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Nuclear Fuel Enrichment Basilar Concepts

Enrichment plants are designed to increase natural uranium 235-isotope content (the most valuable, since the term "enrichment") for use in nuclear reactors or weapons. They can operate by several processes, either physical or chemical, the most common of which are the gaseous diffusion and the gas centrifuge.

In order to focus on the enrichment concepts, it is useful to define several common quantities to clarify the meaning of the rest of the note.

Definition 1 (Value function). *It is called Value function of a material with assay x, $V(x)$, the quantity:*

$$V(x) = (1-2x)\ln\left(\frac{1-x}{x}\right). \tag{1}$$

Definition 2 (Separative Working Unit). *It is called Separative Working Unit (SWU) the quantity of separative work, indicative of energy used in enrichment, when feed, tail and product quantities are expressed in kilograms.*

By the previous definition, it follows that the work W_{SWU} necessary to separate a mass F of feed of assay x_f into a mass P of product assay x_p and tails of mass T and assay x_t, expressed in terms of the number of SWU needed, is expressed by the relation

$$W_{\mathrm{SWU}} = PV(x_p) + TV(x_t) - FV(x_f). \tag{2}$$

To complete the theory, a couple more common definition follow (not used in the present note, but important to the reader).

Definition 3 (Feed to Product ratio). *It is called Feed to Product ratio the quantity*

$$\frac{F}{P} = \frac{x_p - x_t}{x_f - x_t}. \tag{3}$$

Definition 4 (Tails to Product ratio). *It is called Tails to Product ratio the quantity*

$$\frac{T}{P} = \frac{x_p - x_f}{x_f - x_t}. \tag{4}$$

From the definitions above it follows that the most important parameter is the assay of both the incoming and outgoing materials streams. In particular, a predominant role is played by the tails assay: the fraction of ^{235}U which is discarded during the enrichment process determines univocally both the incoming fresh material mass needed and the energy cost of the process itself. It is pale that those aspects react differently when increasing or decreasing the tails assay: the fewer ^{235}U is discarded, the fewer NU is required, but at a higher energy cost (in terms of SWU) due to the more complex process[1].

As an example, the production of 1 kg of LEU at 3.6% of ^{235}U requires about 8 kg of NU and 4.5 SWU if the tails assay is 0.3%, or about 6.7 kg NU and 5.7 SWU if the tails assay is reduced to 0.2%.

In conclusion, it is interesting to see the electrical energy consumption required for the main enrichment processes. The most typical value are shown in the following table.

Enrichment method	Net electrical energy [kWh]	Corresponding energy [MJ]
Gaseous diffusion	2400÷2500	∼8600÷9000
Gas centrifuge	50÷60	∼180÷220

[1] Since the small difference between the ^{235}U and the ^{238}U isotopes, the most common processes cannot achieve the desired enrichment by means of a single enriching operation, needing instead a sequentiality of stages.