24.536 Reactor Experiments and 407.403 Advanced Nuclear Lab

HW #10: "Measuring and Interpreting Reactivity Effects" Pre-lab Exercises

Introduction

The purpose of Reactor Experiment #4 is to develop and validate a model to represent the inherent feedback effects within the UMass-Lowell Research Reactor (UMLRR). In particular, all our previous lab exercises have been performed at low power levels with the intent of minimizing the effects of the inherent temperature and xenon feedback effects on our reactivity measurements and our overall observations of feedback-free reactor dynamics. In contrast, for this lab, the feedback effects are the primary focus area! Thus, all the reactor sequences studied will highlight one or more of the different feedback mechanisms that are inherent to all thermal reactor systems. Several prior reactor sequences will be studied using archived data to help develop, rationalize, and quantify a proposed feedback model, and two new reactors sequences will be performed to help confirm/validate the model. Combined, the exercises performed here should give a good understanding of how to model the various inherent feedback mechanisms and how they affect real reactor operations.

Upon completion of this experiment, the student should have a better understanding of the inherent feedbacks that occur in thermal systems, and be able to identify and discuss the key feedback components that are present in different situations. In addition, you should also be able to understand and utilize a simple 11-equation dynamics model of the UMLRR and be able to design and simulate different reactor sequences to illustrate various feedback mechanisms, including both the fuel and coolant temperatures and the buildup/decay of Xe-135. HW#10 emphasizes these general topics and helps you plan 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 Associated 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 #4. In particular, for this pre-lab HW, you should carefully review the following documents (these are available in the course Dropbox folder):

1. J. R. White, "Temperature Related Reactivity Coefficients and Feedback," part of a series of Lecture Notes for the Nuclear Engineering Program at UMass-Lowell.
2. J. R. White, "Xenon Poisoning in Thermal Reactors," part of a series of Lecture Notes for the Nuclear Engineering Program at UMass-Lowell. This set of Lecture Notes also serves as documentation for the **xenon_gui** code.
3. J. R. White, "Steady-State Temperature Profiles in a UMLRR Fuel Channel," part of a series of Lecture Notes for the Nuclear Engineering Program at UMass-Lowell. This set of Lecture Notes also serves as documentation for the **sstemp_umlr_gui** code.
4. J. R. White, "Reactivity Feedback Effects -- Part I: Prediction, Measurement, and Interpretation," one of a series of PowerPoint Lectures for the Reactor Experiments course at UMass-Lowell.

5. J. R. White, "Reactivity Feedback Effects -- Part II: Prediction, Measurement, and Interpretation," one of a series of PowerPoint Lectures for the Reactor Experiments course at UMass-Lowell.
6. J. R. White, "Lab Description/Procedure: Measuring and Interpreting Feedback Effects within the UMLRR," one of a series of labs for the Reactor Experiments course at UMass-Lowell.

These main references discuss temperature reactivity coefficients, xenon feedback effects, and a relatively simple steady state model for performing thermal analyses of the UMLRR. A good grasp of the material from all these documents and, in particular, a good understanding of the background theory and the ability to use the **xenon_gui** and **sstemp_umlrr_gui** codes, are certainly required for gaining the maximum amount of insight from this lab.

In addition, as part of the class presentation of this material, five prior reactor experiments were analyzed in some detail (see the summary results in Refs. 4 and 5), as follows:

1. **Pool Cooldown Experiment** (012213) -- used to obtain the isothermal temperature coefficient α_{ITC} = -5.9e-5 $\Delta k/k$-^oC for the UMLRR
2. **Xenon Effects Test** (011413) -- used to determine the flux correction factor, cf = 0.88, for the xenon reactivity model of the UMLRR
3. **Model Validation Test** (081612) -- used to test the combined temperature and xenon feedback models for ***constant power operations*** (this evaluation uses only α_{ITC} since $\Delta T_f \approx \Delta T_c$ for this experiment)
4. **Model Validation Test** (082012) -- ***forced flow sequence*** used to test the combined temperature and xenon feedback models for ***variable power operations*** (this test needs separate α_{Tf} and α_{Tc} since $\Delta T_f \neq \Delta T_c$ for this experiment)
5. **Model Validation Test** (082007) -- ***natural convection sequence*** used to test the combined temperature and xenon feedback models for ***variable power operations*** (this test needs separate α_{Tf} and α_{Tc} since $\Delta T_f \neq \Delta T_c$ for this experiment)

The results from the Matlab simulations for each of these five cases were presented and these simulations are available in the course Dropbox folder as examples of the type of analyses that can be performed to help understand the inherent feedbacks within the UMLRR. The three model validation tests, in particular, contain much of the data and the various Matlab processing codes that will be needed for the analysis of the two new experiments performed as part of the in-lab portion of the current experiment. You should review these examples in detail and become familiar with the basic procedures and Matlab code specifics as part of your pre-lab work for this lab exercise.

Note that the Matlab code and data for the first three experiments noted above are contained in separate zip archives within the course Dropbox folder. The post-lab analyses for the last two experiments are combined into the single archive, **fdbk_simulations.zip**, and this example, in particular, should prove to be very useful for your pre-lab and post-lab exercises for the current lab.

Task 1: Answer several general questions concerning the background theory and the specific concepts to be illustrated as part of the "Feedback Effects" lab.

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#10.

Problem 1: Using the **xenon_gui** code, answer the following questions:

a. Roughly how long does it take to reach equilibrium Xe while running at full power (i.e. at 1 MW) starting from a xenon-free core? Is this time consistent with expectations based on the half-lives or mean lifetimes of I-135 and Xe-135? Explain…

b. What is the approximate equilibrium Xe reactivity in the UMLRR for 1 MW operation? How about 50 kW operation? Is it reasonable to assume negligible Xe feedback for steady-state operation with $P < 50$ kW within the UMLRR?

c. Use the GUI to simulate a sequence where the reactor is at full power (i.e. 1 MW) for 8 hours and then is shutdown for 16 hours. Repeat this 8-hr on and 16-hr off sequence for several days until some quasi-equilibrium is reached. What is the maximum Xe reactivity for this operational scenario? How does this compare to the equilibrium worth if operating continuously at full power?

d. Run the GUI with a scenario where the reactor is operated at 1 MW for 4 hours starting with no xenon in the system. How does the reactivity effect after 4 hours compare to the full equilibrium value? What about at $P = 50$ kW? If the RegBlade was at 10 inches out at the start of the run, how far must it be withdrawn at 4 hours to maintain criticality for constant power operation at both 1 MW and 50 kW? Explain…

e. Based on your results for Part d, address the overall importance of Xe feedbacks in the UMLRR for operations less than 4 hours (starting with a Xe-free core).

Problem 2: Using the **sstemp_umlrr_gui** code, answer the following questions assuming that the coolant inlet temperature is fixed at 25 ^oC:

a. For **steady-state forced convection operation at 1 MW with 1650 gpm of flow**, what are the expected maximum coolant, clad, and fuel temperatures in an average fuel channel and plate configuration? For this same situation, estimate rough averages for the fuel and coolant temperature. Finally, based on the data collected here, estimate the change in the average fuel and coolant temperatures when going from zero power to full power.

b. Using your results from Part a, estimate the negative temperature reactivity feedback that is inserted in going from zero power to full power within the UMLRR. If the RegBlade was at 10 inches out at $P = 0$, how far must it be withdrawn to offset this temperature feedback to maintain criticality at $P = 1$ MW? Also approximate the relative reactivity contribution of the fuel and coolant feedbacks. In these calculations, assume the following reactivity coefficients:

$$\alpha_{Tf} = -7.7\text{e-}5\ \Delta k/k/^oC \qquad\qquad \alpha_{Tc} = -4.37\text{e-}5\ \Delta k/k/^oC$$

c. Now, re-do Parts a and b for the case of **natural convection flow with P = 50 kW**. Compare your results for free convection with those for forced convection flow in terms of the total temperature feedback and the relative contributions of the fuel and coolant effects.

d. Based on your comparisons in Problem 2 Part c and your analyses from Problem 1, discuss how experiments that focus on temperature and xenon feedback effects would differ in their ability to highlight certain effects. That is, do forced and natural convection experiments highlight the various feedback components equally well? **Explain -- there should be some good quality discussion here…**

Task 2: Do the required data processing and analysis of the model validation test performed on July 17, 2013.

For this specific pre-lab task, you should do the processing and analysis of the model validation test performed on July 17, 2013 -- the reactor history file, **feedbacks_071713.hst**, is available in the course Dropbox folder. This sequence includes natural convection and forced convection model validation tests similar to Tests #4 and #5 in the above list of reactor experiments and, hopefully, you should get similar results to those discussed in the class discussions concerning these tests (see Ref. 5). However, even if there are no surprises, this pre-lab exercise will be useful since it will get you familiar with the various processing steps needed for studying these runs (in particular, see the **model_test_example_fdbk.m** code and related Matlab files in the **fdbk_simulations.zip** archive).

Task 3: Develop a sequence of RegBlade movements for the Phase I and Phase II portions of the upcoming experiment.

As discussed in class, one of the primary pre-lab tasks for this experiment is to do two formal Matlab simulations to develop a preliminary plan for the natural convection (Phase I) and forced convection (Phase II) sequences described in the Experimental Procedure section of Ref. 6. These simulations should have several distinct calls to the ***ode15s*** ODE solver (and associated point kinetics function file with feedbacks) which solves our 11-equation dynamics model for the planned movement of the RegBlade. Each interval should involve a short ramp (up or down) followed by some period with the RegBlade held constant -- to allow time for the power to increase or decrease and for the feedbacks to have some influence on the system, as appropriate. The design procedure should involve deciding how many intervals to include, the magnitude and direction (out or in) of the blade movement, and the duration of the interval with no blade movement.

In addition to the procedure described in Ref. 6, some things to consider in designing suitable reactor sequence with P_o = 5 kW for both Phase I and Phase II include the following:

The Goal:

To design a reactor operations sequence with a series of RegBlade movements that represents a good test for evaluating the effectiveness of the 11-equation dynamics model, which includes both temperature and xenon feedbacks.

The Limitations/Constraints:

a. Keep the total simulation time around 3 hours so that everything fits within our allotted lab time -- this includes both Phases I and II.

b. Keep any positive periods well above 60 seconds to assure safe reactor operation -- you should probably aim for between 90 – 120 second positive periods.

c. In natural convection mode (Phase I), keep $P(t) < 80$ kW.

d. Have 3-4 sequences of RegBlade movement followed by a movement-free interval, where the last step should induce a power decrease so that we can transition directly to the desired P_o for the Phase II analysis.

e. For forced convection mode (Phase II), keep $P(t) < 800$ kW.

f. The last interval of the Phase II sequence should **not** take the system subcritical via blade movement, since we want to show that the inherent feedbacks will shut down the reactor on their own.

NOTE: The two simulations here are independent of each other -- however, both start at P_o = 5 kW, one in natural convection mode and the other in forced convection mode.

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 discussions for Task 1 Problems 1 and 2, and the Matlab codes, results, and discussions for Tasks 2 and 3. 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) next Sunday**...

Note: I will try to review your Task #3 simulations before class on Tuesday to decide what sequence (or possibly a combination of steps) will be performed during the live lab on Tuesday. Just before the actual lab, we will review the selected Phase I (natural convection) and Phase II (forced flow) sequences -- so be prepared to discuss these -- and we will make a collective decision on how to proceed for the actual reactor run. Only one sequence for Phases I and II will be performed during the actual reactor lab -- these could be selected from a single group entry or I may try to combine several student suggestions into a single "class" sequence for the natural and forced flow cases. I will have to wait to see what you propose next Sunday…

Good luck and have fun…

Final Note: This Feedback Effects experiment will be a relatively long lab since the reactor run times will be necessarily longer so that we can actually "see" the feedbacks affects. Thus, please come to class a little early so that we are "ready to go" at 8 am UML time on next Tuesday…