Fuel Cycle Demand, Supply and Cost Trends

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An IAEA Advisory Group Meeting on Fuel Cycle Demand, Supply and Cost Trends was held in Vienna on 11–14 November 1975 for the purpose of obtaining an overall review of the nuclear fuel cycle. The discussions covered the entire nuclear fuel cycle beginning with projections of world[1] nuclear power capacities through the year 2000 and the resulting demands for fuel cycle services, followed by examination in detail of the steps of the fuel cycle.

The necessity to provide for the greatly expanding uranium requirements, the large financial impacts associated with establishing fuel cycle service and overcoming the lack of adequate fuel reprocessing and recycling capabilities were found to be the most urgent problems in the fuel cycle.

NUCLEAR POWER GROWTH FORECAST

The approximately 70 GWe of nuclear electric generating capacity installed around the world in 1975 was projected to increase to around 500 GWe by 1985 and over 2000 GWe by the year 2000.

The distribution of reactor types expected to provide the nuclear power growth to the year 2000 led for the purposes of the fuel cycle calculation to the following generalized points:

(1) the total of Light Water Reactors (LWR) is assumed to consist of one third Boiling Water Reactors (BWR) and two thirds Pressurized Water Reactors (PWR);

(2) commercial fast breeder (FBR) introduction becomes substantial by the mid-1990's; and

(3) the rate of introduction of High Temperature Reactors (HTR) has decreased compared to earlier projections while that of Heavy Water Reactors (HWR) has increased.

Some detail of this projected distribution of reactor types for the OECD countries (over 90% of the world's nuclear power up to the year 2000) is given in **Table I.**

FUEL CYCLE REQUIREMENTS, SUPPLIES AND COSTS

Based on the nuclear power growth projections and reactor characteristics, the fuel cycle requirements were calculated by various participants and presented for discussion. These demand projections are summarized briefly in **Table II** to indicate the predicted magnitudes and growth rates.

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[1] Omitting centrally planned economies for all data.

Table I. Distribution of Reactor Types (GWe)
OECD (High Estimate)

Year	LWR[1]	PTR[2]	AGR[3]	HWR	HTR	GCR[4]	FBR	Total
1975	60.1	–	1.0	2.5	0.3	5.8	0.5	70
1980	162	–	5.8	7.2	0.6	5.8	1.4	183
1985	434	5.3	6.0	18.4	8.3	4.2	4.0	481
1990	775	22	6.0	41	29	1.1	15	889
2000	1584	79	4.5	115	126	–	200	2089

1 Relation PWR: BWR = 2 : 1
2 Pressure tube heavy-water reactor
3 Advanced gas-cooled graphite-moderated reactor
4 Gas-cooled graphite-moderated reactor.

Table II. Example Projection of World Demand for Nuclear Fuel Cycle Service

	Year					
Fuel cycle service	1975	1980	1985	1990	1995	2000
Uranium production, 1000 tonnes/yr	21	50	100	160	240	300
Uranium production, cumulated from 1975, 1000 tonnes U	21	200	600	1300	2300	3700
Enrichment, 1000 MT SWU/yr	11	35	70	110	180	240
Fuel Fabrication, 1000 tonnes Heavy Metal/yr (only LWR)	2.5	7	15	25	40	55
Reprocessing, 1000 tonnes U/yr (only LWR)	0.5	3.5	10	18	30	45

For a typical demand calculation, an overall load factor of 70% was assumed for all types of nuclear reactors and an enrichment tails assay of 0.25% was used. Plutonium production and its partial recycling in thermal reactors was considered along with plutonium use in the fast reactors. Plutonium recycling was expected to start around 1981, taking into account delays in reprocessing plant schedules and the unclear situation concerning relevant licensing procedures.

In considering these calculated requirements, the different steps of the fuel cycle were discussed as follows:

Uranium

Present estimates of world uranium resources[2] are shown in **Table III.** A comparison of these figures with the projected cumulative demand for uranium **(Table II)** highlighted a potentially serious problem. The reasonably assured reserves in the normally utilized lower price category are only sufficient to meet the demand through the late 1980s. Of perhaps equal significance, the total presently known and estimated resources at < 30$/lb U_3O_8 will be exhausted by about 2000. Therefore the presently expanding efforts to locate and evaluate further reserves of uranium are considered to be very important.

Table III. World Uranium Resources
(1000 tonnes U)

Reasonably Assured		Estimated Additional	
< 15$/lb U_3O_8	15–30$/lb U_3O_8	< 15$/lb U_3O_8	15–30$/lb U_3O_8
1080	730	1000	680

A comparison of the projected production capacities with the annual uranium requirements indicated sufficient potential mining and ore processing capacity until at least 1983. The uranium market however is obviously not simple and it was recognized that there are presently some short-term difficulties in producing adequate amounts of uranium.

The cost of uranium as yellow cake (U_3O_8) was very stable before 1973 at a price of $7 to $8/lb U_3O_8. Since then this cost has increased rapidly. In 1974 prices for mid-1975 deliveries were about $15/lb U_3O_8, increasing by $1.30 to 1.50 per lb for each later year of delivery. Today prices are nearing $30 per lb U_3O_8 deliveries with prices increasing by about $2.00 per lb for each later year of delivery.

The conversion cost component of the uranium supply (U_3O_8 conversion to UF_6) has been stable since 1965. The cost of this service for 1975 delivery was about $3.50 to $4.00/kg U and has escalated at the very stable figure of $0.14/kg/year over the last five years.

Enrichment

Annual and cumulative separative work requirements for the projected nuclear power growth showed, as expected, that the demand increases with the installed nuclear power capacities until the use of plutonium begins to have a small reducing effect on the rate of growth in the late 1980s. Existing and firmly committed enrichment capacities exceed the demand projection until about 1980. For the period after 1980, in view of the long construction lead times involved, and noting the need for expansion at the rapid rate of 6000 to 9000 MT SWU/yr between 1985 and 1990, careful consideration must be given to the timing of future additions and the necessary early decisions must be taken in a timely manner.

² For more detail on uranium resources see "Uranium Resources and Supply" in this issue.

The unit cost of separative work in the USA was $26 in 1967. After 1971 this cost increased gradually until it is presently $60.95/kg SWU for requirement-type contracts and $53.25/kg SWU for fixed long-term commitment contracts. Cost estimates for 1985 have ranged from US $85 to $160/kg SWU. However, the enrichment cost is very sensitive to the electric power cost as well as the construction cost of the enrichment plant and it is very difficult to reliably estimate these future costs.

Fuel Fabrication

Over 90% of the fuel fabrication demand was projected to be for LWR fuel until around 1990 and there is presently sufficient capacity to supply this demand (see **Table II**) at least through 1985. The capacity for fabricating FBR and HTR fuels is at present low, as is the demand. No technological problems were foreseen in expanding any of these capacities as required in the future.

Fabrication costs for LWR fuels have been practically stable over the past years generally ranging around $120 to $170/kg U for standard orders. It is expected that they will decrease or stabilize over the next few years. The cost of mixed oxide fuel processing is significantly higher than that of uranium dioxide fuel. Estimates of mixed oxide fuel fabrication cost for LWRs lie in the region of $300/kg U + Pu, in 1975 value, and those for LMFBR fuels are as high as $800 to $1000/kg U + Pu.

Reprocessing

The projected growth of the required capacity for reprocessing was as shown in **Table II.** Planned and projected reprocessing capacities were examined and it was seen that present requirements are not met by existing capacity. Presently projected reprocessing capacities for LWR fuels in 1975, 1980 and 1985 are 0.1, 3.4, and 6.8 thousand tonnes U per year, respectively. Thus the projected backlog of unreprocessed fuel is 21 000 tonnes by 1985.

In view of the long lead times for design and construction (about 5 to 7 years) and the lack of required experience, continuing shortages of reprocessing capacity are likely to occur in the early 1980s. Thus, under the present power growth assumptions, extensive spent fuel storage capacity is likely to be required until reprocessing capacity can be increased.

With regard to the costs and cost trends of reprocessing, it must be noted that such plant designs are in a dynamic situation, and no reliable figures on reprocessing costs are available. Plant capital costs will be quite high. Estimates of reprocessing costs generally lie in the region of $150 to $200/kg U in 1975 value.

Spent Fuel Storage

This step in the fuel cycle was considered to be especially important in view of the increased need produced by the lag in reprocessing capacity. Nevertheless, the technology needed for the production of adequate storage capacity appeared to be in hand or under design.

Spent fuel storage cost for LWR fuel was estimated at about $10/kg U/yr. The annual spent fuel storage cost for CANDU fuel presently lies in the range of $3 to $5/kg U.

Spent Fuel Transport

The technology of fuel transport appeared to be developing satisfactorily. The transportation cost, under European conditions using new flasks and transport, will be approximately $20 to $35/kg U in 1975 value. These costs are of course influenced by distance and form of transport and by evolving health, safety, and safeguards regulations in this area.

Waste Disposal

This final aspect of the nuclear fuel cycle was considered in a general sense. It was felt that the topic, although of great interest and importance, was too large and in too much of a state of flux to be profitably considered in detail by the group at this time. Nevertheless, the general consensus of the meeting was that acceptable although by no means optimal technology for the disposal of wastes was already available.

EXAMPLES OF NUCLEAR FUEL CYCLE PLANT CONSTRUCTION COSTS

Unit costs of each nuclear fuel cycle step ($/kg U) consist of capital cost and operating cost, with the capital cost being one of the more important parameters. The capital cost of each nuclear fuel cycle step has been rapidly increasing in the past few years because of the escalation of material and labour costs, and costs resulting from environmental requirements. The data on plant construction cost for each step of the nuclear fuel cycle are limited and the accuracy of estimates of construction costs is uncertain. It has therefore been agreed that such estimates must be used only to indicate cost ranges for nuclear fuel cycle economic studies. Recognizing these restrictions on the absolute value of such information, **Table IV** is presented to illustrate the magnitude of these costs. The nuclear electric generating capacity which each facility would be able to service is included to indicate that in general, for economically optimum sizes, these facilities will support and require relatively large related electric demands and systems.

Table IV. Indicative Construction Costs of Fuel Cycle Facilities (1975 Dollars)

Type of Plant	Capacity	Construction Cost (Millions of US $)	Electricity Generation Supported (MWe)
Conversion	5000 MTU/yr[1]	50	6,000–7,000
Enrichment	3000 MTSWU/yr[2]	1,000	40,000
Fuel Fabrication, UO_2	1500 MTU/yr	100	50,000
$(U, Pu)O_2$	1500 MTU/yr	200	50,000
Reprocessing	1500 MTU/yr	1,000	50,000
Storage Facility for spent fuel	1000 MTU	20	~ 9 times MWe LWR core loadings

1 Metric tons of uranium per year
2 Metric tons of separative work units per year

RECOMMENDATIONS

Based on its review of the status of the various steps of the nuclear fuel cycle and the capability of each step to meet the demands for nuclear power, the members of the Advisory Group recommended that a number of actions be taken.

- There are problems, especially for smaller countries, in the implementation of the complete nuclear fuel cycle, due to the necessity for large capacity plants and the resultant high investments in fuel cycle steps such as enrichment and reprocessing. The Advisory Group therefore recommended that increased efforts be made to find technical and organizational approaches for resolving these problems including, as only one aspect, a practical study of the regional fuel cycle centre concept.

- A particularly important problem in the development, exploration and construction efforts required for the nuclear fuel cycle is that of financing and obtaining insurance coverage for such activities. The difficulty of this problem is often exacerbated by the international character of the participation and liability encountered. Therefore, the Advisory Group recommended that the financing and insuring of large nuclear fuel cycle activities be reviewed in depth in the near future.

- Recognizing the International Atomic Energy Agency's activities in the preparation of guides to standardize licencing and operational regulations for nuclear power plants, transport and waste disposal, the Advisory Group recommended the extension of these efforts to include all steps of the nuclear fuel cycle.

Considered to be of particular importance were:

– the preparation of guides for site selection for various nuclear fuel cycle facilities, and
– model international standard security procedures for each step including the level of security to be achieved, criteria for establishing the adequancy of security measures, and cost-benefit analysis of such measures.

- A fundamental key to the development of nuclear power is adequate supply of natural uranium. The group therefore recommended that exploration for uranium throughout the world should be further accelerated.

- When fuel reprocessing plants begin to recover uranium and plutonium from spent fuel at significant rates, they will provide an appreciable amount of the world's fissile material requirements. While the recovered plutonium is valuable for use in the LWR fuel cycle, it is essential for the breeder reactor fuel cycle. For reasons such as this it was felt that activities related to the fuel cycle steps of reprocessing and recycle fuel fabrication should be emphasized (i.e. – through regional fuel cycle centre co-operative activities).

- Projections of requirements for fuel cycle services, from uranium requirements through waste disposal, based on evaluated current nuclear power forecasts, should be published on a regular basis.

- In view of the existence of some concerted efforts to discourage the use of nuclear energy for electric power production, and the sometime distorted presentation of information regarding the safety and reliability of nuclear power plants and the nuclear fuel cycle, it was recommended that, for the benefit of the general public, more reference information be published on this topic. Such publications should provide accurate descriptions of the hazards of nuclear power and elucidate the reliability of existing solutions to such problems.