Nuclear Power Growth and Fuel Requirements, 1975-2000

by E. Goodman and R. Krymm*

The article reviews recent forecasts of the nuclear capacity expected to be in operation in the world over the next 25 years.

An analysis of the margins of uncertainty affecting nuclear power forecasts leads to the selection on a probable and a maximum estimate, on the basis of which uranium and enrichment requirements are derived and compared with present and potential sources of supply.

Apart from its short- and long-term economic effects, the recent energy crisis, which witnessed a quadrupling of the price of crude oil in the major export areas and an induced increase in the prices of other conventional fuels, has sharply brought to the limelight the finiteness of energy resources, a concept which, though often proclaimed in the past, had been somewhat neglected during the heady days of rapid growth of energy consumption over the last two decades.

While estimates of fossil fuel resources vary widely, they cover a general range of 1.5×10^{12} to 15×10^{13} tons of coal equivalent, or, expressed in a somewhat more convenient unit, from 40 to 400 Q (where $Q = 10^{18}$ BTU's $= 250 \times 10^{15}$ kcal), out of which coal represents by far the largest part. The present annual consumption of the world being of the order of 0.28 Q it would at fist sight seem that the problem of exhaustion is not of immediate urgency. However, even if the rate of growth of energy consumption is reduced to 4% from the 5% of the last two decades, these reserves would be exhausted within 50 years if the lower estimate of 40 Q is accepted, and in about 100 years if the higher figure of 400 Q proves true. The developing of new sources of energy independent form fossil fuel is therefore essential. Among these, nuclear power based on fission is by far the leading contender.

It would be entirely misleading to compare with these figures the amounts of energy which could be produced in power reactors of the present type from the low cost uranium resources at present proven and which are of the order of only 1 to 3 Q's. The geology of uranium is relatively new and prospecting has been concentrated

* This projection was prepared for the Economic Commission for Europe Symposium on "The Role of Electric Power in Meeting Future Energy Needs and on International Co-operation in this Field," held in Greece from 19–23 May.

on particularly favourable formations in a few selected countries. For almost two decades there was a stagnation of proving new ore bodies in the face of a very low demands. There seems to be no question that the present resumption and extension of prospecting to regions of the world which had been neglected in the past will yield substantial additions to proven reserves. More important, perhaps, is the possibility of turning to poorer grade ores which had been practically ignored in the past. The relatively small percentage share of uranium costs in nuclear electricity generation makes it possible to consider the economic use of raw materials at five times the average present price without increasing the generating cost of electric power by more than 50%. Finally, the successful development of advanced nuclear systems may make it possible to secure 10 to 60 times more energy from the same amount of uranium than in the proven reactors of today. When all these factors are taken into account, it appears that nuclear fuel resources are of the same order of magnitude as those of fossil fuel if used in present systems, and exceed them by one to two orders of magnitude if used in breeders. The contraints here lie not in fuel resources, but in technological and engineering problems which the last twenty years have shown can be solved.

During the 20 years which have elapsed since the 1955 Geneva Conference, a tremendous development effort has taken palce in the nuclear power field. Roughly speaking, the first decade form 1955–1965 was marked by the emergence of several promising nuclear power systems which bridged the gap between prototypes and industrial plants. The second period from 1965 to 1975 witnessed the rapid introduction of large nuclear stations in the electric systems of industrial countries and the commissioning of a few nuclear power plants in some developing countries.

To illustrate the rapidity of the process, a few figures taken from **Table 1** may prove helpful. In 1955 there were in the world two power reactors with a total capacity of 7.4 MWe in two countries. By 1965, these numbers had risen to 66 reactors operating in 9 countries and with a total capacity of 7,000 MWe. By 1975, we may expect more than 200 stations with a capacity of close to 92,000 MWe operating in 19 countries, and by 1980, 400 plants with close to 250,000 MWe in 26 States.

TABLE 1: Past Growth of Nuclear Power Installed Capacity

	1955	1960	1965	1970	1975
Nuclear Capacity (1000 MWe)	0.007	0.13	7.1	20	92
Number of Power Reactors	2	24	66	98	200
Number of Countries in Which Reactors Were Operating	2	5	9	14	19

This view of the Steam Generating Heavy Water Reactor at Winfrith in England shows the monitoring of the bore of individual pressure tubes during a refuelling shut-down. Photo: UKAEA ▶

NUCLEAR POWER FORECASTS AND THEIR LIMITATION

BEFORE THE ENERGY CRISIS OF 1973–1974.

Together with the threat of exhaustion of fossil fuel sources, the uncertainties inherent in primary and electrical energy forecasting had been somewhat forgotten in the 1945–70 period. Extrapolations of past growth trends sometimes supplemented by correlation analyses of expected GNP expansion and by sectorial demand surveys led to a firm belief that the 4–5% annual rate of growth for primary energy demand and the 7–8% growth rate for electricity consumption were likely to continue undisturbed, at least for the rest of the century for the mature industrial countries, while substantially higher rates would prevail in some rapidly developing States. These scenarios rested on the reassuring assumption of stable energy prices barely keeping up with general inflation, or as had been the case between 1950 and 1970, actually lagging behind it.

In the midst of this satisfying agreement of forecasts with actual experience nuclear power stood out as a disturbing exception. All the difficulties encountered by a new major industry: transition from prototypes to commercial plants, constant design improvements, construction problems, bottlenecks in the supplying of critical materials and components, financing requirements, regulatory issues and legal and public acceptance led to delays and variations of cost estimates which made the picture of the future economic penetration of nuclear power a function of the optimism of the forecaster and of the date of the forecast. This variability is perhaps best illustrated by a summary of forecasts made over the last 12 years of the total nuclear capacity expected to be in operation by 1980 in a leading nuclear power country of the world, the USA. As will be seen from **Table 2**, not only did the 1980 capacity forecasts almost quadruple between 1962 and 1970, which is perhaps explicable in the light of constant improvements in design and successful operation of a series of stations, but it also dropped by 30% between 1970 and 1974 despite the background of rapidly rising fossil fuel costs.

TABLE 2: Variability of Forecast of US Nuclear Capacity for 1980

	1962	1964	1966	1967	1970	1971	1972	1974	1974
Forecasted Installed Capacity for 1980 [1000 MW(e)]	40	75	95	145	150	151	132	102	[a]

[a] Currently being prepared

THE IMPACT OF THE ENERGY CRISIS.

The quadrupling in price of what had become the major fuel of the world, crude oil, in less than three months between December 1973 and February 1974 was an event without precedent in the postwar history of energy. Apart from the short-term economic and financial upheavals which it may cause, its longer term effects on primary and electric energy demand have made forecasting in this field substantially more hazardous than before.

The hazards stem essentially from two questions: how permanent will the present price level become, and what will its impact on demand be?

The first question involves an assessment of the solidity of the OPEC cartel and can only receive hypothetical answers, the most likely of which being that the present level of more than US $10 per barrel of Arabian light crude may be permitted to be somewhat eroded by inflation, but not by much. Forecasters now assume that a level of US $6 to $9 (at constant 1973 prices) would be the lowest range which it would be possible, or even desirable, to achieve. In other words, there is a universal recognition that the days of cheap energy are gone forever.

Regardless, however, of whether oil prices remain steady or drop slightly, the question of their impact on demand for different forms of energy remains extremely difficult to answer. Elasticity co-efficients of the demand functions for different fuels have been estimated only for relatively small price variations and offer but little guidance for the effects of the present discontinuity.

Demand for electric power is, of course, subject to the same question of estimating its sensitivity to price changes. In addition, there is a problem of assessing a possible compensatory effect involved in the switch of certain primary energy users to electricity as a substitute for oil, as well as of possible shifts in the shape of the load demand curve.

It might have seemed that while forecasts of demand for conventional energy sources had become suddenly very uncertain, those concerned with nuclear power should have gained in reliability. From a strictly economic standpoint, the complex and variable picture of the late 1960's and of the early 1970's had suddently become quite clear. Even under the most drastic assumptions of a trebling of uranium ore prices and a doubling of enrichment costs, nuclear fuel cycle costs expressed in constant 1974 dollars were not expected to exceed 4 mills per kWh vs. 16 mills per kWh for fuel oil, thus showing annual savings of US $70 per kWe at the 65% load factor. Within three to four years, such fuel savings would recoup the widest possible differential expected to prevail between the investment costs between nuclear and oil-fired stations in the 1000 MW range.

It would have appeared, therefore, that except for countries with large unexploited hydro and coal resources, a nuclear power forecast might assume that from 1980 on all new power stations for base load duty in large interconnected systems should be nuclear, supplemented only by a few hydro storage and gas turbine plants, until they accounted for about 60% of the total capacity and produced more than 80% of the total energy.

It was soon recognized, however, that theoretical forecasts based on purely economic comparisons ran into constraints, falling into two main categories:

a) The constraints arising from the massive introduction of a new capital intensive technology with a high content of advance engineering, to which reference has already been made, became even more significant when the acceleration of the already sweeping programmes was taken into account. This was particularly true in the case of financing, calling for large capital expenditures at the very time that inflation and interest rates were at their peaks. Nuclear power programmes require sharply higher expenditures during the pre-equilibrium period. In a way, this applies not only to demand for money, but also to demand for energy, since the energy investment in nuclear stations and the supporting fuel infrastructure are initially larger than those involved in a conventional programme.

b) Constraints arising from the specific risks inherent in the operation of nuclear power stations and in the control of their fuel cycles. In contrast to the first category, these are problems specific to a nuclear programme without parallel in other technologies and for which original solutions must therefore be found. The risks of minor accidents are greater in combustible power plants, though there are more potentially dangerous phases in the nuclear fuel cycle. However, the issues of safety of nuclear stations construction and operation and of strict supervision of all the complex steps of the nuclear fuel cycle were apparent to most observers before the energy crisis. They received a new impetus as much larger nuclear power programmes appeared economically justified, leading to new and expanded efforts whose results in terms of public acceptance of nuclear programmes and of possible delays still remain to be judged.

It is not so surprising, therefore, that forecasts of nuclear power over the next 25 years continue to bracket a rather wide range of possible targets as exemplified by **Tables 3** and **4.**

TABLE 3: Maximum and Minimum Forecasts of Nuclear Installed Capacity (1000 MWe)

(USAEC December 1974 [1])

	1980		1985		1990		2000	
	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
United States	85	112	231	275	410	575	850	1400
Rest of World	113	157	290	420	640	900	1600	2550
WORLD TOTAL	198	269	521	695	1050	1475	2450	3950

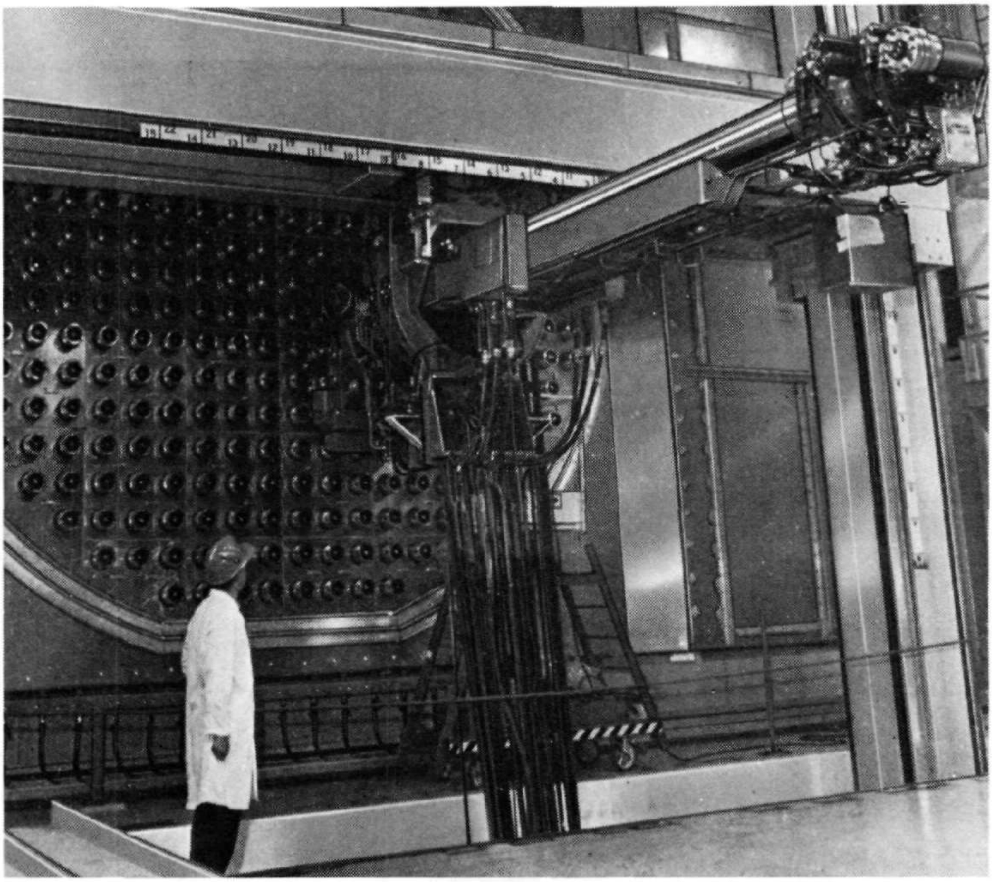
TABLE 4: Most Likely and Maximum Estimates of Nuclear Installed Capacity (1000 MWe)

(IAEA September 1974 [2] revised)

	1980		1985		1990		2000	
	Most Likely	Max.	Most Likely	Max.	Most Likely	Max.	Most Likely	Max.
World Total	255	287	663	850	1350	1850	3600	5300

REFERENCE AND MAXIMUM ESTIMATES FOR NUCLEAR POWER CAPACITY GROWTH

The general considerations developed in the preceding sections make it abundantly clear that a realistic assessment of the future role of nuclear power in a given electric system requires much more than the determination of an economically optimal plant mix. It calls,



The fuelling system of the Pickering atomic power plant near Toronto. Photo: AECL

in fact, for optimization under a series of constraints, several of which cannot at present be quantified. Among these are licensing and regulatory factors, pulic attitudes and the degree of commitment to nuclear power by national governments. For many developing countries, the problems of financing additional foreign exchange expenditures are so actue as to force them to defer otherwise highly profitable ventures. In the case of nations with large low-cost fossil fuel and hydro resources such as, for instance, the USSR, a great degree of flexibility has been and is likely to be maintained in establishing medium- and long-term objectives for nuclear energy.

The wide uncertainties besetting national forecasts are expanded and multiplied when an attempt is made at aggregating these forecasts on a global level. Not only are the input data heterogeneous in scope and reliability, which makes their aggregation a somewhat questionable procedure, but the possible interaction of national plans upon each other is almost always ignored in a simple summation. Caution, therefore, dictates that any estimates of future nuclear power penetration must be presented in the form of probable minimum and maximum figures, and it is on this basis that **Tables 5** and **6** present a reference and a hypothetical maximum case.

THE REFERENCE CASE (TABLE 5)

Because of the difference of methodology and availability of data, the countries of the world are grouped in three categories:

a) The OECD countries for which the estimates are based on a series of analyses carried out by groups of national experts and revised as recently as November 1974 [3,4].
b) The developing countries which are not members of OECD and which do not belong to the group of centrally planned states for which the estimates are vased on an extensive market survey carried out by the IAEA through field missions to eleven of these countries and an extension of the methodology used to others [5,6].
c) The countries with centrally planned economies for which available national planning objectives were used whenever possible and supplemented in the case of the USSR by an extrapolation of the past relationship of its nuclear power programme and that of the USA.

The estimates contained in this table imply an ultimate penetration of nuclear power to a total capacity of about 3,600,000 MWe by the turn of the century when it would represent close to 40% of the total electric capacity of the world. They do not appear to be very sensitive to any moderate decrease in fossil fuel prices from their present high level and would remain practically unchanged even if the latter were cut by one-third.

TABLE 5: Estimated Nuclear Power Growth (Reference Case)*

	Installed Nuclear Capacity in 1000 MWe at End of Year				
	1975	1980	1985	1990	2000
EEC	20.6	51.7	129	264	
OECD Europe (including EEC)	25.8	75.7	175	345	
North America	49.8	108.6	275	531	
Japan and Other	4.6	22	62	107	
Total OECD	80.2	206.3	512	983	2600
Developing Countries	2.0	10.5	47	126	360
Subtotal	82.2	216.8	559	1109	2960
Countries with Centrally Planned Economies	9.5	38.4	104	246	640
TOTAL	91.7	255.2	663	1355	3600

* Does not include mainland China for which no information is available

THE HYPOTHETICAL MAXIMUM ACCELERATED CASE (TABLE 6).

It should be clearly stressed from the beginning that the assumptions underlying this case are designed to establish a maximum in order to estimate the possible pressure on fuel cycle services which could arise if the reference programmes were sharply accelerated. It presupposes that the present ratio of nuclear fuel cycle costs to fossil fuel prices will remain of the order of one-fifth throughout the period, and that for all major systems cost optimization would be the only criterion with all constraints specific to nuclear power removed over the next ten years. Under these conditions, the nuclear share of total installed capacity might rise to 60% by the year 2000 while the intermediate figures would have to be adjusted to assure a smooth transition.

Although admittedly hypothetical, the conditions on which this example is based are likely to be fulfilled by several countries, among which are France and Japan, and it sets a useful maximum against which requirements for uranium ore and separative work may be assessed.

TABLE 6: Estimated Nuclear Power Growth (Hypothetical Accelerated Case)*

	Installed Nuclear Capacity in 1000 MWe at End of Year			
	1980	1985	1990	2000
EEC	58	167	367	
OECD Europe (including EEC)	83	227	480	
North America	119	358	743	
Japan and Other	35	82	146	
Total OECD	237	667	1369	3800
Developing Countries	12	66	185	500
Subtotal	249	733	1554	4300
Countries with Centrally Planned Economies	38	117	290	1000
TOTAL	287	850	1844	5300

* Does not include mainland China for which no information is available

ESTIMATED DEMAND FOR AND SUPPLY OF URANIUM AND SEPARATIVE WORK

DEMAND

To calculate requirements for natural uranium and separative work implied by the nuclear installed capacity forecasts of **Table 5** it is necessary to specify reactor types and load and timing factors. **Table 7** shows the assumed mix of reactor types for the two cases considered. The "referece case" is based on the revised early-1973-basis forecast of Table 5, and the "accelerated case" as given in **Table 6.** In both cases the countries with centrally planned economies (C.P.E.) have been excluded, since the object of making the demand projection is to make a comparison with supply and little information is available on the uranium resources and separative work capacity of these countries.

The reactor mix shown in **Table 7** for the reference case up to 1990 is very similar to the most likely case considered in the OECD/NEA-IAEA report [3] of August 1973 as revised [4] with a heavy preponderance of light water reactors. Similar delay times for the various steps of the fuel cycle were used and a 70% load factor was assumed throughout. It is possible that a somewhat lower, gradually decreasing, load factor might be appropriate in the 1990's for the accelerated case, as the nuclear capacity becomes a more substantial fraction of total capacity. However, this possibility must be weighed against potential increasing requirements for nuclear heat expected to occur in the 1990-2000 decade which offset the effect of this decrease. The reactor characteristics used are those developed in the joint OECD/NEA-IAEA report. [3]

TABLE 7: Nuclear Capacity Mix Assumed for Purposes of Projecting Requirements for Uranium and Separative Work [a)]

	Installed Capacity (GWe)						
	1970	1975	1980	1985	1990	1995	2000
I Reference Case [b)]							
Magnox	5	7	7	7	7	7	7
AGR	–	4.3	6	6	6	6	6
HWR	1	4	11	23	46	73	101
HTR	–	–	2	10	43	116	206
FBR	–	–	1	5	43	247	856
LWR	8	66.9	190	508	964	1421	1734
Total	14	82.2	217	559	1109	1920	2910
II Accelerated Case [c)]							
Magnox	5	7	7	7	7	7	7
AGR	–	4.3	6	6	6	6	6
HWR	1	4	11	29	62	104	147
HTR	–	–	2	12	57	163	302
FBR	–	–	1	6	57	348	1228
LWR	8	66.9	222	673	1365	2177	2710
Total	14	82.2	249	733	1554	2805	4400

Notes:

a) The LWR capacity is assumed to be 60% PWR and 40% BWR.

b) Based on Table 5, excluding the C.P.E. countries.

c) Based on Table 6, excluding the C.P.E. countries.

The indicated requirements for uranium and separative work are shown in **Tables 8** and 9 respectively. The plutonim recycle cases assume that after allowing for fast breeder requirements all plutonium in excess of a 50-ton minimum stockpile is recycled in light water reactors. It will be noticed that recycling or plutonium causes relatively small relative changes in the cumulative amounts of natural uranium and separative work required for the two programmes of nuclear plant construction, a phenomenon attributable to the substantial leads and lag times involved in the fuel cycle. In addition much of the demand is for initial cores during these periods and initial cores do not benefit from plutonium recycle.

TABLE 8: Projected Uranium Requirements [a] (10^3 Tonnes U)

	Without Pu Recycle		With Pu Recycle	
	Annual	Cumulative	Annual	Cumulative
I Reference Case [b]				
1973	19	19	19	19
1975	19	52	19	52
1980	56	253	52	243
1985	114	696	104	651
1990	180	1463	166	1358
1995	235	2560	225	2380
2000	258	3830	258	3650
II Accelerated Case [c]				
1973	19	19	19	19
1975	24	57	24	57
1980	73	303	69	292
1985	160	917	149	866
1990	263	2028	244	1896
1995	353	3660	339	3430
2000	377	5550	377	5300

Notes:

a) Based on 0.275% enrichment plant tails.

b) Based on Table 5, excluding the C.P.E. countries.

c) Based on Table 6, excluding the C.P.E. countries.

TABLE 9: **Projected Separative Work Requirements** [a] **(10^3 Tonnes U)**

	Without Pu Recycle		With Pu Recycle	
	Annual	Cumulative	Annual	Cumulative
I Reference Case [b]				
1973	10	10	10	10
1975	12	29	12	29
1980	30	132	27	124
1985	67	388	59	349
1990	116	868	103	774
1995	168	1610	159	1450
2000	184	2500	184	2340
II Accelerated Case [c]				
1973	10	10	10	10
1975	13	30	13	30
1980	38	153	34	142
1985	94	499	83	452
1990	168	1186	151	1069
1995	241	2270	228	2070
2000	276	3620	276	3400

Notes:

a) Based on 0.275% enrichment plant tails.

b) Based on Table 5, excluding the C.P.E. countries.

c) Based on Table 6, excluding the C.P.E. countries.

SUPPLY

Table 10 presents a summary of assured reserves and estimated aditional resources with recovery costs smaller than \$15 per 1b of U_3O_8. The latter are defined as surmised uranium ore bodies in unexplored extensions of known deposits or in as yet undiscovered deposits of known uranium districts. The upper recovery cost limit has been taken at \$15 per 1b of U_3O_8 since relatively little prospecting effort has been devoted so far to areas with higher anticipated ore costs.

A comparison with the demand figures of the previous section indicates that assured reserves in this cost category would be almost exhausted by 1990 in the base case and by about 1988 in the accelerated case, and that plutonium recycling would postpone exhaustion by hardly more than one year.

It should be borne in mind, however, that the uranium mining industry should on the average maintain proven reserves of the order of eight years requirements for future consumption. Additional reserves of the order of 2 million tons should therefore be proven by 1990 in the base case while about 2.5 million tons of reserves should be developed by

TABLE 10: **Estimated Resources of Uranium with Recovery Costs US $15 per 1b of U_3O_8 [a] as January 1973 (1000 tons)**

	Reasonably Assured	Estimated [b] Additional
USA	400	679
Canada	307	526
South Africa	264	34
Australia	100	107
Rest of World (not including C.P.E. Countries)	475	202
TOTAL	1546	1548

Notes:

a) Value of $ of March 1973 = 0.829 SDR (Special Drawing Rights)

b) As defined on p.12 of Reference [3].

1988 in the accelerated case. Nor should any sharp discontinuities be permitted to occur in prospecting efforts, so that a smooth increase in the mean discovery rate of 65 000 tons per year which prevailed in the last eight years, to a 230 000 tons annual rate by 1990, would prove highly desirable.

In the case of separative work, this article does not intend to discuss precise timing of requirements for new plants in addition to those already announced whose capacity is indicated in **Table 11**. It is seen that under the assumptions made, and neglecting available stocks, additional separative work facilities will be needed in the early 1980's in both cases. Plutonium recycling postpones this probable date by about two years. Increasing the tails assay can have a similar effect but requires additional uranium feed.

Lack of information has prevented any assessment of the supply and demand of uranium and the separative work sitiuation in the countries with centrally planned economies. A substantial capacity of enrichment services and possibly of uranium supply might be available. This could possibly delay substantially the date when major new capacity is required for world-wide demand. Recent agreements between users of enriched uranium and the Soviet Union has already had an impact on the enrichment capacity situation.

It should be emphasized that neither natural uranium resources nor separative work facilities are likely to represent serious bottlenecks in the expansion of nuclear power, provided suitable forward planning is followed by effective action designed to avoid short-term disruptions. With regard to uranium the estimated additional resources mentioned in **Table 10** which would secure a forward supply up to 1995 even in the case of the accelerated programme, represent a conservative estimate. More important, however, is the possibility of substantial reserves with higher recovery cost than the $15 per pound of U_3O_8 used as a cut-off point in the present analysis.

TABLE 11: Estimated Separative Work Capacity (excluding USSR) (1975–1985)

	Tons of Separative Work Units		
	1975	1980	1985
USA	17 000	27 000	27 000
Urenco	250	2 000	10 000
Eurodif	200	5 000	9 000
UKAEA	400	400	400
TOTAL	17 850	34 400	48 400

Even a rise to $30 per pound of U_3O_8 would involve an increase of about 1.3 mills/kWh in the present generating cost of electricity from light water reactors, which would hardly alter the competitive position of nuclear power. Evaluation of resources in the $15 to $30 per lb of U_3O_8 range has not as yet been systematically undertaken, and a continuously expanding effort in the promising areas, both of industrial and developing countries, is expected to yield reserves at least as large as those in the up to $15 per lb of U_3O_8 cost range.

With regard to separative work, the effort required, however large in absolute value, must be judged in perspective against the financial requirements of the nuclear plant construction programmes. The investment in gas diffusion enrichment plants (including requisite power stations) is less than 7% of the total capital costs of the nuclear capacity they are expected to support, those in centrifuge facilities less than 5%. In this area, as in that of uranium prospecting, the main problems lie more in the field of optimal timing than in that of coping with insuperable shortages.

Unfortunately, many planning decisions related to uranium enrichment capacity are needed in the near future which require knowledge of nuclear power capacity in the early 1980s. New enrichment capacity should be planned and be under construction so that its product is ready in a timely manner for future nuclear power growth. A further complication is the sensitivity of when the new enrichment plant is needed to the extent of plutonium recycle and possible additional sources of enriched uranium supply. Planning for U_3O_8 resources, conversion, fabrication and reprocessing naturally also depend on the level of nuclear capacity.

This level of the early 1980s is most important to the fuel cycle business, which has been plagued mostly by over-capacity in the past. There are indications already that sellers' markets and scarcity may be possible problems in the 80s. The sellers' market developing in ore procurement and the paucity of reprocessing capacity in the U.S. are early indications of this possibility. The risk of lack of enrichment capacity is so great to the basic nuclear economy and the lead times to develop additional capacity are so long that perhaps some form of international or regional co-operation should be devised to ameliorate this problem.

On the reprocessing end, a one or two year delay in capacity availability is not as critical. Spent fuel can be stored for this period preferably at the reactor site without major economic penalty if planned in advance. In fact, postponing the startup date of new reprocessing plants could lead to larger size plants with potential economies of scale. This potential benefit must be balanced against the loss in the present worth value of the plutonium and uranium in the stored fuel.

This past line of reasoning is not all applicable with the advent of a breeder economy. The total economics of such a system centers on the production, recovery and re-use of bred material. In fact, processing of fuel with short cooling times seems to be beneficial to the overall economics. It therefore appears timely to initiate a wide ranging research and development programme on the reprocessing of spent breeder fuels. The current paucity of reprocessing capacity for LWR fuels would be intolerable for a breeder economy. The IAEA already is studying regional co-operation in reprocessing and hopes to continue to promote international co-operation and planning in other aspects of the fuel cycle.

CONCLUSIONS

This article has dwelt at some length on the uncertainties besetting any attempt at pinpointing the nuclear capacity which will be in operation at a given time in the future. These uncertainties should, however, be contrasted with the certainty that nuclear power will play a decisive role in the energy supply of mankind. The successful operation of several proven nuclear plant types combined with the promising development of several advanced systems offers a comprehensive insurance against any unforseen difficulties which may arise for a particular reactor line. Furthermore, the supply of nuclear fuel depends on a raw material which is present in the earth's crust in much more abundant quantities than the estimates of assured reserves. These assured reserves are limited to high-grade ore bodies in selected countries and thus tend to underestimate total availability. The complexity of the nuclear fuel cycle has as its counterpart an inherent flexibility permitting trade-offs between its different steps, as for instance, between natural uranium feed and separative work or between stocking and recycling of plutonium. While this flexibility does not remove the necessity for forward planning and advance action which are essential for every phase of the nuclear fuel cycle, it does however offer some degree of protection against sudden disruptions and intense price fluctuations.

Thus, regardless of temporary delays and possible setbacks, a good case can be made for the expectation that nuclear stations will provide more than half of the electricity which will be generated in the world by the turn of the century.

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TRAINING COURSE IN ITALY

These were the participants at the first Inter-regional Training Course on Plant Breeding for Disease Resistance, including the Use of Induced Mutation Techniques, which was held late last year in Casaccia, Italy. It was attended by 15 candidates from an equal number of countries.

The course was jointly organized by the IAEA and FAO; it was sponsored by the Swedish International Development Authority (SIDA) and the Italian Government. The CNEN Laboratory for Agricultural Applications was the host Institute, and Professor A. Bozzini, the Director of the Institute, acted as Course Director. Ing. E.A. Favret from Castelar, Argentina, was the Scientific Adviser and Co-Director.

The course programme consisted of lectures, seminars, discussions and laboratory work. It covered general aspects of plant breeding and plant protection, a number of individual crops and pathogens, an introduction into mutation induction, techniques for screening desired types from genetically diverse populations, the management of resistance in plant varieties and some allied subjects.