TOMSK POLYTECHNIC UNIVERSITY

Fundamentals of Nuclear Fuel Cycle

Lecturer
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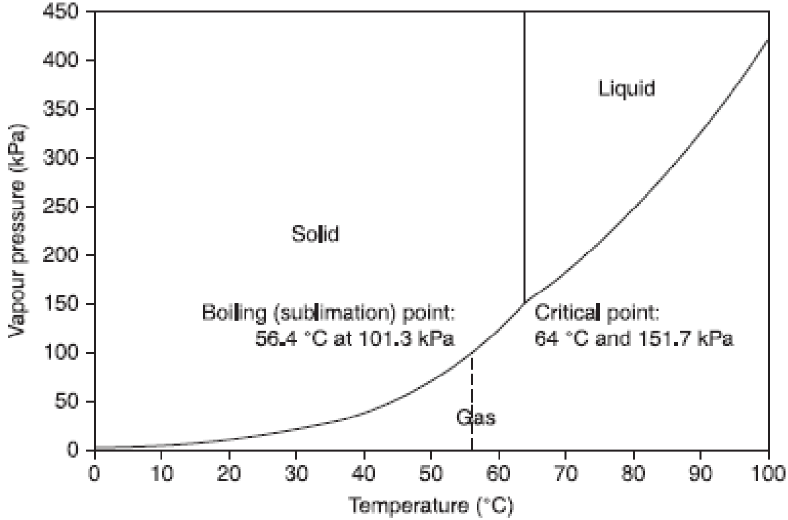
Uranium hexafluoride (HEX)

$U_3O_8 + F_2 = 3UO_2F_2$ 450 – 500 °C

$3UO_2F_2 + 6F_2 = 3UF_6 + 3O_2$ 270 °C



Uranium hexafluoride (HEX)

Properties

- Soli phase - ivory crystals
- Density – 5.09 g/cm^3
- Pyrophoric on the air
- hydrolyzed with water vapor
- High corrosion activity

Suppliers

	1000 kg-SWU/yr
1. Russia – SC Rosatom (Tvel)	26578
2. USA – Honeywell (Converdyn)	4700
3. France – Areva NC (Comurhex)	7000
4. Canada – Comeco	-
5. UK+Germany+Holland – Urenco	14400
6. China	
7. Japan	
8. India	
9. Pakistan	
10. Brasilia	
11. Argentina	
12. Iran	

Enrichment

is a process of increasing U^{235} concentration in the mix

Natural U

99.2745 U^{238} 0.7200 U^{235} 0.0055 U^{234}

Weapons programme – 90% and higher of U^{235}

Peaceful programme – 3 – 5% of U^{235}

Separated work unit

Is used for expression of the enrichment degree

$$W = PV_p + TV_t - FV_f$$

W – Separative work

P – Mass of products

T – Mass of tails

F – Mass of feed material

V_p, V_t, V_f – Value function for the product, tails, and feed

$$V = (1-2x)Ln((1-x)/x)$$

x – Concentration of U^{235} in the the product, tails, and feed

Separated work unit

Mass of product (kg)	Target product enrichment (%)	Target tails enrichment (%)	SWU required	Mass of feed (kg)
1	4	0.5	3.8	17.0
1	4	0.4	4.4	12.0
1	4	0.3	5.3	9.0
1	4	0.2	6.5	7.4
1	4	0.1	9.0	6.4
1	4	0.05	12.0	6.0

Enrichment methods

- Gaseous diffusion
- Gas centrifuge
- Electromagnetic isotope separation
- Aerodynamic isotope separation
- Laser enrichment
- Plasma separation

Enrichment methods

Supply source:	2000	2010	projected 2017
Diffusion	50%	25%	0
Centrifuge	40%	65%	93%
Laser	0	0	3%
HEU ex weapons	10%	10%	4%

Gaseous diffusion

1896 – Rayleigh "... A mixture of two gases with different atomic weights may be partially separate, if we force the mixture to diffuse through the porous membrane into the vacuum"

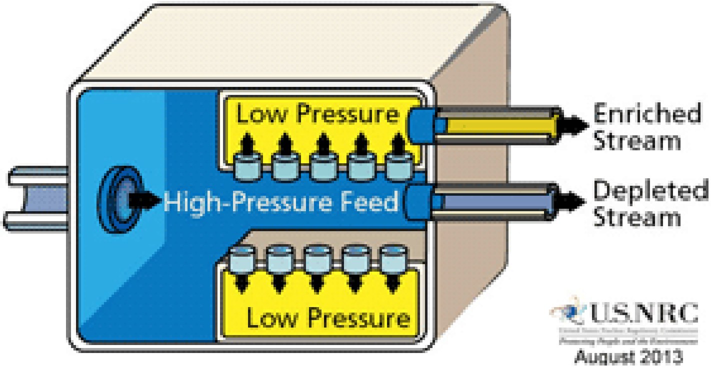
$$\frac{mv^2}{2} = \frac{3kT}{2} \Rightarrow v = \sqrt{\frac{3kT}{m}}$$

Difference in the masses ⇒ Difference in speed

$^{235}UF_6$ travels more quickly than $^{238}UF_6$

Gaseous diffusion

Gaseous diffusion unit



The greater speed of $^{235}UF_6$ - more frequent interaction with the membrane

Gaseous diffusion

Separation factor

Shows the growth of gas concentration after diffusion barrier

$$\alpha = \sqrt{\frac{m_{end}}{m_{start}}} \qquad \alpha^{max} = 1.00429$$

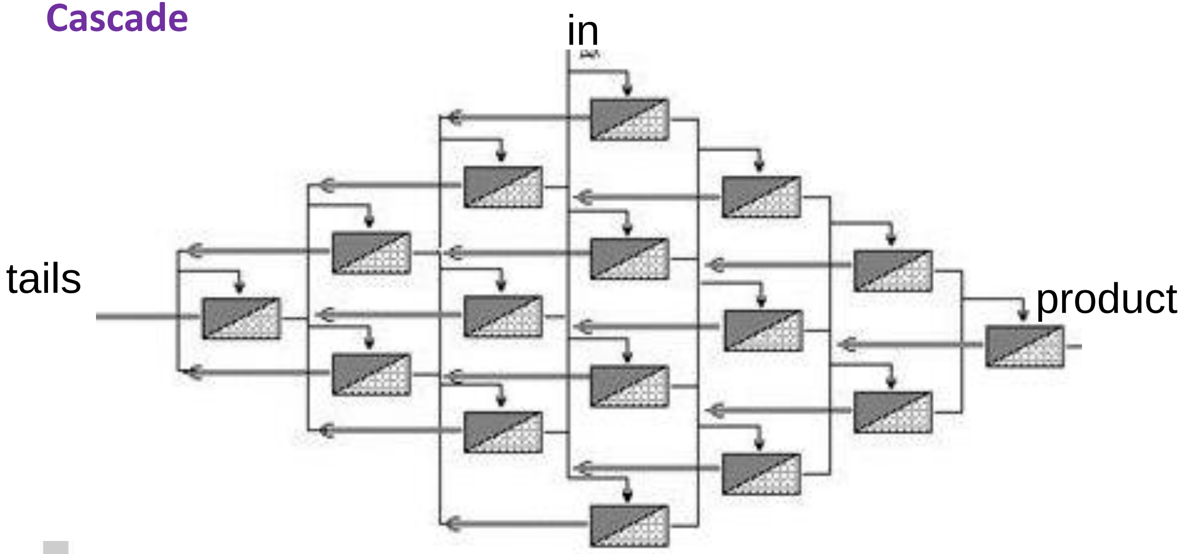
Enrichment factor

$$\varepsilon = \alpha - 1 \qquad \varepsilon^{max} = 0.0043$$

$^{235}UF_6$ in 0.71% → $^{235}UF_6$ out 0.7143%

Gaseous diffusion

Cascade



Gaseous diffusion

Membrane

Small pore size – 20 nm or less

Numbers of pores must be maximized

Chemical resistance of materials

Ni, Al_2O_3, CaF_2, Teflon

Disadvantages of gaseous diffusion

- Big numbers of cascades
- Low enrichment factor
- High energy consumption

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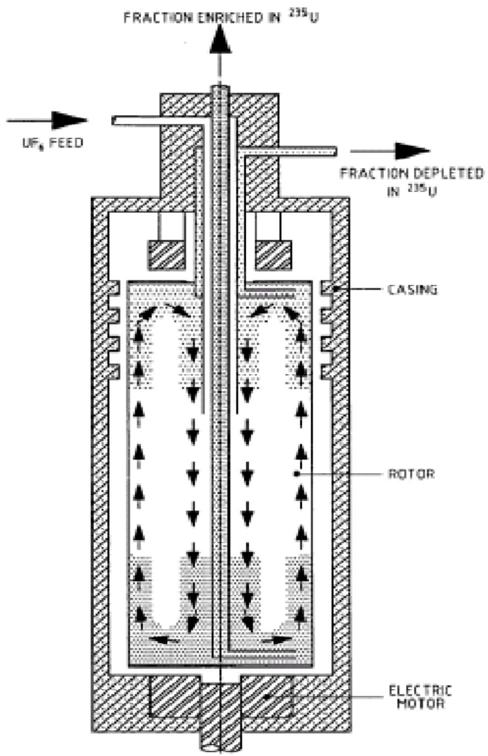
Gas centrifuge

Based on the difference in behavior of isotopes in gravity field

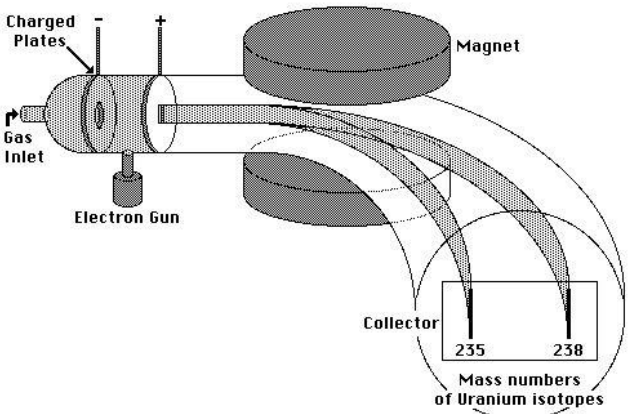
Enrichment factor

350 m/s – 0.0682
400 m/s – 0.0976
500 m/s – 0.1520



Electromagnetic isotope separation

$$\text{Solid } UCl_4 \xrightarrow{t} \text{Vapor } UCl_4 \xrightarrow{\text{Electron beam}} U^+ \text{ and } Cl^-$$



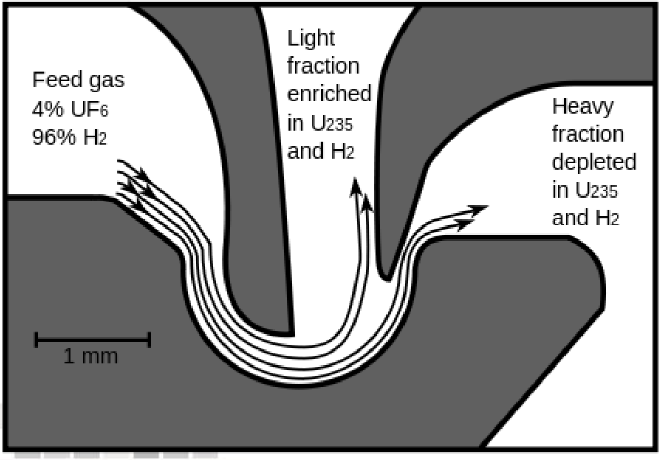
Electromagnetic isotope separation

Disadvantages

- Low conversion to ions
- Ions can “miss” collector
- It is periodical process with a significant time between beam runs
- Material is deposited within the equipment

Aerodynamic isotope separation

1. Jet nozzle technology



Aerodynamic isotope separation

2. Advanced vortex tube

Laser enrichment

- Atomic Vapor Laser Isotope Separation (AVLIS)
- Molecular Laser Isotope Separation (MLIS)
- Chemical Reaction Isotope Selective Laser Activation (CRISLA)
- Condensation Repression Isotope Selective Laser Activation (CRISLA)
- Separation of Isotopes by Laser Excitation (SILEX)