22.251 Systems Analysis of the Nuclear Fuel Cycle
Fall 2005
PROBLEM SET #7

1. (a) What is the waste fee of 1 mill per kWhre (that utilities pay DOE for disposal of spent fuel) equivalent to in \$/kgU when the thermal efficiency of a nuclear plant is 32% and the average fuel burnup at discharge is 33,000 MWD/TU.

   (b) What is the effect of the rise in average burnup of discharge fuel to 45,000 MWD/TU on the disposal fees per kgU?

   (c) What was the total of disposal fees collected in 1998 if the national nuclear electrical capacity was 101 GWe and the plants operated at an average capacity factor of 0.75?

2. Compare the decay heat from discharged fuel of a 1000 MWe plant after 18 months of continuing operation at full load to the decay heat of discharged fuel from a plant that operated 0.5 yr before it shutdown for 0.5 yr then re-operated for 1 yr before the fuel was discharged.

   Compare the decay heats at (1) two months after discharge, (2) 1 yr after discharge and (3) 100 years after discharge.

   Based on these results, how does the intermittent operation affect: (i) the required cooling of a storage pool? and (ii) the amount of heat to be deposited in the repository?

PROBLEM SET #7 SOLUTION

PROBLEM 1:

(a) The waste fee of 1 mill/kWhre can be converted to \$/kgU as following

$$1\,\text{Mill/kWhre} = \frac{1\,\text{Mill}}{1\,\text{kWhre}} \times \frac{10^{-3}\ \$/\text{Mill}}{\frac{1}{0.32}\,\frac{\text{th}}{\text{e}} \times \frac{1\,\text{MWe}}{1000\,\text{kWe}} \times \frac{1\,\text{day}}{24\,\text{hr}} \times \frac{1\,\text{kg}}{33\,\text{MWd(th)}}} = 253.44\,\$/\text{kg}$$

(b) If the average burnup of discharge fuel is raised to 45,000 MWD/TU and the waste disposal fee is still 1 Mill/kWhre, the disposal fee in units of \$/kgU will be 345.6 \$/kgU using above formula. Hence, the plant is paying more for waste disposal fee based on \$ per kgU, which increases the fuel cycle cost.

(c) In 1998, the total electricity output of nuclear power plants is

$$101\ \text{GWe} \times 365\ \text{days} \times 0.75 = 273.75\ \text{GW}\cdot\text{day(e)} = 663.57\times10^{9}\ \text{kWhr(e)}.$$

The waste disposal fee collected in 1998 is therefore

$$1\ \text{mill/kWhr(e)} \times 663.57\times10^{9}\ \text{kWhr(e)} = 663.57\ \text{million dollars.}$$

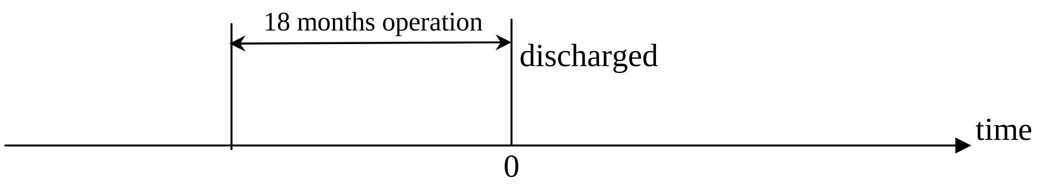
PROBLEM 2:

The electricity output is given as 1000 MWe. But the decay heat is related to the thermal power level. Assuming the thermodynamic efficiency to be 32% (given in Problem 1), the thermal power P_0 of the plant is

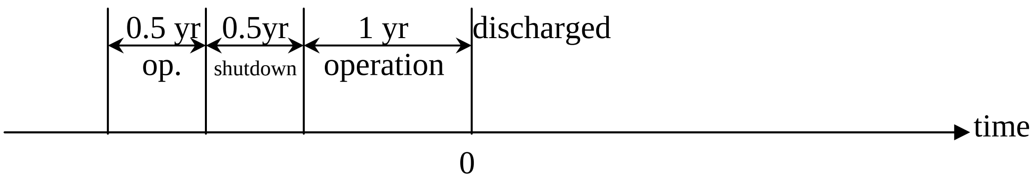
$$P_0 = 1000\ \text{MWe}/32\% = 3125\ \text{MW(th)}.$$

The power histories of two cases are shown as follows:

Case 1.



Case 2.



And we will use the decay heat correlation of spent fuel as (from attachment to the problem)

$$\frac{P}{P_0} = 0.0592\left[t^{-0.2} - \left(t+T\right)^{-0.2}\right],$$

where P_0 = operating power
t = time after shutdown in seconds
T = time of operation at P_0 in seconds

For Case 1 (18-month cycle), the decay heat after discharge is

$$\left.\frac{P}{P_0}\right|_{\text{case 1}} = 0.0592\left[t^{-0.2} - \left(t+4.7304\times10^{7}\right)^{-0.2}\right].$$

For Case 2 (intermittent operation), the decay heat after discharge is

$$\left.\frac{P}{P_0}\right|_{\text{case 2}} = 0.0592\left\{\left[\left(t+4.7304\times10^{7}\right)^{-0.2} - \left(t+6.3072\times10^{7}\right)^{-0.2}\right] + \left[t^{-0.2} - \left(t+3.1536\times10^{7}\right)^{-0.2}\right]\right\}$$

The decay heats at two months, 1 year, and 100 years after discharge can be computed using above two formula and the results are shown in following table

Time after discharge	Decay heat, (P/ P_0) and P (MW)		
	Case 1. 18-month cycle	Case 2. intermittent op.	Difference
Two months	9.8916×10^{-4} 3.0911 MW	9.5057×10^{-4} 2.9705 MW	3.9%
1 year	3.1364×10^{-4} 0.9801 MW	2.9831×10^{-4} 0.9322 MW	4.9%
100 years	2.2172×10^{-6} 6.9286 kW	2.2128×10^{-6} 6.9151 kW	0.2%

Based on our results, the intermittent operation will reduce the requirement of cooling of a storage pool since there is longer time for spent fuel to decay. And the amount of decay heat deposited in the repository has also been reduced. From above figure, it can seen that after long time (100 years) the decay heat of two spent fuels is essentially the same since the time after discharge is much longer than the intermittent operation so that the fuel tends to forget about the power history.