Due : Oct. 13, 2005

22.251 Systems Analysis of the Nuclear Fuel Cycle
Fall 2005
PROBLEM SET #5

Economics and linear reactivity

1. Assume that a reactor is running at equilibrium with n equal size batches. The core power distribution is flat, so each batch accrues the same burnup each cycle (and it equals the cycle burnup). Assume both a technical and economic equilibrium - all batches are designed and built the same and cost the same. Thus one n-th of each batch is expensed (recovered from the customer) each cycle. Show that the time-averaged UNexpensed value of the fuel in the core equals 1/2 the value of a full core of fresh fuel.

This fact is of interest because the carrying charge on the fuel is proportional to the unexpensed value of the fuel.

2. A reactor with a specific power of 40 kWt/kgU operating on 18 month cycles is being considered for uprating by 25%.

   Each cycle includes a 30 day refueling outage with the remaining time spent at full power but with a capacity factor of 95% (not counting the refueling). Assume equilibrium operation.

   A. What are the values of cycle burnup in the base and uprated cases?

   B. How many equal-sized core regions are allowable in each case if the maximum allowable discharge burnup is 50 MWD/kgU. How many if the discharge burnup limit is raised to 70 MWD/kgU? (That is, what is the value of n in the linear reactivity formulas? Remember that non-integral values of n are perfectly acceptable.)

   C. What are the values of B1, the core average burnup at EOFPL in all four cases?

   D. If the "linear" reactivity equation for enrichment, e, for this reactor is

   $$e = 0.41 + 0.115B_1 + 0.000239B_1^2$$

   as given by Z. Xu for a core with the base specific power of 40 kWt/kgU, what U235 enrichment is required in each case? B1 is to be expressed in MWd/kgU in this equation.

   E. Discuss why this equation might not be as accurate for the uprated core as for the original core.

   F. What is the fuel cost in mills/kWhe in each of the four cases?

Unit prices for the fuel components are:

U_3O_8 - \$20/lbU_3O_8 (2 year lead time before irradiation)

Conversion - \$8/kgU (1.5 year lead time before irradiation)

Enrichment - \$100/kgSWU (1 year lead time before irradiation)

Fabrication - \$250/kgU (0.5 year lead time before irradiation)

Cost of money - 10% per year

3. Calculate the "incremental cost" of enriched uranium (U_3O_8 + conversion + SWU) over the enrichment range from 2 w/o to 20 w/o. Express the result as the incremental \$/kgU per 0.10 w/o increase in enrichment, and plot it vs enrichment over the requested range. You need only plot a few points spread over the whole range. Note that 0.10 w/o is 1 gram per kgU, so you are really plotting the incremental cost per gm of U235 in each kgU of fuel.

   HINT: It is easier to do this numerically than to attack it by differentiating - but take your choice.

   What do you notice about the shape of the curve?

   How might this be useful in evaluating the fuel management alternatives of operating for 12, 18 or 24 month cycles?