

DEVELOPMENT OF URANIUM ENRICHMENT

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ABSTRACT

Nuclear Fuel Bureau of Ministry of Nuclear Industry (MNI) of China has experiences of diffusion enrichment. This paper describes the development & comparison of the different enrichment techniques. It deals with the centrifuge development currently being undertaken in China. It also describes the status of R & D work about Laser Isotope Separation. The paper concludes with our preference of development programme on uranium enrichment.

THE DEMAND AND SUPPLY OF URANIUM ENRICHMENT SERVICE

The development of uranium enrichment depends on the need of military and civilian purposes, especially the latter. Thus, the construction programme of the power reactors gives strong commercial incentives for the further research and development of uranium enrichment technologies.

In recent years, the forecasts on installing nuclear electricity generating capacity has been retracted gradually. Based on early forecasts in 1970, a requirement of about 42 million separative work units (MSWU) was predicted for 1980 in the western countries. Major activities were undertaken to avoid an expected shortage in the supply of enrichment services. The U.S. Department of Energy (DOE) began the CIP and CUP programmes to increase the capacity of their existing three diffusion plants in the United States. In France the EURODIF plant was built and in addition the USSR entered the market for enrichment services. In parallel, the URENCO partners developed and installed centrifuge enrichment plants in the United Kingdom, the Netherlands and the Federal Republic of Germany. As a result, in 1982 a total diffusion capacity of about 37 million SWU per year (MSWU) was reached in the western countries.

However, from 1970 to 1987 the requirement forecasts of SWU have shown a declining trend. Maybe the drop in the price of oil and the two accidents of Three Mile Island and Chernobyl are the main reasons. The current demand to fuel the power reactors is estimated to be about 25 MSWU/yr. In response to the declination, the major suppliers of enrichment services in the world market namely DOE, EURODIF, URENCO and TECHSNABEXPORT have taken actions. The Oak Ridge diffusion plant of DOE was placed in standby in 1985. This reduced the capacity in the United States by 7.7 MSWU/yr. The DOE uranium enrichment complex of the U.S. government operates two gaseous diffusion plants with a capacity of 19.2 million SWU per year. Although the diffusion process is a mature technology DOE has made significant improvements and as a result the technology is more competitive than was projected in the 1970's. In 1983, their unit cost of production was \$90 per SWU.

EURODIF is a European supplier of SWU. It also utilizes gaseous diffusion, with an installed capacity of 10.8 million SWU per year. As a supplier, EURODIF maintains a

strong position. Its diffusion plant construction is complete and it has some expansion capability without major investments.

URENCO uses the more energy efficient centrifuge technology, and is known for its highly competitive pricing. Today URENCO has a production capacity of 2.3 million SWU per year.

TECHSNABEXPORT, the sales agent of Soviet Union, has supplied enriched uranium to European utilities ever since the early 1970's. The Soviet Union utilizes the gaseous diffusion process. Currently, TECHSNABEXPORT has about 2-3 million SWU available per year for sale to western countries.

Comparing the current demand to fuel reactors of 25 MSWU with the total existing capacity of 34-35 MSWU/yr, including the USSR exports, results in a over capacity of 9-10 MSWU/yr.

Furthermore, the projected demand in the nineties is to increase only slowly from 25 MSWU in 1987 to about 35 MSWU in the year 2000. With the existing capacity of 34-35 MSWU/yr, one can expect that throughout the nineties the world's enrichment capacity will be sufficient to meet the predicted demand.

The above situation that the supply exceeds the demand, and that the demand is predicted to increase only slowly in the nineties means that the existing enrichers will have to face fierce competition for new contracts. To have better technology and cheaper SWU costs is the only solution.

China is a developing country, we are planning to develop nuclear power in suitable scale to meet the power shortage throughout this century and thereafter, the existing diffusion plants in China can support our development of nuclear power generation, but their production is not enough for the nuclear power plants scheduled during the nineties. According to our policy of self reliance and independence, attention has been paid to meet the demand of SWU both domestically and economically.

GASEOUS DIFFUSION

This method has been used in a number of countries. France and U.S as well as USSR continue to offer commercial services based on this technology. 94% of the designed present enriched capability is by this process. It is a mature enriched technology. The plant can be operated for a long period of time with high reliability. The main components are sturdy and have quite long lifetime.

The principle of gaseous diffusion is well known. It's enrichment factor for uranium separation is very less, the

value so far reached is about 2×10^4 . This is why the process has to be repeated in many stages to obtain a useful concentration of enriched UF₆. The economical scale of a diffusion plant is accordingly quite large, of the order of several millions of SWU per year. It could not be easily or inexpensively adjusted to accommodate changing demands.

The specific energy consumption for this process is very high, about 2400 KWH/SWU for DOE and EURODIFF.

China has had experiences in the field of uranium enrichment for many years. The diffusion plants in China have played an important role both for the military and for the civilian purposes. To meet the demand of nuclear power stations, enriched low concentration product of good quality has been supplied to the plant for manufacturing fuel elements for the PWR nuclear power station. Some of the product has been exported. The long period of successful operation has proved that the diffusion plant is dependable. Through long terms of research and development we have been able to improve the plant efficiency and raise its productivity, for example, the structure efficiency of the diffusion cascade is more than 97%. We are capable of designing and manufacturing different types of diffusing machines. We also have the experiences in designing, constructing, installing, operating, maintenance, as well as accident handling of diffusion plant. Recently, since the price of electricity is increasing, to reduce the spending on energy consumption we have been adjusting the rate of production of the plants according to the seasonal price of the power supply. Because our plants are moderate in scale, their specific investment and power consumption are comparatively high. However by the time when the existing plants are completely depreciated, but the machines are expected to be still in good working order, the unit cost of SWU will certainly be much lower then.

GAS CENTRIFUGES

The theory of separation by gas centrifuges is also well known. On first principle, the enrichment factor of the gas centrifuge process for UF₆ is much higher than that of gaseous diffusion process (by 1-2 orders of magnitude) and the specific power consumption is much lower (by about a factor of 10). As a consequence of former, for the same degree of enrichment, the number of stages of a centrifuge cascade is much less than that of a diffusion cascade, and the economic scale for a centrifuge plant is also much smaller. Furthermore, the centrifuge plant can be built up by modular units of much smaller size, allowing the plant installed on a step by step basis, making the plant size more flexible to meet the changing demand, as well as allowing newly improved version of the centrifuge to be used as early as possible.

The output of a centrifuge increases very fast with the

increase of the rotor peripheral speed. The ultimate allowed speed of a rotor depends on the material used for the rotor construction. The choice of rotor material is of prime importance.

China started the investigation of the centrifuge process in the late fifties. During the first stage, we carried out applied research on the mechanical and physical aspects of the machine as well as the choice of the rotor material. Until now we have developed many types of centrifuges in which the rotors are made of aluminium alloy, maraging steel and carbon fiber reinforced plastics. The output of the centrifuge has shown obvious increase through the increase of the peripheral speed of the rotor. We have also obtained some useful information about the centrifuge service lifetime as well as its failure rate on the old models. We aim at operating many thousands of high speed rotating rotors in a plant continuously for about ten years or more with no maintenance. The non-maintenance policy is preferred similar to the policy of URENCO, since the output of our centrifuge is moderate. On the latest model many studies have been made after its successful operation. Cascade of the latest model machines is expected to run better than the old ones. We believe our designing and manufacturing process will be proved to be successful. Along with paying more attention to the improvement of manufacturing process for mass production and the centrifuge service lifetime as well as the economics of the centrifuge plant, we are still doing a lot of research and development work to improve the mechanical and physical properties of centrifuges made of different materials.

LASER ISOTOPE SEPARATION

The possible high selectivity of the Laser Isotope Separation (LIS) makes this process very attractive, especially the tail assays could be lower than that of the diffusion and centrifuge process. LIS is divided into two categories, namely the Molecular Laser Isotope Separation (MLIS) and the Atomic Vapor Laser Isotope Separation (AVLIS) according to the separating medium used. With the future in mind, the United States and other countries are today actively developing the AVLIS process, in the United States separative work at a factory cost of \$30 to \$45 per SWU has been predicted. Although the LIS is quite attractive, many major problems have to be solved. As laser light is one of the most expensive light source one has to use it very efficiently. The requested energy densities require pulsed laser systems with a high repetition rate. Problems regarding the endurance of the optical systems have to be solved to keep the maintenance cost at sufficiently low level. This means AVLIS hasn't been brought to technical and commercial maturity.

China has developed LIS technology from early 1970's. Both routes, MLIS and AVLIS were investigated, but with initial emphasis on the molecular route since the use of UF₆ as the working gas is well established in enrichment technology of diffusion and centrifuge processes. The two routes were

pursued in parallel until 1985 when from a assessment of scientific progress and financial situation, it was decided to place primary emphasis on the atomic route for more detail R & D work, although we haven't stoped the molecular route completely. We had confirmed the principle experiment of AVLIS in 1985. Studies of a three photon ionization process have been undertaken in several Institutes which belong to MNI and Academy of Science of China. We have been pursuing an integrated development programme of AVLIS which will extend early ninties under the organization of MNI in China. We will emphasize the following studies. The copper vapour lasers which provide the light power needed for the process will continue to be developed for higher power and longer life. Spectroscopic work will be continued with the objective of finding energy levels which would enable U-235 to be ionized more efficiently. The uranium vapour properties, electron beam gun and techniques for the separation of ions from uncharged atoms are being explored by our Institutes. Application of these techniques to uranium vapour, and the subsequent product and tail collection and handling will also be investigated. It is programmed that we could be in a technical position to install a pilot AVLIS separation device in the early 1990's. We hope we can confirm the priority of centrifuge and AVLIS by the turn of the century.

CONCLUSIONS

China is a developing country, we have to develop nuclear power generation to meet the serious power shortage particularly in the east sea shore and remote areas. To meet the SWU demand of nuclear power stations, according to the self reliance policy proper arrangement of the development programme on uranium enrichment is quite important. Since our diffusion plants are reliable SWU supplier, we intend to use the diffusion plants to supply the enriched uranium for nuclear power stations throughout 1990's and 2000 alongwith the economic improvement of the diffusion process. After fully depreciation we believe it can give the enriched uranium with acceptable cost.

According to our experience on the centrifuge, particularly the centrifuge process is much more flexible than diffusion process to meet the gradually increasing demand and lower specific power consumption, we would like to use the centrifuge plants to supply SWU also. In the meantime we'll do our best to improve the economics of the process. We'll pay more attention to the investigation of centrifuge service lifetime & failure rate as well as the manufacturing process to raise the passing rate. We think after successful improvement the specific investment of the process will be lower, so that under our condition the SWU cost of centrifuge process could be lower than that of the diffusion process considering the possible increase of power price.

As to LIS, much R & D work are being undertaken, particularly on AVLIS. We hope we can confirm the priority of the centrifuge and the AVLIS by about the turn of the

century since it isn't mature technology for uranium enrichment.

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