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FINANCING OF NUCLEAR POWER IN DEVELOPING COUNTRIES

Memorandum by the Board of Governors

1. At the end of the report on the financing of nuclear projects which the Board of Governors made to the General Conference last year, it undertook to keep the Conference informed of the progress made by the Director General in the further investigations it had asked him to make. [1] The Board is accordingly communicating to the Conference, in the Annex to this memorandum, a study of the subject made by the Secretariat.

2. The study has been prepared on the basis of further information provided by Member States in response to the Secretariat's inquiries and questionnaires, the proceedings of the Agency's Symposium on Small and Medium Power Reactors held at Oslo last October, and the results of the four research agreements that have been concluded with institutions and corporations in Member States for studies of the technical and economic feasibility of smaller power reactors. It also draws upon two more detailed working papers which the Secretariat has written, copies of which can be made available upon request.

3. The study in the Annex shows that there is a gradual but significant trend in many developing countries to rely increasingly on nuclear energy to meet their electric power needs. This is attributable to the fact that nuclear power is becoming increasingly competitive in developing countries in which there is a substantial demand for electricity. The number of developing countries which are embarking on nuclear power programmes is also increasing, and there is a consequent increase in the amount of assistance requested from and the number of missions sent out by the Agency. It is of interest to note that the total investment that will be required by 1980 to meet the electric power needs of the developing countries will be of the order of $40-45 000 million; if only oil-fired plants were used, the investment would be of the order of $40 000 million, and if 20% of the power was generated in nuclear plants the investment would be about $45 000 million. Another interesting conclusion is that over the next ten years there is likely to be a potential market in developing countries for nuclear power plants with a total capacity of from 40 000 to 60 000 MW(e).

[1] GC(XIV)/436, para. 5.

4. The study represents the best evaluation of the financing of nuclear projects in developing countries that the Secretariat can make at this time with the data available to it. It should be borne in mind that all estimates of the economic competitiveness of nuclear power depend chiefly on three factors which have varied considerably in recent years, namely interest rates, the price of crude oil and the estimated construction costs of nuclear plants. The financing of nuclear projects in developing countries and the competitiveness of smaller reactors will, moreover, be discussed at the Fourth International Conference on the Peaceful Uses of Atomic Energy in Geneva next September, at which it is expected that the International Bank for Reconstruction and Development will be presenting a paper. The matter will also be kept under continuous review at smaller meetings of experts that the Director General intends to convene. These will include a panel on reactors of interest to developing countries which will meet shortly after the General Conference this year, following a preparatory exchange of views on the subject at a small meeting during the Geneva Conference. The advice of the panel will be sought on the possibilities of carrying out a market survey covering several areas of the world to determine the requirements for power reactors in the developing countries.

5. It may be appropriate here to draw the Conference's attention to certain current activities of the Agency which have a direct or indirect bearing on the subject of the Secretariat's study. Reference has already been made in paragraph 2 above to the research agreements that have been concluded with institutions and corporations in Member States for studies of the technical and economic feasibility of smaller power reactors. Missions have been sent to the Philippines, to assist in the review of an earlier United Nations Development Programme (Special Fund) study of the feasibility of introducing nuclear power in the Luzon area, and to Peru and Singapore, to help in making a preliminary evaluation of the prospects of a combined nuclear power and desalting plant in each of these countries, and staff members have visited Thailand, which is also considering the introduction of nuclear power. A mission sent to Romania at the end of 1970 advised the Government on proposals for the introduction of nuclear power. In Brazil, an Agency mission has this year given advice on several matters involved in the introduction of nuclear power, particularly the participation of local industry in the manufacture and maintenance of nuclear plant. The Secretariat is keeping in touch with the progress of nuclear power production in Argentina, and arranging for assistance in regard to the fabrication in that country of fuel elements and the testing of components, as well as with plans and progress in Chile, Greece, the Republic of Korea, Pakistan and other developing countries. The Agency has also arranged a training course to help economists from the developing countries to evaluate bids for nuclear power plants. Similar activities will, of course, be continued in 1972.

6. In the Board's opinion there are thus several decisions that the General Conference might take with a view to the Agency's continuing to make positive contributions towards the solution of the financing problems that are faced by the developing countries in the introduction and use of nuclear power. It accordingly submits the draft resolution set forth below for the latter's consideration.

THE INTRODUCTION, USE AND FINANCING OF NUCLEAR POWER IN DEVELOPING COUNTRIES

The General Conference,

(a) Convinced that the Agency can be of valuable assistance to developing Member States in their efforts to introduce and use nuclear power,

(b) Recalling Resolution GC(XIII)/RES/256 on the financing of nuclear projects, and

(c) Having considered a memorandum from the Board of Governors on the financing of nuclear power in developing countries, to which a study by the Secretariat was annexed[1],

1. Decides that it will be in the interest of developing Member States for the Agency to continue, within the means at its disposal, its study of the financing problems which they face in their efforts to introduce and use nuclear power; and

2. Accordingly invites Member States to continue to provide the Agency with information, as follows:

(a) In the case of developing Members, information in respect of their plans for, and progress already made in, the introduction and use of nuclear power, and their relevant needs for external financing; and

(b) In the case of industrialized Members, information:

(i) In relation to relevant technological developments in the nuclear generation of power, and to the economics of such power generation;

(ii) To the extent possible, in relation to the results of market surveys for nuclear power made by private industry, financing agencies and governmental or semi-governmental organizations, in respect of reactors of interest to developing countries; and

(iii) In relation to the terms on which they would be prepared to make available the external financing that developing Members will need for the introduction and use of nuclear power.

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[1] GC(XV)/458.

ANNEX

STUDY BY THE SECRETARIAT

INTRODUCTION

1. It has been possible, largely as a result of the Symposium on Small and Medium Power Reactors convened by the Agency at Oslo in October 1970, to obtain more information on the economic possibilities of smaller reactors, and this is presented in paragraphs 4-9 and Tables 1 and 2 below. It has also been possible to bring up to date the information available on the demand for and the costs of nuclear power plants in developing countries, and this information is presented in paragraphs 10-14 and Tables 3-6 below.

2. It has not been possible to obtain much information on the ways and means to secure financing for the projects in question from international and other sources to supplement the information provided in the Board's report to the General Conference last year [1]. The most likely method of financing continues to be through bilateral arrangements between the country buying a nuclear power plant and the country supplying it, and this is the way in which the reactors ordered recently have been financed. However, both the International Bank for Reconstruction and Development and the different regional banks finance conventional oil-fired power plants, and it is expected that in the future they will be prepared to finance nuclear power plants as well.

3. Research agreements relating to smaller reactors and discussions with individual manufacturers indicate that the question of standardization, involving the use of components which have been developed and tested in existing reactors, is now being looked at much more carefully. This is a very welcome development and could lead to more competitive prices and quicker licensing procedures, but it should be borne in mind that the buyer of the plant would have to be prepared to accept the plant offered without demanding major changes which would involve the loss of the advantages of standardization.

PRESENT COMPETITIVE STATUS OF NUCLEAR POWER

4. As a result of the Oslo symposium and in the light of further information obtained during the year new estimates have been made of the economic competitiveness of smaller reactors, and in the Figure at the end of this study the present competitive status of nuclear power is expressed in terms of the range of "break-even" fuel-oil costs, as a function of plant size and of the annual fixed-charge rate on capital investment, for base load (80% load factor) applications. The break-even oil cost is a function of the financing terms, expressed in the Figure in terms of the annual fixed-charge rate on the additional investment required for a nuclear plant, since the comparison with oil costs can only be made when the extra capital cost of the nuclear plant is offset by the savings in fuel costs. The break-even oil cost is a function of plant size since the additional investment required for a nuclear plant, expressed as cost per unit size (for example $/kW(e)), decreases with increasing size. However, it is not possible to give a single curve of break-even oil cost versus plant size for a given fixed-charge rate because the costs of both nuclear and oil-fired plants, and especially the difference between them, vary from time to time and from place to place.

[1] GC(XIV)/436.

5. Thus, for a 10% fixed-charge rate the expected range of break-even oil costs as a function of plant size is given in the Figure. When oil costs are above this range, nuclear plants would be expected to be more economical for base-load application; when oil costs are below this range, oil-fired plants would be expected to be more economical; and when oil costs are within this range a more careful study of the alternatives under local conditions would have to be made to establish the comparative costs. Given the actual oil cost, the same curves determine a range of plant sizes within which further study would be required to establish whether nuclear power is competitive; above this range, nuclear plants would normally be expected to be more economical and, below this range, oil-fired plants.

6. The curves for a 14% and 7% fixed-charge rate in the Figure show how the financing terms affect the comparative competitiveness of nuclear and oil-fired plants. The curve for 14%, which represents a combination of a relatively high interest rate and a relatively short repayment period, relates to the upper range of estimated differences in capital costs between nuclear and oil-fired plants and is thus directly comparable with the upper curve for a 10% fixed-charge rate, which represents a combination of medium interest rates and medium or longer repayment periods. The curve for 7%, which represents relatively low interest rates and relatively long repayment periods, relates to the lower range of estimated capital cost differences between nuclear and oil-fired plants and is thus directly comparable with the lower curve for a 10% fixed-charge rate. It will be seen that the effect of the financing terms on competitiveness is quite substantial.

7. Since the likely range of fuel-oil prices throughout the world is projected to be 35-50¢ per million British thermal units (Btu), the Figure indicates that:

(a) Nuclear plants of 500-600 MW(e), even with relatively high fixed-charge rates and capital cost differences at the upper end of the range can be expected to be competitive with oil-fired plants. In the near future some developing countries will be able to utilize plants of this size;

(b) Nuclear plants of 100 MW(e) cannot be expected to compete with oil-fired plants unless there is the most favourable combination of very low fixed-charge rates and capital-cost differences at the lower end of the range; and

(c) Nuclear plants of 200-400 MW(e) should be competitive if financing terms equivalent to a fixed-charge rate of 10% or lower are available, especially if, because of the potential cost reductions made possible by multiple orders, design standardization, etc., the capital cost difference as compared with oil-fired plants is reduced.

FUEL COST CONSIDERATIONS

8. One of the most important characteristics of a nuclear power plant is the lower fuel cost which can be expected as compared with that of an oil-fired plant. For a nuclear plant to be more economic than an oil-fired plant these savings in fuel cost must offset the additional capital cost of the nuclear plant. A 400-MW(e) nuclear plant might have an extra capital cost of between $65 and $135 per kilowatt installed, that is a total of $26-54 million. However, the annual fuel cost of such a nuclear plant is estimated as $6.3 million, and is largely unaffected by changes in the price of uranium. Table 1 below gives, for different oil prices, the annual fuel costs of a 400-MW(e) oil-fired plant and the additional annual fuel costs as compared with those of a nuclear plant.

Table 1

Annual fuel costs of a 400-MW(e) oil-fired plant

Oil price in ¢ per million Btu	35	40	45	50
Annual fuel cost in millions of dollars	10.1	11.4	12.7	14.0
Additional annual fuel costs compared with those of a nuclear plant in millions of dollars	3.8	5.1	6.4	7.7

9. The number of years over which the accumulated savings would equal the additional capital cost is only an approximate indication of economic competitiveness, as neither the interest rate nor the economic life of the plant are taken into account. More meaningful information can be obtained by calculating the return on additional investment to which the annual fuel-cost savings are equivalent. Thus, the following table shows the return on additional investment in the case of a 400-MW(e) plant, assuming that the annual savings are effected for 25 years.

Table 2

Return on additional investment
(percentage per year)

Additional investment ($/kW(e))	Fuel oil cost, ¢ per million Btu			
	35	40	45	50
65	14.2	19.5	24.6	29.6
100	8.3	12.1	15.6	19.0
135	5.0	8.2	11.0	13.7

POTENTIAL DEMAND FOR POWER

10. During the past year a more detailed survey has been made of the potential demand for electrical generating capacity in the developing countries and of the amount of power that could be generated in nuclear plants. Apart from any questions of financing, there are limits to the latter amount, which are determined by the size of existing and planned electrical grid networks and the economic competitiveness of smaller nuclear plants. The estimates of demand are based on information obtained from the atomic energy commissions and electrical authorities in the individual countries. In Table 3 below the estimated total demand for the different regions is shown.

Table 3

Estimated demand for electrical generating capacity in developing countries[a/]
(in thousands of MW(e))

	1975		1980		1985	
	Total	Nuclear	Total	Nuclear	Total	Nuclear
Africa	20	0	28	0	40	1
Asia and Middle East	67	2.3	111	10	168	21
Latin America	58	0.3	87	6	127	19
Europe[b/]	66	0.4	100	7	148	18
Total	211	3	326	23	483	59

a/ For the purpose of the study, developing countries are defined as those countries for which a programme under the Technical Assistance component of the United Nations Development Programme had been approved by its Governing Council for 1969.

b/ Bulgaria, Greece, Hungary, Poland, Romania, Turkey and Yugoslavia.

11. The following table shows the estimated increases in electrical installed capacity in developing countries in thousands of MW(e) over the period 1975-85.

Table 4

Estimated increases in installed capacity in developing countries
(in thousands of MW(e))

	Total increase	Nuclear component	Nuclear percentage
Period 1975-80	115	20	18%
Period 1980-85	157	36	23%
Period 1975-85	272	56	21%

These estimated increases in installed capacity represent the upper limit of what is likely to be achieved; the actual increases are unlikely to be less than two thirds of these estimates.

FINANCING REQUIRED

12. Financing has to be arranged at the time the plants are ordered, which is some four or five years before commissioning, that is during the period 1971-76 for plants needed in 1975-80, and during the period 1976-81 for those needed in 1980-85. The average amounts in dollars per kilowatt installed that are expected to be needed, which have been arrived at by making some general assumptions, are given in Table 5 below. It is to be noted that the location and size of a particular power station may result in a cost significantly different from the average figure.

Table 5

Average amount in dollars per kilowatt installed

	Oil-fired plant	Nuclear plant
Cost of plant	150	250
Foreign exchange component (1971-76 orders)	100	200
Foreign exchange component (1976-81 orders)	75	150

The reduction in the foreign exchange component during the period 1976-81 is based on the assumption that countries will then be able to finance a greater proportion of the work involved with local currency.

13. On the basis of the same general assumptions it is possible to estimate the financing requirements for the installation programme referred to in Table 3 above. Table 6 below shows the financing required for a combined programme of oil-fired and nuclear plants, all oil-fired plants, and the extra financing required for the combined programme.

Table 6

Financing required
(in thousands of millions of dollars)

	Combined programme			All oil-fired plants	Extra financing required for combined programme
	Oil-fired plant	Nuclear plant	Total		
Financing required for 1971-76	14	5	19	17	2
Financing required for 1976-81	18	9	27	23.5	3.5
Total	32	14	46	40.5	5.5
Foreign exchange component for 1971-76	9.5	4	13.5	11.5	2
Foreign exchange component for 1976-81	9	5.5	14.5	12	2.5
Total	18.5	9.5	28	23.5	4.5

14. The figures show that the combined programme, in which the installation in the developing countries of about 20% of the required new electrical generating plant as nuclear plant is envisaged, would require financing amounting to $46 000 million as against $40 500 million if all plants were oil-fired. Although the increase of $5500 million (about 14%) or $4500 million in foreign exchange requirements (about 20%) is appreciable, the extra investment would provide a nuclear power plant generating capacity which would be about equal to the base load requirements, with an appreciably lower annual fuel cost than that of oil-fired plants.

CONCLUSIONS

15. It is estimated that over the next ten years, there will be a potential market in developing countries for nuclear power plants with a total capacity of about 60 000 MW(e). Even if this estimate should prove to be too high by as much as a third, a market in developing countries for 40 000 MW(e) of nuclear power would still be considerable.

16. To prove economic, these smaller reactors could have a capacity as low as 200 MW(e) with advantageous financing terms and high oil prices, and as high as 400 or 500 MW(e) with less advantageous financing terms and low oil prices.

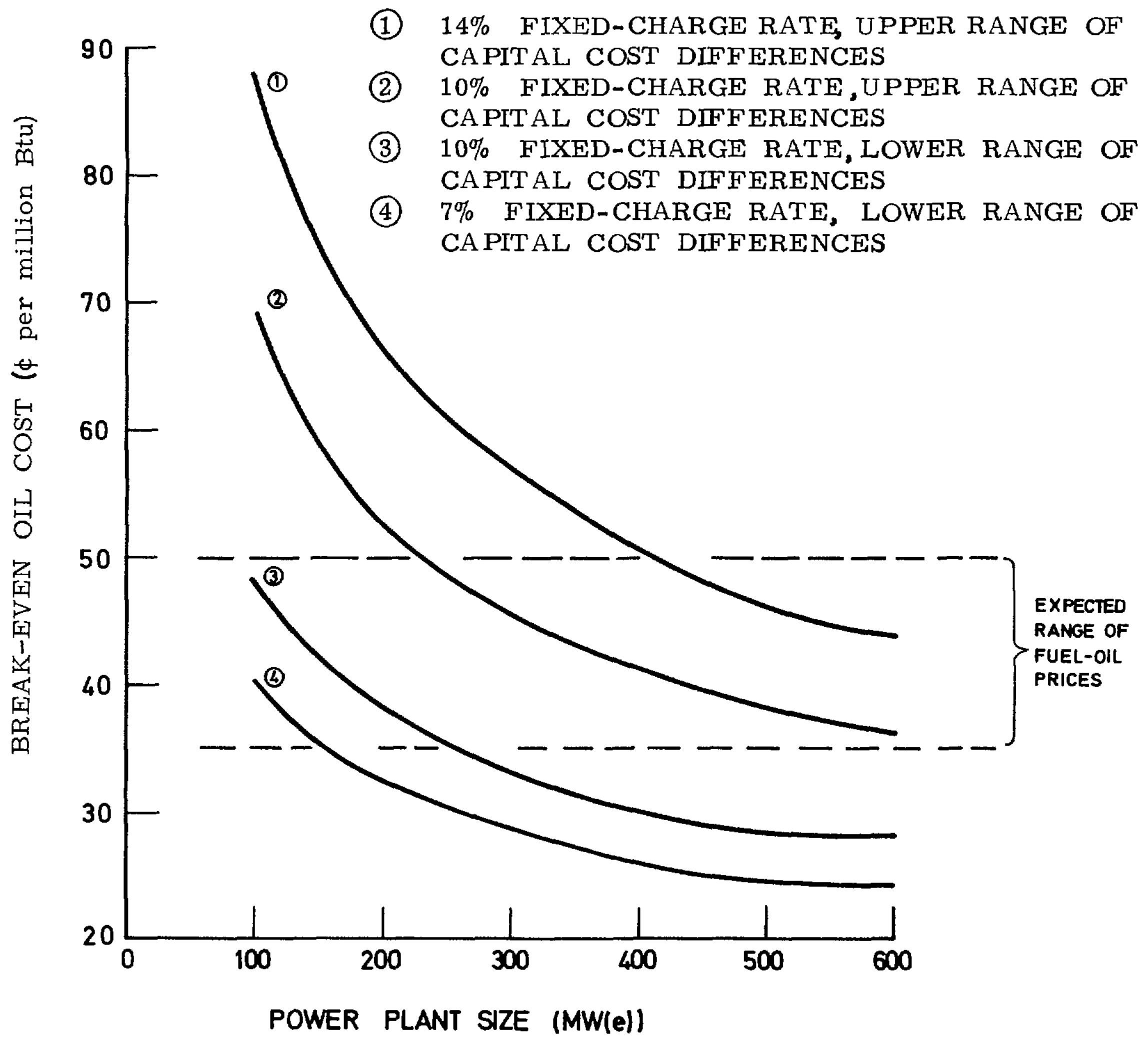
17. There is at present a large factor of uncertainty in the cost of these smaller reactors, which could be reduced by standardizing requirements. For this standardization, the co-operation of the potential buyers and suppliers would be required. It is to be noted that their co-operation should lead to a reduction not only in the capital cost of the reactor, but also in the construction time and hence the interest charges during construction; it should also reduce the time needed for the procedures for licensing reactors.

18. At present it seems that the most likely way in which such reactors could be financed would be through bilateral or multilateral arrangements with the countries supplying the reactor and the fuel services. Here again, the financing arrangements should be easier and more favourable to the country buying the reactor if the requirements could be standardized to some extent. It is hoped that international and regional banks will play a much larger part in financing nuclear power plants in the future. The Agency will continue to do all it can to contribute to a solution of the problem of financing by assembling information on the performance and reliability of existing plants through discussions with the suppliers and operators of such plants.

19. The Agency will also continue to promote the standardization of nuclear plants in order to reduce their additional capital cost. With a view to assessing the competitiveness of nuclear plants in relation to oil-fired plants, the Agency can do no more than keep itself as well informed as possible on current and future trends in oil prices throughout the world.

F I G U R E

BREAK-EVEN FUEL-OIL COST AS A FUNCTION OF PLANT SIZE, FIXED-CHARGE RATE ON INVESTMENT, AND EXPECTED RANGE OF ADDITIONAL CAPITAL COSTS OF NUCLEAR PLANTS AS COMPARED WITH OIL-FIRED PLANTS



NOTE: THE CURVES FOR 14% FIXED-CHARGE RATE, LOWER RANGE OF CAPITAL COST DIFFERENCES AND FOR 7% FIXED-CHARGE RATE, UPPER RANGE OF CAPITAL COST DIFFERENCES WOULD EACH LIE ABOUT MIDWAY BETWEEN THE TWO CURVES FOR 10% FIXED-CHARGE RATE.

(see para. 2)

International Atomic Energy Agency

Division of Nuclear Power and Reactors
Economic Studies Section

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Potential Demand for Nuclear Power in Developing Countries and the Associated Capital and Foreign Exchange Requirements

Introduction

This report presents estimates of nuclear power demand in developing countries to 1985, and the associated capital and foreign exchange requirements, based on revision and expansion of earlier studies 1/ 2/.

For the purpose of this presentation, "developing countries" are regarded as those countries for which a programme under the technical assistance component of the United Nations Development Programme (UNDP) has been approved by the UNDP Governing Council. Table I lists the 74 IAEA member countries for which a programme has been approved by UNDP for the year 1971. Of these countries only about 20 to 25 now seem likely to be in the market for nuclear power plants for operation by 1985. There are another 57 developing countries, based on the 1971 UNDP programme, that are members of the United Nations (UN) but not of IAEA; however, none of these, except perhaps Hongkong, now seem likely to have nuclear power plants in operation by 1985. The list of countries receiving UNDP technical assistance changes from year to year; for example, Czechoslovakia and Spain were not included on the 1969 list.

The projections presented in this paper of total installed electrical capacity and of nuclear capacity in developing countries to 1985 are based in part on the replies received to a circular letter addressed to developing member countries of the IAEA by the Director General in November 1969. The information supplied by the countries has been updated and supplemented by information from other sources and by IAEA staff estimates, especially in the cases where no answers were received from the countries. Because Spain and Czechoslovakia were not on the 1969 UNDP list, they were not sent the November 1969 circular letter and questionnaire.

Projections of Installed Capacity

Table II summarizes the projected total installed electrical capacity and nuclear capacity in 1975, 1980 and 1985 for countries which are considered to be in the "developing" category in 1971 and which are expected to have nuclear plants in operation by 1985. The 1970 installed capacity figures are included for reference. The present and projected total installed electrical capacities in other developing countries are also included, in groups according to major geographical region, for comparison purposes; these figures include UN members who are not IAEA members; Since the nuclear capacity shown for 1975 has already been ordered, the future nuclear demand in developing countries is indicated by the increases from 1975 to 1980, and from 1980 to 1985. In addition to the countries indicated in Table II as likely to have nuclear power plants in operation by 1985 or sooner, other developing countries which have been indicated as possible candidates for nuclear power plants in this time period include Algeria, Columbia, Hongkong, Iran, Jamaica, Morocco, Nigeria, Peru, Rhodesia, Singapore and Venezuela. It is felt that possible nuclear additions in these countries are within the uncertainties in the 1980 and 1985 figures for total nuclear capacity in developing countries given in Table 2, which uncertainties probably are greater than ± 20 % and ± 30 %, respectively.

Table III summarizes the projected nuclear installed capacities in the "industrialized" countries. The 1980 - 85 estimates for Canada, Denmark, France, Germany (Fed. Rep. of), Italy, Japan, Netherlands, Portugal, Spain, Sweden, Switzerland, U.K. and U.S.A. are based on information supplied by national sources to a joint ENEA/IAEA Working Party for the purpose of projecting uranium demand 3/. In order to complete the table, this information was supplemented by information from other sources and by IAEA staff estimates. Ireland and Luxembourg have not been included in the European section of the table though the possibility of nuclear plants in one or both of these countries by 1985 is not excluded.

Part A of Table IV gives a projection of total electrical capacity in the industrialized countries, together with the comparable figures for developing countries taken from Table II. The projection for the industrialized countries is based on the 1970 total and an assumption of a doubling time of approximately 10 years (equivalent to a growth rate of 7.18 %/year) for electrical capacity in these countries. This assumption is debatable, of course, since some industrialized countries presently have lower growth rates than this and since a declining growth rate in the future is often assumed. On the other hand, some of the major industrialized countries are still experiencing growth rates of 9 - 10 %/year and are projecting such growth rates for some time to come.

Capital Investment and Foreign Exchange Requirements

Table IV presents a comparison of the projected growth of electrical and nuclear capacity in the developing countries and the industrialized countries. In Part A of Table IV, in spite of what might otherwise be considered to be an impressive increase of about 260 % in total electrical capacity in the developing countries over the next 15 years, the share of the developing countries in the world total electrical capacity is projected to increase only from about 14 % to about 17 %. Since the developing countries have about two-thirds of the population (not counting mainland China, which is not included in Tables II, III and IV) this means that according to these projections they are "catching up" with the industrialized countries only very slowly. Since the developing countries typically have higher birth rates than the industrialized countries, the rate of "catching up" is even slower than indicated in Table IV.

In Part B of Table IV, which compares projected nuclear electrical capacities in developing countries with those in industrialized countries, the rate of "catching up" by the developing countries is higher than was the case for total electrical capacity. The developing countries are, however, starting out even further behind in the nuclear "race" and are projected to have only 11 % of the world nuclear electrical capacity by 1985.

Part C of Table IV presents the same data as Parts A and B in a somewhat more optimistic light. It can be interpreted as indicating that the developing countries are lagging behind the industrialized countries in the rate at which they are converting their electrical systems to nuclear power by only about five years.

Attaining the goals for nuclear power capacity in developing countries given in Tables II and IV, which seem "modest" enough when expressed in terms of percentages, actually will require quite an ambitious programme in terms of money. The indicated 74,000 MWe increase in nuclear electrical capacity from 1975 to 1985 in developing countries will require more than $ 18,000 million of capital investment, of which probably more than $ 12,000 million represent foreign exchange requirements. These totals are based on an average cost, expressed in 1970 dollars, of $ 250/kWe or more for nuclear plant and first fuel loading with an average foreign exchange component of $ 200/kWe for plants coming into operation during 1976 - 80 and of $ 150/kWe for plants coming into operation during 1981 - 85 [1/]. These amounts will have to be committed during the coming decade, even though the expenditures themselves will stretch over the period until 1985, and this represents the "potential demand" for nuclear power orders during the next 10 years. That this is ambitious in the context of international financing can be seen by comparing it with the total current level of international aid, bilateral and multilateral, including both "hard" and "soft" loans for electric power in developing countries, which is of the order of $ 1000 million per year. (This level will have to increase substantially by 1980 - 85, of course, whether for nuclear or conventional power, if the overall growth targets are met.) Thus, though the total projected nuclear electrical capacity in developing countries in 1980 - 1985 represents only about half of the uncertainty in the estimates of nuclear power in the industrialized countries in the same time period, the achievement of these goals will be contingent on the availability of very substantial amounts of foreign capital financing on terms which the developing countries can afford.

Re-defining the term "developing country" by dropping out some of the more "advanced" ones, which already have relatively high rates of per capita energy consumption, would make the problem appear smaller in terms of megawatts or money, but would not change the apparent difficulty of "catching up" or the difficulty of obtaining the required foreign financing except to add emphasis since the poorer countries have even bigger problems in this regard. (The relatively advanced European developing countries account for approximately half of the total potential demand for nuclear power in developing countries by 1985, as projected in Tables II and IV, with Spain and Czechoslovakia accounting for about one fourth of the total.)

It should be kept in mind that it is the <u>additional</u> capital investment in a nuclear power plant compared to a conventional plant which must be justified. Very approximately, a medium-size nuclear power plant has a total capital cost of about \$ 100/kWe more than the same-size oil-fired plant and also has about \$ 100/kWe in extra foreign exchange requirements for most developing countries [4/]. The incentive for making this eytra investment is the resulting savings in fuel costs. As discussed in Reference 4, for the expected range of fuel oil costs of 35 - 50 $¢/10^6$ BTU an extra \$ 100/kWe investment in a nuclear plant should be recovered in about 5 - 10 years out of lower fuel costs, and these also are usually mostly foreign exchange costs for the developing countries concerned.

Summary and Conclusions

Table V summarizes the potential level of orders for nuclear plants in developing countries to be expected during 1971 - 75 and 1976 - 80, assuming that an order is placed five years before a plant comes into operation and based on the projections of Table II. Obviously, the current rate of orders will have to increase substantially in the next few years if it actually is to average 6000 MWe/year during 1971 - 75 as the table indicates.

These nuclear power plants for developing countries will not necessarily all be in the "small and medium power reactor" (SMPR) category, as currently defined. Already, China (Taiwan), Korea and Mexico have firm plans for power reactors larger than 500 MWe during 1976 - 1980. Spain has plans for several 500 MWe plants during this period and presumably will be ready for larger sizes by 1980. Brazil's first power reactor apparently will be about 500 MWe in size. India and Argentina have started with 200 MWe and 300 MWe reactors, but have indicated an interest in 500 MWe sizes during 1976 - 1980. Greece, Israel, Thailand and Turkey have plans for first power reactors in the 300 to 500 MWe size range. The Eastern European countries seem to be standardizing on 440 MWe unit size for their initial phase of power reactor installation. The Philippines, Chile and Cuba apparently would prefer sizes under 500 MWe until 1985.

In addition to the developing countries, there could develop some demand for SMPR in the industrialized countries 5/. In the IAEA's May 1970 edition of "Power and Research Reactors in Member States" 6/, there are 14 such power reactors of 500 MWe or less listed as planned by industrialized countries for 1976 or later, though some of these are already on order and a few represent fast breeder reactor proto-types.

It was suggested at the Oslo symposium 7/ that the SMPR category be defined relatively as including units smaller than about half the size of the largest commercial units on order, rather than defining an arbitrary fixed upper limit such as 500 MWe.

It seems reasonable to conclude that there is considerable potential demand for nuclear power in developing countries, but that the projections presented in this paper are subject to substantial uncertainties. Whether the potential demand is actually satisfied depends strongly on competitive pricing, especially for reactors smaller than 500 MWe, and on availability of acceptable financing terms for the foreign exchange component of the cost.

JTR:rbb

References

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3/ "Uranium Resources, Production and Demand, September 1970", a Joint Report by the ENEA and the IAEA, Paris and Vienna (1970)

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5/ "Potential Contribution of Nuclear Power to the On-Site Generation of Electric and Steam Power in Japan", G. Yabe and M. Okazaki, IAEA-SM-140/5, p. 319 - 328 in Ref. 7/

6/ "Power and Research Reactors in Member States, May 1970 Edition", IAEA, Vienna (1970)

7/ "Small and Medium Power Reactors 1970", Proceedings of a Symposium held in Oslo, 12 - 16 Oct. 1970, IAEA, Vienna (1971)

Table I

Developing Countries * - Members of the IAEA

Afghanistan
Albania
Algeria
Argentina
Bolivia
Brazil
Bulgaria
Burma
Cambodia
Cameroon
Ceylon
Chile
China
Colombia
Congo, Democratic Republic of the
Costa Rica
Cuba
Cyprus
Czechsolovak Socialist Republic
Dominican Republic
Ecuador
El Salvador
Ethiopia
Gabon
Ghana
Greece
Guatemala
Haiti
Hungary
India
Indonesia
Iran
Iraq
Israel
Ivory Coast
Jamaica
Jordan
Kenya
Korea, Republic of
Kuwait
Lebanon
Liberia
Libyan Arab Republic
Madagascar
Malaysia
Mali
Mexico
Morocco
Niger
Nigeria
Pakistan
Panama
Paraguay
Peru
Philippines
Poland
Romania
Saudi Arabia
Senegal
Sierra Leone
Singapore
Spain
Sudan
Syrian Arab Republic
Thailand
Tunisia
Turkey
Uganda
United Arab Republic
Uruguay
Venezuela
Viet-Nam
Yugoslavia
Zambia

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* "Developing countries" are regarded as those countries for which a programme under the technical assistance component of UNDP has been approved by the UNDP Governing Council. This classification has been accepted by the IAEA Board of Governors in relation to the Review of the Agency's activities carried out in 1967. The list of countries changes from year to year: the above list shows the countries for which a programme has been approved for the year 1971.

Table II

Projections of total installed electrical capacity and nuclear capacity in developing countries

(GWe)

	1970 Tot.	1970 Nucl.	1975 Tot.	1975 Nucl.	1980 Tot.	1980 Nucl.	1985 Tot.	1985 Nucl.
The Americas								
Argentina	7	0.0	11	0.3	16	1.6	23	3.0
Brazil	10	0.0	16	0.0	24	1.5[1]	35	6.0[1]
Chile	2	0.0	3	0.0	5	.4	7	1.2
Cuba	1	0.0	2	0.0	3	.4	5	1.4
Mexico	7	0.0	10[1]	0.0	16[1]	2.0[1]	25[1]	7.5[1]
Others	11	0.0	16	0.0	23	0.0	32	0.0
Subtotal	38	0.0	58	0.3	87	6	127	19
Africa								
U.A.R.	4	0.0	6	0.0	78	0.0	12	1.0
Others	9	0.0	14	0.0	20	0.0	28	0.0
Subtotal	13	0.0	20	0.0	28	0.0	40	1
Europe								
Bulgaria	4	0.0	9[3]	0.4	14[3]	0.9	20	2.4
C.SS.R.	10	0.0	14[3]	0.1	20[3]	1.3	27[3]	3.2
Greece	2	0.0	4[1]	0.0	6[1]	1.0[1]	10	2.6[2]
Hungary	3	0.0	5[3]	0.0	7[3]	0.4	10[3]	1.2
Poland	14	0.0	20	0.0	28[3]	1.0[3]	40[3]	2.4[3]
Romania	7	0.0	13[3]	0.0	22[3]	1.3	34	4.1
Spain	17	0.2	26	1.1	37	7.0[2]	52	17.0[2]
Turkey	3	0.0	5	0.0	8	0.8[2]	12	2.4[2]
Yugoslavia	6	0.0	9[3]	0.0	14[3]	1.2	20[3]	2.4[3]
Others	1	0.0	1	0.0	1	0.0	2	0.0
Subtotal	67	0.2	106	1.6	157	15	227	38

cont'd

Table II cont'd

	1970 Tot.	1970 Nucl.	1975 Tot.	1975 Nucl.	1980 Tot.	1980 Nucl.	1985 Tot.	1985 Nucl.
Asia + Middle East								
China (Taiwan)	3	0.0	6	0.6[1]	9	2.0[1]	13	3.6
India	18	0.4	30	1.0	50	2.7	78	6.0
Israel	1	0.0	2	0.0	3	0.4	4	1.0
Korea	3	0.0	6	0.6[1]	10	2.7[1]	15	5.4[1]
Pakistan	2	0.0	4[1]	0.1	8[1]	1.0[1]	11[1]	2.6[1]
Philippines	1	0.0	3[1]	0.0	5[1]	0.4[1]	8[1]	0.9[1]
Thailand	1	0.0[1]	2	0.0	3	0.4[2]	5	1.1[2]
Others	8	0.0	14	0.0	23	0.0	34	0.0
Subtotal	37	0.4	67	2.3	111	10	168	21
WORLD TOTALS (Developing countries)	155	0.6	251	4.2	383	30	562	78

Notes:

(1) Based on official response to IAEA questionnaire.

(2) Based on May 1970 estimates of the ENEA and IAEA Secretariat, as reported in Table 4 of "Uranium Resources, Production and Demand", a joint report of the European Nuclear Energy Agency and the International Atomic Energy Agency (published Sep. 1970)

(3) Based on "Energetyka Jadrowa 1969" (Nuclear Energy 1969) published by Osrodek Informacji o Energii Jadrowej (Nuclear Energy Information Center) Warsaw, Poland 1970

All other figures are estimates by IAEA Secretariat (Economic Studies Section, Division of Nuclear Power and Reactors).

Table III

Projections of nuclear installed capacity in industrialized countries, 1970 - 1985 1/

(GWe, end of year)

	1970	1975	1980	1985
Europe				
Austria	0.0	0.0[2]	1.8	3.8
Belgium	0.0[2]	1.5[2]	3.6	6.6
Denmark	0.0	0.0	0.6	1.8
Finland	0.0	0.4	1.4[2]	2.4
France	1.6[2]	2.6	9.2	25.0
Germany, Fed. Rep. of	0.9[2]	7.0[2]	25.0	45.0
Germany, Eastern	0.1[2]	0.8[2]	2.6[2]	4.6[2]
Italy	0.6	1.4	8.0	20.0
Netherlands	0.1	0.5	2.0	4.0
Norway	0.0	0.0	0.5	2.0
Portugal	0.0	0.0	0.5	1.1
Sweden	0.4	3.2[2]	7.5	17.0
Switzerland	0.4	1.8	3.5	5.8
U.K.	4.7[2]	10.5[2]	26.2	46.0
U.S.S.R.	1.6[2]	6.8[2]	27.5[2]	67.0[2]
Others	0.0[2]	0.0[2]	0.0[2]	0.0[2]
Subtotal	10.4	36	120	252
America				
Canada	0.5[2]	2.5	8.0	18.0
U.S.A.	7.5[2]	65.0	150.0	277.0
Subtotal	8.0	67.	158	295

CONT'D

Table III cont'd

	1970	1975	1980	1985
Asia				
Australia	0.0	0.0[2]	1.0	2.0
Japan	1.2[2]	7.1[2]	27.0[2]	60.0
New Zealand	0.0	0.0	0.8	3.1
Subtotal	1.2	7	28	65
Africa				
South Africa	0.0	0.0[2]	2.0	4.7
Subtotal	0.0	0.0	2.0	5
WORLD TOTALS (Industrialized countries)	19.6	110 ± 10 %	308 ± 20 %	617 ± 30 %

Notes:

(1) Unless otherwise indicated, based on May 1970 estimates of the ENEA and IAEA Secretariats, as reported in Table 4 of "Uranium Resources, Production and Demand", a joint report of the European Nuclear Energy Agency and the International Atomic Energy Agency (published Sep. 1970)

(2) Estimate by IAEA Secretariat, Economic Studies Section, Division of Nuclear Power and Reactors

(3) Based on "Energetyka Jadrowa 1969", (Nuclear Energy 1969) published by Osrodek Informacji o Energii Jadrowej (Nuclear Energy Information Center), Warsaw, Poland, 1970

Table IV

Comparison of total electrical capacity and nuclear electrical capacity in developing countries and industrialized countries

A. Total Electrical Capacity, GWe (and % of total)

	1970	1975	1980	1985
Industrialized Countries 1/	945	1336	1890	2672
Developing Countries 2/	155 (14.1 %)	251 (15.8 %)	383 (16.8 %)	562 (17.4 %)
World Totals 4/	1100	1587	2273	3234

B. Nuclear Electrical Capacity, GWe (and % of total)

	1970	1975	1980	1985
Industrialized Countries 3/	19.6	110	308	617
Developing Countries 2/	0.6 (3 %)	4 (4 %)	30 (9 %)	78 (11 %)
World Totals 4/	20.2	114	338	695

C. Percentage of Total Electrical Capacity which is nuclear

	1970	1975	1980	1985
Industrialized Countries	2.1	8	16	23
Developing Countries	0.4	2	8	14
World 4/	1.8	7	15	22

Notes:

1/ Based on IAEA estimate for 1970 and an assumed doubling time of 10 years.
2/ Based on Table II
3/ Based on Table III
4/ Excluding Mainland China

Table V

Potential Level of Nuclear Power Plant Orders by Developing Countries during the Coming Decade 1/

(GWe)

	1971-1975 2/	1976-1980 3/
Americas		
Argentina, Brazil, Chile, Cuba, Mexico	5.6	13
Columbia, Jamaica, Peru, Venezuela	?	?
Africa		
U.A.R.	0.0	1
Algeria, Morocco, Rhodesia	?	?
Europe		
Bulgaria, C.S.S.R., Hungary, Poland, Romania	4.4	9
Greece, Turkey, Yugoslavia	3.0	4
Spain	5.9	10
Europe : Subtotal	13.3	23
Asia + Middle East		
China (Taiwan), Korea, Philippines, Thailand	4.3	5
India, Pakistan	2.6	5
Israel	0.4	1
Singapore, Iran, Hongkong	?	?
Asia: Subtotal	7.3	11
TOTALS	26	48

Notes:

1/ Based on Table II
2/ Equal to the increase in nuclear capacity between 1975 and 1980, assuming orders placed five years before plant comes into operation.
3/ Equal to the increase from 1980 to 1985 (see Note 2/).

International Atomic Energy Agency

Division of Nuclear Power and Reactors
Economic Studies Section

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Influence of Financing Terms on the Competitive Status of Nuclear Power

Introduction

As a result of the differing fixed-cost and variable-cost characteristics of the various types of electric power generation plants, an optimal system usually consists of a balanced mixture of the types, depending on local fuel costs, capital charges, and system load characteristics. Nuclear power is at present a strong competitor for the base-load part of system capacity, at least for plant sizes above 500 MWe. Of the various types of conventional power plants, the most widespread and toughest competition to nuclear plants is offered by oil-fired steam plants. Oil is relatively easy to transport, especially with the help of large tankers. The capital cost of an oil-fired station is typically less than that of a coal, hydro or nuclear station, but its fuelling costs are typically higher, so that the competitive position is determined by striking a proper balance between the two types of costs. This balance is strongly influenced by the terms under which the plant capital cost is financed.

Before comparing the generating costs of power from nuclear and oil-fired stations some general comments may be in order on the three major cost components, namely capital, fuel, and operation and maintenance. There are considerable uncertainties in the capital costs of nuclear power stations in all sizes, especially in the under-500 MWe range. Costs have varied by a factor of two even for large nuclear plants, depending upon the location, the time when purchased, escalation, delays due to regulatory and safety reviews, and other reasons. There have also been considerable variations (of the order of 50 %), in the cost of oil-fired stations for some of the same reasons. In general, however, the cost of oil-fired plants has stabilized within a comparatively narrower range because of repetitive designs, strong competition among a large number of suppliers and the experience gained by architect engineers in building these plants around the world. Further, the utilities purchasing usually have prior experience with similar units and are able to negotiate more effectively.

In contrast, it is the conventional fuels which have exhibited large fluctuations in prices together with uncertainties in supply, while the quoted and projected nuclear fuel cycle costs have varied relatively little over the past several years. Unlike the unit capital costs, the fuel cycle costs for intermediate-sized nuclear power plants do not differ very much from those for large plants. Even a smaller nuclear plant can benefit greatly from the existence of large facilities for fuel enrichment, fabrication and reprocessing.

The operation, maintenance and insurance costs for nuclear power plants are somewhat higher than those of corresponding oil-fired plants, largely because of higher insurance coverage required. However, the difference is not controlling in comparing costs of power generated by nuclear and oil-fired plants.

This report presents an updating and enlargement of previous IAEA studies of the subject 1/ 2/.

Fuel Costs

An analysis of the main elements comprising nuclear fuel cycle costs shows that the total costs are likely to remain fairly stable within a narrow range and can be predicted with reasonable assurance. For example, the contribution of uranium to the overall fuel cycle cost of an enriched-uranium reactor is about 20-25 % of the total. If credit is taken for the plutonium produced, the net cost for the fuel material may be of the order of 10 % only. Continuing exploration and discoveries for new uranium reserves indicate that there is no likelihood of uranium shortages and that uranium prices should not be expected to increase very rapidly as far as one can analyse at present [3]. Further, the net effect of any uranium price increases on the overall fuel cycle cost is relatively small and is likely to be offset by improvements and adjustments in other areas. The largest segment of the enriched-uranium nuclear fuel cycle cost is attributable to industrial-type operations such as conversion, enrichment, fabrication and reprocessing, which together account for about 2/3 of the total. The unit costs for these operations are a function of the plant throughput and are expected to be reduced significantly as the scale of operations increases with the growth of the nuclear industry. There already exists an overcapacity for the near-term future and competition between suppliers will tend to keep prices low. For the enrichment plants, where the scale of operation is already large, economies resulting from improvements in technology will tend to offset inflationary increases in costs. The capital charges on fuel inventories constitute the remainder of the enriched-uranium fuel cycle cost, about 1/4 of the total, depending on the interest rate and the hold-up times. With improvements in fuel cycle technology and fuel management schemes and with the emergence of centralized fuel services the hold-up times should be reduced. It may be noted that a decrease of 1 % in interest rates would offset an increase of almost \$ 1/kg in the cost of uranium oxide. As an illustrative example, Table 1 presents a breakdown of estimated fuel cycle costs for a 200 MWe PWR with a 10 %/year fixed-charge rate on fuel investment. These costs are given for assumed 1980 conditions, expressed in 1970 dollars. Tables 2 and 3 give estimated total fuel cycle costs for plant sizes of 100 to 600 MWe and for fixed-charge rates of 7 % to 14 %.

Fuel oil price predictions are subject to large uncertainties, as shown by events of the past few years. In 1968, fuel oil prices in major harbours of the world typically varied from 25 cents to 35 cents per million BTU, depending on the amount purchased, shipping costs, and individual contract conditions. This corresponds to \$ 10-14/ton, including \$ 8-10/ton for the fuel oil and \$ 2-4/ton for transportation. The cost of delivery to power stations and on-site storage added another 2-5 cents/10^6 BTU for locations reasonably close to the harbours. Thus, a price range of 27-40 ¢/10^6 BTU covered most locations not far from major harbours. In 1970-71 the price of fuel oil registered a very sharp rise, climbing to \$ 20-25/ton (50-62 ¢ per 10^6 BTU) in major ports in Western Europe and the USA. This resulted primarily from a large increase in tanker rates and a smaller increase in taxes and royalties to producing countries. The tanker shortage is likely to be temporary and the fuel oil prices are expected to come down, though not to the low levels of 1968. It may be reasonable to assume that, after the situation normalizes, a price range of 35-50 ¢/10^6 BTU, not including escalation or duty and taxes to the consuming country, will cover most cases. Very approximately, a typical breakdown for Persian Gulf crude oil might be as follows:

	$/barrel	$/ton	¢/10^6 BTU
Exploration, production, marketing, profit	0.4	3	7
Taxes + royalties to producing country	1.2	8	20
Subtotal, FOB Price	1.6	11	27
Tanker transport to Europe via Cape of Good Hope	1.6	11	27
Delivered cost at European port (not including escalation)	3.2	22	55

By comparison, Algerian crude oil has a lower transport cost to Europe but the FOB price has been set high enough not only to offset the lower transport cost but to command a premium price for its low sulfur content, which is in demand as a result of increasingly restrictive air pollution regulations. Fuel oil prices are normally lower than crude oil prices, so that the above estimate of 55 ¢/10^6 BTU for crude oil at the port might correspond to 40 ¢/10^6 BTU for fuel oil at the port, or 42-45 ¢/10^6 BTU at the power plant. The escalation provision in recent agreements will add an estimated 6-7 ¢/barrel per year to the payments to producing countries. In five years this will increase crude oil costs by the equivalent of 5-6 ¢/10^6 BTU. (Note: the "posted" price for Persian Gulf crude oil is about $ 2.30/barrel in 1971, subject to automatic escalation for five years. For Algerian oil the posted price is about $ 3.60/barrel. The posted price is important for purposes of determining the amount of taxes and royalties to the producing country, but the actual FOB selling price is usually signficantly lower than the posted price.)

Capital Costs

There is a serious lack of reliable and up-to-date information on the capital costs of nuclear plants in the intermediate size range even though a considerable number of them have been built and ordered. The cost data are not generally released by the manufacturers or the utilities and the figures reported in the literature are not clearly identified as to what they contain and exclude. Since 1965 no large manufacturer has published a detailed list price for nuclear plants. At present the best sources of information are the engineering estimates prepared by responsible organizations and consulting groups and occasional reports made available on the results of competitive building.

The estimates used on this paper are based upon the data presented at the Agency's Symposium on "Small and Medium Power Reactors" held in late 1970, the proceedings of which have now been published 4/. An allowance has been made for indirect costs, to take care of architect-engineers fees, owner's general and administrative expenses, miscellaneous construction and engineering costs, start-up training, licensing, spare parts, and site development costs. Interest during construction has been estimated at 8 %/year with a total construction time of 55 months. The cost figures shown in Table 2, expressed in 1970 dollars, refer to 1976 start-up and are representative of conditions in the suppliers' countries, with no extrapolation to any specific overseas application.

The costs of conventional plants shown in Table 2 also refer to conditions in the supplying countries. They are somewhat higher than the prices which have been paid for some plants as a result of international competition and independent financing. It is reasonable to expect that prices of nuclear plants ordered under similar conditions could also be lower. The capital costs of a nuclear and a conventional plant at a particular location could vary considerably from the average or representative current figures. The cost difference between nuclear and conventional plants, however, may not be as sensitive to local conditions since they are likely to affect both plants in the same way if not exactly to the same degree. Even so, the difference may vary substantially, as indicated in Table 3. Using this difference as the basis, calculations can be made of a "break-even" price of fuel oil at which the nuclear and conventional plants would have equal generation costs at a given fixed-charge rate.

Nuclear Generation Costs and Equivalent "Break-Even" Fuel-Oil Costs

For purposes of presenting an illustrative example, a PWR-type nuclear plant has been used in Table 1, 2 and 3. In Table 3 a range of estimated additional capital investment required for a nuclear plant compared to an oil-fired plant has been indicated for each plant size. The range is intended to indicate the variations which may be encountered due to varying local conditions and fluctuations in bid prices with market conditions. For example, in Table 2 the difference in capital cost between nuclear and oil plants of 300 MWe is indicated to be \$ 120/kWe; however, if the nuclear plant bid price were 8 % higher and the oil plant bid price 8 % lower than the "mid-range" numbers shown in Table 2 the difference would be \$ 160/kWe. If the 8 % variations were in the opposite direction the difference would be only \$ 80/kWe. Such variations could easily occur and thus in Table 3 a range of \$ 80-160/kWe is shown. This range corresponds to a range of equivalent generation costs, depending on the fixed-charge rate on investment and on the plant load factor. In Table 3 the load factor has been assumed to be 80 % and the fixed-charge rate has been varied as a parameter with illustrative values of 7 %, 10 % and 14 %/year. The 7 % value corresponds to fairly-favourable financing conditions; the 10 % value is typical of many state-owned electric utilities; and the 14 % value corresponds to fairly-high interest rates or to cases where taxes more-or-less proportional to investment are included in the fixed-charge rate. (See also Table 4, discussed subsequently.)

Table 3 also shows the additional operation and maintenance costs of nuclear plants compared to oil-fired plants, and representative nuclear fuel cycle costs as a function of plant size and fixed-charge rate on investment in fuel-cycle inventories. Adding the generation-cost equivalent of the additional capital investment in nuclear plants to the additional operation and maintenance costs and to the nuclear fuel cycle cost gives a range of costs, in mills/kWh, which could be allowed for fuel-oil costs to give equal total generation costs for nuclear and oil-fired plants. This total is shown in Table 3, and is converted to a range of equivalent "break-even" oil costs, expressed in cents/10^6 BTU. For example, Table 3 indicates that for a 300 MWe plant at 10 % fixed-charge rate the expected competitive range of oil costs is 33-45 ¢/10^6 BTU. For electric utilities with oil costs in this range, and with fixed-charge rates of 10 % (or less), nuclear plants of 300 MWe (or larger) should be considered as potentially serious competitors for oil plants for base-load applications; and detailed cost estimates under local conditions should be made to narrow down the range of uncertainty in the comparison. For oil prices above this range, 300 MWe nuclear plants are indicated to be more economic than oil plants, at 10 % (or lower) fixed-charge rate, even if the capital cost difference is at the upper end of the indicated range. Figure 1 is a plot of the break-even oil costs indicated in Table 3 as a function of plant size and fixed-charge rate.

Since a likely range of world fuel oil prices of 35-50 ¢/10^6 BTU is projected, Figure 1 and Table 3 suggest that

1) 100 MWe nuclear plants cannot be expected to compete with oil-fired plants except under the most favourable combination of capital-cost difference at the low end of the indicated range and a low fixed-charge rate;

2) 500-600 MWe (and larger) nuclear plants can be expected to be competitive for base-load applications even with relatively high fixed-charge rates and with capital-cost differences at the upper end of the indicated range;

3) 200-400 MWe nuclear plants may be competitive for base-load applications if financing terms equivalent to a 10 % (or lower) fixed-charge rate are available, especially if the potential cost reductions associated with multiple orders, design standardization, etc., push the nuclear-oil capital cost difference toward the lower end of the indicated range.

It should be noted that the industrialized countries are mostly ordering larger size plants than these sizes which are of most interest to developing countries. In 1970 the average unit size of nuclear plant ordered was almost 900 MWe, with the largest being more than 1200 MWe, and with only one being smaller than 500 MWe.

The Relationship between Financing Terms and Fixed-Charge Rate

Table 4 shows the basic fixed-charge rates corresponding to a veriety of combinations of interest rate and length of capital recovery period. The basic fixed-charge rate is defined as equal to that constant fraction (or percentage) of the initial investment which if set aside at the end of each year of the capital recovery period would be sufficient to pay the interest each year on the unrecovered balance of the investment and to reduce the unrecovered balance to zero by the end of the last year. It is also referred to as the "uniform series capital recovery factor". Actual fixed-charge rates may be greater than the basic rate in some cases; for example, some electric utilities add to the basic rate an amount sufficient to cover taxes related to investment or to return on investment and to cover property insurance and interim replacement of items with a physical life shorter than the capital recovery period. Also, the financing terms may specify larger payments in the earlier years and lower payments in later years rather than constant annual payments, and this is equivalent to an effective fixed-charge rate somewhat higher than the basic rate. Further complications in calculating the appropriate fixed-charge rate to use in making economic comparisons between nuclear and conventional power (or between any two alternative investments) may be introduced when the loan repayment period is shorter than the economic life of the plant, as is frequently the case. There is also the question of what is the most appropriate interest rate to use for evaluation.

As can be seen in Table 4, at zero interest rate the basic fixed-charge rate is simply the reciprocal of the capital recovery period, equal to the "straight-line" depreciation factor. As the interest rate increases the basic fixed-charge rate can be thought of as equal to a straight-line depreciation allowance plus interest on the average unrecovered investment, or as equal to a "sinking fund" depreciation allowance plus interest on the original investment. For long capital recovery periods the basic fixed-charge rate is only slightly higher than the interest rate.

Power plant financing usually involves an initial "grace period" during which no repayment of principal is required and during which interest may be either accumulated or paid currently. The grace period is usually equal to or somewhat greater than the construction period. In our calculations we have assumed that "interest during construction" is accumulated and becomes a part of the initial capital investment to which the fixed-charge rate is applied.

As examples of financing terms, IDA * terms of 10 years grace period and 50 years repayment period, with no interest but with a service charge of 3/4 of 1 %, represent extremely favourable terms, but are available only in very special circumstances. (IDA loans for power during the 1960's were only about 5 % of IBRD** power loans.) IBRD terms for (conventional) thermal power plants have been about 3-5 years grace period, depending on consturction period, with repayment period averaging 20 years; the current interest rate is about 7 1/4 %. (IBRD loans also carry a commitment charge on the undisbursed loan balance of 3/4 of 1 %). Bilateral financing terms for power plants in developing countries have varied over a wide range, including some approximately as favourable as IDA/IBRD terms. For example, in the case of KANUPP nuclear power plant in Pakistan approximately half of the financing was by the Export Development Corporation of Canada under terms of 6 % interest and 20 years maturity, and the remainder was by the Canadian International Development Agency under terms of 3/4 % interest and 50 years maturity. Another example is U. S. Export-Import Bank (EIB) financing of conventional and nuclear power plants and nuclear fuel, which can be summarized briefly (and approximately) as follows:

(1) For power plant equipment - - 10 % cash investment by purchaser, 45 % financing by EIB at 6 % interest, 45 % financing by other U. S. or foreign institutions (whose loans may or may not be guaranteed by EIB) at negotiated interest rates, interest payments semiannually on amounts outstanding from dates when disbursements are made, 1/2 %/year commitment fee on the undisbursed balances of authorized credits, 1/2 %/year fee for financial guarantee of other loans by EIB, repayment of principal spread over up to 15 years after plant startup.

(2) For initial nuclear fuel inventories, the terms are similar to those for plant financing except repayment of principal spread over five years after use of fuel commences. Fuel sold separately from the plant can also be financed

* IDA = International Development Association
**IBRD = International Bank for Reconstruction and Development

on slightly different terms.

(3) Local cost financing - - EIB can assist by guaranteeing repayment of loans made by non-U.S. institutions to finance local costs in amounts not exceeding 15 % of the U.S. costs of equipment and services.

"Payout Time" for the Additional Investment in Nuclear Plants from Savings in Fuel Costs

As has been mentioned already, the additional investment in a nuclear plant compared to an oil-fired plant must be justified by the subsequent savings in fuel costs. This is sometimes expressed as the number of years required for the fuel cost savings to equal the additional investment, which may be thought of as a "payout time". As an example, consider the following estimates of annual fuel cost plus operation and maintenance cost for 400 MWe nuclear and oil plants, based on Tables 2 and 3:

Nuclear:	$ 6 310 000
Oil - at 35 ¢/10^6BTU:	$10 150 000
- " 40 ¢	$11 440 000
- " 45 ¢	$12 730 000
- " 50 ¢	$14 020 000

The annual savings of the nuclear plant vary from $ 3.8 million to $ 7.7 million per year, depending on fuel-oil costs. The extra capital cost of the nuclear plant is estimated at $ 65-135/kWe, or a total of $ 26 million to $ 54 million. Thus the payout time for the additional investment could range from 3.4 years to 14 years, depending on actual oil cost and actual additional nuclear plant cost.

Return on Additional Investment in Nuclear Plant

The payout time is only an approcimate indication of economic competitivity as neither interest rate nor economic life of plant enter into its calculation. It is more informative to calculate the return on additional investment to which the annual fuel cost saving is equivalent. Thus, the following table shows the return on additional investment to which the annual fuel-cost savings are equivalent in the 400 MWe example mentioned in the preceding section on payout time, assuming that the annual savings are realized for 25 years:

Additional Investment $/kWe	Fuel Oil Cost, ¢/10^6 BTU			
	35	40	45	50
	Return on Additional Investment, %/year			
65	14.2	19.5	24.6	29.6
100	8.3	12.1	15.6	19.0
135	5.0	8.2	11.0	13.7

In general, the return on additional investment should be at least as high as the interest rate paid on the additional capital required and preferably as high as or higher than the return which could be obtained in the best alternative use of this capital. The latter criterion often is difficult to apply as the loan may be "tied" to the equipment purchase, directly or indirectly, and thus is not necessarily available for an alternative use.

JTRoberts:rbb

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3/ "Uranium Resources, Production and Demand", L. Boxer, W. Häussermann, J. Cameron and J. T. Roberts, Joint ENEA/IAEA paper to be presented at the Fourth International Conference on the Peaceful Uses of Atomic Energy, Geneva, 6 - 17 Sep. 1971

4/ "Small and Medium Power Reactors 1970", Proceedings of a Symposium held in Oslo, 12 - 16 Oct. 1970, IAEA, Vienna (1971)

Table 1

Example of Fuel Cycle Costs for a 200 MW(e) PWR

	Mills/kWh(e)		% of Total
1. Fuel Material			
a) - U_3O_8 purchase, gross	0.572	0.417	22.5
- Credit for U_3O_8 equivalent in recovered uranium	(0.155)		
b) Credit for recovered plutonium	(0.250)		(13.5)
Subtotal	0.167		9.0
2. Industrial Operations			
a) - Conversion, gross	0.065	0.047	2.5
- Credit for conversion equivalent in recovered uranium	(0.018)		
b) - Enrichment, gross	0.784	0.700	37.9
- Credit for enrichment equivalent in recovered uranium	(0.084)		
c) Fabrication	0.310		16.8
d) Recovery	0.150		8.1
Subtotal	1.207		65.3
3. Fixed Charges on Fuel Cycle Investment			
...	0.475		25.7
TOTAL	1.85		100

Notes: Assumptions and Ground Rules

1) U_3O_8 : $ 7.5/lb
2) Losses: conversion 0.5 %, fabrication 1.0 %, recovery 1.0 %
3) Diffusion: plant tails essay -- 0.2 % U-235
4) Separative work costs: $ 32/kg SWU
5) Conversion costs: $ 2.20/kg U
6) Plutonium credit: $ 9/gm fissile Pu
7) Fabrication: $ 70/kg U
8) Recovery including reprocessing, shipment and reconversion: $ 35/kg U
9) Hold-up times: 3 months for each step (pre-irradiation, fabrication, enrichment, post-irradiation and recovery)
10) Fixed charge rate on fuel inventory and working capital: 10 % p.a.
11) Initial enrichment: 3.5 %
12) Final enrichment: 1.14 %
13) Fissile Pu (239 + 241): 6.5 gm/kg U discharged
14) Burnup: 30,000 MWD/MT
15) Specific power: 32,3 KWth/kg U
16) Thermal efficiency: 31 %
17) Plant capacity factor: 80 %

Table 2

MID-RANGE COST ESTIMATES FOR INTERMEDIATE-SIZE NUCLEAR AND OIL-FIRED POWER PLANTS (1970 Basis) 1/

Net output, MWe	100	200	300	400	500	600
NUCLEAR PLANTS						
- Capital cost, $/kWe						
- Direct	345	255	214	191	174	161
- Indirect	76	51	41	34	30	26
- Interest during construction 2/	74	54	45	40	36	33
TOTAL	495	360	300	265	240	220
- Operation and maintenance cost, 3/ mills/kWh	1.80	1.00	0.75	0.60	0.50	0.50
- Fuel cycle cost, 4/ mills/kWh	2.10	1.85	1.75	1.65	1.60	1.60
OIL-FIRED PLANTS						
- Capital cost, $/kWe						
- Direct	186	159	142	130	125	119
- Indirect	45	27	21	19	15	13
- Interest during construction 5/	24	19	17	16	15	13
TOTAL	255	205	180	165	155	145
- Operation and maintenance cost, mills/kWh	1.05	0.60	0.50	0.40	0.35	0.35
- Fuel cost, mills/kWh	-- Varies widely, depending on fuel oil price --					

Notes:

1/ For 1970 cost levels, without allowance for escalation during construction.
2/ Accumulated interest during 55 months construction period at rate of 8 %/year, total about 17.5 % of direct and indirect costs.
3/ Including nuclear liability insurance.
4/ Including 10 %/year fixed charges on fuel cycle working capital.
5/ Accumulated interest during construction period at rate of 8 %/year, total about 10.5 % of direct and indirect costs.

Table 3

Comparative Economics of Small- and Medium-Power Nuclear and Oil-Fired Power Plants

Net output, MWe	100	200	300	400	500	600
Range of estimated additional capital investment required for nuclear plant						
-- $/kWe	160-320	105-205	80-160	65-135	55-115	50-100
-- mills/kWh 1/						
- at 7 % FCR	1.6-3.2	1.0-2.0	0.8-1.6	0.6-1.4	0.6-1.2	0.5-1.0
- " 10% FCR	2.3-4.6	1.5-2.9	1.1-2.3	0.9-1.9	0.8-1.6	0.7-1.4
- " 14% FCR	3.2-6.4	2.1-4.1	1.6-3.2	1.3-1.7	1.1-2.3	1.0-2.0
Estimated additional operation & maintenance costs of nuclear plant, mills/kWh	0.75	0.40	0.25	0.20	0.15	0.15
Estimated nuclear fuel cycle cost, mills/kWh:						
- at 7 % FCR	1.95	1.70	1.60	1.50	1.50	1.50
- " 10 % FCR	2.10	1.85	1.75	1.65	1.60	1.60
- " 14 % FCR	2.30	2.05	1.95	1.80	1.75	1.75
Indicated range of competitive fuel oil cost, mills/kWh 2/ :						
- at 7 % FCR	4.3-5.9	3.2-4.2	2.6-3.4	2.4-3.0	2.2-2.8	2.2-2.6
- " 10 % FCR	5.1-7.4	3.8-5.2	3.1-4.3	2.8-3.8	2.5-3.4	2.5-3.2
- " 14 % FCR	6.2-9.4	4.6-6.6	3.8-5.4	3.3-4.7	3.0-4.2	2.9-3.9
Average heat rating of oil-fired plant, BTU/kWh	10 700	10 000	9 500	9 200	9 000	8 900
Equivalent competitive oil costs, ¢/million BTU 2/ :						
- at 7 % FCR	40-55	32-42	28-36	26-33	24-31	24-30
- " 10 % FCR	48-69	38-52	33-45	30-41	28-38	28-36
- " 14 % FCR	58-88	46-66	40-57	36-51	33-47	33-44

Notes:

1/ Calculated at 80 % load factor for the annual fixed-charge rate on investment indicated (including interest, depreciation, and any other capital charges).

2/ For oil costs lower than the lower end of the indicated range nuclear is unlikely to be competitive. For oil costs higher than the upper end of the indicated range oil is unlikely to be competitive. For oil costs within the indicated range a closer estimate of capital, operation and maintenance, and fuel costs of nuclear and oil-fired plants under local conditions is required to determine competitive status.

Table 4

Basic Fixed-Charge Rate Table (%/year) 1/

Interest Rate %	Capital Recovery Period (years)					
	10	15	20	25	30	40
0	10.00	6.67	5.00	4.00	3.33	2.50
2	11.13	7.78	6.12	5.12	4.46	3.66
4	12.33	8.99	7.36	6.40	5.78	5.05
6	13.59	10.30	8.72	7.82	7.26	6.65
8	14.90	11.68	10.18	9.37	8.88	8.39
10	16.27	13.15	11.75	11.02	10.61	10.23
12	17.70	14.68	12.75	13.39	12.41	12.13

1/ The basic fixed-charge rate, also referred to as the uniform-series capital recovery factor, is given by:

$$F.C.R. = \frac{i\,(1+i)^n}{(1+i)^n - 1} = \frac{i}{1 - (1+i)^{-n}}$$

multiplied by 100 to convert from a fraction to a percentage .

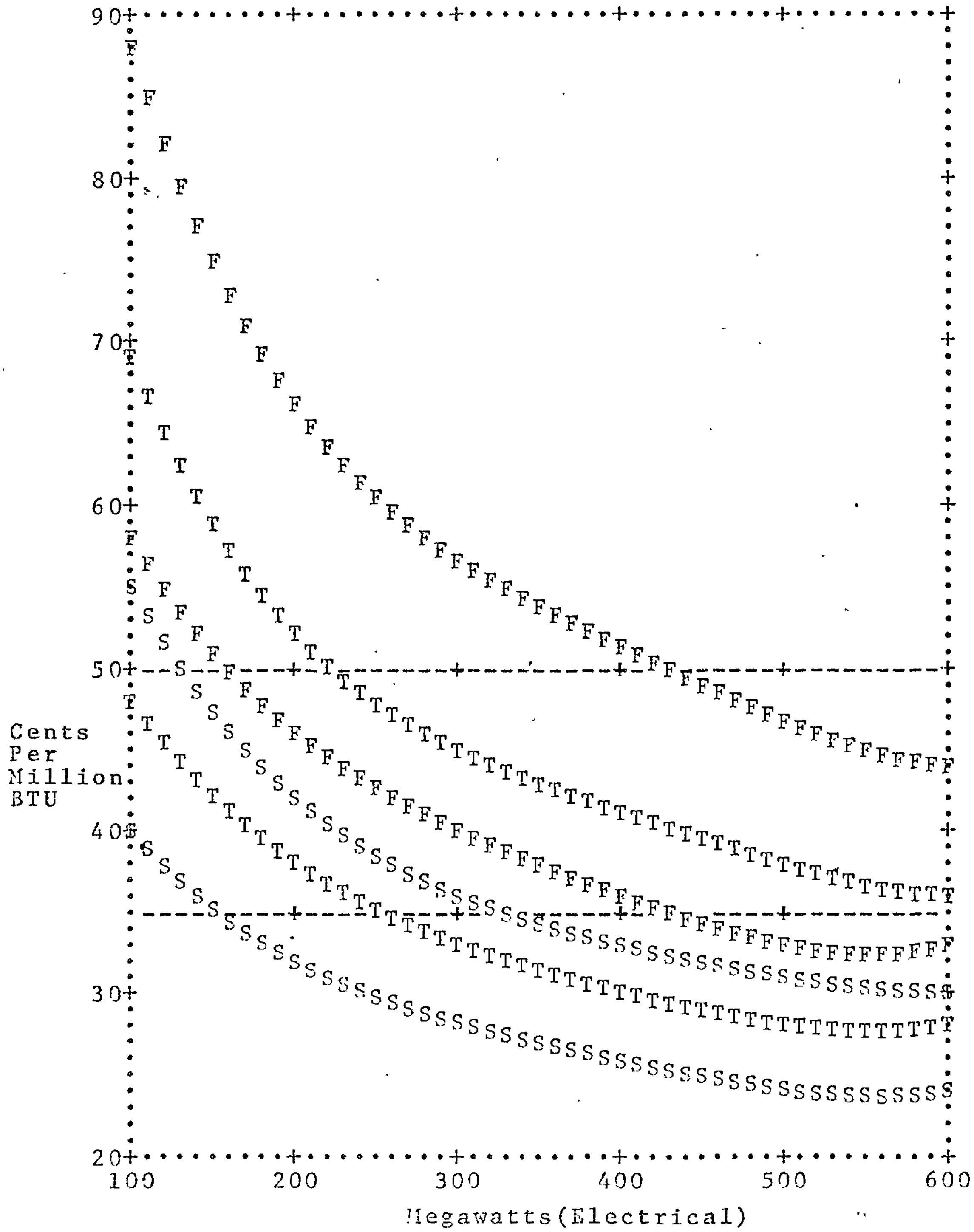

Fig. 1

Breakeven Oil Cost as a Function of Plant Size
and Fixed-Charge Rate

Legend: SSSSSSSSSSS indicates range for 7% FCR
TTTTTTTTTTT indicates range for 10% FCR
FFFFFFFFFFF indicates range for 14% FCR

+---------+ indicates estimated range
of expected fuel-oil prices