22.251 System Analysis of the Nuclear Fuel Cycle
Fall 2009
Homework Set #9

Problem 1 The behavior of minor actinides in the course of uranium enrichment is becoming increasingly important. Problem Set 2 discussed some issues pertaining to ^{236}U. Here we consider how the behavior of ^{234}U during enrichment has potential use in non-proliferation and how it relates to ASTM specifications intended to limit worker dose.

1.1 Forensic activities have become important in relation to non-proliferation and the nuclear fuel cycle. This problem demonstrates that a knowledge of how minor actinides behave in an enrichment facility might assist in determining whether weapons-grade material has been processed in such a facility.

^{234}U is a naturally occurring isotope of uranium, with a natural abundance of 0.000054 (expressed as a mass fraction of total uranium). It has been suggested that the concentration of ^{234}U in the tails of an enrichment facility would be a useful indicator of the product ^{235}U enrichment. Since the tails usually remain on-site after the product has been removed, this could provide a valuable after-the-fact indication of illegal enriching activities. Investigate this by making a plot of 234 enrichment in the tails vs 235 enrichment in the product, all the way up to 93% enriched product. Do this for tails of 0.20% and 0.30%.

A generalized form of the equation used to solve problem 2 of Problem Set 2 for ^{236}U can be applied to any of the other minor actinides to determine their behavior during uranium enrichment. It is perhaps not intuitively obvious from the discussion in Benedict and Pigford, but the exponent in the denominator of Eq. 12.327 is equal to:

$$1 - (2/3)(M_m - 235)$$

where M_m is the atomic mass of the minor actinide.

When the minor actinide is 234U, the value of the exponent is -5/3, and the equation becomes:

$$\frac{M_p y_p}{\left(\frac{x_p}{1-x_p-y_p}\right)^{5/3}}+\frac{M_w y_w}{\left(\frac{x_w}{1-x_w-y_w}\right)^{5/3}}-\frac{M_f y_f}{\left(\frac{x_f}{1-x_f-y_f}\right)^{5/3}}=0$$

where

p represents product

w represents waste (tails)

f represents feed

x refers to U235

y refers to the minor actinide, U234 in our case.

1.2 What could a proliferator nation do to frustrate such surveillance?

1.3 In order to control worker dose, ASTM C 996 standard limits the ^{234}U concentration in enriched uranium to 10,000 ppm (expressed as ^{234}U fraction of ^{235}U, not total U). What value do you get for this ^{234}U fraction if the product ^{235}U enrichment is 5%, 10% or 20%?

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