24.536 Reactor Experiments and 407.403 Advanced Nuclear Lab

HW #4: Subcritical Multiplication and "Approach to Critical" Pre-lab Exercises

Introduction

The purpose of Reactor Experiment #1 is to use the concept of the subcritical multiplication factor to predict the critical height of a control blade within the UMass-Lowell Research Reactor (UMLRR). Performing an "Approach to Critical" experiment by plotting the traditional 1/M curves is an excellent means for illustrating the behavior of subcritical systems, for highlighting the importance of the subcritical multiplication factor, and for showing how knowledge of the detector count rate in different configurations can give an experimental methodology for predicting when a system will reach the critical state.

Upon completion of this experiment, the student should have a better understanding of subcritical systems and how to use the 1/M method to predict when criticality will occur in the system. HW#4 emphasizes these topics and assures that everyone has the proper background for the actual lab that will take place during our next class meeting. The specific tasks and deliverables for this pre-lab assignment are described below:

Task 0: Review/Study the Lecture Notes, Examples, and Additional Reference Materials

Before starting the formal tasks listed below, you should be sure that you have a good understanding of the main topics under study and be familiar with the overall experimental procedure to be followed for Reactor Lab #1. In particular, for this pre-lab HW, you should carefully review the following documents (all these are available on the Dropbox share drive for this course):

1. J. R. White, "Subcritical Multiplication," part of a series of Lecture Notes for the Nuclear Engineering Program at UMass-Lowell.
2. J. R. White, "Reactor Lab #1 Description/Procedure: Understanding Subcritical Multiplication via an Approach to Critical Experiment," part of a series of procedures used within the Reactor Experiments course at UMass-Lowell.
3. J. R. White, "Analysis of the Blade #4 Approach to Critical Experiment #1 Performed on July 13, 2005," part of a series of Demos & Expts. available at www.nuclear101.com.
4. J. R. White, et. al., "Calculational Support for the Startup of the LEU-Fueled UMass-Lowell Research Reactor," Advances in Reactor Physics and Mathematics and Computation, Pittsburgh, PA (May 2000).
5. "Report on the HEU to LEU Conversion of the University of Massachusetts Lowell Research Reactor," submitted to the US Nuclear Regulatory Commission in fulfillment of Amendment No. 12 to License No. R-125 (April 2001).
6. J. R. White and L. Bobek, "Startup Test Results and Model Evaluation for the HEU to LEU Conversion of the UMass-Lowell Research," 24th International Meeting on Reduced Enrichment for Research and Test Reactors (RERTR 2002), San Carlos de Bariloche, Argentina (Nov. 2002).

Task 1: Answer several general questions concerning the theory of subcritical systems and the specific Approach to Critical pre-lab exercises.

Answer each of the following questions/problems fully and include your responses, calculations, and Matlab simulations, as needed, as part of your complete package for HW#4.

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?

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?

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 = αN.

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.

Problem 5: Using the assumption that the proportionality constants, α_i, don't change much, this problem simply wants you to create a series of plots that show the relative count rate or relative subcritical multiplication factor (i.e. $M_r(\rho) = C(\rho)/C_o$) versus subcriticality level, ρ. In particular, generate the following four plots with ρ starting at ρ_o = -13 dollars:

M_r vs ρ and $1/M_r$ vs. ρ and M_r vs k and $1/M_r$ vs. k

Are these curves meaningful? Are they self consistent? Is the behavior as $\rho \to 0$ as expected? In your opinion, which format is the most informative? Explain your choice…

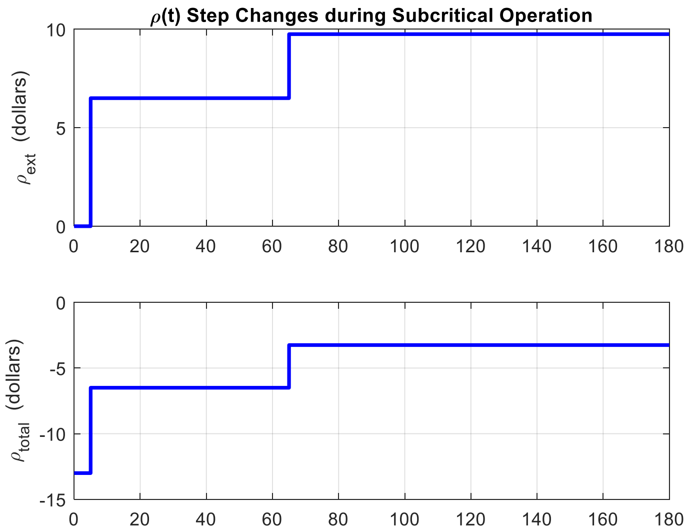
Problem 6: This problem deals specifically with getting prepared for the Approach to Critical lab that we will perform during our next class. Clearly you should review of the Lab Procedure (referenced above) and you should also print and review the "Worksheet for Experimental Data" associated with this lab (located in the Appendix to the Lab Procedure file). Finally, you also need to develop and test a method for predicting the critical height given the blade height and count rate data from your worksheet. This procedure must be available for use during the lab so that you can fill in the Estimated Critical Height column and decide on a suitable new blade height for the next step in the approach to critical sequence. You may use any appropriate method that you choose to accomplish this task (i.e. Matlab, Excel, etc.).

As a check on your planned procedure, use the explicit data given in Table 2 and Fig. 4 of Ref. 3 to make sure that your method gives similar results. Document both your both quantitative and graphical results as part of this HW assignment -- just discuss briefly what you did and then show the results using the raw data from Ref. 3. Validating your procedure on a set of test data before the actual experiment certainly makes good sense, and it will also help in your understanding of the overall procedure and goals for this experiment.

Problem 7: For this problem, you should use the ***pkeqns_nofdbk.m*** function to simulate the behavior of a subcritical system with a series of positive step changes in reactivity. At each step, the level of subcriticality should be reduced by a factor of two until one gets close to critical -- within -0.25 dollars should be sufficient to show the desired behavior here. Start your simulation at steady state subcritical with ρ_o = -13 dollars and add sufficient positive reactivity at each step to reduce the total reactivity by a factor of two each time. Use the kinetics data for the UMLRR, including the source strength, S, and other parameters as obtained from the ***kinetics_data.m*** function file. You can use the ***pksim_test.m*** file as a starting point, making sure that you set the initial conditions properly and that you get the **tt** and **rhot** vectors to properly mimic the desired sequence of step reactivity changes. The first few reactivity steps in the process might look as follows:

```
tt =   [0 5   5.01 65.0  65.01  180 ];
rhot = [0 0   6.5  6.5    9.75 9.75 ]*Be;
```

This gives $\rho_{ext}(t)$ and $\rho_{total}(t)$ profiles as shown in the figure below. Your job will be to continue this sequence until the system nears criticality, being careful to allow sufficient simulation time after each change so that the system nears steady state before another change in ρ_{ext} is made. Be sure to show the input reactivity (as shown below) and the resultant P(t)/Po profiles. You will need to complete the simulation as described above, and show and explain the key results…



Documentation and Submission of HWs

In general, I expect a professional, well-written, semi-formal report for each HW assignment in this course. Please refer to HW#1 regarding the format for each HW assignment in this course -- **they should all be done and submitted in a similar fashion!!!**

For this HW, you will need to include your hand solutions to Problems #1 and #2, the Matlab code, results, and discussions for Problem #3 and, for Problem #4, some example results to demonstrate that you can compute and plot a 1/M curve to predict where criticality will occur (also be sure to include your Matlab code or Excel file that does the desired calculation and plotting of the 1/M curve). Finally, for Problem #5, also include the codes, results, and discussion for the requested simulation. As done previously, please put everything together, including all your Matlab m-files, in a single zip file -- **only one zip file per HW please** -- and **email this to me before 4 pm (UML time) on the Sunday** before our next class.

Good luck…