Problem 1:

a. Using the development on the first page of Ref. 1, determine the number of neutrons in each generation (rounded to the nearest integer) after the source is initially turned on if q = 1000 neutrons/generation and k = 0.6 for the system. For this configuration, approximately how many generations does it take to reach equilibrium?

b. Using eqn. (3) from Ref. 1, calculate n_∞ for this system -- is this value consistent with the steady-state value computed in Part a?

(a) $k = 0.6$ and $q = 1000$ n/gen

$n_0 = q = 1000$

$n_1 = k n_0 + q = 600 + 1000 = 1600$

$n_2 = k n_1 + q = 960 + 1000 = 1960$

$n_3 = k n_2 + q = 1176 + 1000 = 2176$

$n_4 = k n_3 + q = 2306$ etc.

$n_5 = k n_4 + q = 2384$

$n_6 = k n_5 + q = 2430$

$n_7 = k n_6 + q = 2458$

$n_8 = k n_7 + q = 2475$ etc.

$n_9 = 2485$

$n_{10} = 2491$

$n_{11} = 2495$

$n_{12} = 2497$

$n_{13} = 2498$

$n_{14} = 2499$

$n_{15} = 2499$ } steady state $\approx$ 15 generations

(b) $n_\infty = \frac{1}{1-k} q = \frac{1}{0.4}(1000) = \boxed{2500 \text{ neuts/gen}}$

ok, this makes sense...

Conceptual

note: $k^n = 0.001$ ← small

$\therefore n \log k = \log 0.001$ or $\boxed{n = \frac{\log 0.001}{\log k}}$

for $k = 0.6$ $n \approx 14$

for $k = 0.95$ $n \approx 135$

for $k = 0.99$ $n \approx 687$

} rough estimate of # generations to reach steady state

Problem 2: Using the reactor-specific data for the UMLRR as needed (see ***kinetics_data.m***) and the normalized Generation Time Formulation of Point Kinetics with P(t) in watts and <Q(t)> in neutrons/second, determine the steady-state power level in watts for the following two subcritical scenarios:

a. k = 0.90 and b. ρ_o = -0.01 dollars

From your results here, what can you say, in general, about feedbacks effects during subcritical operation in any reactor? None power level is too low

from kinetics_data.m

$\beta_{eff} = 0.0075$ $\Lambda = 65\times10^{-6}$ s

$\nu = 2.43$ neuts/fis $\kappa = 3.204\times10^{-11}$ J/fis

$\langle Q\rangle = S = 1.3\times10^{7}$ n/s

The kinetics eqns are:

$$\frac{dP}{dt} = \frac{\rho-\beta}{\Lambda}P + \sum_i \lambda_i C_i + \frac{\kappa}{\nu}\frac{1}{\Lambda}\langle Q(t)\rangle \quad (1)$$

$$\frac{dC_i}{dt} = \frac{\beta_i}{\Lambda}P - \lambda_i C_i \quad \text{for } i = 1, 2, \cdots 6 \quad (2)$$

from eqn (2) with $\frac{dC_i}{dt} = 0$ ← s.s.

$$\frac{\beta_i}{\Lambda}P_o = \lambda_i C_{io} \quad \text{and} \quad \sum_i \lambda_i C_{io} = \frac{\beta}{\Lambda}P_o$$ ← SS power level.

putting this into eqn (1) with $dP/dt = 0$, we have

$$0 = \frac{\rho_o}{\Lambda}P_o - \cancel{\frac{\beta}{\Lambda}P_o} + \cancel{\frac{\beta}{\Lambda}P_o} + \frac{\kappa}{\nu}\frac{1}{\Lambda}\langle Q_o\rangle$$

$$\text{or} \quad P_o = -\frac{\Lambda}{\rho_o}\left(\frac{\kappa}{\nu}\frac{1}{\Lambda}\langle Q_o\rangle\right) = \boxed{-\frac{1}{\rho_o}\frac{\kappa}{\nu}\langle Q_o\rangle}$$

(a) $k = 0.90$ $\therefore$ $\rho_o = \frac{k-1}{k} = \frac{0.9-1}{0.9} = -0.1111$

$$\text{and} \quad P_o = \frac{1}{0.1111}\left(\frac{3.204\times10^{-11}\ \text{J/fis}}{2.43\ \text{neut/fiss}}\ 1.3\times10^{7}\ \frac{\text{neuts}}{\text{s}}\right)$$

$$= \frac{1}{0.1111}\left(1.714\times10^{-4}\ \text{W}\right) = \frac{1}{0.1111}(0.1714\ \text{mW})$$

$$\boxed{P_o = 1.54\ \text{mW}}$$

(b) $\rho_o = -0.01\$$
$= -0.01(0.0078)$
$= -0.000078$

$$\text{and} \quad P_o = \frac{1}{7.8\times10^{-5}}(0.1714\ \text{mW})$$

$$= 2197\ \text{mW} = \boxed{2.2\ \text{W}}$$

Problem 3: The excess reactivity within the current UMLRR M-5-8 configuration is roughly 2.5 %Δk/k and the total worth of the four large control blades is about 12.5 %Δk/k.

a. If the reactor is shutdown with all the control blades inserted, estimate the subcriticality level, ρ_o, in dollars, the multiplication factor, k, and the subcritical multiplication factor, M, for this configuration.

b. The approximate strength of the Am-Be source in the UMLRR is about 1.3×10^7 neutrons/sec. If all the control blades are fully inserted, estimate the total steady state neutron source level, N, (in neutrons/sec) in the system. Note that N is just the total neutron production rate or neutron loss rate since, at steady state, the production and loss rates are in balance.

c. If the startup counter (SUC) reads approximately 26 cps (counts/sec), estimate the value of the proportionality constant, α, for this configuration, where $C = \alpha N$.

(a) with no control inserted, the excess ρ is about 2.5 %Δk/k, which means that k would be

$$k_{excess} = \frac{1}{1-\rho_{excess}} = \frac{1}{1-0.025} = 1.0256$$

Note that k_{excess} and ρ_{excess} are a little different, but these are often used interchangeably ...

If the blades are fully inserted and the total worth is 12.5 %Δk/k, then the subcriticality level will be

$$\rho_o = \rho_{excess} - \rho_{blades} = 2.5 - 12.5 = -10\ \%\Delta k/k$$

or $\boxed{\rho_o = -0.10\ \Delta k/k}$ $\quad \rho_o = \frac{-0.10}{0.0078} = \boxed{-12.82\ \$}$

$$k_o = \frac{1}{1-\rho_o} = \frac{1}{1+0.10} = \boxed{0.9091}$$

$$M_o = \frac{1}{1-k_o} = \frac{1}{1-0.9091} = \boxed{11.0}$$

ans

(b) for $S = 1.3\times10^7$ n/s

$$N = M_o S = (11.0)(1.3\times10^7) = \boxed{1.43\times10^8\ n/s}$$

ans

(c) if the SUC rate is $C_o = 26$ cps, then

$$C = \alpha N \quad \text{or} \quad \alpha = \frac{C}{N} = \frac{26\ \text{counts/sec}}{1.43\times10^9\ n/s}$$

$$\boxed{\alpha = 1.82\times10^{-7}\ \frac{\text{counts}}{\text{neut}}}$$

ans

Problem 4:

A system is known to be 5 dollars subcritical (i.e. ρ_o = -5 dollars). The detector count rate, C_o, in this subcritical system is 20 cps. If 2.5 dollars of positive reactivity is added, estimate the relative subcritical multiplication factor and the detector count rate in the new configuration after reaching equilibrium.

$$\boxed{M_r = \frac{C_1}{C_o} = \frac{\rho_o}{\rho_1}}$$

assuming α_i does not change much

$\therefore \quad \rho_o = -5\,\$ \qquad \rho_1 = \rho_o + \rho_{ext} = -2.5\,\$$

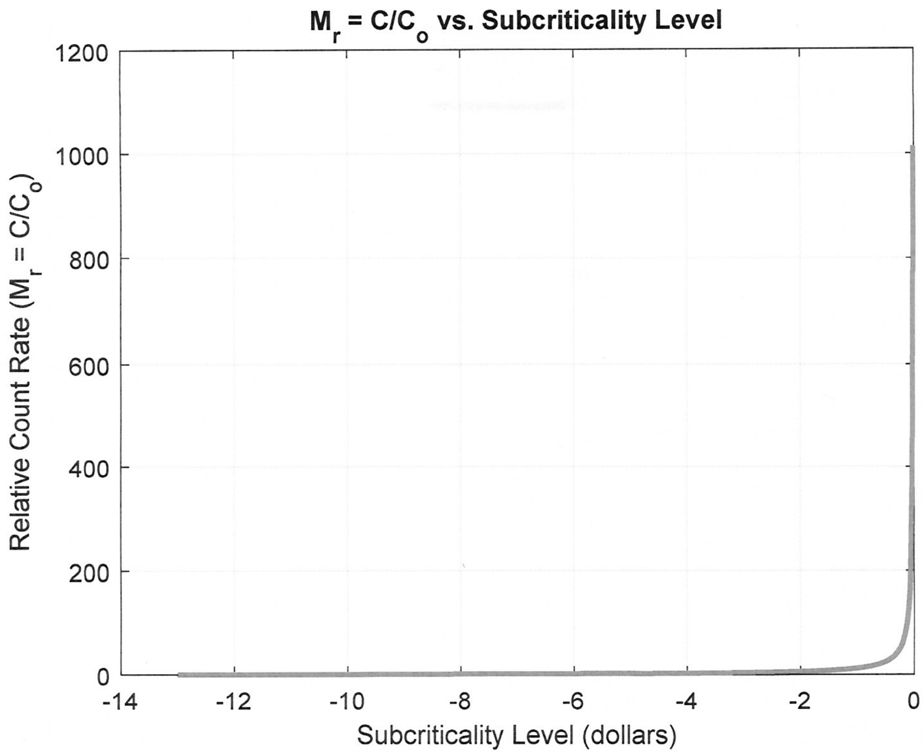
thus $\dfrac{\rho_o}{\rho_1} = \dfrac{-5}{-2.5} = 2$ ← subcriticality has been reduced by a factor of 2

$\therefore \quad \boxed{M_r = 2}$ and $C_1 = 2\,C_o = \boxed{40 \text{ cps}}$

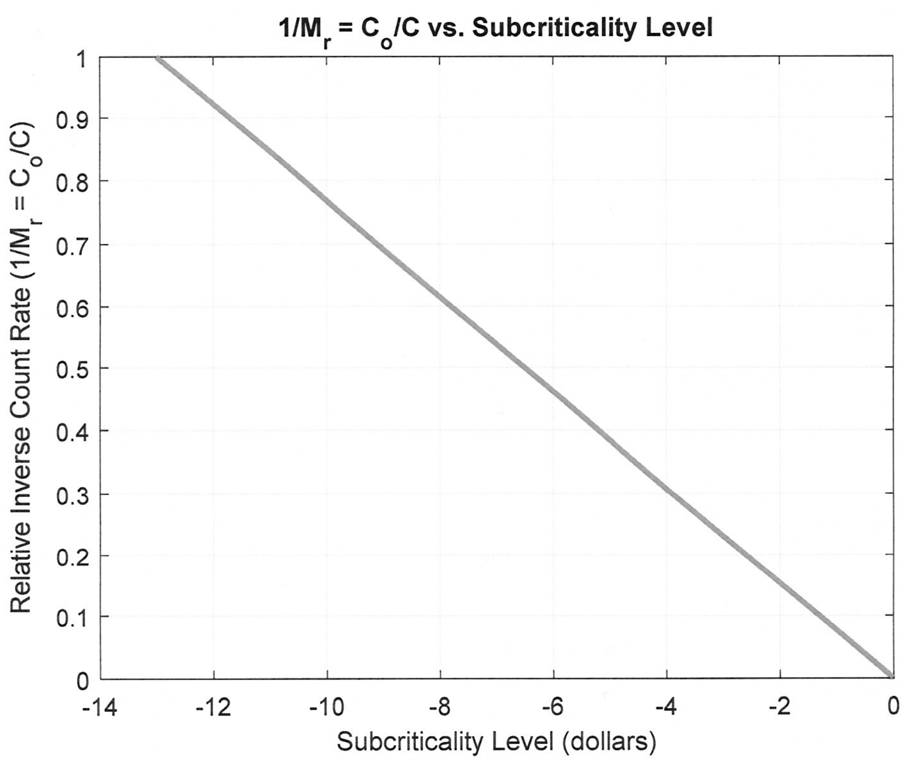
ans ans

This relationship is very important for subcritical operation

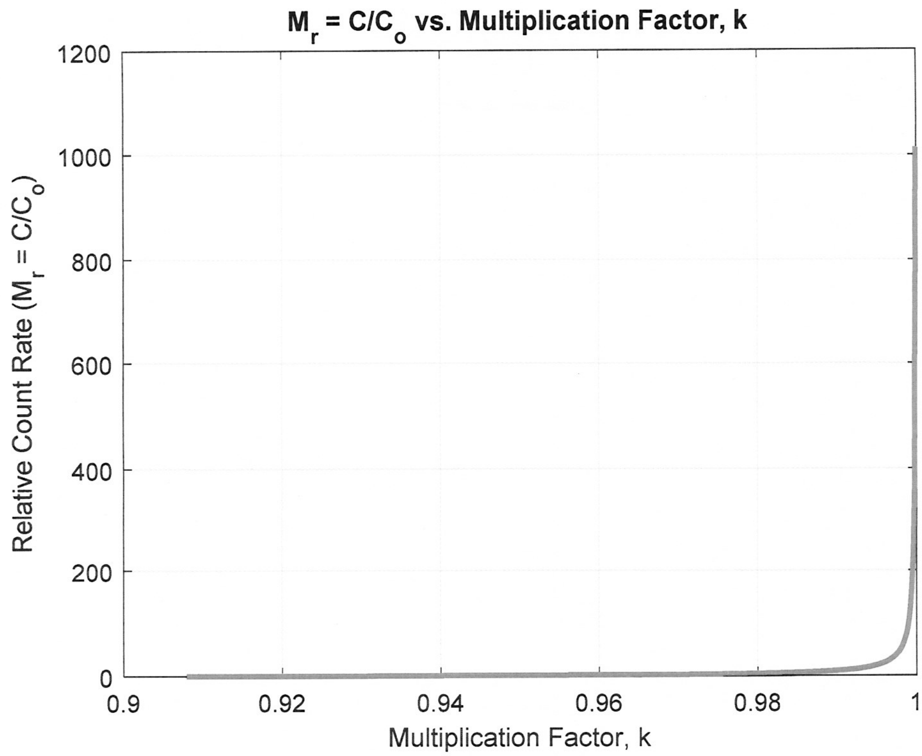
If the count rate increases by a factor of two (2), the subcriticality level has decreased by a factor of two (2)



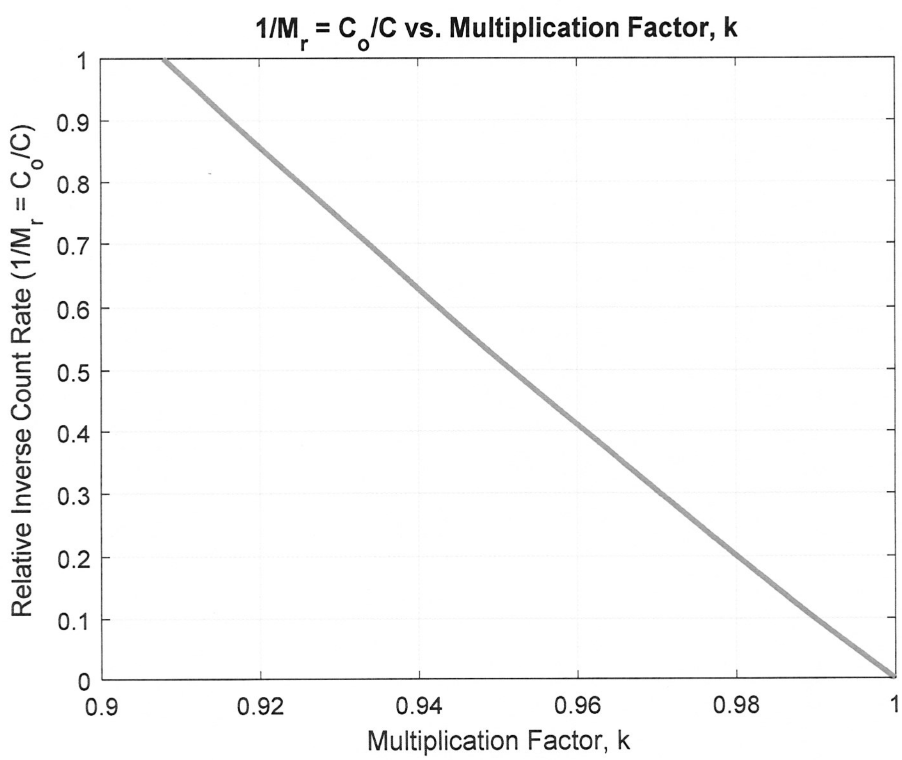
$M_r = C/C_o$ vs. Subcriticality Level
Relative Count Rate ($M_r = C/C_o$)
1200
1000
800
600
400
200
0
-14
-12
-10
-8
-6
-4
-2
0
Subcriticality Level (dollars)



$1/M_r = C_o/C$ vs. Subcriticality Level
Relative Inverse Count Rate ($1/M_r = C_o/C$)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-14
-12
-10
-8
-6
-4
-2
0
Subcriticality Level (dollars)



$M_r = C/C_o$ vs. Multiplication Factor, k
Relative Count Rate ($M_r = C/C_o$)
1200
1000
800
600
400
200
0
0.9
0.92
0.94
0.96
0.98
1
Multiplication Factor, k



$1/M_r = C_o/C$ vs. Multiplication Factor, k
Relative Inverse Count Rate ($1/M_r = C_o/C$)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.9
0.92
0.94
0.96
0.98
1
Multiplication Factor, k

Data from Blade #4 Approach to Critical (July 2005)
use to evaluate Prob #6 in HW #4

Table 2 Screen output from the critical_height sample run.

Summary Data for 1/M Plot and Estimate of Critical Height

Expt. Pt	Blade Pos. (inches out)	Count Rate (cps)	M = Ci/Co	1/M	Est. Crit. Ht. (inches out)
0	6.000	12	1.00	1.000	
1	10.000	17	1.42	0.706	19.600
2	14.000	42	3.50	0.286	16.720
3	15.400	68	5.67	0.176	17.662
4	16.500	124	10.33	0.097	17.836
5	17.200	240	20.00	0.050	17.948
6	17.600	455	37.92	0.026	18.047

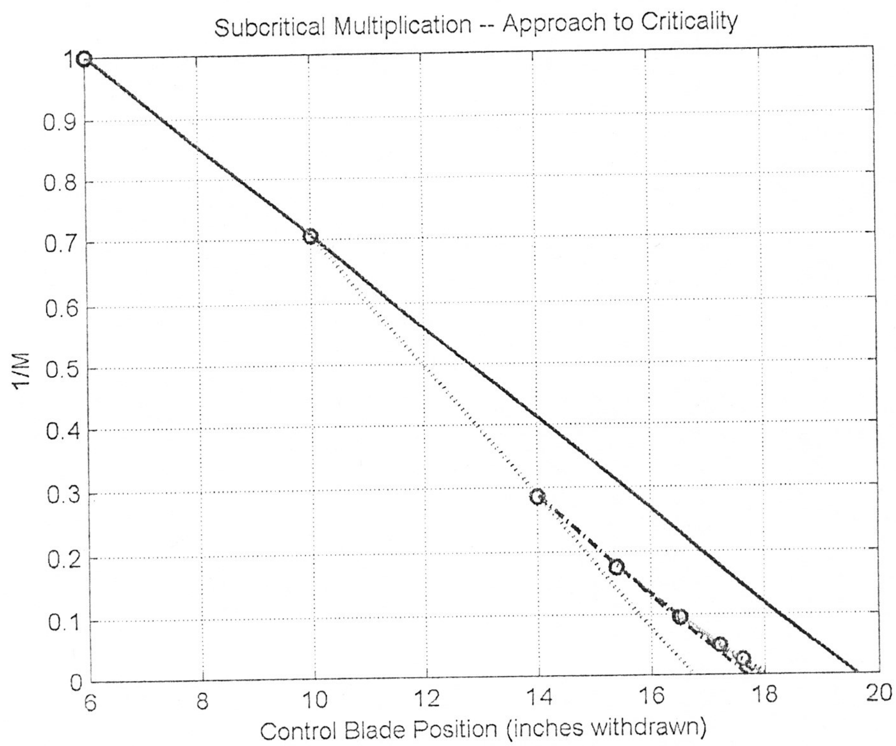
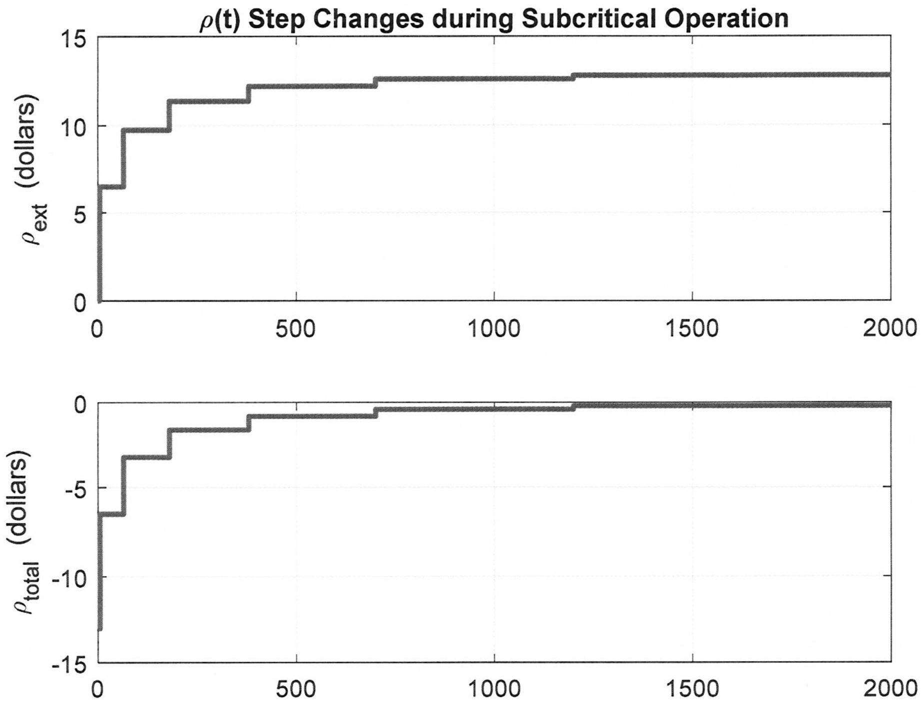
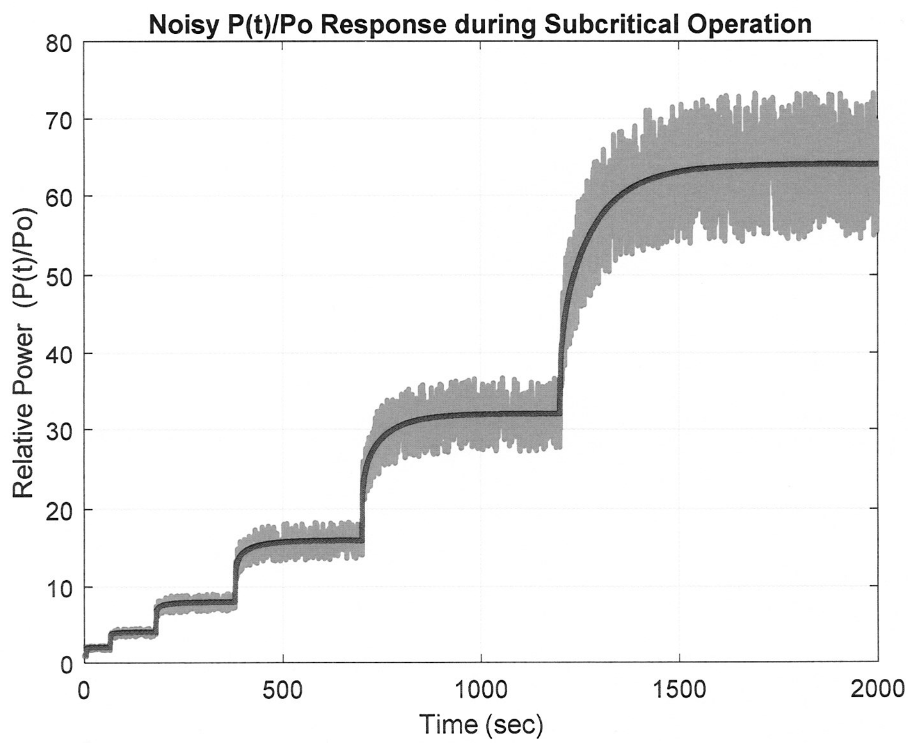


Fig. 4 1/M plot for the Blade #4 approach to critical experiment performed July 13, 2005.

Summary/Conclusions

This report summarizes the reactor operations data and key results from the **Blade #4 Approach to Critical Experiment #1** performed in the UMLRR on July 13, 2005. The goal of the experiment was to illustrate several theoretical concepts associated with subcritical systems (i.e. the subcritical multiplication factor, M, the behavior of 1/M as criticality is approached, etc.) and to use these to predict the critical height of a given control blade under the conditions of this particular experiment. As seen from the above results, the physical experiment and prediction






```
%   introduce a series of additive step changes and do the full transient simulation
    tt =    [0  5   5.01     65   65.01    180  180.01      380   380.01       700 ...
         700.01      1200  1200.01      2000];
    rhot = [0  0   6.50  6.50     9.75  9.75  11.375  11.375  12.1875  12.1875 ...
         12.5938  12.5938  12.7969  12.7969]*Be;
```