Enrichment and Conversion of Fission Reactor Fuel Elements

- **Two fissile isotopes commonly considered:**
  - ^{235}U **(Use enrichment)**
  - ^{239}Pu**(Use reprocessing)**

- **U.S.(weapons---->submarines---->civilian)**
  1944 ***present***

- **Canada..Commercial..Heavy Water + Nat. U**

Gaseous Diffusion Process - UF_6

- **Relies on the fact that UF_6 is solid at RT and a vapor at moderate temperatures.**

(Figure)

- **Gaseous diffusion relies on the difference in the rate which $^{235}UF_6$ and $^{238}UF_6$ diffuse through a barrier containing many holes.**

- **The relative speed of the two molecules can be derived from their kinetic energies;**

$$kT = \frac{MV^2}{2} \quad M = \text{molecular mass}$$

or,

$$\frac{V_L}{V_H} = \sqrt{\frac{M_H}{M_L}} = \alpha$$

- **Relative frequency at which molecules of different species pass through a small hole is proportional to the speed of the molecule.**

Hence the ratio of $\frac{^{35}U}{^{38}U}$ on the low pressure side is greater than the $\frac{^{35}U}{^{38}U}$ ratio on the high pressure side.

For $^{235}UF_6$ and $^{238}UF_6$, maximum α is;

$$\alpha = \sqrt{\frac{(238 + 6 \bullet 19)}{235 + 6 \bullet 19}}$$

$$\alpha = 1.004289$$

(more realistic value is 1.003 due to down stream back pressure and leaks)

- **Low value of α requires a very large number of steps**

Figures (2)

- **<u>What is the Barrier? (mostly classified)</u>**
  - **Very thin and delicate**
  - **100's of millions of holes/cm3**
  - **$\approx$ 20 Å diameter hole**
  - **Must exclude organic materials and air to avoid plugging**
  - **Materials reported to be sintered Ni and anodized Al**

More complete analysis of U enrichment, see ;

Benedict, M, T.H. Pigford, and H.M. Levi, "Nuclear Chemical Engineering", 2nd ed., McGraw Hill Book Company, NY, 1981

Villani, S, ed., "Uranium Enrichment", Springer Verlag, NY, (1979)

Cochran, R. C. and N. Tsoulfanidis, "The Nuclear Fuel Cycle: Analysis and Management", American Nuclear Society, La Grange Park, IL, (1990)

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Important Variables and Equations

kg U Feed (F) = kg Enriched U Product (P)
+ kg U Waste (W)

$$x_f^F F = x_p^P P + x_w^W W$$

where x_f **= wt. fraction of** ^{35}U **in feed**

x_p **= wt. fraction of** ^{35}U **in product**

x_w**= wt. fraction of** ^{35}U **in waste**

(Note: F, P, & W could be in kg or kg/unit time)

- **2 eqs. and 6 variables, F, P, W,** x_f, x_p, x_w
- **Trick is to solve for 2 in terms of the other 4!**

1.) x_f**= 0.711% now (1996)**

2.) x_p **= as requested by the customer**
Table 1.1 and 2 figures

3.) x_w **= could be between 0.2 and 0.3 %, currently in the U.S. is 0.3%**

4.) P = mass of desired product

One can solve the equations above;

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

$$W = P\frac{\left(x_p - x_f\right)}{\left(x_f - x_w\right)}$$

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Feed factor is defined as;

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

Waste factor ;

$$\frac{W}{P} = \frac{F}{P} - 1$$

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How Much Energy is Required to Reach a Given Enrichment?

Define Separative Work Unit (SWU) as;

"resource required to perform the enrichment to the desired level of x_p given x_f and x_w. For gaseous diffusion this is equivalent to electrical energy"

# of SWU's produced by an enrichment plant

during a time period t,

$$SWU = \left[P \bullet V(x_p) + W \bullet V(x_w) - F \bullet V(x_f)\right]t$$

The quantity $V(x_i)$ is called the separation potential and is given by;

$$V(x_i) = (2x_i - 1)\ln\left[\frac{x_i}{1 - x_i}\right]$$

where i = f,p,w

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We normally quote SWU's per unit of product (P•t) where P is feed rate.

$$S = \frac{SWU}{P \bullet t} = V(x_p) + \left(\frac{W}{P}\right) \bullet V(x_w) - \left(\frac{F}{P}\right) \bullet V(x_f)$$

$$S = \text{"SWU" factor}, \frac{SWU}{kg}$$

Figure 3.6 plus Schematic

<u>Problem -1</u>

a.) What is the number of kgs of natural U that has to be provided as feed in an enrichment plant if one requests 30,000 kg of U enriched to 3% in ^{35}U? Assume the tails assay is 0.2%.

b.) What is the number of SWU's needed for separation?

$$\frac{F}{P} = \frac{(3 - 0.2)}{(0.711 - 0.2)} = 5.479 \quad \frac{kg\ feed}{kg\ product}$$

Total feed is then;

F= 30,000 • 5.479 = 164,370 kg U feed

$$\textit{b.)}\ V(x_f) = (2 \bullet 0.00711 - 1)\ln\left[\frac{0.00711}{1 - 0.00711}\right]$$

$$=4.869$$

$$V(x_w) = (2 \bullet 0.002 - 1)\ln\left[\frac{0.002}{1 - 0.002}\right]$$

$$=6.188$$

$$V(x_p) = (2 \bullet 0.03 - 1)\ln\left[\frac{0.03}{1 - 0.03}\right]$$

$$=3.268$$

S = 3.268 +(5.479-1)(6.188) - (5.479)(4.869)= 4.307

Hence the total number of SWU's is then;

30,000 kg • 4.307 SWU/kg = 129,210 SWUs