24.536 Reactor Experiments

Lab #1 Description/Procedure: Understanding Subcritical Multiplication via an Approach to Critical Experiment

Objective

The purpose of this experiment 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.

Introduction

A subcritical system has a multiplication factor, k, that is less than unity, where k is the ratio of the neutron production rate from fission to the neutron loss rate. If there is no independent source of neutrons added to the subcritical system, the neutron population, in steady state, completely vanishes. However, if a neutron source is present, a steady state flux profile will develop throughout the system due to the diffusion of the source neutrons and the neutrons generated from subcritical multiplication of the original source neutrons via the fission process. Thus, in source-driven subcritical systems, the concept of subcritical multiplication is extremely important. This subject is treated in some detail in Ref. 1, where the subcritical multiplication factor, M, is defined, derived, discussed, and used within the context of an approach to critical example involving the initial fuel loading for the low-enriched uranium (LEU) core conversion in the UMLRR in the summer of 2000.

However, performing an approach to critical experiment by moving fuel elements is quite time consuming, somewhat tedious for the reactor staff, and potentially problematic if done too frequently. Thus, an alternate application, that uses that same concepts yet is more straight-forward, is certainly preferable for illustrating the basic concepts of subcritical multiplication. In particular, in this experiment we will apply the same methodology as discussed in Ref. 1 to estimate the critical height of a control blade within the UMLRR. The basic idea here starts with the blade of interest near full insertion, with the other three control blades and the regulating blade at some fixed position -- where the overall blade configuration, of course, must give a subcritical configuration. Then, the blade of interest is pulled out by some amount and some time is given for the count rate on the startup counter to stabilize. From an estimate of the count rate for the current configuration, one can determine the relative subcritical multiplication factor and make a rough estimate, using a 1/M plot, of the critical height of the blade. With a new estimated critical height, a new blade position is requested (usually about 1/2 of the predicted change needed for criticality), and the process is repeated. After several steps, one should have a very good estimate of the real critical location (for the given configuration of the other blades and the overall system state).

Experimental Procedure

The above overview can be formalized with the following experimental procedure:

1. Select the blade of interest (Blade N, for example) and place this blade in some initial position and the remaining blades at some fixed position that gives a subcritical system. The initial configuration needs to be sufficiently subcritical so that substantial movement of Blade N will occur before reaching criticality. However, it cannot be more subcritical than the full worth of Blade N, or criticality will never be reached. Thus, proper selection of the initial configuration is important -- and your lab instructor and/or the reactor staff can assist in the proper selection of an appropriate initial state.

2. Record the time, date, blade of interest, and the position of all control blades for the initial state on the worksheet provided in the Appendix. Note that all the blades except Blade N will be left in their initial locations for the duration of the experiment. Also record the initial count rate, C_o, on the startup counter making sure that this is above the background detector count rate.

3. Ask the reactor staff to withdrawn Blade N by some amount (usually several inches) from the initial state. This will add positive reactivity, bringing the system closer to critical. This state will have a higher value of subcritical multiplication, M. After the blade movement, wait several minutes until the transient dies out and take a new count rate, C_1, corresponding to the new control blade height. Note that, as M increases, the neutron population increases -- thus, C_1 should be greater than C_o. Using the new count rate, fill in the line for Expt. Point #1 on the worksheet and make your first estimate of the critical height of Blade N.

4. Based on this estimated value, request that the reactor operator withdraw the control blade about half way between its current height and the estimated critical height from the previous step, being careful not to withdraw the blade too close to the real critical value to prevent unexpected criticality.

5. Again wait several minutes until the transient dies out and obtain an estimate of the new steady state count rate in this configuration, C_i, corresponding to the new control blade height for the i^{th} configuration. Now fill in the line for the i^{th} experimental point on the worksheet and obtain your next estimate of the critical height of Blade N.

6. Repeat Steps 4 and 5 several times until the blade position is about 0.3 to 0.5 inches below the estimated critical position. At this point, the experiment is essentially complete and you should have a very good estimate of the actual critical position for Blade N under the specific conditions of the experiment. Thus, ask the operator to bring the reactor to the predicted critical state with Blade N so we can observe what happens to the count rate as the reactor nears (or slightly exceeds) criticality. Record your observations -- is this what you expected? Explain...

7. To complete the reactor operations sequence, ask the reactor staff to go to a reactor power of approximately 500 W by moving the RegBlade, as needed, and then to go into Auto Mode so that we can observe exactly where criticality occurs with the RegBlade (relative to its initial fixed position). Once steady state operation at about 500 W has been achieved, record the RegBlade position and compare this to its initial value. Did we over or under predict the critical height for Blade N? Explain...

You should note that in collecting data for the count rate for the i^{th} state, you will find that the startup counter is indeed rather noisy. Thus, after the transient has decayed away after each movement of Blade N, you should observe the count rate data for a few minutes and take a suitable average during the latter part of this time interval to use as C_i for the i^{th} step of the experiment.

During the experiment, you should also be able to observe the effects of delayed neutrons while the reactor is approaching the critical state. This effect can be seen by noticing the length of time it takes for the detector count rate to stabilize after each blade movement. Initially, the count rate reaches steady state quite rapidly, but when the reactor gets close to critical, it takes longer for the count rate to stabilize because of the delayed neutron effect. Is this general observation consistent with your data?

The estimated critical control blade height calculated using the 1/M extrapolation method described in Ref. 1 should be close to the actual critical control blade height measured from the reactor. A specific example using data from an experiment performed on July 13, 2005 with Blade #4 as the control blade of interest is illustrated in Ref. 2. In that example, excellent agreement was obtained. Do the results from your experiment compare as well? If not, try to explain the observed differences…

Finally, it is important to note that the critical blade position obtained from a given experiment is strongly dependent upon several factors, such as the specific core fuel element arrangement, the positions of the regulating blade and the other control blades, the average core temperature at the time of the experiment, the amount of xenon buildup in the system (which depends on previous operating history within the last few days), and the burnup level of the core. Thus, the results obtained for a particular control blade may be quite different each time this experiment is performed.

References

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, "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.
3. 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).
4. "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).
5. J. R. White, J. Byard, and A. Jirapongmed, "Calculational Support for the Startup of the LEU-Fueled UMass-Lowell Research Reactor," Proceedings of Topical Meeting on Advances in Reactor Physics and Mathematics and Computation, Pittsburgh, PA (May 2000).

Application of Subcritical Multiplication to Determine the Critical Height of a Control Blade within the UMLRR

Worksheet for Experimental Data

Date of Experiment: _____________ **Blade of Interest:** __________

	Blade 1	Blade 2	Blade 3	Blade 4	Regulating Blade
Initial Height (inches withdrawn)					

Expt. Point	New Blade Height (in)	Start Time	Finish Time	Elapsed Time	Count Rate (cps)	$M_{ri} = C_i/C_o$	$1/M_{ri} = C_o/C_i$	Estimated Critical Height (in)	Proposed ΔH (in)
0		---	---	---				---	
1									
2									
3									
4									
5									
6									
7									
8									
9									

Notes:

1. **Be sure to let the count rate, C_i, settle to near equilibrium before recording C_i for the given configuration. You should use a minimum of 8-10 minutes between blade movements and longer if C_i has not stabilized (give at least 3-5 minutes to reach steady state and then use the data from the last several minutes to estimate the average steady state count rate).**
2. **The count rate at full shutdown in the UMLRR is usually quite low (about 5-15 counts per second). Make sure that the initial count rate, C_o, for this experiment is above the background level (about 20-30 cps or above should work fine).**