PAPER 1

NUCLEAR ENERGY IN AUSTRALIA

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SUMMARY

Reactor types and major overseas programmes for nuclear power are reviewed, and an outline is given of future developments. At present in the world the capacity of nuclear power stations in operation, under construction, or committed, totals some 129,500 MW(e). By 1980 the installed nuclear generating capacity outside the Soviet area should be 250,000 - 300,000 MW(e), and in 1990 the U.S.A. alone is expected to have 500,000 MW(e) of nuclear plant in operation. Nuclear power has been established as a technically and economically viable industry, which will not add to atmospheric pollution.

The proposed nuclear power station at Jervis Bay heralds the beginning of Australia's nuclear power industry, which is destined to play a major role in the development of this country. By 1985 nuclear power stations should be competitive with conventional stations in all States of the Commonwealth, except possibly Tasmania, and the installed nuclear generating capacity is expected to be 4,000 MW(e). By the turn of the century Australia could have 36,000 MW(e) of nuclear power in operation, representing about one-third of the country's total installed generating capacity.

The introduction of nuclear power into Australia will give rise to new ancillary industries, such as fuel fabrication and reprocessing. Nuclear energy has made an important contribution in the field of radioisotopes and radiation applications. In the future it is expected to lead to new developments in Australia in saline water conversion, civil and mining engineering uses of nuclear explosives, and possibly in "nuclear energy centres" for agro-industrial complexes. These applications are surveyed briefly.

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1. INTRODUCTION

The generation of electricity from nuclear energy is now a well-established, technically and economically viable industry. Great progress has been made since the demonstration of the uranium fission reaction in 1942 at Chicago, and since the first commercial nuclear power station was commissioned in 1956 in Great Britain. At present throughout the world there are 67 nuclear power stations in operation, with a total of 91 nuclear reactors and an aggregate output of 15,656 megawatts of electricity (MW(e)). If stations under construction or definitely committed are included, these figures rise to 197 nuclear power stations with 261 reactors and a total output of 129,411 MW(e).

The widespread adoption of nuclear power has been achieved by engineering and technical improvements in design and operation, by the adoption of larger units, and by standardization and consequent replication of major plant items. The specific capital cost ($/kW output) of nuclear stations was falling significantly until recently when inflationary pressures in the U.S.A. altered this trend. (Similarly, increases have occurred in the specific capital cost of conventional power plant). Nevertheless, nuclear power has become competitive in many places with conventional power. As a consequence, orders are being placed for nuclear stations even in relatively low-fuel-cost areas of the world. By 1980, the installed nuclear generating capacity outside the Soviet area is expected to be 250,000 - 300,000 MW(e). Recently, Dr. Seaborg, Chairman of the United States Atomic Energy Commission, has estimated nuclear power capacity in that country alone, in 1990, at 500,000 MW(e). (By comparison, the total generating capacity in Australia is now about 15,000 MW(e)).

1.1. Impact of Nuclear Power

Nuclear power is undoubtedly the most important peaceful use of atomic energy, and it is destined to have a profound effect on the industrial and economic growth of all nations.

The advantages of nuclear power may be summarized as follows:

(i) The specific capital cost of nuclear plants decreases more rapidly than that of conventional power plant with increasing unit size. This characteristic is important since the world trend is toward larger central station power plants.

(ii) Nuclear power plants have a significant potential for improved operating economics. Nuclear fuel costs are expected to fall further as technology is improved, as a larger fuelling industry is realized, and as breeder reactors are developed.

(iii) The economics of nuclear power are in considerable degree independent of geographical location. This will be important for regions remote from fuel supplies. When engineered safeguards are further developed for nuclear plant, it will be possible to build future stations adjacent to large cities and industrial areas where the load occurs.

(iv) Nuclear power does not add to atmospheric pollution. Today this is a most important factor in many decisions to install nuclear stations.

(v) The advent of nuclear power has brought competition in other energy sources - coal, gas, oil, and hydro - and this benefits the consumer by keeping power costs down.
The advantages of nuclear power indicate that it has had, and will continue to have, a far-reaching effect on industrial and economic development in many nations. In those countries where nuclear power is already making a significant contribution to power demand the effect on local industry has been dramatic. Many new ancillary industries, such as fuel manufacture and fuel reprocessing, new metals technology, new developments in electronics, have been created or expanded. The strict engineering design, observance of fine tolerances, assurance of proper functioning of vital components, and "clean" conditions during building of nuclear reactors has led to "quality control" and "quality assurance" never before encountered in a large and complex engineering industry.

The above progress has not been achieved by chance. It has come about by careful research, development, and demonstration efforts. It has been a co-operative effort involving the industries and Governments of many nations. The projected nuclear power station at Jervis Bay will herald the beginning of the nuclear power industry in Australia, and this country will be joining other nations which are exploiting this beneficial source of energy. Before dealing with the prospects and impact of nuclear power in Australia, it is desirable to survey briefly the principal overseas developments.

2. REACTOR TYPES AND MAJOR OVERSEAS PROGRAMMES

2.1. Reactor Types

Commercial power reactors operating at present fall mainly into two classes of systems, which are usually referred to as "first generation reactors". One is the natural uranium metal fuelled, graphite moderated, carbon dioxide cooled system. Although these reactors have proved very reliable in operation and their technology is established firmly, their generation costs are high, and it is unlikely that further reactors of this type will be built. The second group of "first generation reactors" is those using uranium dioxide fuel which has been enriched in its U235 content and which are moderated and cooled with high purity, ordinary light water. The fuel is sintered uranium oxide pellets canned in zirconium alloy. Two methods of operation have been developed for this type of reactor. In one, the pressure is maintained high enough to prevent boiling in the reactor core, and external heat exchangers are required to generate the saturated steam supply for the turbo-alternator. This system is known as a "pressurized water reactor" (PWR). In the other, boiling is allowed to occur in the reactor core, and after separation of the steam-water mixture, the saturated steam passes direct to the turbo-alternator. Such a system is called a "boiling water reactor" (BWR). Both types have operated satisfactorily and there is little to choose between them on either technical or economic grounds.

"First generation reactors" of the above types are all "thermal" reactors of the converter type, capable only of utilizing about 2% of the total theoretical energy that could be obtained from the uranium if it were completely consumed.

The "second generation reactors" which have been developed, and those which are being studied, have as their principal aim an improvement in generation costs. They are referred to as "advanced converter reactors", and whilst some offer the possibility of better utilization of the world's uranium resources they still fall short of the utilization aimed for in breeder reactors. A direct development of the early "Magnox" reactors in Great Britain has led to the "advanced gas-cooled reactor". In this system higher carbon dioxide coolant temperatures, which make possible the generation of high pressure,
superheated steam leading to improved thermal efficiency, have been achieved by replacing the magnesium alloy fuel cans with stainless steel, and sintered uranium dioxide fuel is used instead of uranium metal. The fuel has to be enriched in U235 content to counteract the neutron absorption in the fuel and its cans. Graphite is retained as the moderator. The other group of "second generation reactors" are those moderated with heavy water. A variety of coolants is possible, including heavy water, light water, carbon dioxide, or organic liquid hydrocarbons. Natural uranium dioxide fuel canned in zirconium alloy may be used in this class of reactor, although in the system cooled with light water it is necessary to employ enriched fuel. Recirculation of recovered plutonium in heavy water moderated reactors is another possibility which is being investigated. Heavy water moderated systems offer the prospect of low fuel cycle costs and further significant development in their technology.

The "third generation reactors" may be regarded as the systems of the future, even though small prototypes are already in operation and several larger power stations are under construction which will employ reactors in this category. The first type is the "high-temperature gas-cooled reactor" (H.T.G.C.R.), and it represents the most advanced technology in gas-cooled systems. By adopting an all-ceramic fuel element, and eliminating the metal fuel cans, coolant temperatures in the range 800-1000°C can be achieved. This permits the generation of steam with conditions equal to those obtaining in the most modern fossil-fuelled power stations, and offers the possibility of using gas turbines for power generation.

Another type in this category is the "molten salt reactor" (M.S.R.), in which the fuel consisting of enriched uranium fluoride is dissolved in a molten mixture of lithium, beryllium, and zirconium fluorides. The fluid passes through a graphite core as moderator, and steam is raised in external heat exchangers. A small prototype M.S.R. is operating. The system offers advantages of continuous chemical reprocessing of the fuel, the elimination of costly fuel element fabrication, high thermal efficiency, and the possibility of thermal breeding by using the U233 – thorium fuel cycle. However, the M.S.R. would require extensive development before it could be adopted for commercial power generation, and its place in the successive line of reactors will be influenced by developments in fast breeder reactors.

All countries having major nuclear power programmes are engaged in research and development of fast breeder reactors (F.B.R.). Several small reactors of this type have operated successfully for some years, and large prototype stations are under construction to demonstrate the technology of this class of "third generation reactor" for commercial power generation. Most of the effort is concerned with the plutonium - U238 fuel cycle and the use of sodium as the coolant. Studies are also being undertaken on the use of steam or gas as alternative coolants.

In all power reactors, neutrons are produced in the fission process. Some of these are required to continue the chain reaction, and some convert fertile material (U238 or thorium 232) into fissionable material, plutonium 239, or uranium 233. Thus the fissionable fuel is to some extent self-replacing. In the converter reactors this replacement is less than 100%. For example, in the light-water reactors fission of 100 atoms produces about 50 new fissionable atoms from fertile material. In the heavy-water reactors it can approach 90. In either case the fissionable content of the reactor core slowly declines and spent fuel must be withdrawn and replaced.

In the breeder reactors more than 100 atoms are produced from fertile material, for each 100 atoms fissioned. Hence the fissionable inventory increases.
Fissionable inventories may double in from 10 to 15 years. This enables not only all fertile material to be used but surplus fissionable material becomes available as the inventory for new power stations. The most promising fast reactor system, still under development, uses plutonium as the fissionable fuel and uranium 238 as the fertile material.

No moderator is used in a fast reactor. The F.B.R. is aimed at efficient use of the stocks of plutonium which are being accumulated from the world's thermal power reactors, and the conversion of U238 contained in natural uranium (or in "depleted" uranium from enrichment plants) into fissile plutonium. Large, commercial F.B.R's are expected to be in operation in the middle 1980's, and they will be capable of utilizing about 70% of the uranium atoms produced from the world's mines. This greatly improved fuel utilization, compared with today's thermal reactors, makes the successful development of fast breeder systems a vital aspect of atomic energy programmes.

2.2. Overseas Programmes

Table 1 summarizes the position of nuclear power throughout the world.

In the United Kingdom, the first nuclear power programme called for eight stations to be built using natural uranium, CO₂-cooled, graphite-moderated reactors (Magnox systems). The aggregate output will be 4,800 MW(e) when the last station is commissioned this year. At present about 15% of the electricity generated in the U.K. is derived from nuclear stations. A second nuclear power programme was announced in 1964 to bring the total capacity to 13,000 MW(e) by 1975. Six stations are now under construction or committed for this programme; all will have A.G.R.'s, and the total capacity will be 8,850 MW(e). A prototype steam generating, heavy water reactor (S.G.H.W.R.) of 100 MW(e) capacity came on power early in 1968, and an experimental fast reactor has been in operation since 1959. A prototype 250 MW(e) F.B.R. is planned for operation in 1972.

The military programme in the U.S.A. has had a profound influence on nuclear power development in that country, and has been responsible for the development and installation of enriched fuel, light water reactors. Table 1 shows the importance of P.W.R. and B.W.R. systems in the U.S.A., and also reflects the success of reactor manufacturers in that country in exporting light-water reactors. A 40-MW(e) prototype H.T.G.C.R. has operated successfully for some years, and the first commercial power station (330 MW(e)) using this type of reactor is under construction. Two small fast reactors are in operation, but as yet no decision has been announced for construction of large, commercial F.B.R.'s in the U.S.A. By 1980, the installed nuclear power capacity in the U.S.A. is expected to be more than 150,000 MW(e), comprising mainly P.W.R. or B.W.R. systems. This will represent an investment of about $U.S. 19 billion. At that time some 35% of the electrical energy generated in the U.S.A. will come from nuclear power plants. By the turn of the century it is expected that nearly all new power plants in that country will use nuclear energy.

France based its early nuclear power programme on natural uranium, CO₂-cooled, graphite-moderated reactors, and has 1,310 MW(e) of such plant operating in five stations. Improvement in the technology of this system was not as significant as expected, and it appears that future developments will be based partly on light-water reactors. A 250-MW(e) F.B.R. is under construction, and France is interested in the technology of heavy-water systems, and may also develop this system.
Table 1 shows the impact that nuclear power has had in other European countries. Because of shortages of indigenous fuel, Western Europe will be depending more heavily on nuclear power in the future.

Canada has pioneered development of the natural uranium fuelled, heavy water moderated and cooled system ("CANDU"). This reactor utilizes a calandria vessel to obtain the cool moderator, and the heavy-water coolant under pressure is circulated through pressure tubes containing the fuel elements. In concept, therefore, it is quite different in design from the light-water reactors which use a large steel pressure vessel. Canada has a 203-MW(e) power reactor in operation, and has 5,020 MW(e) of plant under construction in two stations with CANDU reactors. In addition, a 250-MW(e) station using heavy-water moderator but boiling light water as coolant is under construction.

Other countries having heavy-water reactors in operation or under construction are Argentina, France, Western Germany, India, Pakistan, and Britain. Japan, Italy, and New Zealand are studying reactors of this type for future power generation.

3. NUCLEAR POWER PROSPECTS IN AUSTRALIA

Traditionally, power generation in Australia has depended principally on coal for its energy supplies. Within the last decade or so most of the large central power stations have been built on the coalfields, and today coal-burning stations provide over 80% of all electrical energy generated. The remainder, apart from several per cent derived from oil-fired or diesel plant, is generated by hydro plant, mainly in Tasmania and the Snowy Mountains. Coal will remain the principal energy source for electricity generation for many years, but the pattern will change gradually with increased use of fuel oil, natural gas, and nuclear power.

The demand for electrical energy in Australia has increased at the rate of about 10% per annum (compounded) over the last decade. This is higher than the figure for other industrialized countries (e.g. Britain and the U.S.A.) and arises from the impetus given to population growth by immigration, a rapid increase in industrial development, and a rise in general living standards. The growth of the Australian electricity industry since 1932 is shown in Fig. 1, which also gives predictions of installed capacity and energy generated to the end of the century. In 1966 the electricity consumption in Australia was 2,571 kWh/capita/annum, whilst the corresponding figures for other countries were: Canada 7,527; U.S.A. 6,377; Britain 3,204; and Western Germany 2,731 kWh/capita/annum. Electricity consumption is some measure of the development and living standards of a country (though the consumption of other fuels is important also), and as these factors are expected to increase further in all countries - at different rates - each country's growth of its electricity industry will continue as far into the future as one cares to predict.

In Australia, Fig. 1 shows that the average rate of increase of installed generating capacity over the last 40 years or so has been 9.3% per annum. If this trend continued unabated to 2000 A.D., the expected installed capacity would be some 160,000 MW(e). However, taking account of the state of industrialization here at present, and to be in line with thinking in the major overseas countries on their future rate of growth of power demand, it would seem prudent and more realistic to base predictions on slightly lower rates of increase - namely 8% from 1969 to 1985, about 7% for the next 10 years, and reducing to 6% until the year 2000. On this basis, the total installed capacity in Australia in 2000 A.D. would be 110,000 MW(e). To meet this expansion will require a major capital investment, particularly when it is realized that the total fixed
capital (original cost) of the Australian electricity supply industry at the end of 1969 was $4,975 million. The electricity industry is one of the largest in Australia in terms of capital, and the most important in terms of the benefits of its future growth.

3.1. Interconnected Power Systems

The predictions of the Australian Atomic Energy Commission (A.A.E.C.) on the rate of growth of power (derived as discussed above and shown in Fig. 1), and the possible role of nuclear power up to 2000 A.D., are given in Table 2.

The estimates in Table 2 assume that in the last decade of this century about 50% of the new plant additions will be nuclear, and by the turn of the century about one-third of the total installed capacity of power generation plant will be nuclear. Predictions over such a long period are subject to a fair margin of error, and the total nuclear capacity in the year 2000 might range from 25% to 40% of the total installed capacity. However, the steadily increasing importance of nuclear power in Australia is evident from the above predictions. For instance, by the late 1980's, Australia should have in operation or under construction the equivalent of some twenty 500-MW(e) power reactors, representing an investment of more than $2 billion if ancillary industries are included.

Before considering, in a general fashion, the pattern of nuclear power development in the various State generating systems, it is necessary to refer to the present position and the predicted future maximum demand on each system. These data are given in Table 3.

The factors which will have a bearing on the relative cost of nuclear and conventional power are the unit sizes that can be installed in a particular system, the availability of fossil fuels and their location in relation to centres of demand, trends in capital costs of fossil-fuelled and nuclear-fuelled plant, and changes in the fuel costs of both types of plant. There is no doubt that nuclear power is in a more favourable competitive position when unit sizes of 500 MW(e) or larger can be considered. The size of a power system and the rate of annual increase largely determine the optimum unit size of plant being installed. For larger systems such as New South Wales, with an annual increase of about 9%, the optimum size of unit is about 10% of the system maximum demand. For smaller systems having growth rate of some 14% (e.g. Western Australia) the optimum unit size would be 15-20% of the peak load.

Careful studies of the capital and generation costs of nuclear power plant indicate that in the late 1970's nuclear plant will be competitive with black-coal plant in New South Wales in unit sizes larger than 600 MW(e). A few years later, nuclear plant of 500 MW(e) should compete in Victoria with brown-coal-fired plant, and by about 1985 nuclear power, in the applicable unit sizes, should be competitive in the remaining States with the possible exception of Tasmania. In this State, although future hydro schemes will be more expensive to construct than those now in operation, at present there are estimated to be 1000 MW(e) (continuous) capacity of unexploited economic hydro resources (about 1500 MW(e) installed capacity). Considering the size of the power demand in that State, nuclear power is unlikely to be introduced until the late 1980's.

3.2. Isolated Power Developments

At present the major mining and/or mineral processing centres in remote parts of Australia - such as Mt. Isa, Kalgoorlie, and Dampier (W.A.) - which are not connected to State electricity supply systems, have power demands too small to justify consideration of nuclear power.
Within the last decade there have been world-ranking discoveries of minerals in the northern part of the continent and there is now growing pressure not merely to export raw minerals but to process them to refined products. These mineral fields generally are far removed from fossil fuel resources. If large-scale processing, requiring substantial amounts of electrical energy, is to be undertaken in the future close to the mineral fields, cheap nuclear power could be the solution. Typical examples would be aluminium smelting associated with the bauxite deposits at Gove, N.T., and Admiralty Gulf in the Kimberleys, and a central power station to supply the requirements of the various developments in the Hamersley iron province, Western Australia. By the turn of the century, such prospects could mean significant industrial progress and the opening-up of sparsely populated regions of the continent.

5. **ANCILLARY INDUSTRIES OF NUCLEAR POWER**

The introduction of nuclear power in Australia means far more than merely building and operating power stations. The country will need to become self-sufficient in the various supporting industries, and this development will have a great influence on Australia's industrial potential, both for the home market and for its export trade to south-east Asia, New Zealand, and elsewhere. The scope and significance of these developments are worthy of brief mention.

5.1. **Nuclear Fuel Reserves**

Australia is fortunate in having uranium (and thorium) resources, and they will be required as raw materials for the future fuel fabrication industry essential for nuclear power development. At present reserves of uranium which could be recovered at less than $10/\text{lb.} of U_3\text{O}_8$ are of the order of 23,000 short tons U_3O_8, sufficient to supply fuel for only about 6,000 MW(e) of power plant over its expected life. Australia should have this amount of nuclear power in operation by 1986. Another way of expressing the uranium requirements for installation of thermal reactors as shown in Table 2 is that the cumulative requirements of U_3O_8 (for inventory and fuel consumption) up to the year 2000 would be some 74,000 short tons U_3O_8 for light-water reactors (PWR and BWR) and 48,000 short tons U_3O_8 for CANDU reactors. The adoption of fast breeder reactors in the latter part of the century would reduce these uranium requirements, but it is not possible to predict the extent to which they will be adopted during this period in Australia. It will be evident that the predicted fuel requirements are in excess of known, low cost reserves of uranium, and this is the reason for the Government's export policy which was announced in 1967. Prior to this there had been a complete ban on export of uranium, but the present policy relaxed this and gave encouragement to exploration. Whilst some discoveries have been made, there is no evidence of movement towards a position of over-supply and it would appear prudent until the reserves are increased substantially, to keep the matter under continuous study. It should be remembered that when fast breeders are in operation each ton of uranium exported is a loss in energy resources equal to that of 2,000,000 tons of black coal. Notwithstanding what is said above, there are reasons for quiet confidence that uranium reserves in Australia will expand steadily as exploration continues.

5.2. **Fuel Fabrication**

Reactors cooled with either light or heavy water use uranium dioxide (UO_2) fuel clad in zirconium alloy. Manufacture of nuclear-purity UO_2 from Australian uranium concentrates ("yellow cake") is a relatively simple operation. For CANDU reactors no enrichment of the UO_2 would be required, but for PWR, BWR, or SGHWR systems enrichment to less than 5% U_235 content would be needed. This might be achieved in Australia by the gas centrifuge process of enrichment, should this finally prove to be economic.
Australia presently supplies about 70% of the free world's requirements of zircon, the raw material for zirconium metal production, which is derived from the beach sand industry. Zircon, worth about 9 cents per kg of contained zirconium, is exported as Australia currently has no zirconium manufacturing industry. Zirconium metal sponge is worth about $10 per kg, and zirconium alloy tubing for fuel elements costs about $70 per kg. Clearly, there will be an incentive, when the local nuclear power industry is established (and from an export viewpoint), to consider the creation of an industry to refine zirconium in Australia.

By 1990, if 11,500 MW(e) of nuclear power plant were installed in Australia, the annual value of the nuclear fuel fabrication industry would be some $170 million per annum for light-water reactors and about $35 million for CANDU reactors. If imported this would involve an expenditure of foreign exchange, thus giving weight to the argument that we should become self-sufficient in our nuclear power industry.

5.3. Fuel Reprocessing

Nuclear fuel after removal from the reactor contains valuable residual uranium and plutonium. The plutonium will be required in the future to fuel fast breeder reactors, and when these systems are available commercially (overseas from 1985), the value of plutonium will increase on the world market.

The value of the residual enriched uranium in PWR, BWR, and SGHWR fuel necessitates early chemical reprocessing of the fuel to achieve desirable fuel cycle economics. The minimum economic fuel throughput for a reprocessing plant of this type is considered to be 1 tonne U/day. For natural uranium reactors (e.g. CANDU), immediate reprocessing is not so urgent, and the economic throughput of a plant is more of the order of 5-10 tonnes U/day.

The alternative of not reprocessing fuel in Australia, when it can be undertaken economically, is costly and complicated transport of the highly radioactive spent fuel to an overseas plant. This should be avoided, and Australia should plan on establishing fuel processing facilities in the future.

5.4. Heavy-Water Production

All hydrogenous materials (water, natural gas, etc.) contain deuterium, the heavy isotope of hydrogen, which is the moderating nucleus in heavy water. The separation of deuterium from ordinary light hydrogen is possible by several well-established chemical exchange techniques, but because of the low initial concentration of deuterium (about 150 ppm in natural waters), pure heavy water is an expensive material (present price from U.S.A. is $U.S. 30.00/lb).

If heavy-water reactors are adopted in Australia, heavy-water production facilities will become of considerable interest. The CANDU system requires about 0.3 tonne heavy water per MW(e), and the SGHWR system about 0.4 tonne heavy water per MW(e). On the basis of present technology, the water-hydrogen sulphide chemical exchange process would appear to be the most attractive for large-scale production, and by the mid 1980's possibly one plant of an output of 400 tonnes per annum of heavy water could be justified in Australia.

5.5. Radioactive Waste Disposal

Normal operation of a power station results in insignificant amounts of radioactive waste for disposal. However, once chemical reprocessing of fuel is undertaken, in which the highly radioactive fission products are separated from
the residual uranium and plutonium, long-term storage of the highly radioactive waste has to be undertaken. Up to the present, overseas practice has been to store the liquid waste in high-integrity underground stainless steel tanks. This has been regarded as an interim measure, and there are now developments overseas which indicate that processes will be adopted which convert the waste into a solid, non-leachable form which can be safely stored on a permanent basis.

This is a matter which Australia will have to consider at the appropriate time. A new industry will be required for treatment and safe disposal of radioactive wastes arising from the country's nuclear power programme.

6. THE JERVIS BAY PROJECT

The Commonwealth Government initiated discussions early in 1969 with the State Governments on the introduction of nuclear power into Australia. Subsequently the New South Wales Electricity Commission (E.C.N.S.W.) was invited to collaborate with the A.A.E.C. in studying the feasibility of establishing a Commonwealth-owned nuclear power station. A number of sites were investigated, and, following Cabinet consideration, the Prime Minister announced in October 1969 that the Commonwealth would undertake the construction of a nuclear power station at Jervis Bay.

The Jervis Bay site was selected after study of a number of prospective sites in New South Wales and the Australian Capital Territory. It is an almost ideal site in terms of minimum construction cost since foundation conditions are good, ocean water can be used for cooling purposes, and it is close to high-voltage transmission lines. Furthermore, it is removed from existing population centres, and is not far from an area which promises to see substantial industrial development.

The nominal 500-MW(e) station will be financed and owned by the Commonwealth, which will supply fuel and retain the spent fuel. The E.C.N.S.W. will accept the energy into the State network and will reimburse the Commonwealth on a basis yet to be determined. The Agreement will also guarantee the long-term power requirements of the Australian Capital Territory.

The station is planned to be in commercial operation by the end of 1975, and thus careful planning and scheduling of all aspects will be required to meet this date. Overall responsibility for the project has been entrusted to the A.A.E.C., working in close collaboration with the E.C.N.S.W. In November, 1969, Bechtel Pacific Corporation Inc., a United States firm of engineering consultants with experience in the nuclear field, were appointed to assist the Commission in preparation of specifications and assessment of the proposals. The specification for the nuclear steam supply, fuel, and certain services was issued in February, 1970, to ten of the organizations which had earlier accepted the Commission's invitation to tender. A separate tender will be issued later for the turbo-generator. The tenders for the nuclear portion of the plant closed in June, and covered fourteen proposals from four countries (U.S.A., U.K., Western Germany, and Canada) for pressurized water, boiling water, steam generating heavy water, and heavy water moderated and cooled reactor systems. The detailed assessment of these proposals is proceeding. The A.A.E.C. plans to submit its recommendation to the Government toward the end of the year. Major site construction could commence about March 1971.

The Government has decided that the reactor should be capable of operating on fuel which can be prepared and manufactured within Australia from Australian resources. This is an important matter if Australia's future nuclear
power industry is to have an assured fuel supply and one which does not require use of foreign exchange to import this commodity. Another feature of the Jervis Bay station will be the use of metric units, thus setting the pattern for subsequent nuclear power plant which will be built after the country has adopted the metric system.

The Jervis Bay nuclear power station is regarded by the Commonwealth as a pilot project for Australia, in which the engineering, reliability, and safety of nuclear power will be demonstrated fully to the country and to State generating authorities. From a national viewpoint, there will be many advantages in such fields as fuel-element fabrication and reprocessing if an orderly and uniform development of nuclear power occurs. In order to achieve this, State Governments have been invited to join with the Commonwealth on a National Consultative Committee on Nuclear Energy. This Committee will deal with such matters as licensing of reactor sites, reactors, and reactor operators; international obligations in respect of safeguards on nuclear materials; disposal of radioactive wastes; and liability in nuclear accidents. The process of designing, building, and operating the first station will provide valuable training and experience for engineers from the States as well as the Commission. Australian industry will be given opportunities to participate as much as possible in construction of the station.

The capital cost of the Jervis Bay station is expected to be higher than that of an equivalent coal-fired station, but the station will provide substantial operating economies during its life owing to its lower fuel costs. At this time, since the successful tenderer is not known, it is not possible to give actual capital or expected generation costs for the Jervis Bay station. However, the expenditure involved will be justified and is necessary if Australia is to enter, without further delay, the nuclear age and thus join the many other nations which are already benefiting from this important, new, but well-established technology.

7. NUCLEAR ENERGY IN OTHER FIELDS

This paper has been concerned with nuclear energy in power generation. There are, of course, other fields in which nuclear energy has a significant contribution to make in the development of a country's resources and the betterment of mankind's ability to utilize these resources and thus improve his living standards. Space permits only brief mention of these applications.

7.1. Nuclear Desalination

Australia is a relatively dry continent, the average annual rainfall being only 17 inches. The mean annual run-off is rather less than 2 inches, compared with an average of almost 10 inches for all land surfaces of the globe. Mean annual flow from Australia's rivers is some 280 million acre-feet compared with about 1,300 million acre-feet for the U.S.A. The two countries have much the same area.

The large-scale desalination of water using nuclear energy is technically feasible today, but generally costs are not yet competitive with natural water supplies. Costs can be improved by combining desalination with power generation, thereby making maximum use of the thermal energy in steam. Water costs from large dual-purpose plants - say, producing at least 500 MW(e) of power and several million gallons/day of water - are expected to fall with further development of the technology. Such processes do not depend upon the use of nuclear power, coal would do as well, but since such units to be economical will have to be very large nuclear power is likely to be the preferred choice. Before the
1-12
turn of the century it would not be unreasonable to expect Australian capital
cities to be relying on desalinated sea water to meet the rising demands for
their water supplies.

7.2. Nuclear Energy Centres

The concept of "nuclear energy centres" has been studied overseas,
principally in the U.S.A. These large nuclear reactors would provide low-cost
energy for an integrated industrial complex of chemical and electrometallurgical
processes producing such materials as synthetic ammonia, phosphorus, fertilizers,
caustic soda, chlorine, and non-ferrous metals, as well as supplying electricity
for urban requirements. Another concept visualizes agro-industrial complexes,
in which, along with fertilizer and chemicals production, large reactors would
be used for desalination to produce water cheap enough for controlled irrigation
of a sophisticated and scientifically managed agricultural programme in arid
areas. Power outputs of several thousand MW(e) and/or water productions of
hundreds of million gallons per day would be required to achieve acceptable
costs, and obviously the capital investment in any such scheme would be very
large. Nevertheless, countries such as the U.S.A., Israel, Mexico, the United
Arab Republic, and Italy have expressed interest in the future potential of
"nuclear energy centres". With the passage of years it would not be unreasonable
to expect that such developments might find application in Australia.

7.3. Peaceful Nuclear Explosives

The technology of peaceful uses of nuclear explosives is being developed
overseas, since there are applications envisaged in the civil and mining
engineering fields which could not be undertaken by conventional means. These
applications range from harbour and dam construction, overburden removal, natural
gas stimulation (in which gas is released from a deeply buried, low permeability
rock formation by fracturing the rock), preparation of underground ore-bodies
for in situ leaching, and formation of underground reservoirs for gas or
oil storage.

There are still problems to be overcome before nuclear explosives can
be used for peaceful purposes. However, progress is being made in the technical,
safety, and political aspects, and future applications can be envisaged in
Australia where sparse population and remoteness would not prevent a particular
project from being undertaken, on seismic damage or radiological health grounds.

7.4. Radioisotopes

Radioisotopes are now being more widely used in Australia in such fields
as medicine (research and therapeutic), agriculture, industry, and general
research. The A.A.E.C. has concentrated on producing two general types of
radioisotope - those with a short half-life which otherwise would be difficult
or impossible to obtain from overseas, and those with a high specific activity
(such as cobalt 60 used for cancer treatment).

It is 10 years since the first radioisotope was produced at Lucas Heights.
Revenue from sales now exceeds $1 million and shipments are presently averaging
about 800 per month. A worthwhile export business has been developed, and
Australia can look forward to increasing benefits from the widespread use of
radioisotopes.
3. CONCLUSION

This year has been a dramatic one in the history of Australia's industrial development. Practical steps have been taken to introduce nuclear power to this country with the calling of tenders for the Jervis Bay station.

The Atomic Energy Commission has, since its inception, been laying the foundations by undertaking research and by building up a body of highly trained personnel experienced in the many fields of nuclear energy, for this new era upon which Australia is now embarking. There can be no doubt that the country is on the threshold of economic nuclear power.

Electricity from the Jervis Bay station will cost marginally more than from a coal-fired station, but within a decade of its operation, power from a multi-unit station of some 2,500 MW(e) will be competitive with coal in N.S.W. A short time thereafter nuclear power will be competitive in the other States, and from then on nuclear power will play an increasing role supplementing the conventional methods of power generation. The complexities of nuclear power and its ancillary industries - both technical and financial - are beyond the resources of the individual States, and the Commonwealth is giving a lead in these fields.

Nuclear technology has much to offer Australia. It is expected that between now and the turn of the century a great new industry will be established in this country. The short-term aim is one of application and orderly development of nuclear power. The ultimate aim will be complete self-sufficiency and the development of a healthy export business.
### TABLE 1. NUCLEAR POWER - REACTOR SYSTEMS AND COUNTRIES (June, 1970)

<table>
<thead>
<tr>
<th>Reactor Type</th>
<th>No. of Units</th>
<th>Generating Capacity MW(e)</th>
<th>Main User Countries and Capacity (MW(e))</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Gas-cooled graphite moderated</td>
<td>60</td>
<td>Operating: 6,990, Under Construction or Committed: 10,230, Total: 17,220</td>
<td>U.K. 14,120; France 1,855; Spain 480; U.S.A. 370; Italy 200; Japan 157.</td>
</tr>
<tr>
<td>2. Pressurized water</td>
<td>98</td>
<td>Operating: 4,880, Under Construction or Committed: 57,363, Total: 62,242</td>
<td>U.S.A. 46,098; U.S.S.R. 3,365; W. Germany 2,147; Japan 1,666; Belgium 1,610; Sweden 809; Bulgaria 800; Czechoslovakia 800; Hungary 800; Switzerland 700.</td>
</tr>
<tr>
<td>3. Boiling water</td>
<td>72</td>
<td>Operating: 3,243, Under Construction or Committed: 38,083, Total: 41,326</td>
<td>U.S.A. 29,762; W. Germany 3,219; Sweden 2,280; Japan 2,522; Switzerland 1,106; Italy 719; Taiwan 550; India 380.</td>
</tr>
<tr>
<td>4. Heavy water</td>
<td>24</td>
<td>Operating: 451, Under Construction or Committed: 6,830, Total: 7,281</td>
<td>Canada 5,492; India 800; Argentina 318; Czechoslovakia 150; W.Germany 150; Sweden 141; Pakistan 125; U.K. 100.</td>
</tr>
</tbody>
</table>

### TABLE 2. ESTIMATED GROWTH OF CONVENTIONAL AND NUCLEAR POWER IN AUSTRALIA

<table>
<thead>
<tr>
<th>Year (ended 30th June)</th>
<th>Total Installed Capacity MW(e)</th>
<th>Conventional Plant MW(e)</th>
<th>Nuclear Plant</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>MW(e)</td>
</tr>
<tr>
<td>1976</td>
<td>22,000</td>
<td>21,500</td>
<td>500</td>
</tr>
<tr>
<td>1980</td>
<td>30,000</td>
<td>29,000</td>
<td>1,000</td>
</tr>
<tr>
<td>1985</td>
<td>43,000</td>
<td>39,000</td>
<td>4,000</td>
</tr>
<tr>
<td>1990</td>
<td>61,000</td>
<td>49,500</td>
<td>11,500</td>
</tr>
<tr>
<td>1995</td>
<td>83,000</td>
<td>60,500</td>
<td>22,500</td>
</tr>
<tr>
<td>2000</td>
<td>110,000</td>
<td>74,000</td>
<td>36,000</td>
</tr>
</tbody>
</table>
TABLE 3. AUSTRALIAN ELECTRICITY INDUSTRY - PRESENT AND FUTURE

<table>
<thead>
<tr>
<th>State</th>
<th>Installed capacity (MW(e))</th>
<th>Electricity generated (million kWh)</th>
<th>Principal fuel used ('000 tons)</th>
<th>Total fuel expenditure ($'000)</th>
<th>Year Ended June, 1969</th>
<th>Forecast Future Maximum Demand* MW(e)</th>
</tr>
</thead>
<tbody>
<tr>
<td>New South Wales</td>
<td>4,166</td>
<td>15,532</td>
<td>6,647 (black coal)</td>
<td>30,364</td>
<td>8,100 11,000 16,500</td>
<td>1976 1980 1985</td>
</tr>
<tr>
<td>Victoria</td>
<td>2,738</td>
<td>12,005</td>
<td>18,047 (brown coal)</td>
<td>21,724</td>
<td>4,100 5,200 7,000</td>
<td>1976 1980 1985</td>
</tr>
<tr>
<td>Queensland</td>
<td>1,546</td>
<td>4,968</td>
<td>2,225 (black coal)</td>
<td>15,004</td>
<td>1,900+ 2,700+ 4,000+</td>
<td>1976 1980 1985</td>
</tr>
<tr>
<td>South Australia</td>
<td>969</td>
<td>3,857</td>
<td>2,135 (sub-bituminous coal)</td>
<td>N.A.</td>
<td>1,600 2,300 3,200</td>
<td>1976 1980 1985</td>
</tr>
<tr>
<td>Western Australia</td>
<td>564</td>
<td>2,058</td>
<td>913 (black coal)</td>
<td>7,595</td>
<td>1,400 2,100 3,500</td>
<td>1976 1980 1985</td>
</tr>
<tr>
<td>Tasmania</td>
<td>1,009</td>
<td>4,610</td>
<td>Mainly hydro</td>
<td>311</td>
<td>950 1,200 1,500</td>
<td>1976 1980 1985</td>
</tr>
</tbody>
</table>

* The forecast future maximum demands are A.A.E.C. estimates. The installed capacity would be about 15% greater than the peak demand.
+ Figures are for the Southern Queensland interconnected system only.
Fig. 1  GROWTH OF ELECTRICITY SUPPLY INDUSTRY IN AUSTRALIA

AVERAGE RATE OF INCREASE 9.3% PER ANNUM

GROWING ELECTRICITY SUPPLY INDUSTRY IN AUSTRALIA