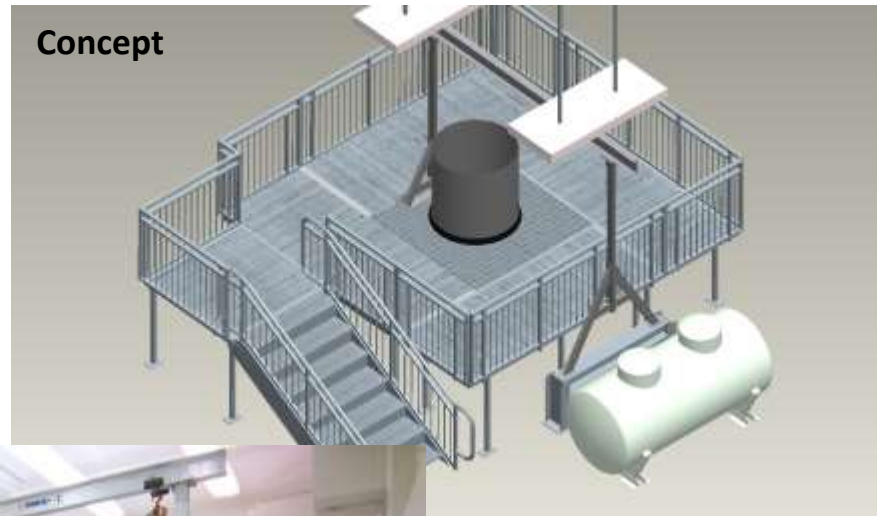
- Fuel specifications
 - Un-irradiated
 - 93 wt-% $g^{235}\text{U}/g\text{U}$
 - U_3O_8 -Al encapsulated in Al
 - 11.58 or 12.21 $g^{235}\text{U}$ per plate
 - 19 plates per assembly
 - 27 assemblies
- Security Rules for < 8 kg (34 assemblies)
 - Attractiveness Level D
 - Category IV
- Free except cost of transportation
 - ES3100 shipping containers



OWR fuel was an ideal choice for Security Category IV operations

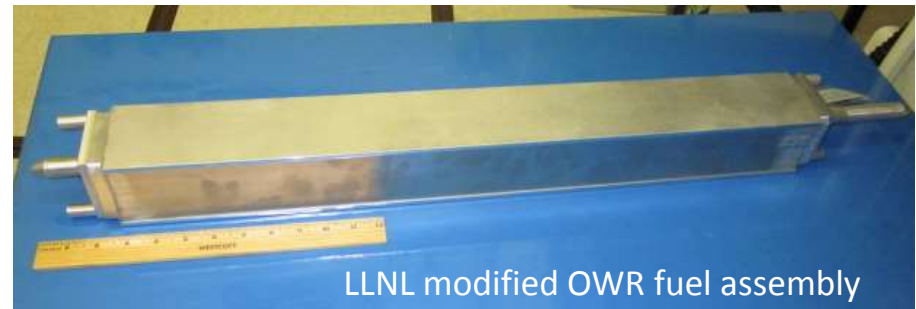
Surplus materials used to minimize project costs

- Surplus equipment
 - Reactor tank
 - Dump tank
 - Overhead hoist
 - Platforms and supports
 - Stairway and railing
- Purchases
 - Pumps and pipes
 - Tank penetrations
 - Anchors
 - Seismic restraints
- Labor
 - Machinist, crafts
 - Summer students



OWR fuel assembly modifications

- Modifications
 - Length only 3 feet
 - Weight only 12 pounds
 - Added “feet” and handles
 - Reactor tank extended
- Fabrications from scrap
 - Matching all aluminum “mock” assemblies
 - Fuel stand
 - Lattice support structure
 - Detector tube wells
 - Tube well supports
 - Supports for E-600 detectors



ISSA as-built assembly

- Detectors

- Small ^3He tubes
- 3-ft ^3He tubes
- E-600 detectors
- Fission meter



- Sources

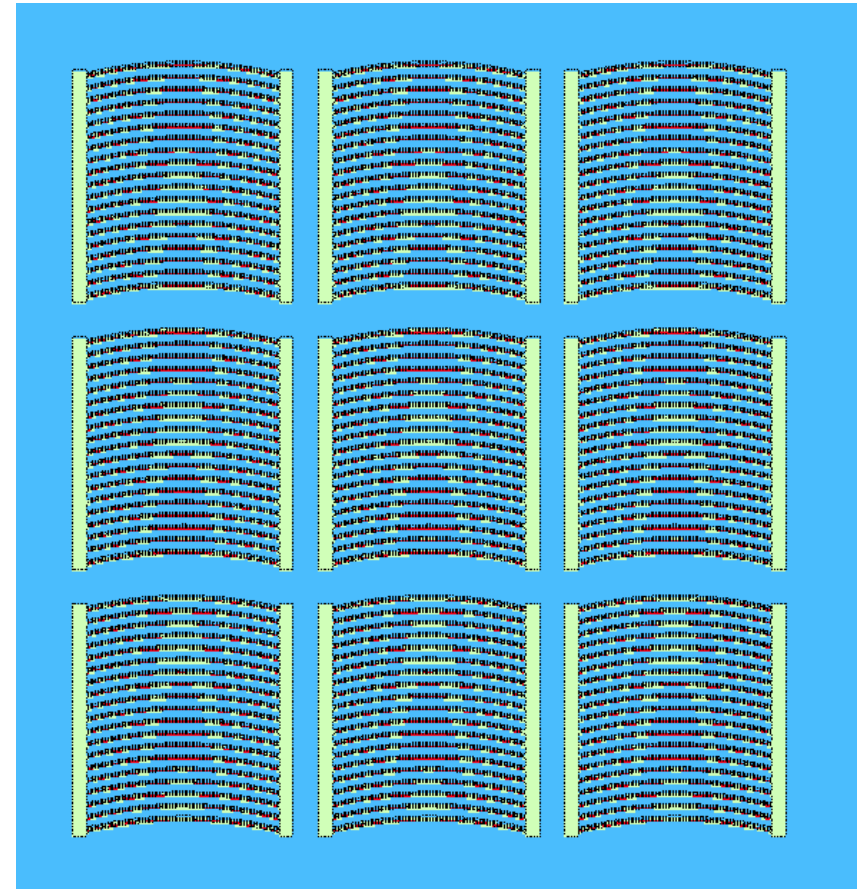
- ^{252}Cf
- SF
- (α, n)



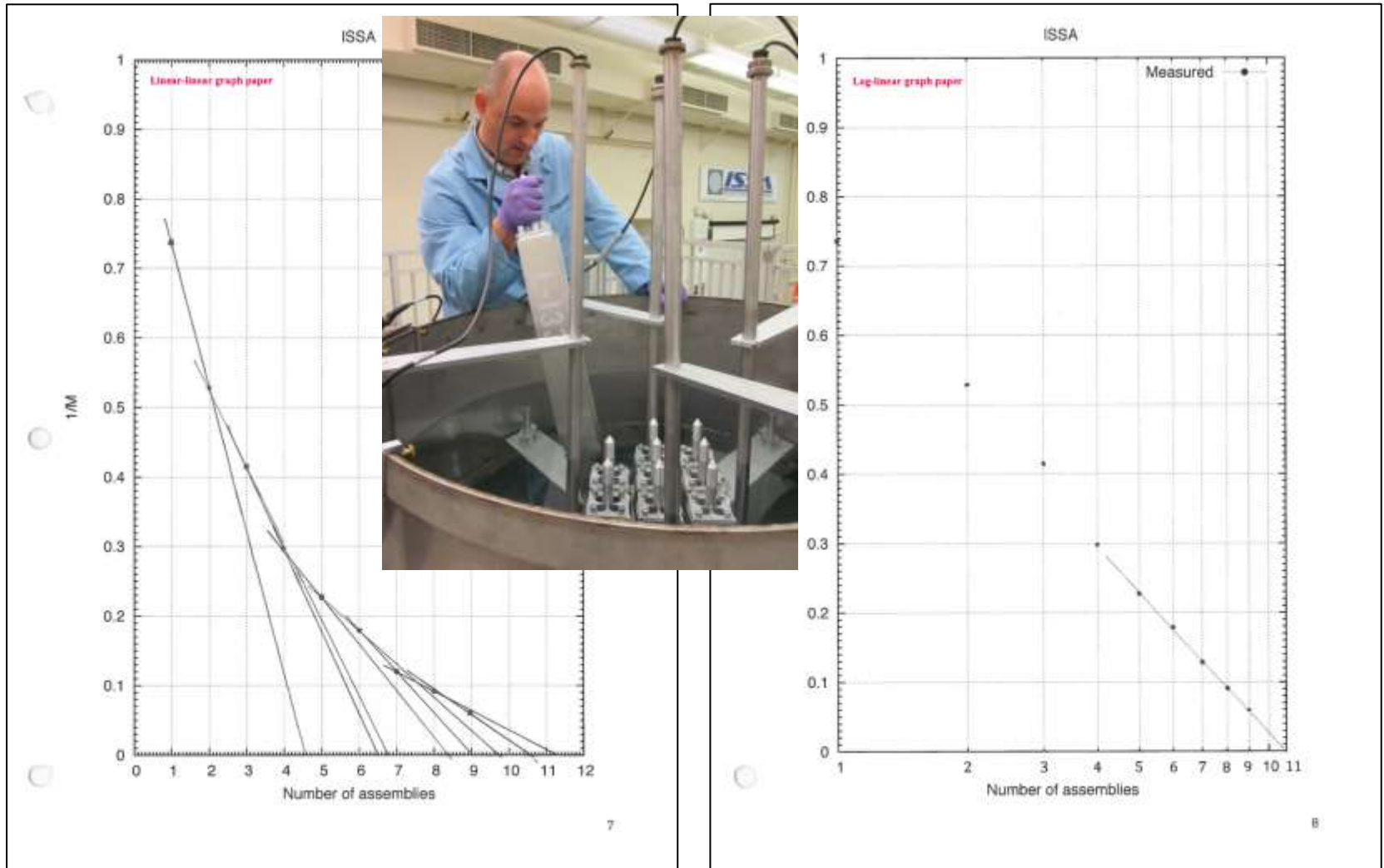
ISSA Criticality Modeling with COG10 Code

Detailed COG10 Model Geometry

- Criticality Modeling
 - $N_C = 10.5 \pm 0.5$ assemblies
 - $N_{SAFE} = 9$ ($k\text{-eff} = 0.958$)
- 1/M measurement results
 - $N_C = 11$
 - $M = 20$ (for 9 assemblies)



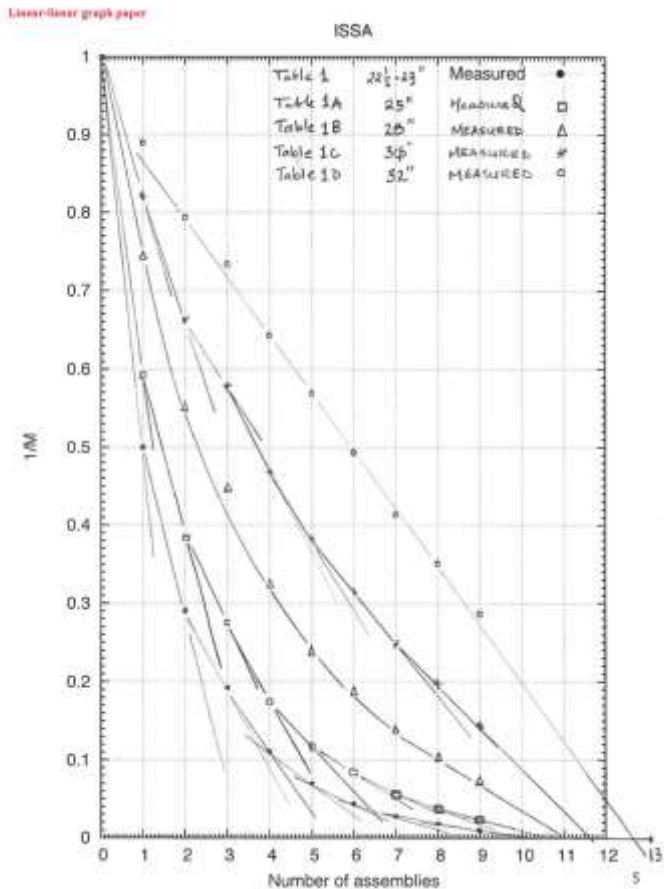
ISSA approach-to-critical (by mass)



ISSA training available today (✓) and in development (•)

Lectures	Experiments
Basic physics • Inherent sources of neutrons • External neutron sources (^{252}Cf) • Neutron cross sections ✓ Physics of chain reactions • Diffusion and Fermi age theory ✓ Modified one group diffusion equation ✓ Neutron kinetics equation • Statistics of chain reactions Hand calculations • Six factor formula ✓ Diffusion constants ✓ k-infinity, migration area and buckling ✓ <u>Nucleonics</u> data sheet no. 38 ✓ Alpha, k_{eff}, reactivity • Count distributions and Feynman-Y Computer codes ✓ RHEINGOLD (Diffusion) [8] ✓ ARDRA (S_N) ✓ COG (Monte Carlo)	Source multiplication experiments ✓ 1/M vs. mass (or number of assemblies) ✓ Detector placement effects ✓ Source effects ✓ 1/M vs. moderator height • 1/M vs. pitch • Effect of over/under/optimum moderation • Effect of isolation by water • Effect of neutron poisons (including flux traps and control rods) • Effect of reflector materials ✓ Effect of core shape on leakage • Temperature reactivity coefficient • Fuel reactivity coefficient • Void reactivity coefficient Dynamic experiments • Source jerk • Pulse die-away ✓ Feynman-Y Spatial methods ✓ Buckling and extrapolation length

ISSA experiments demonstrating detector placement effects

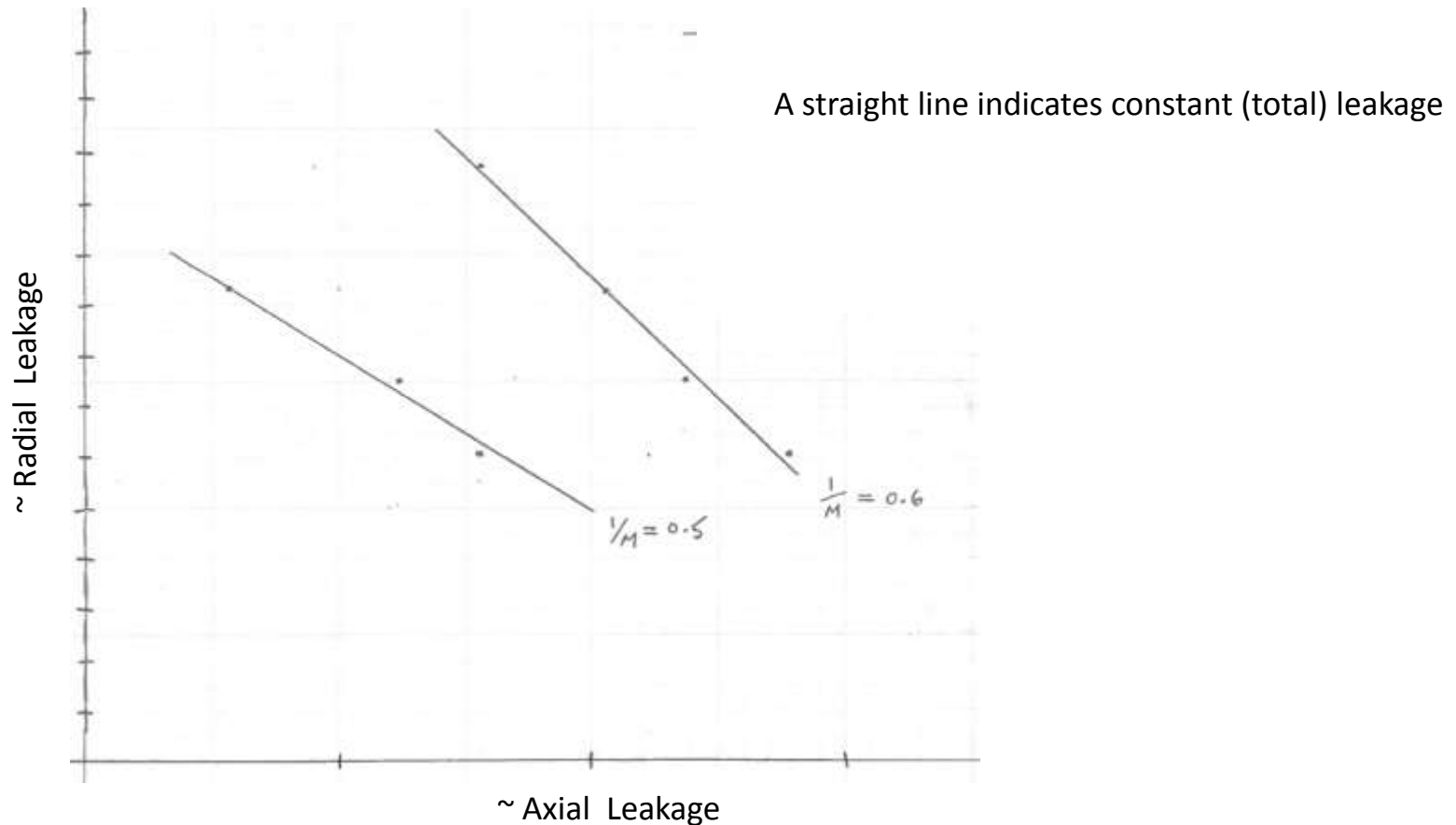


SCSU summer students Crystal Green and Una Stephens



Lesson-learned: apparent multiplication is not an absolute measure of reactivity

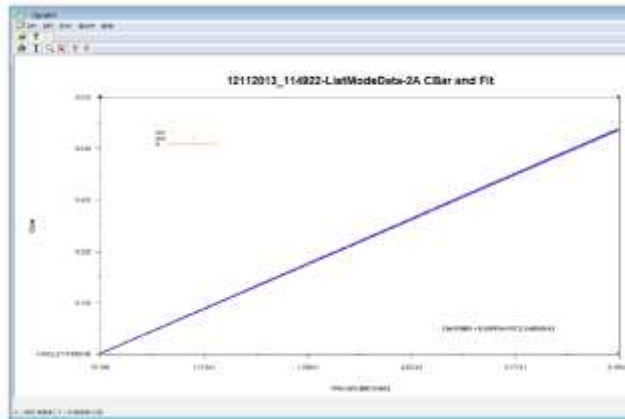
ISSA experiments demonstrating axial and radial leakage effects



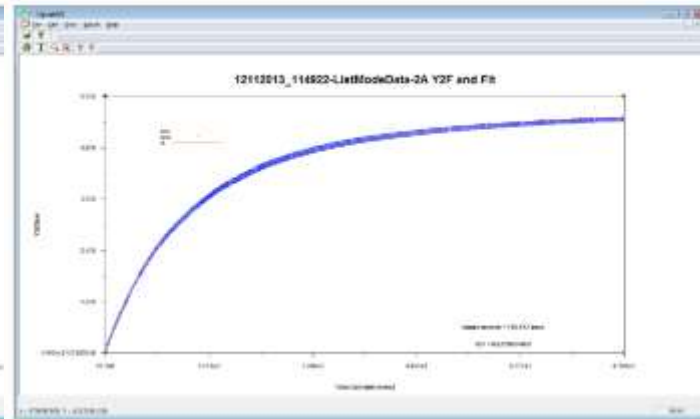
One-group modified diffusion theory used to analyze $1/M$ experimental results

ISSA count distribution experiments and Feynman–Y analysis

First Moment: count rate = 86 cps

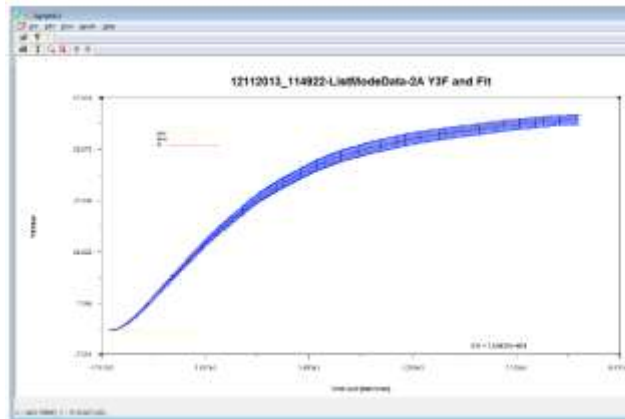


Second Feynman Moment Y2F:

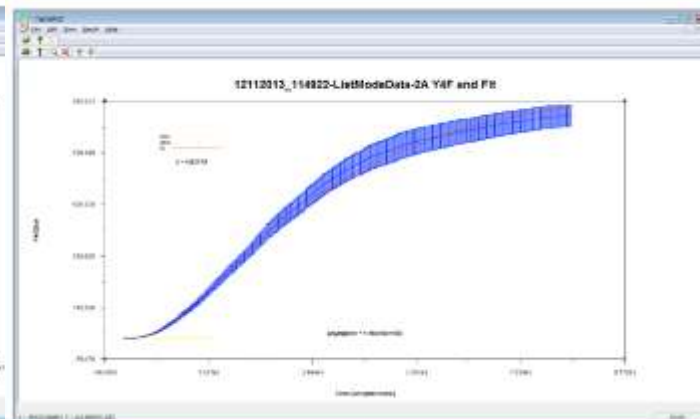


LLNL time-tagger suitcase

Third Feynman Moment Y3F:



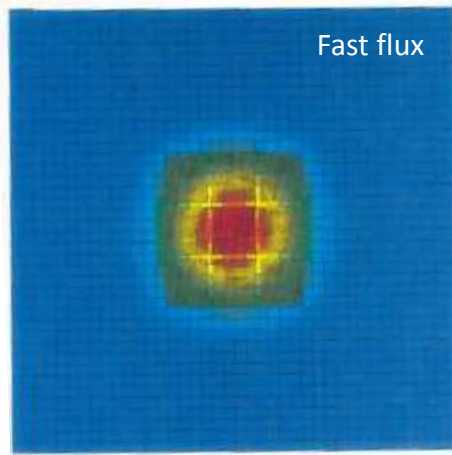
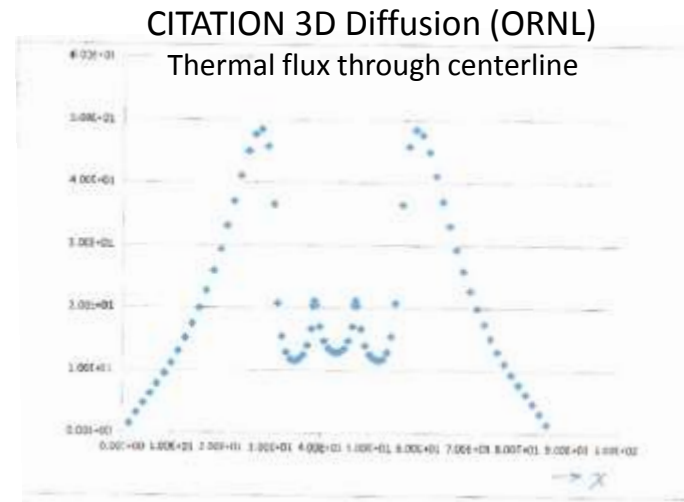
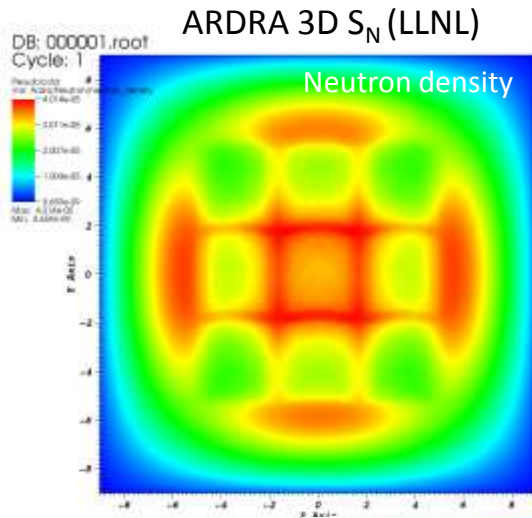
Fourth Feynman Moment Y4F:



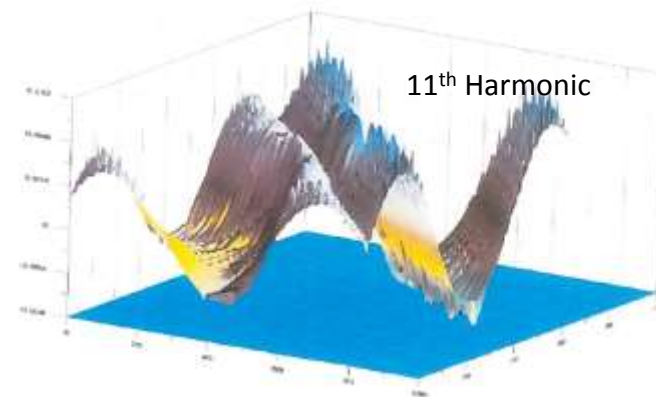
with RS-P4-1636-210 tubes

BIGFIT analysis results for nine assemblies: $M=22.5$

ISSA other (deterministic) analysis methods



NEWT 2D Discrete Ordinates (ORNL)



RHEINGOLD 2D Higher Harmonics Analysis (JAEA)

J. Nucl. Sci. Tech. **40** (2) 77-83 (2003)

ISSA current and future activities

- Training
 - Institutional asset
 - Available to external users
- ICSBEP benchmark
 - Fundamental physics (multiplicity)
 - In partnership with LLNL N-Division
 - In collaboration with IRSN
- Source-jerk experiment
 - Install jerk-able source or neutron generator
 - Use time-tagger suitcase and large ^3He tubes
 - Possible student project



Acknowledgements

- DOE Office of Fissile Material Disposition
- DOE Nuclear Criticality Safety Program
- Babcock & Wilcox Corporation
- Livermore Field Office
- South Carolina State University



ISSA other (handbook) analysis methods

■ NUCLEONICS

- Vol. 18, No. 7, p. 59, 1960
- Data Sheet No. 38
- k_{∞} and M^2 curves
- Sample calculation for:
 - δ (extrapolation length)
 - B^2
 - k_{eff}

