24.536 Reactor Experiments and 407.403 Advanced Nuclear Lab

HW #2: Reactor Kinetics & Dynamics and UMLRR Startup Demo

Introduction

The goals of this lesson were to review/overview several key concepts from Reactor Kinetics and to relate these to the routine operation and control of the UMLRR. A typical reactor startup was performed which allows observation of the operator's interaction with the facility as the reactor was taken from a shutdown state to power operation. Movement of the four large safety/control blades and the low-worth RegBlade allowed the operator to approach critical and to change power levels. The approximate time-dependent behavior of the neutron level (or power level) during these routine operational procedures is governed by the Point Kinetics equations, and these equations were derived, discussed, and solved under the condition of a step change in reactivity.

Upon completion of this lesson, the student should have a good understanding of point kinetics and how the UMLRR is brought from a subcritical shutdown condition to critical power operation. HW#2 emphasizes these topics, with two separate tasks, as follows:

1. Summarize the UMLRR Startup Demo
2. Answer several general questions concerning Point Kinetics and the typical behavior of a reactor following a step change in reactivity, ρ.

The specific tasks and deliverables for each of these topic areas are described below:

Task 0: Read/Study the Lecture Notes

The initial task in every HW assignment will be to carefully read all the theoretical and background material provided on the course website for the topic of interest. For this HW, in particular, you should study the following three documents and be prepared to discuss these during our next class:

1. J. R. White, "One-Speed Point Kinetics Equations," part of a series of Lecture Notes for the Nuclear Engineering Program at UMass-Lowell.
2. J. R. White, "Normalization of the Generation Time Formulation of the One-Speed Point Kinetics Equations," part of a series of Lecture Notes for the Nuclear Engineering Program at UMass-Lowell.
3. J. R. White, "Solution of the Point Kinetics Equations," part of a series of Lecture Notes for the Nuclear Engineering Program at UMass-Lowell.

Task 1: Summarize a Typical UMLRR Startup

This task simply wants you to create a series of plots that summarize a typical reactor startup and to use these to help describe and explain the basic UMLRR startup procedure. The history file from the reactor startup performed on Tuesday Jan. 30, 2018 will be available shortly after the live lab -- check out the Dropbox share folder for a file named **umlrr_startup_013018.hst**. You should use the **umlrr_data** GUI to read this history file and generate the plots needed to support your discussion of a typical startup of the UMLRR. Be thorough in your discussions here and be sure to select only the time period of interest in the reactor history file (i.e. from the initial withdrawal of the blades for startup to the point where steady state operation at about 500-600 kW power is observed for 10-15 minutes -- but do not include the early operational data during the reactor checkout phase…).

As part of your general discussion, also address the following specific items:

1. In the early phase of the reactor startup, the four large control blades were withdrawn to about 12 inches out (full range is about 25-26 inches withdrawn). After this initial step to get things started, what philosophy or procedural rule was used to determine the remaining positions until criticality was reached (note that the estimated critical height is known based on previous operations)?
2. When did the reactor reach critical (approximately)? How can you identify criticality from the data available to you? Explain…
3. The neutron source was removed from position G5 when the reactor was at 500 W. Describe what happened at this point to the RegBlade when in Auto Mode (i.e. does it remain roughly stationary or does in move inward or outward?). If measurable movement was observed, explain why this happened and justify the direction of motion.
4. What was the approximate position of the RegBlade when the reactor was critical at 500 W with no source? What was its approximate location when the reactor was critical again at about 500-600 kW? Was there a measurable difference with the RegBlade location at these two critical states? If so, explain/justify this difference in critical RegBlade height…
5. From the available reactor data, estimate the coolant $\Delta T = T_{out} - T_{in}$ across the core when the reactor was at about 500-600 kW. Is this value consistent with the estimated maximum ΔT computed in HW#1? Explain/justify your answer…

Hints:

To get a P(t) profile similar to those discussed in class, turn on the Linear Power 1, Linear Power 2, and Log Power indicators, with the kilowatt button unchecked.

For the core temperature profiles, only selecting the Core Inlet and Core Outlet temperatures will give you a cleaner plot for analysis and discussion.

Finally, the easiest way to capture the plot in the **umlrr_data** graphics window is to hit the "Print Window" button, name the *.jpg file, and then subsequently insert this into your Word document for viewing and discussion. The plots generated using this method are not great, but they are sufficient for discussion here…

Task 2: Answer several general questions concerning Point Kinetics theory and applications.

Answer each of the following questions/problems fully and include your responses and calculations, as needed, as part of your complete package for HW#2.

Problem 1: The solution of the **Generation Time Formulation** of the point kinetics equation with no reactivity feedback and no external source for a **step change** in external reactivity (step change in k or ρ) is typically given in terms of the so-called **reactivity equation**. For six delayed neutron groups using the generation time formulation, the reactivity equation can be written as

$$\rho = \Lambda\omega + \sum_i \frac{\beta_i \omega}{\omega + \lambda_i}$$

Now, your job for this problem is to explain, in detail, your understanding of feedback-free point kinetics via a thorough discussion of the **reactivity equation**. In your discussion you should address such things as:

What does this expression mean and where does this come from? **Note:** A formal derivation is not required here since this is done for you in the Lecture Notes -- a good summary explanation of the general process will suffice.

Discuss its interpretation in terms of the actual time dependent behavior of the neutron density for both positive and negative reactivity insertions.

How many roots are there? What is the sign of the roots for both positive and negative reactivity? What is the significance of the dominant root?

Be sure to introduce the concepts of reactor period and prompt jump/drop in your discussions.

Also use appropriate sketches as needed in your discussions…

Problem 2: Using the **kinetics_gui** program create a plot of reactor period, τ, vs. reactivity, ρ, for U235 fuel with $\beta = 0.0068$ and $\Lambda = 0.1$ msec.

a. From this plot, estimate τ for reactivities of +0.14 %Δk/k and -2.0 dollars.

b. If a reactor period of about 5 minutes is observed in a low-power facility, estimate the multiplication factor, k, for this system.

Problem 3: A U235-fueled thermal system with $\beta = 0.0068$ and $\Lambda = 0.1$ msec originally operating at a constant power of 500 W is placed on a positive period of 1.5 minutes. Estimate how long it takes for the reactor power level to reach 250 kW? State any assumptions…

Problem 4: A U235-fueled system is operating at a steady state fission power level of 5 MW. The system is scrammed by the instantaneous insertion of 3 dollars of negative ρ. Ignoring feedback effects, estimate how long it takes for the reactor fission power level to reach 10 W.

Problem 5: A U235-fueled research reactor is critical with an operating power level of 6 kW. As a demonstration experiment for a reactor theory class, the reactor is put on a positive power transient with the insertion of 10 cents of positive reactivity. As expected, the power level increases for several minutes, and then it eventually stabilizes at a new power level of about 84 kW.

a. With this information, estimate the power coefficient of reactivity for this system in units of $\Delta k/k$ per kW.

b. If the maximum licensed power level of the reactor is 200 kW, what is the upper limit for reactivity (in dollars or cents) that can be added in this experiment for the same initial state?

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!!!**

Note that no Matlab files or data files are needed for this HW. Please integrate the plots requested as part of Task #1 directly within the Word file that discusses the UMLRR startup procedure -- make this a professional treatment. For Task #2, answer each question separately -- the solution to the discussion questions should be done in Word and, for the application-oriented questions, these can be either typed within your document or neatly hand-written and scanned into your document. As done previously, put everything together 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** just before our next class.