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Provisional agenda, Item 2

Background paper

APPLICATION OF NUCLEAR ENERGY FOR POWER PRODUCTION AND FOR WATER DESALINATION

Prepared for the Symposium

Presented by the International Atomic Energy Agency

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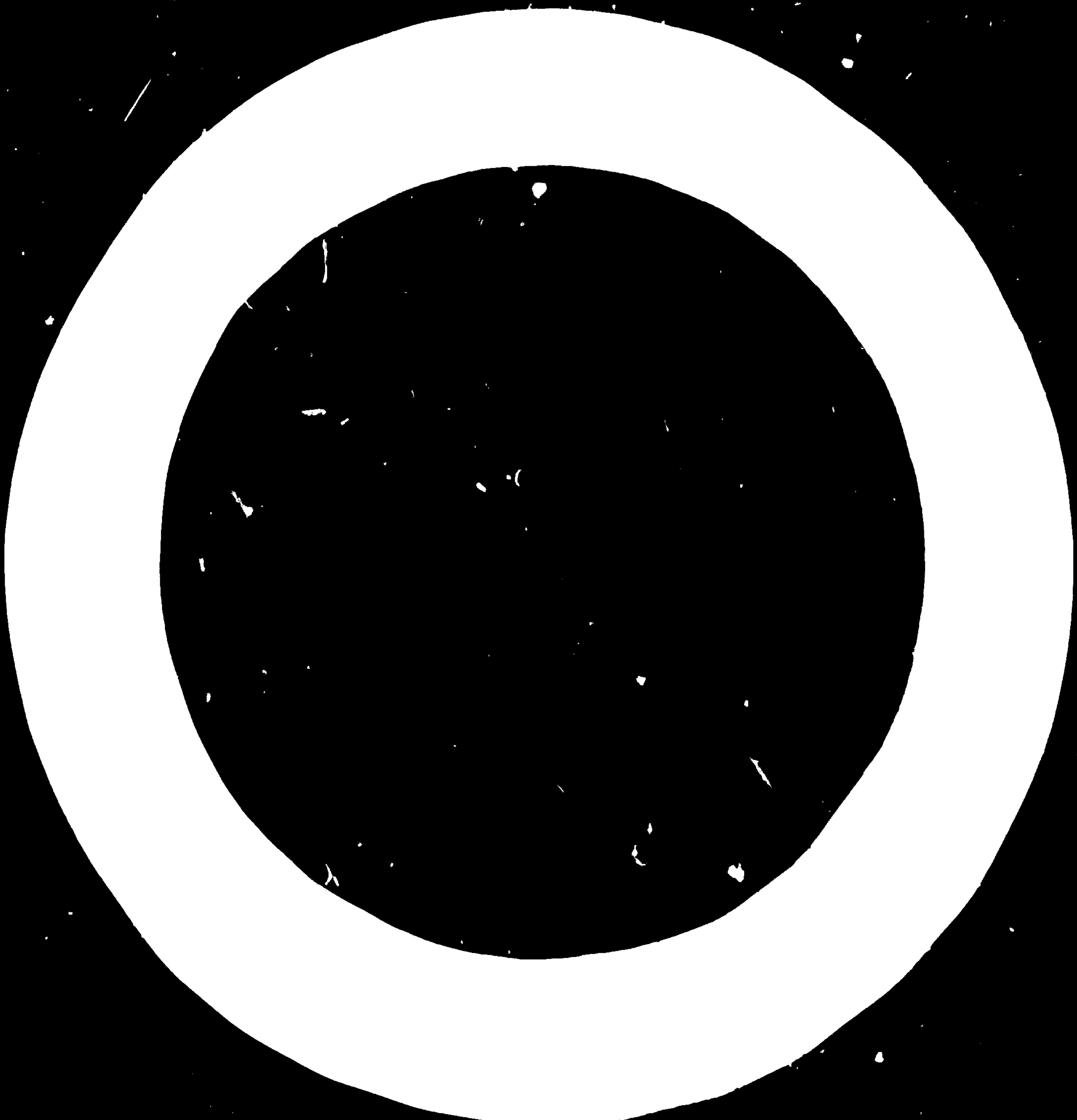

Introduction

1. The availability of adequate supplies of electricity and water at reasonable cost can accelerate industrialization of an area and help developing countries make better use of their resources. One of the chief contributions of the International Atomic Energy Agency to economic welfare and industrial development in developing countries is in the domain of nuclear energy for power and water development.

2. The improved economic prospects for nuclear power have altered the framework in which the Agency operates. Its programme is, therefore, laying more stress on the services it can offer to Member States during the early stages of a nuclear power project, on the application of proven reactor types for power production and desalination and on the long-term economics of nuclear fuel supply.

3. The Agency's work in health, safety and waste management has also been affected. The services offered for evaluating the safety of sites for nuclear reactors have been utilized by industrialized and developing countries. Having completed its standard-setting work on most of the main questions of radiation protection, the Agency is devoting more effort to the problem of finding safe and inexpensive means of disposing of nuclear waste; to providing services which will facilitate international transport of fuel elements and other radio-active materials; and to helping individual Member States to solve local health and safety problems.

CURRENT STATUS OF NUCLEAR POWER

4. In the twenty-five years since the world's first self-sustaining nuclear chain reaction, the progress in developing nuclear power reactors has been remarkable. Several reactor types have reached the stage at which they are considered proven in that there is adequate technical and operating experience to ensure reliability and safety in operation and their performance and cost can be satisfactorily guaranteed by the suppliers. Other, more advanced systems are at various stages of development.

Proven reactor types

5. The proven reactor types are gas-cooled-magnox, advanced gas-cooled, boiling- and pressurized-light-water and heavy-water.

6. Magnox reactors, which have been developed in France and the United Kingdom, use natural uranium metal fuel clad in magnox, a magnesium alloy. The moderator is graphite and the coolant is pressurized carbon dioxide. Early reactors used steel for the pressure vessel but this has been superseded by pre-stressed concrete. On-load refuelling has been used on all commercial stations. The target fuel irradiation is currently 3600 MWd/t and is expected to be raised to at least 4000 MWd/t. Temperature limitations associated with the metal fuel and the magnox cladding limit the gas outlet temperature to about 400°C and the over-all plant efficiency to about 33 per cent. Improvements in the system are in progress in France. The main development is the use of annular fuel elements cooled internally and externally by the carbon dioxide.

7. In the United Kingdom, the advanced gas-cooled reactor (AGR) system is being operated. The AGR retains graphite as the moderator and carbon dioxide as the coolant, but the fuel is slightly-enriched uranium dioxide clad in stainless steel, each fuel element consisting of a cluster of fuel pins. The gas outlet temperature is about 650°C which leads to an over-all plant efficiency of over 40 per cent. Commercial stations will have a pre-stressed concrete pressure vessel and on-load refuelling. The design fuel irradiation is 18 000 MWd/t.

8. Boiling water (BWR) and pressurized-light-water (PWR) reactors developed in the Soviet Union and the United States are similar in many respects. Both use light water as coolant and moderator and have clustered fuel elements of slightly-enriched uranium dioxide clad in zircaloy. The design fuel irradiation is currently about 20 000 MWd/t. The reactors produce saturated steam giving an over-all plant efficiency of about 33 per cent. In the boiling water reactor, steam is produced, separated and dried within the reactor vessel before passing to the turbine. There has already been encouraging experience with nuclear superheat, but it may be a few years until this feature is incorporated in standard designs. In the PWR, steam is raised in external heat exchangers. Both types use steel pressure vessels and the reactor is shut down for refuelling.

9. Reactors using heavy-water as both moderator and coolant have been developed mainly in Canada and Sweden and in the Federal Republic of Germany. The fuel element, of cluster form, uses natural uranium dioxide clad in zircaloy. The fuel irradiation is about 9000 MWd/t at which level reprocessing is not necessary for economic operation under present conditions. In the Canadian design, each fuel

channel is contained in a pressure tube and refuelling is on-load. Saturated steam is produced giving an over-all plant efficiency of about 30 per cent. Heavy-water losses have been reduced to a low level.

10. There is one further reactor type which may almost be considered proven in that the technology has much in common with that of the existing heavy-water and light-water reactors. This is the heavy-water moderated, light-water-cooled system, the first prototype of which is due to begin operating in the United Kingdom this year. The fuel is slightly-enriched uranium dioxide clad in zircaloy and again the fuel element consists of a cluster of fuel rods. Pressure tubes containing the fuel channels separate the heavy-water from the light-water which provides some of the moderation as well as the two-phase cooling of the fuel elements. The steam produced is separated and dried and then passes direct to the turbine. The prototype has provision for superheat which will be tried at a later stage. The design irradiation is 18 000 MWd/t and refuelling may be on- or off-load. A reactor of basically similar design but using natural uranium is being built in Canada. The fuel irradiation is expected to be 7000-8000 MWd/t.

Further developments in nuclear reactors

11. The above proven systems, with the exception of the heavy water reactors, do not make efficient use of the primary fuel material, natural uranium.

12. In the absence of other factors, as nuclear capacity grows, this would lead to the known reserves of low-cost uranium being committed in two or three decades. However, such a tendency will be countered, firstly, by new finds of uranium which are confidently expected as prospecting increases, secondly, by the development of advanced converter reactors and breeder reactors which promise to give lower generating costs than those of the proven reactors.

13. Advanced converters include further developments of light-water reactors, heavy-water reactors, high-temperature gas-cooled reactors, and liquid-fuelled reactors. In some of these reactors, a low specific fuel inventory and good fuel utilization may be achieved by the use of a mixture of thorium and enriched uranium as fuel and by designs which improve the neutron economy. Thorium is a fertile material (i.e., it is converted in the reactor into a fissile material - uranium 233) of which there are large low-cost reserves in several countries.

14. High-temperature gas-cooled reactors use graphite for the cladding, structure and moderator, high pressure helium as the coolant; and oxide or carbide fuel contained in small, spherical, coated particles which retain fission products to very high burn-ups (about 100 000 MWd/t). Two types of liquid-fuelled reactor are currently under development. In the first, the moderator is again graphite through which is circulated a molten salt consisting of a mixture of fluorides. In the second, small spherical particules of oxide fuel are circulated, in suspension, in the heavy-water moderator.

15. Thermal breeder reactors may evolve from the advanced thorium converters mentioned above, particularly the liquid-fuelled reactors. Fast breeders are being developed in several countries. Most effort has been devoted to those using a mixture of uranium and plutonium oxides as the fuel, stainless steel cladding and sodium as the coolant. However, the use of carbides for the fuel and of gas or steam for the coolant is also under consideration. The successful development of breeder reactors would free mankind for a very long time from concern about fuel resources for the production of power and process steam.

Economy of nuclear power

16. By the end of 1966, there were seventy-five nuclear power reactors in operation in ten countries of the world, with a total capacity of nearly 9000 MW(e). Although, in general, these existing plants do not generate electricity as cheaply as a corresponding conventional plant, they have given invaluable experience in the construction and operation of industrial nuclear reactors and have provided a firm basis for developments and for the costing of further plants of similar types.

17. These developments have improved the economics of nuclear power to the extent that many utilities in the industrialized countries are adopting nuclear power on economic grounds backed by the very satisfactory operational record of power reactors already commissioned. Perhaps the most striking example is that 55 per cent of all new steam-electric generating capacity announced by United States utilities in 1966 was nuclear. Estimates of additions to nuclear and total electric power plant capacity throughout the world are shown in table 1, while table 2 shows the expected cumulative growth of nuclear and total capacity to 1980.

18. One of the most important developments leading to nuclear power's economic break-through has been the increase in size of reactors. The relative advantage

which an increase in unit size gives to nuclear as compared with conventional plants is illustrated in figure 1 for proven reactor types. The reactor capital costs (which exclude the cost of the fuel inventory) refer to the conditions and assumptions of the countries of origin and do not, therefore, afford a basis for comparison between reactor types.

Factors in the adoption of nuclear power

19. The question of whether to initiate a nuclear power programme in any particular country demands a careful study and analysis of the many factors involved for the actual condition of the country. This section attempts only to indicate some of the considerations which should be taken into account.

20. The initial decision on whether a nuclear plant may be economically justified will depend on considerations such as the availability and cost of hydroelectric power and the availability and cost of fossil fuels. Also, because of the strong dependence of nuclear plant capital cost on size, it will depend on the maximum unit size which can be accommodated in the system - generally in the range of 10-20 per cent of the total network capacity. For developing countries and for small developed countries, the maximum unit size is unlikely to exceed 400 MW(e); where it is less than 100 MW(e), the unit capital cost is likely to make a nuclear plant uneconomic except in very special circumstances.

21. Estimation of the capital cost will require a comparison of the cost and productivity of labour for the actual location with that for the countries which have developed nuclear power plants. Most important, perhaps, are the economic ground rules, viz. interest rate, load factor and amortization period.

22. Fixed-charge rates vary from about 6 per cent to about 15 per cent depending on the country and on whether a utility is State-owned or private. The lower the fixed-charge rate the more favourable will be the case for a nuclear plant because of its relatively high capital cost.

23. The appropriate load factor depends not only on the availability which the plant could achieve but also on the system to which it will belong. Many existing reactors have been shown to be capable of an annual availability of over 75 per cent and current designs of proven reactor types are expected to achieve at least 80-85 per cent availability. The higher the load factor the better is the case for

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a nuclear plant, because of the latter's relatively high capital cost. In competition with fossil-fuelled plants, the low fuel cost of a nuclear plant justifies its use as a base-load station throughout most if not all of its life, but where a system is at present dominated by hydro-power the problem of assigning a realistic load factor is more difficult.

24. While no power reactor has been in operation for more than about eleven years, careful measurements and analysis, and, in some cases, accelerated tests, have been made of the factors which could limit plant life. Based on this work current designs of proven reactor types are expected to have a life of thirty years or more. For economic comparisons, an amortization period shorter than the expected plant life may, of course, be chosen.

25. Several important considerations arise in respect of the fuel cycle for the various reactor types, particularly the likely cost trends in basic components and their effect on the total cost. Before discussing these components, two general points may be mentioned. Firstly, the very small quantity of fuel required by a nuclear plant as compared with a conventional plant tends to minimize the required provision of transport to the plant site and thus to reduce the effect of the uneven distribution of fuel resources in the world. Secondly, considerable progress has been made in dealing with the special problems associated with the transport of reactor fuel elements and, particularly, irradiated fuel.

26. The percentage contribution of the components of the fuel cycle cost is shown in table 3 for an enriched reactor. The ranges allow for a variation in uranium ore price of $6-10/lb U_3O_8 and in fuel enrichment of 1.5-3.0 per cent; no credit has been given for plutonium in the irradiated fuel.

27. The cost of uranium in the near future (ten to twenty years) is the subject of considerable discussion in which conflicting views appear. It depends, of course, primarily on the requirements for uranium and the resources of low-cost ore. The present reasonably assured low-cost ($5-10/lb U_3O_8) reserves of over 600,000 tons U_3O_8 were established as the result of intensive prospecting in the 1950's. It is expected that further prospecting now beginning will reveal further reserves, at least as great, in this price range. The consensus is that the price of U_3O_8 will stabilize at about $8/lb in the 1970's. The effect on the generating cost (mills/kWh) of an increase in ore price of $1/lb U_3O_8 is shown in table 4 for the proven reactor types.

28. The current cost of converting U_3O_8 to UF_6, for feeding to the enrichment plant, is about $2.5 per kg U_3O_8. With an increasing scale of operations as nuclear capacity grows, this cost is expected to fall gradually to perhaps $1 per kilogramme in 1980.

29. Gaseous diffusion plants for uranium enrichment are in operation in France, the Soviet Union, the United Kingdom and the United States although the only firm prices available are those published by the United States Atomic Energy Commission. These are based on a separative work price of $30 per kg U. It is not expected that this price will increase, and it may even fall in the next decade or two to $20 per kg U. The effect on the generating cost of a $1/kg decrease in the price of separative work would be a reduction in the range of 0.01 to 0.02 mills/kWh for the current enriched reactors.

30. The present costs of fuel-element fabrication vary widely depending on the complexity of the element and on the scale of manufacture. Thus, for magnox reactors the fabrication cost is about $30/kg U; for heavy-water reactors and AGR about $55/kg U; and for light-water reactors about $95/kg U. Process improvements and increasing throughput are expected to give large reductions of 25-40 per cent by 1980, for the reactors using clustered fuel elements; for magnox reactors with their simpler fuel elements, the reduction will be less. A 20 per cent reduction in fabrication costs would decrease the generating cost by about 0.1-0.15 mills/kWh.

31. A rather similar situation exists with respect to reprocessing. For the Windscale plant in the United Kingdom, with a throughput of about 5 tons U per day, the cost is about $17/kg U for magnox fuel and about $30/kg U for AGR fuel. In the latter case, a reduction of 10 per cent in reprocessing cost would reduce the generating cost by about 0.02 mills/kWh.

32. Heavy-water production plants are in operation in Canada, Norway and the United States and present prices are around $45/kg. The heavy-water inventory for heavy-water reactors accounts for about 10 to 15 per cent of the total capital cost. The cost of heavy water is expected to fall to about $30/kg in the coming years. This would reduce the generating cost by about 0.1 mills/kWh.

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Nuclear desalination

World-wide activities

33. The main building of the USSR Caspian Sea fast breeder dual-purpose plant at Shevchenko is nearly completed and the major equipment is being manufactured. The 1000 MW(th) fast breeder will provide 150 MW of electricity and 120,000 m^3/day of desalted water. Start-up is expected in 1969.

34. Other main developments in the past year include the following:

(a) The Spanish Government, together with private interests, has formed an organization to study the feasibility of a dual-purpose nuclear facility of 1200 MW(e) combined with 500 000 m^3/d of desalted water, for location in the vicinity of Almeria on the southern Mediterranean coast.

(b) Plans were announced by the USSR to build a dual-purpose facility in the Don Basin industrial area that will consist of twin 350 MW(e) nuclear power plants combined with 380 000 m^3/d of desalted water from the Sea of Azov.

(c) Plans were announced to build a large dual-purpose desalting plant and electric power station in southern California (US). This project will comprise a desalting plant having an output of 190 000 m^3/d and a power station producing 1600 MW(e) net. Ultimately it is expected that the capacity of the desalting plant will be increased to a total of 570 000 m^3/day.

35. The Agency believes that the chief need today is to gain direct practical experience in building and operating nuclear desalting plants. It is only in this way that it will be possible to obtain reliable data about the capital costs of such plants, the actual costs of desalted water and the problems of operating large-scale desalting equipment in conjunction with a nuclear reactor. The operation of such plants will offer indispensable information for assessing the potential of nuclear desalination.

36. Other developments have included the following:

(a) The engineering feasibility study of a dual-purpose plant for Israel producing 200 MW(e) and 380 000 m^3/day of desalted water has been completed. Means of financing the project are under consideration.

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(b) The United Arab Republic is studying the problems of financing a nuclear desalting project of 150 MW(e) and 20 000 m^3/day of desalted water at Borg el-Arab. Tenders have been submitted by a number of potential suppliers.

(c) A Greek-US study team carried out a preliminary feasibility study on various possibilities for supplying water and power to the Athens area, including a dual-purpose nuclear power and sea-water desalination plant.

(d) Other countries in Asia, Latin America and the Mediterranean Region have study projects for possible nuclear dual-purpose plants underway.

Dual-purpose plants

37. All the processes for desalting water use energy, whether thermal, electrical or mechanical. Thermal energy is utilized in the multi-stage, flash-distillation process, which is one of the most practicable for large-scale dual-purpose application in the near future. Only this process is discussed here. The maximum evaporator brine temperature for this process is at present limited by economic means of scale control to about 120°C (about 250°F). On the other hand, the generating costs of electric power plants are lowest when the steam is produced at higher temperatures. Because of these two facts, there are economic advantages in combining the production of water with the production of power.

38. Such a dual-purpose plant, rather than a power-only plant, gives two advantages to nuclear as compared with fossil-fuelled plants,

(a) The unit cost of reactors falls more rapidly with increasing size than does that of fossil-fuelled plants;

(b) For economic production of desalted water, such installations should operate at very high load factor which favours a power plant with low fuel costs.

39. The normal method of coupling the power and desalting plants is by means of a back-pressure turbine in which the steam is expanded from the initial pressure and temperature of the reactor to the conditions acceptable to the brine heater of the desalination plant.

40. With standard back-pressure turbines there is a range in this ratio of water to power over which the incremental water cost is nearly constant, the upper value of this range depending on the steam conditions. For example, for high-temperature reactors producing superheated steam, this value is around 0.3 mgd (US/MW(e) (about 50 litres/kWh). For reactors producing saturated steam it is about 0.8 mgd (US)/MW(e) (about 125 litres/kWh).

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41. The actual ratio of water to power-use varies enormously, reaching several thousands of litres/kWh for some developing countries. If, however, water for agriculture is excluded, on the grounds that the cost of desalted water will remain too high for this use for some time, the range is much less. Although in many developing countries the resulting ratio still exceeds 125 litres/kWh, in more developed countries it is generally less; the average for Europe, for example, is about 85 litres/kWh.

42. It should be borne in mind also that power-use is increasing more rapidly than water-use, e.g. by over 3 per cent per annum in France. If this trend continues, as is likely for a considerable time, ratios of water-to-power use will fall by a factor of two in about twenty years and by a factor of five in about fifty years. Thus, while the water-to-power ratio of dual-purpose plants may be restrictive at present in some applications, it is unlikely to prove a severe limitation in general.

Cost of water

43. Ten years ago, the cost of desalted water was at least 100 US cents per m^3. For some of the larger plants (4000 - 6000 m^3/d), built within the last few years, the cost is about 25 cents per m^3. The cost of desalted water from very large desalination plants with capacities of the order of 400 000 m^3/d, operated in conjunction with power generation, has been estimated to be as low as 6 cents per m^3. Some past, present and near-future costs of desalting sea water are given in Table 5.

44. The current research and development programmes for nuclear power reactors will continue to produce improved reactors with progressively lower steam costs. However, improvements in heat sources alone will not be sufficient to yield water costs below about 3 US cents per m^3. If the cost of desalted water is to be brought below this figure, considerable efforts must also be made to improve desalting technology.

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AGENCY ACTIVITIES

Nuclear power

45. The Agency has completed the UNDP pre-investment study on power, including nuclear power, in Luzon, the Philippines, having sub-contracted to the United Nations the investigations relating to conventional resources. The final report was submitted in September 1966. The study concludes that the country lacks the necessary indigenous resources to meet the projected requirements of the Luzon Grid and will have to rely upon imported fuels, nuclear or conventional. A 300 MW nuclear reactor at a fixed annual charge of about 16 per cent would be competitive with an oil-fired station even if the cost of oil, exclusive of import duties and taxes, dropped to $13.4 per ton from the present price of $15.2 per ton. The study recommends a nuclear programme of 1000 MW, comprising three units of 300, 300 and 400 MW, to be brought into operation at intervals of a year, beginning in late 1971. The initial plant investment for the nuclear programme would be $182 million as opposed to $147 million for the conventional alternative of four oil-fired plants of 250 MW each. However, the lower fuelling expenses for nuclear stations would help recover the higher initial investment by 1979, after which the relative annual saving would be about $14 million. The study urges the Government to train more technical manpower and enact appropriate atomic legislation to pave the way for using nuclear power.

46. These recommendations are being considered by the Philippine Government which has agreed to release the study for the information of other countries which may be considering making nuclear power feasibility studies.

47. In September 1966, at an international survey course on economic and technical aspects of nuclear power (attended by 55 senior engineers and scientists from 30 countries) the latest developments in the technology, cost and economics of nuclear power were reviewed and the best means of evaluating the possible role of nuclear power in a given country were discussed including its use in desalination.

48. A study group meeting on problems and prospects of nuclear power applications in developing countries was held in Manila in October 1966. It was attended by 45 participants from nine countries in the ECAFE region. The improving prospects for nuclear power in the region were noted but it was thought that the problems of finance and of the training of technical manpower may slow down its early introduction.

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Nuclear desalination

49. Since it may be economically advantageous to combine the production of electric power and water in the same dual-purpose plant, the Agency has been giving special attention to this matter and convened a panel on the subject in November 1966. The panel studied especially the reactors that are suitable for single- or dual-purpose desalting applications, and the means of varying the ratio of production of water to production of power so as to satisfy different local conditions and needs.

50. The Panel identified six methods of increasing the water-to-power ratio:

(a) Steam may be by-passed around a back-pressure turbine. With present reactors and nuclear fuel costs this is extremely expensive (the incremental cost of heat is doubled at least) but evidence was presented that when fuel cost is very low, this can be the preferred technique.

(b) The reactor may be redesigned to produce heat at a lower temperature, and hopefully at a lower cost per unit of heat output. No evidence was presented suggesting that the types of reactors in commercial use could usefully be so adapted.

(c) The acceptable maximum brine temperature in the evaporator can be increased. This is a problem of evaporator design and was not discussed, but it is the subject of extensive research programmes in several Member States.

(d) The mechanical energy available from the high-temperature steam could be used in an additional desalination process that requires mechanical energy.

(e) In a suitable terrain it may be possible to provide some peaking power by pumped storage.

(f) Finally, it may be possible to develop a market for low-priced power supplied on an interruptable basis for special industrial applications.

51. Advice and assistance to Member States is provided by the Agency by missions such as those last year to Chile and Peru in which experts from the United Nations Secretariat took part. As a continuation of the study in Chile, an engineering feasibility study is underway by the Chilean Government with assistance by the United Kingdom, which will consider the major aspects of providing water and power to the region.

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52. In order to provide the authoritative advice needed by Member States, the secretariat of IAEA must keep in close touch with developments. It has been able to do so by taking some part in the Greek-US, the Isreeli-US and the United Arab Republic-US studies referred to in paragraph 36, and the joint IAEA/Mexico/United States study described in paragraph 53.

53. A project of particular interest to IAEA is the joint Agency/Mexico/United States study of the technical and economic practicability of constructing a dual-purpose plant to supply water and electricity to the border states in both countries near the head of the Gulf of California. The study is detailed and far-reaching and includes surveys of hydrological and soil conditions, seismological and geological surveys of possible plant sites, arrangements and distributing the water produced, and of using the power produced. The study will provide the IAEA secretariat with valuable experience for making similar detailed studies in other parts of the world.

CONCLUSION

54. Present commercial power reactors are also likely to be attractive for combined water and power production in the near term. For the future, however, the development of special reactors for desalination applications may have economic merits.

ANNEX

Contents

Table 1

Estimated Additions to Electric Power Plant Capacity during the Period 1966-1980

Region	1966 - 70 Total Additional Electric Power MWe	1966 - 70 Nuclear Power Component MWe	%	1971 - 75 Total MWe	1971 - 75 Nuclear MWe	%	1976 - 80 Total MWe	1976 - 80 Nuclear MWe	%
Africa	4 000	-	-	5 500	200	3.6	7 000	700	10
Asia and Oceania	56 000	1 730	~3	90 000	6 700	7.5	150 000	11 400	7.6
Latin America	15 000	-	-	20 000	800	4	25 000	4 200	17
North America (USA and Canada)	90 000	12 520	14	112 000	29 000	26	150 000	59 400	40
USSR and Eastern European Countries	99 000	960	~1	178 000	5 400	3	250 000	19 600	~8
Western European Countries	82 000	8 220	10	112 000	27 500	~25	150 000	45 800	~30
World, Total	~345 000	23 430	6.8	~520 000	~70 000	~13	~730 000	~140 000	~18

Table 2

Estimated Cumulative Electric Power Plant Capacity in The World 1965 - 1980

Region	1965 (End of Year) Total Installed Capacity	Nuclear Power Component		End-1970 Total	Nuclear		By 1975 Total	Nuclear		By 1980 Total	Nuclear	
	GWe	GWe	%	GWe	GWe	%	GWe	GWe	%	GWe	GWe	%
Africa	13.5	-	-	17.5	-	-	23	0.2	0.9	30	0.9	3
Asia[a] and Oceania	74	0.17	0.2	130	1.9	1.5	220	8.6	3.9	370	20	~ 5
Latin America	30	-	-	45	-	-	65	0.8		90	5	~ 6
North America (USA and Canada)	283	1.08	0.4	373	13.6	3.7	485	42.6	8.8	635	102	16
USSR and Eastern European Countries	148	1.04	0.7	247	2.0	0.8	425	7.4	1.7	675	27	4
Western European countries	216	4.48	2.1	298	12.7	4.3	410	40.2	10	560	86	15
World, Total	765	6.77	0.9	1110	30.2	2.7	~1630	~100	~6	~2360	~240	~ 10

a/ Excluding USSR.

Table 3

Breakdown of Fuel Cycle Costs for Current Enriched Uranium Reactors[a]

Items	Percentage of Total Fuel Cycle Cost
Uranium concentrate supply	25 - 35
Conversion to UF_6	~ 5
Enrichment	25 - 35
Fuel element fabrication	15 - 25
Reprocessing	5 - 15

Notes

The ranges shown allow for uranium concentrate prices of $ 6 - 10 per lb and for enrichments of 1.5 - 3.0%. No credit is made for plutonium in the irradiated fuel.

a/ C. Allday, Nuclear Engineering, Vol. 12, No. 130 (March 1967).

Table 4

Increase in Generating Cost (mills/kWh) for an Increase in Uranium Ore Price of $ 1 per lb U_3O_8[a]

Reactor Type	Increase in Generating Cost (mills/kWh)
Magnox	0.12
AGR	0.07
BWR	0.09
PWR	0.09
HWR	0.0[illegible]

a/ C.A. Rennie, Journal of the British Nuclear Energy Society, 5, No. 3, (July 1966).

Table 5

Cost of Desalinated Sea Water from Distillation Plants[a]

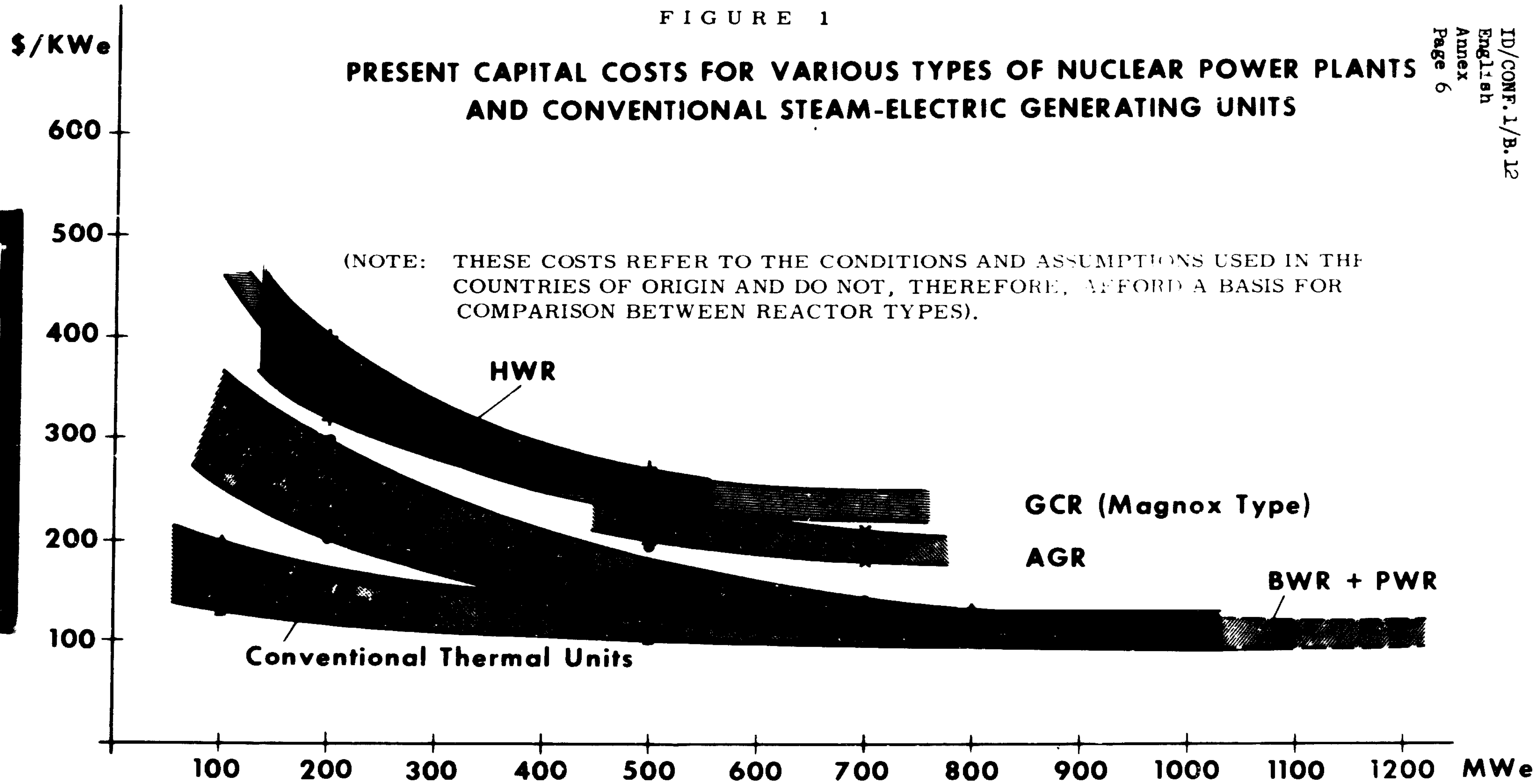
Plant Type	Plant Capacity, m^3/d	Period	Desalinated Water Cost US Cents/m^3
Shipboard and Small Commercial	200	1945–50	100 - 130
Commercial	2 000– 4 000	1950–60	50 - 80
Advanced Commercial	4 000	1960–66	25 - 55
Advanced Technology	4 000	1967–70	21 - 24
Single and Dual-Purpose Intermediate Size	20 000–60 000	1968–70	16 - 21
Single and Dual-Purpose Large Capacity	200 000–600 000	1972–75	7 - 13

a/ Hearings before the Subcommittee on Irrigation and Reclamation of the Committee on Interior and Insular Affairs, House of Representatives, Eighty-Ninth Congress, Second Session USA, Serial No. 89 - 31, dated 28 February 1966.

FIGURE 1

PRESENT CAPITAL COSTS FOR VARIOUS TYPES OF NUCLEAR POWER PLANTS AND CONVENTIONAL STEAM-ELECTRIC GENERATING UNITS

(NOTE: THESE COSTS REFER TO THE CONDITIONS AND ASSUMPTIONS USED IN THE COUNTRIES OF ORIGIN AND DO NOT, THEREFORE, AFFORD A BASIS FOR COMPARISON BETWEEN REACTOR TYPES).



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