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Lawrence Livermore National Laboratory

Hands-on Nuclear Criticality Safety Training at Lawrence Livermore National Laboratory

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LLNL Uranium 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 Fissile Material Handlers
- 1980's- Training discontinued for handlers at LLNL
- 2006- DOE NCS Program Manager requests LLNL to start-up hands-on NCS training while LANL Critical Experiments Facility moves to Nevada

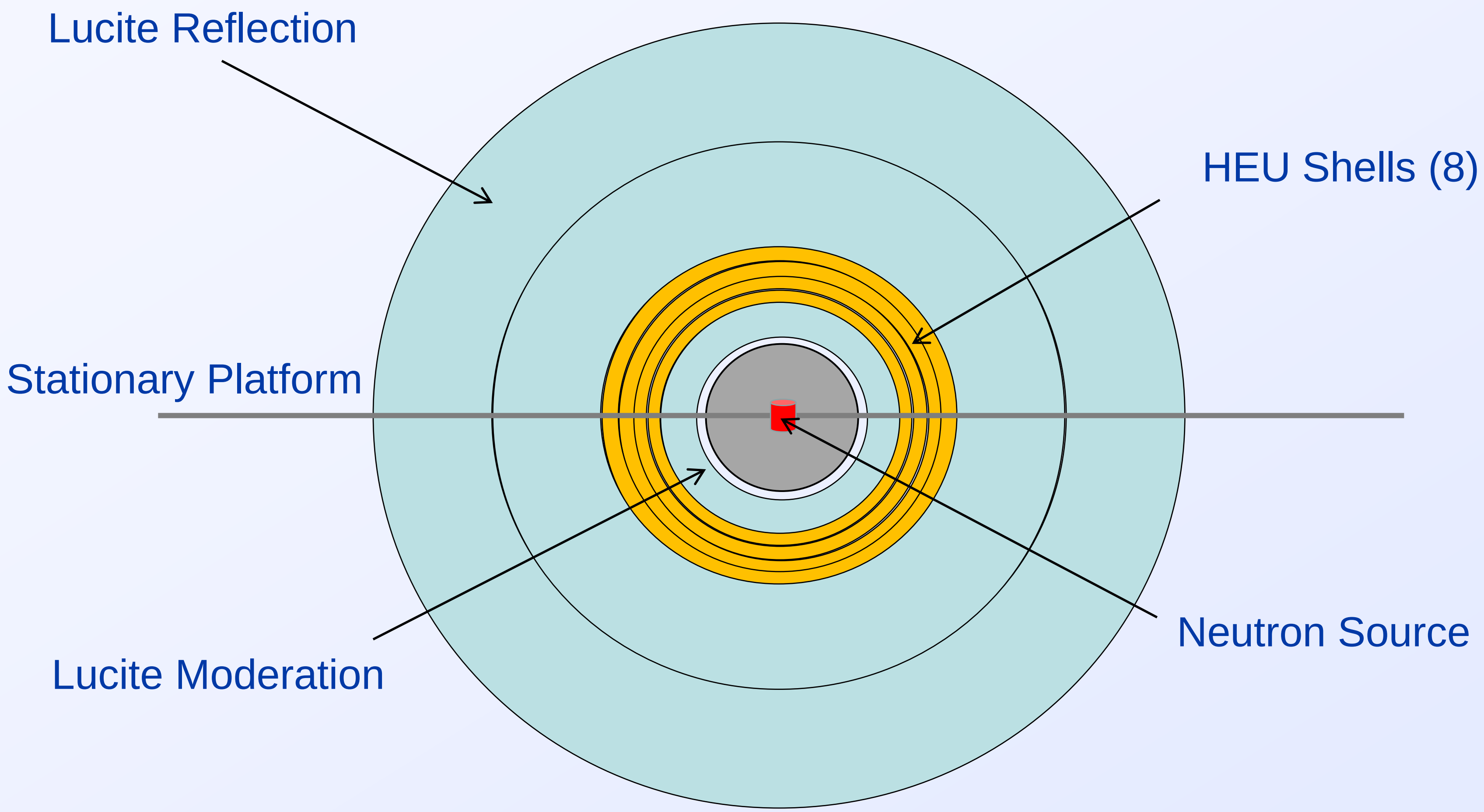
Training Assembly for Criticality Safety (TACS)

- 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



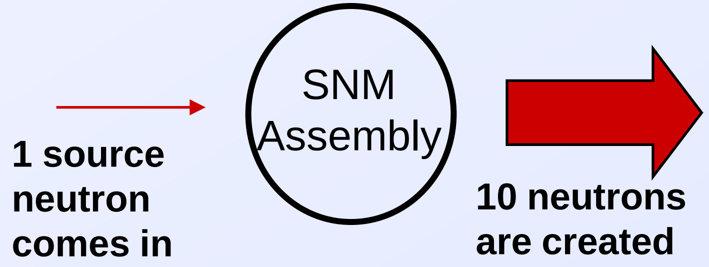
Experimental Method- Defining Multiplication

- Multiplication, M
  - Ratio of the number of neutrons per unit time in the assembly to the number of neutrons due to the source alone (not from fission):

$$M = \frac{\nu F + S}{S}$$

Where ν is the average number of neutrons per fission (nubar), F is the fission rate, and S is the rate at which the source neutrons enter the assembly

  - The assembly has in effect “amplified” the number of neutrons through fission



Experimental Method: Relating M to k

- Criticality Safety Engineers refer to k, not M, of a system
- Definition of k:

$$\mathrm{k} = \frac{\#\text{ of neutrons in current generation}}{\#\text{ of neutrons in preceding generation}}$$

- The S source neutrons will generate Sk first generation neutrons; these in turn will generate (Sk)k or Sk^2 second generation neutrons, and so on
- Adding all neutrons from all generations and substituting for total neutrons (source plus fission) yields:

$$M = \frac{\nu F + S}{S} = \frac{S(1 + k + k^2 + \ldots)}{S}$$

Experimental Method: Relating M to k

- For k values less than one, the series in this equation can be reduced to:

$$M = \frac{S(1+k+k^2+...)}{S} = \frac{1}{1-k}$$

- Example: For a system with a multiplication of 10 (source is multiplied 10 times), the k value would be 0.9

Experimental Method: Determining M

- Measure the neutrons that leak out of the assembly with ^{3}He detectors
  - What does this tell us?
    - Number of neutrons that manage to escape from the assembly, make it to our detector active volume, and get absorbed in the detector
    - Detector cannot tell us the number of neutrons in entire assembly
    - Detector hits are only a fraction of the total number of neutrons leaking from the assembly
- To determine M, we must be clever
  - We know that

$$M = \frac{\nu F + S}{S}$$

Neutrons in assembly with source and with fission

Neutrons in assembly with source and without fission

  - What if we were able to turn fission "off" and do a count rate measurement?

Experimental Method: Two Experiments

Experiment 1: Conduct experiment with neutron source and depleted Uranium (D38) shells and use ^{3}He 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.

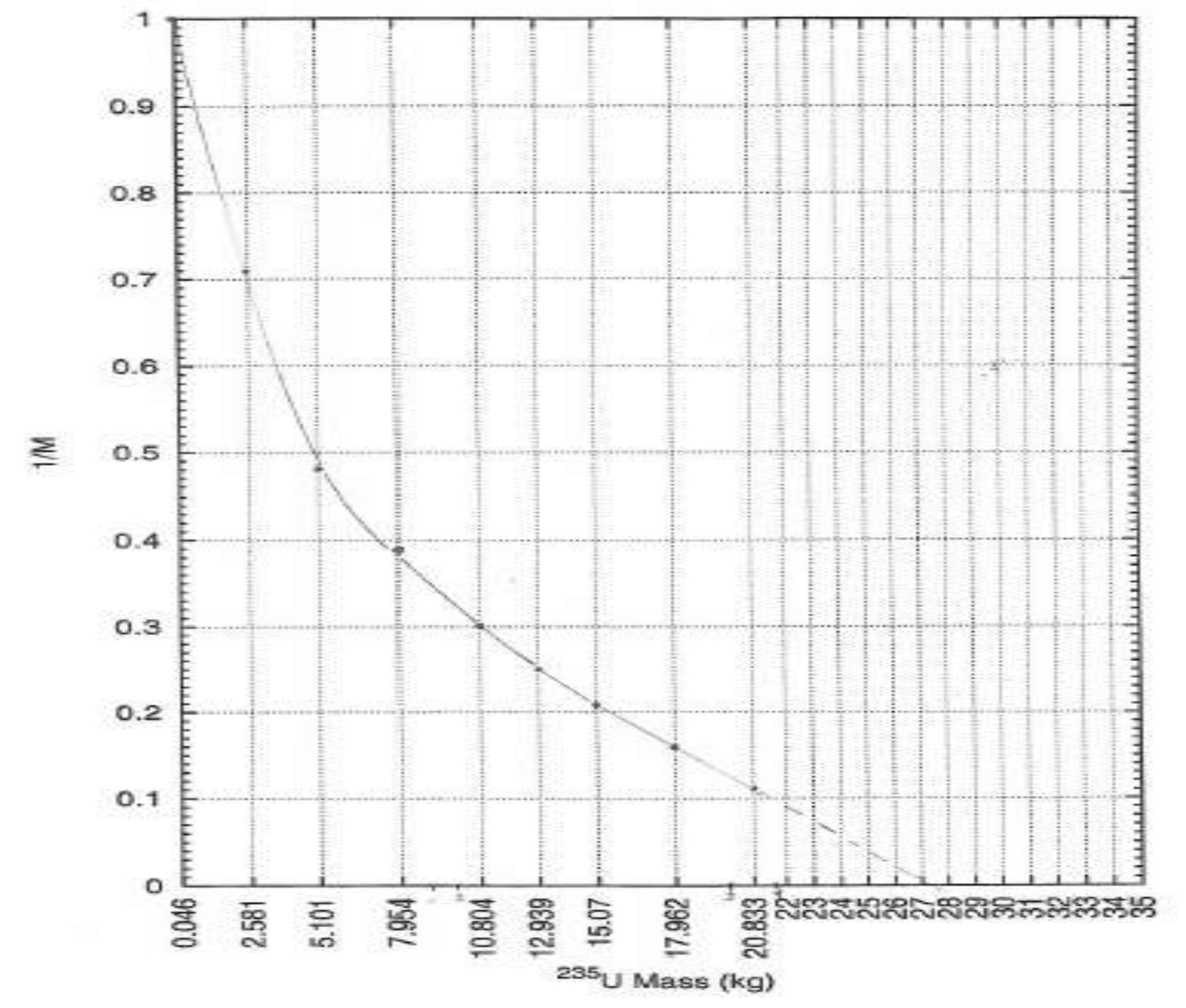
Use data collected from experiments to determine *observed* M

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

Experimental Method: Approach to Critical

- Approach to Critical by Mass
  - Step 1: Assemble TACS with D38 shells, determine neutron count rate, C_o
  - Step 2: Add a known subcritical amount of mass (exchange one shell), determine neutron count rate, C_1. Determine M_{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_{obs2} ($=C_2/C_0$). Plot 1/M versus mass.
  - Step 4….

Class Data: Approach to Critical by Mass



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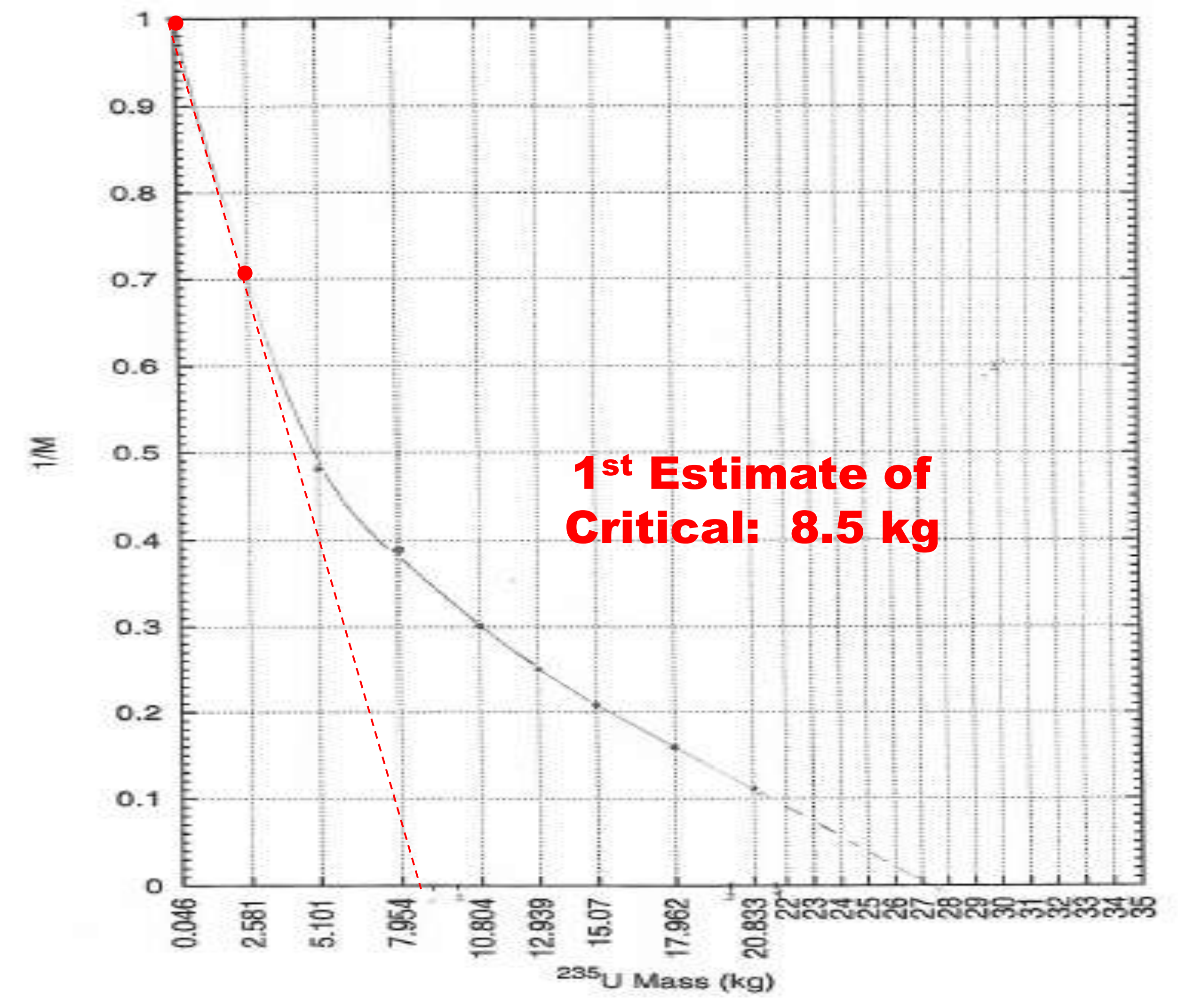

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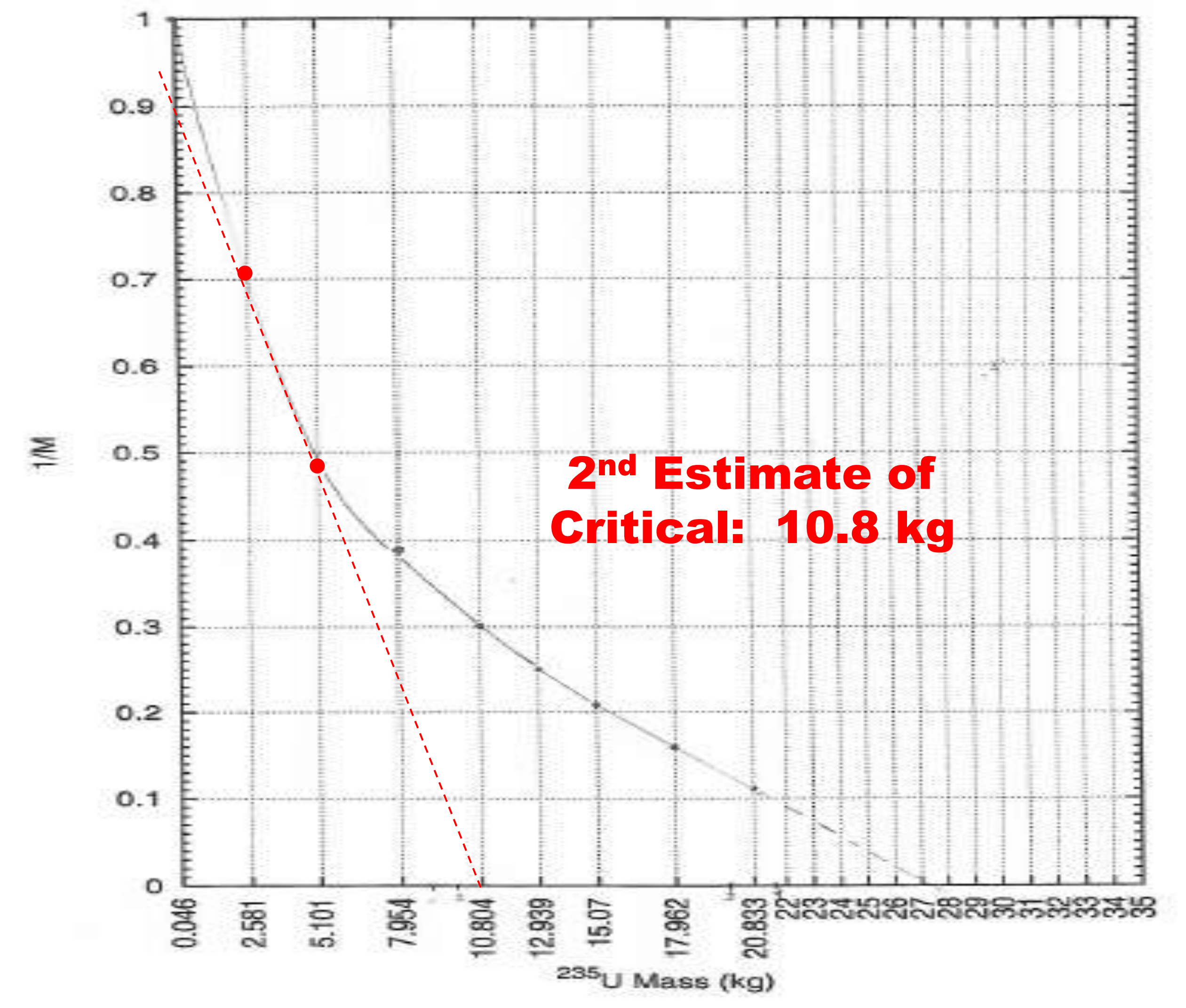

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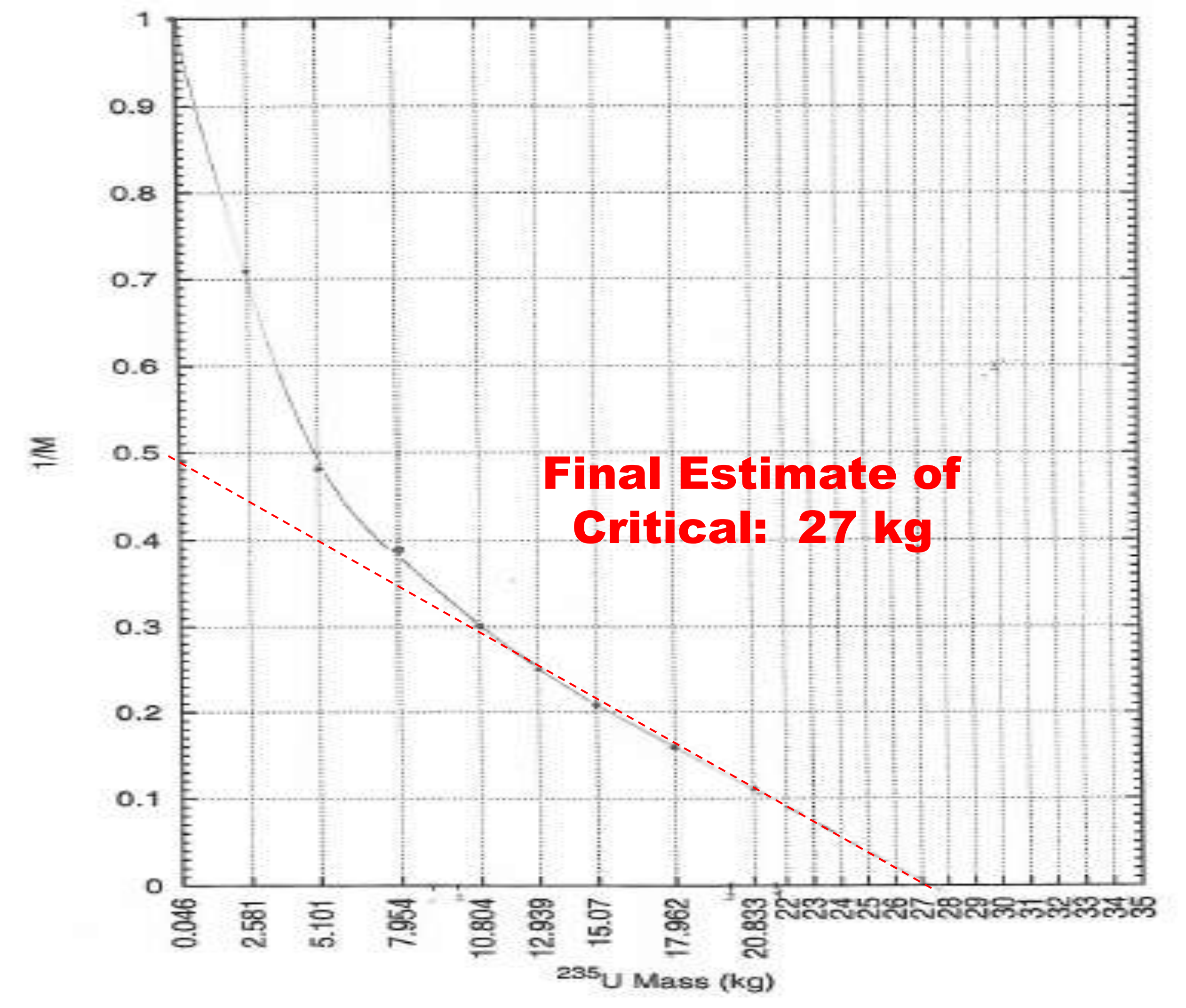

Experiments

- 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
- Effect of Neutron Poisons

NCS Lecture Topics

- Course satisfies DOE-STD-1135-99 requirement for hands-on NCS training
- Additionally, lecture topics include the following:
  - Criticality Safety Fundamentals
  - DOE NCS Regulations
  - Hand Calculations and Computational Methods
  - NCS Evaluations
  - Nuclear Instrumentation
  - Criticality Accidents, including in-class exercises with the Criticality Accident Slide Rule

Course Dates Scheduled at LLNL for 2011

January 24 – January 27, 2011
January 31 – February 3, 2011
February 28 – March 3, 2011
March 7 – March 10, 2011
April 4 – April 7, 2011
April 11 – April 14, 2011

Registration Website:

http://ncsp.llnl.gov/classMain.html

Questions?