

PROBLEM SET #6
SOLUTION

Question 1

According to Federal law, reactor operators are required to pay the U.S. government a fee of 0.1 cents for each kilowatt hour of nuclear electricity sold in order to cover the costs of high-level nuclear waste disposal. For a PWR operating with a thermal efficiency of 33% and discharging spent fuel with an average burnup of 35,000 MWD(th)/MTHM, what is the cost of disposal expressed in dollars per kg of HM? How would this cost be changed by an increase in discharge fuel burnup to 50,000 MWD(th)/MTHM?

Solution:

The question posed is one of unit conversion:

$$\frac{35000MWD(th)}{MTHM} \times \frac{1MW(e)}{3MW(th)} \times \frac{10^3kW}{1MW} \times \frac{24h}{1D} \times \frac{1MTHM}{(10^3)kgHM} \times \frac{\$0.001}{kWh} = \frac{\$280}{kgHM}$$

$$\frac{50000MWD(th)}{MTHM} \times \frac{1MW(e)}{3MW(th)} \times \frac{10^3kW}{1MW} \times \frac{24h}{1D} \times \frac{1MTHM}{(10^3)kgHM} \times \frac{\$0.001}{kWh} = \frac{\$400}{kgHM}$$

So, for burnup of 35,000 MWD(th)/MTHM, the cost is \$280 per kgHM, and for burnup of 50,000 MWD(th)/MTHM, the cost is \$400 per kgHM.

Question 2

- a. The U.S. uranium mining industry has long been struggling with weak domestic demand and competition from low-cost foreign producers. One strategy for increasing the demand for natural uranium would be to raise the tails enrichment assay at U.S. enrichment plants. If the tails assay were raised from a level of 0.2 weight percent of U-235 to 0.35 percent, by how much would the demand for natural uranium increase? (NOTE. Assume that the enrichment plants produce low-enriched uranium for light water reactors with an average U-235 enrichment of 4.5%.)

Solution:

Given 0.2% enriched tails, 4.51% enriched product, and 0.711% enriched feed, the ratio of feed to product is 8.43.

$$\frac{F}{P} = \left(\frac{x_p - x_w}{x_f - x_w} \right) = \left(\frac{0.0451 - 0.002}{0.00711 - 0.002} \right) = 8.43$$

If the tail enrichment were raised to 0.35%, the resulting ratio of feed to product would be:

$$\frac{F}{P} = \left(\frac{x_p - x_w}{x_f - x_w} \right) = \left(\frac{0.0451 - 0.0035}{0.00711 - 0.0035} \right) = 11.52$$

The increase in feed requirement would therefore be

$$\frac{11.52 - 8.43}{8.43} \times 100\% = 36.7\%$$

- b. Another reason to increase the tails assay is that it would reduce the amount of electric power consumed by the enrichment plants. Assuming that the energy consumption is proportional to the amount of separative work, by how much would the energy requirement be reduced if the uranium tails assay is increased from 0.2 to 0.35 weight percent (again assume the average uranium product enrichment is 4.5%).

Solution:

We know that the amount of separative work required is given by the equation:

$$S = P(2x_p - 1) \ln\left(\frac{x_p}{1 - x_p}\right) + W(2x_w - 1) \ln\left(\frac{x_w}{1 - x_w}\right) - F(2x_f - 1) \ln\left(\frac{x_f}{1 - x_f}\right)$$

Let us calculate the required separative work required for the old tailings enrichment

$$S = P(2x_p - 1) \ln\left(\frac{x_p}{1 - x_p}\right) + \left(\frac{F}{P} - 1\right) P(2x_w - 1) \ln\left(\frac{x_w}{1 - x_w}\right) - \left(\frac{F}{P}\right) P(2x_f - 1) \ln\left(\frac{x_f}{1 - x_f}\right)$$

$$\begin{aligned} \frac{S}{P} &= (-.910) \ln(.047) + 7.43 \times (-.996) \ln(.002) - 8.43 \times (-.986) \ln(.00716) \\ &= 7.72 \end{aligned}$$

Using the same algebra, we can express the separative work equation in terms of P for the new tails enrichment:

$$S = P(2x_p - 1) \ln\left(\frac{x_p}{1 - x_p}\right) + 10.52P(2x_w - 1) \ln\left(\frac{x_w}{1 - x_w}\right) - 11.52P(2x_f - 1) \ln\left(\frac{x_f}{1 - x_f}\right)$$

$$\frac{S}{P} = 5.71$$

For each kilogram of product, 5.71kg of separative work would be required. Thus, the energy requirement would decrease as follows:

$$\frac{7.72 - 5.71}{7.72} \times 100\% = 26\%$$

The energy requirement would decrease by 26%.