# K-eff vs Fraction of Critical Mass

LA-UR-14-21818

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March 26, 2014

# Background

- Execution of Approach to Critical via mass additions
  - Critical mass estimated via 1/M
  - Eventually, operators reach a mass where smallest insertion results in system ABOVE delayed critical
  - ➔ Accurate estimation important to ensure system stays below reactivity limit
  - Traditional approach at LANL
    - Plugging limits and predicted critical numbers into equation, based on fit of simulated data while applying expert judgment
  - Options of available mass, ie units, must be evaluated

# Traditional LANL Approach

- Based on 1996 memo by R. Odell for spherical systems
  - Analyzed metal and solutions, both bare and reflected systems

$$\Rightarrow \quad k_{eff} = \left(\frac{m}{m_c}\right)^E$$

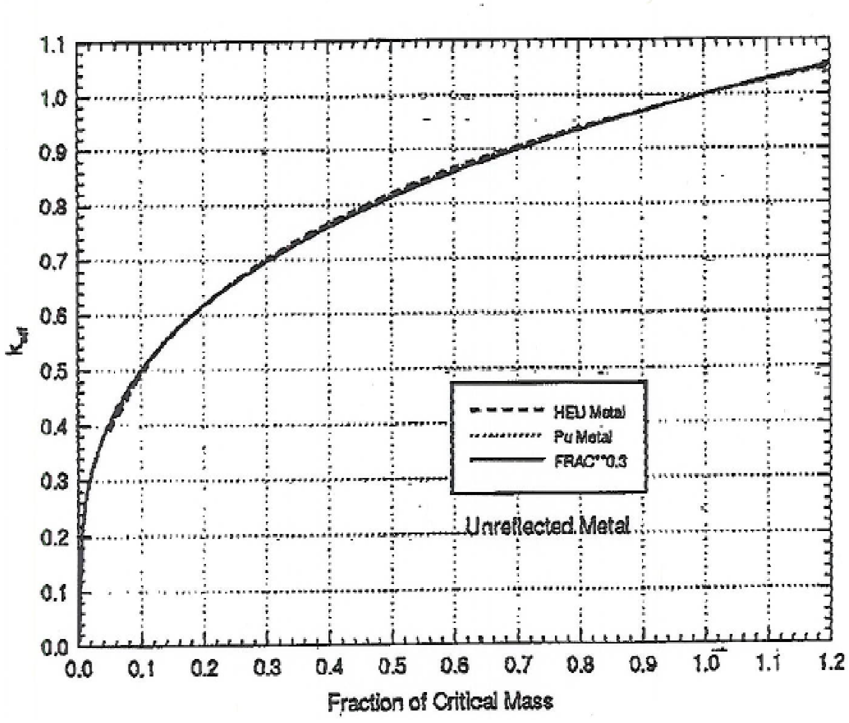
  - m = mass of system
  - $m_c$ = estimated critical mass
  - E= exponential constant
    - Metal: E=0.30
    - Solution: E=0.25

# Reactivity Determination

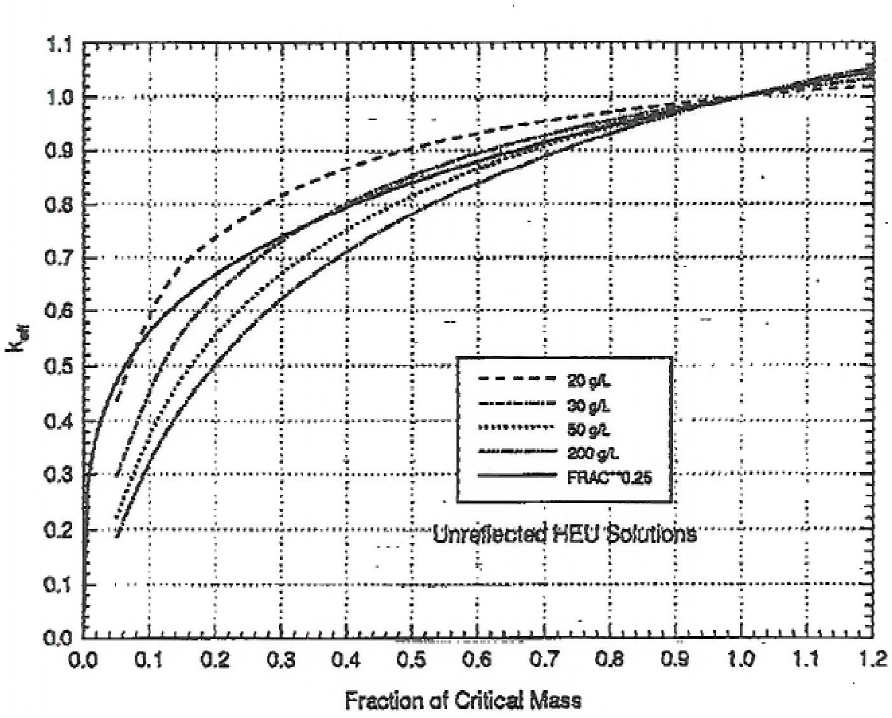
- Reactivity limit defined in dollars ($)
  - $\left(\frac{\rho}{\beta_{eff}}\right)[\$] = \frac{k_{eff}-1}{(k_{eff}*\beta_{eff})}$
    - $\rho/\beta_{eff}$ is reactivity
    - $\beta_{eff}$ is effective delayed neutron fraction
    - $k_{eff}$ is calculated multiplication factor, based on fraction of critical mass

# O'Dell memo

- Metal System

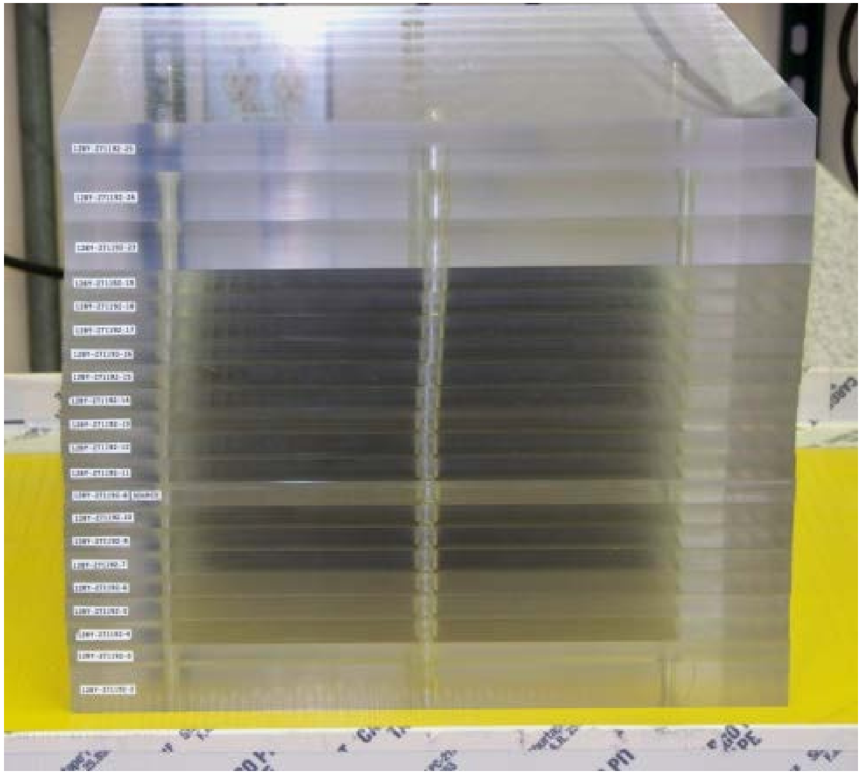



- Solution System



# Application at LANL

- This method used in nearly all approach to critical experiments at National Criticality Experiments Research Center (NCERC) in which mass additions are performed
  - Assume E=0.30
- Class Foils
  - HEU metal foils
    - 9x9x0.003 in.; ~70 g each
  - Moderated and Reflected by Lucite plates
    - 14 x 14 x 0.5 in.
  - 3 in. thick top and bottom



# Class Foils Experiment

- Used for criticality safety training courses
- Consists of approach-to-critical as a function of number of units
  - 1 unit= 1 HEU foil + 1 Lucite plate
  - Prior to mass addition which is expected to be above delayed critical, the resulting $k_{eff}$ after last mass addition is predicted
    - $k_{eff} = \left(\frac{\#\ foils\ after\ addition}{\#\ estimated\ foils\ for\ critical}\right)^{0.30}$
    - # estimated foils for critical based off last 2 points of 1/M plot

➔ Is E=0.30 the best value for this system???

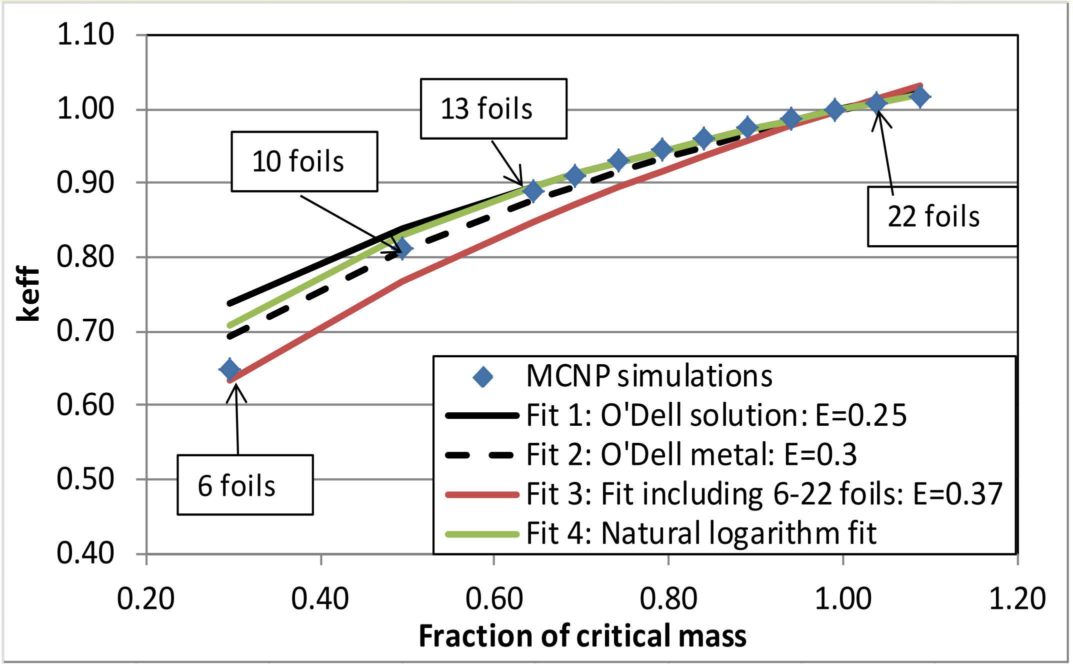
# Simulation of Class Foils Experiment

- While fissile material is metal, the system includes primarily Lucite [$C_5O_2H_8$], density= 1.18 (g/cm$^3$)
  - Lucite acts as a moderator, very similar to water
  - Result: system behaves like solution
- Based in MCNP
  - approximately 93% fissions caused by thermal neutrons
- Simulation Details:
  - 6-22 foils, $k_{eff}$=0.65 to above delayed critical
  - S(α,β) for polyethylene used since these data do not exist for Lucite

# Simulation of Class Foils Experiment

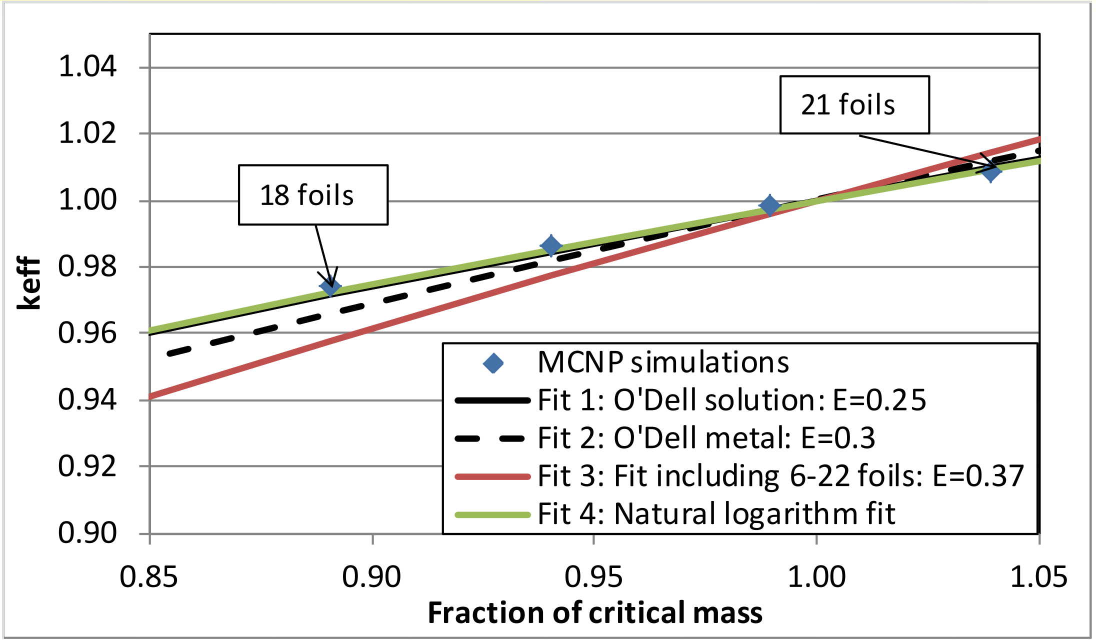
- 1/M curve with 19-22 foils used to estimate $m_c$ of 20.21 foils
- $k_{eff}$ calculated with 4 ways
  - Odell, E=0.30
  - Odell, E=0.25
  - Odell, Least squares fit of 6-22 foils, E=0.37
  - Logarithmic fit, 6-22 foils, $k_{eff}=0.24*\ln(m/m_c)+1$

# Simulation of Class Foils Experiment




- Fits 1, 2, 4 all grossly overestimate $k_{eff}$ when fraction critical low
  - Much more important to know $k_{eff}$ when close to critical

# Simulation of Class Foils Experiment




- Fit 3 is not accurate near criticality and as such, should never be used
- Fits 1, 2, 4 match reasonably well
  - Fits 1 and 4 clearly match the data better than Fit 2 near criticality

# Measured Results of Real Class Foils Experiment

- 5 repetitions between 2012 and 2013 at NCERC

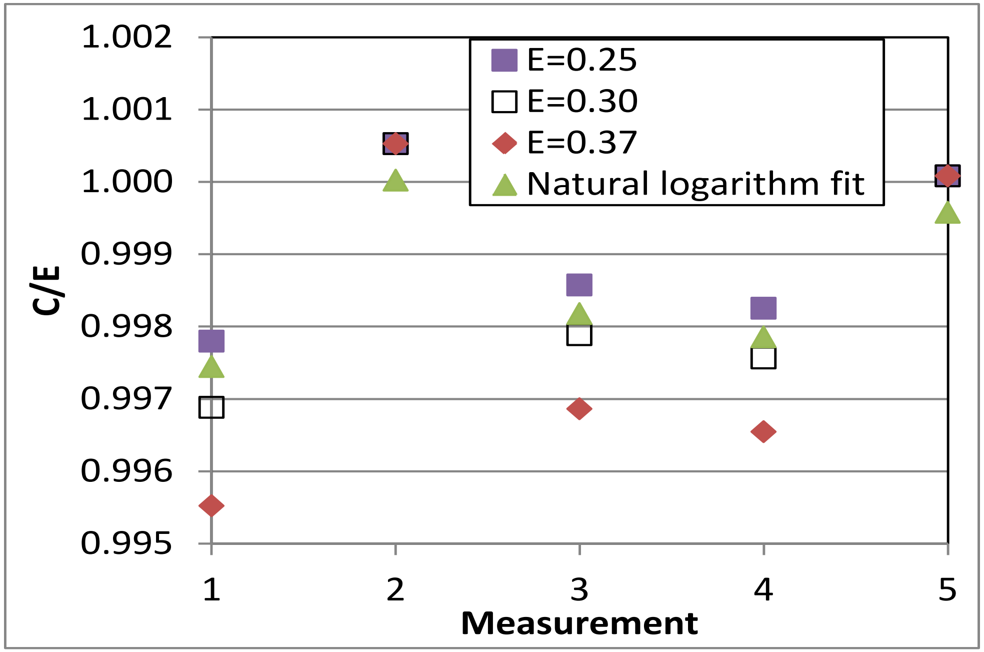
| Predicted # of foils | Actual # foils used | Predicted $k_{eff}$ | Actual $k_{eff}$ | rho ($) | fraction critical |
|---|---|---|---|---|---|
| 21.60 | 22.00 | 1.005 | 1.002 | 0.30 | 0.981 |
| 21.70 | 22.00 | 1.004 | 1.002 | 0.25 | 0.986 |
| 23.30 | 23.50 | 1.003 | 1.003 | 0.40 | 0.991 |
| 23.40 | 23.50 | 1.001 | 1.002 | 0.31 | 0.996 |
| 21.50 | 21.50 | 1.000 | 1.000 | 0.01 | 1.000 |

# Measured Results of Real Class Foils Experiment

- Approach to critical performed until last foil added
  - $k_{eff}$ predicted using Odell equation with E=0.30
- Last Foil added and reactor period measured
  - Inhour equation used to relate reactor period to $k_{eff}$
    - $\beta_{eff}$=0.008
- Average measured # foils: 21.7
  - simulated # foils: 20.21
- Large bias (~1.5 foils) expectedly due to lack of S(α,β) card for Lucite

# Measured Results of Real Class Foils Experiment

- Compared experimental $k_{eff}$ with simulated $k_{eff}$ for each fit




- Odell E=0.25 closest to experimental, ie where C/E =1.000

# Conclusions

- For the Class Foils Experiment
  - Both simulated and experimental results show E=0.25, originally for solutions, accurately predicts $k_{eff}$ better than E=0.30
  - When $m/m_c>1$, ie above delayed critical, an exponent of 0.30 results in a higher $k_{eff}$ than an exponent of 0.25 (The opposite is true below criticality)
    - Current method is conservative
  - At low multiplication, the logarithmic fit should be used
  - To improve on accuracy of simulations, work should be completed to obtain an S(α,β) for Lucite

# Thank you

This work was supported by the Department of Energy Nuclear Criticality Safety Program, funded and managed by the National Nuclear Security Administration for the Department of Energy