AC 2007-740: CONDUCTING FUEL TEMPERATURE COEFFICIENT OF REACTIVITY LABORATORY VIA REMOTE CONNECTION

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Conducting Fuel Temperature Coefficient of Reactivity Laboratory via Remote Connection

Introduction

The University of Texas at Austin offers nuclear engineering courses as part of the undergraduate curriculum in mechanical engineering. These courses have up to 35 students and are taught on the main campus in downtown Austin, TX. To complement these courses a remote laboratory on fuel temperature coefficients of reactivity has been developed that utilizes The University of Texas at Austin 1.1 MW TRIGA Mark II nuclear research reactor located on the Pickle Research Campus (about 12 miles north of the main campus where most courses are taught). A live display of the reactor instrumentation outputs has been created and may be accessed via remote desktop with Windows XP. As a result, the reactor instrumentation outputs may be displayed real-time in a classroom on the main campus via the classroom computer.

The first remote experiment was conducted on December 7, 2006 for the ME 337C "Introduction to Nuclear Power Systems" course. It received excellent reviews from the students in attendance. The entire experiment was digitally recorded and was also viewed by distance learning students in the course. Data and procedures presented below are from this initial experiment.

Procedure

The laboratory starts with the reactor at 1 kW. This is a low power where fuel temperature is still in equilibrium with the reactor pool temperature (~ 23 °C). At this point, the reactor power, fuel temperature, and control rod positions are recorded. The reactor power and fuel temperature data may be obtained from the reactor instrumentation output display shown live in the classroom. The control rod positions are reported to the class via speaker phone by the reactor operator.

After data is taken at the first power level, the reactor is increased in power to the next level. Data for this laboratory is taken at reactor power levels of 1, 50, 100, 250, 500, 750, and 950 kW. The reactor power, fuel temperature, and control rod positions are recorded at each power level. These power levels seem to adequately cover the range of the UT TRIGA reactor and the number of points is reasonable for the one hour time allotted for the laboratory.

Each power change takes seven to ten minutes. During this time, students look up the reactivity of each control rod position, calculate total core reactivity, and enter the data into a spreadsheet. The change in reactivity from the 1 kW power level is then calculated. A plot is made showing reactor power versus the change in core reactivity.

Figure 1 shows the display of the reactor conditions displayed in class. These data are shown live. For this particular figure, only reactor power and fuel temperature are shown. Two charts are displayed of the data. These charts are set to show the data on different time scales. The chart on the right displays about 40 seconds of data while the chart in the middle displays about 1 hour of data. This allows the students in the class to easily see the current conditions along with the historical perspective of the entire laboratory. Utilizing a mouse, the user may click on the lines on the chart and the numerical values at that point will be displayed. The software utilized for this display is TrendServer Pro Version 6.0.7.

Figure 1. Display shown in classroom. It shows reactor power (% power) and fuel temperature (°C).

Results and Discussion

The data taken for this experiment are shown in Table 1. Reactor power, fuel temperature, and control rod positions were recorded for each steady-state power level. As seen in this table, The University of Texas at Austin TRIGA reactor has four control rods. An effort was made to bank the rods at each power level. When the data was taken, the reactor was operating in "Auto" mode with a control loop adjusting the "Regulating" rod as necessary. Steady-state power was achieved about five minutes after initially reaching the power level. This time allowed for delayed neutron populations to equilibrate and for the control rod positions to stabilize.

Table 1

Data Taken for Temperature Coefficient of Reactivity Laboratory

		Control Rod Positions			
Power (kW)	**Fuel Temperature (°C)**	**Transient**	**Shim1**	**Shim 2**	**Regulating**
1	23.0	578	578	580	582
50	66.0	589	587	591	592
100	103.4	600	601	599	595
250	189.9	630	630	629	633
500	285.2	683	683	681	686
750	343.3	732	727	724	728
950	381.0	770	769	769	765

Table 2 shows the rod reactivity calculated for each data point shown in Table 1. These rod reactivates were extracted from control rod calibrations conducted yearly on The University of Texas at Austin TRIGA reactor. The values of reactivity are in cents with the β_{eff} (the effective delayed neutron fraction) for the core calculated to be 0.007. The rod reactivity is the amount of reactivity inserted into the core through control rod withdrawal. The change in reactivity is the amount of negative reactivity caused by fuel temperature increase. Moderator temperature did not change over the course of the experiment due to forced cooling of the pool water, so no effects from the moderator coefficient of reactivity may be seen in these data.

Table 2

Rod Reactivity

Power (kW)	**Transient (cents)**	**Shim1 (cents)**	**Shim 2 (cents)**	**Regulating (cents)**	**Reactivity Change (cents)**
1	228.903	210.213	217.742	228.038	0
50	233.9515	213.873	222.2655	232.317	17.511
100	238.906	219.426	225.493	233.581	32.51
250	251.886	230.334	237.092	248.798	83.214
500	272.663	247.971	255.104	267.279	158.121
750	289.108	260.152	267.794	279.45	211.608
950	299.89	269.607	278.863	288.293	251.757

The change in reactivity is compared to fuel temperature in Figure 2. If this relationship was assumed to be linear, the fuel temperature of reactivity is calculated to be 0.7 ¢/°C. This is commensurate with values expected for TRIGA type fuel. It should be stated that the fuel temperature coefficient of reactivity is know to be non-linear, but a linear assumption is fair over this power range resulting in an error of about 10% or less.

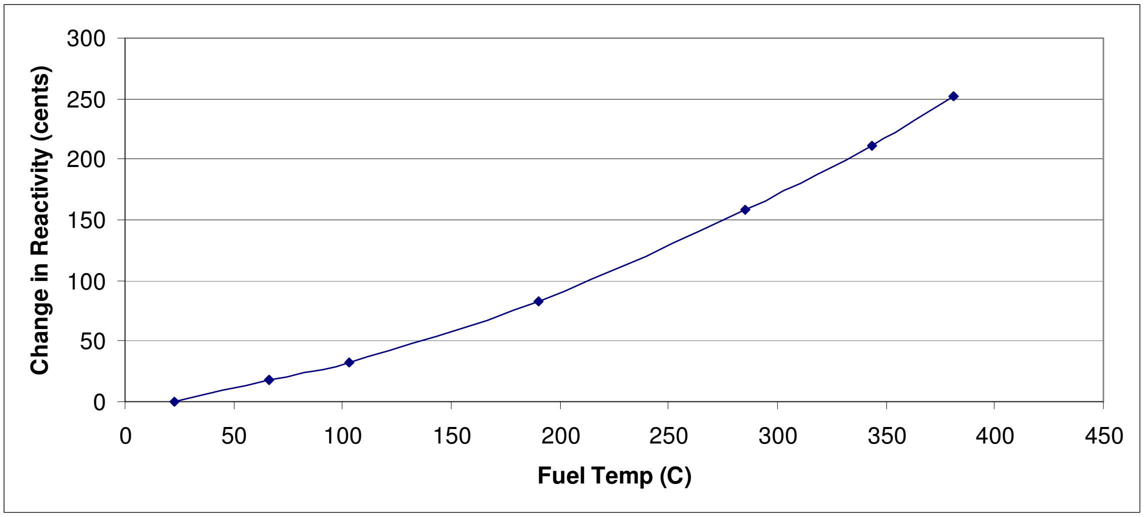

Figure 2. Plot of reactor power versus change in core reactivity.

Conclusions

In summary, the key advantages utilizing this remote experiment with the reactor include:

1. Experiment reinforces concepts covered in class material.
2. The remote conduction of the experiment allows for large class sizes to be accommodated. This experiment was conducted with over 30 students while only six students could be accommodated at a time at the reactor facility.
3. No travel is required to/from nuclear reactor facility.
4. Security and safety concerns for the students and facility are minimized.
5. Experiment may be conducted in the time of one normal course lecture.
6. Experiment is digitally recorded with on-campus infrastructure. This allows it to be viewed by off-campus students and by students at a later time.

Some key disadvantages to the experiment include:

1. Students do not see nuclear reactor facility in person.
2. Reactor parameters seen by students are limited to those presented on display.
3. Control rod positions had to be communicated to classroom from the reactor operator via telephone.

Student feedback for this experiment was very positive. As a start they found this experiment to be a welcomed break from the nominal class lectures. In addition, students indicated that the experiment facilitated a greater level of understanding of how temperature coefficients of reactivity add to the control of a nuclear reactor. The students did not have any negative comments regarding the distance learning nature of the experiments. However, none of the students have conducted this (or similar) experiments in person at the reactor as a baseline for comparison.

The audience size for this laboratory is only limited by classroom size. For the first trial of this experiment, the class size was 35 students. However, this could easily be expanded if necessary.

This laboratory could also be made available to courses at other colleges or universities. If anyone is interested in conducting this experiment in collaboration with The University of Texas at Austin, please contact the first authors of this manuscript.

Additional experiments are planned for future classes. These include the prompt jump, prompt drop and reactor pulse experiments that showcase time-dependent nuclear reactor kinetics.