CANADA

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## ATOMIC RESEARCH IN CANADA*

The high-energy yield from the fission of uranium is the key to the prospect of economic nuclear electric power. The yield is so high that the cost of the raw uranium is a very minor component of the cost of electric power. It will be about 5 per cent of the total and may be contrasted with 50 per cent or more paid for coal in some large conventional generating stations. The largest component in the overall economy of nuclear power systems is reactor-plant construction, and a minor (10 per cent to 20 per cent) component is fuel fabrication.

For a few more years yet, the major atomic-energy activity in Canada is likely to be uranium mining and refining for export in support of military uses. A major transition, however, is taking place in which uranium production will give place to engineering and construction of nuclear electric generating stations. This phase will last until nuclear plants are established in such numbers and capacity throughout the world that the market for uranium revives and regains its former peak.

### Future of Heavy-Water Reactor

There is some prospect that the economic advantages of the heavy-water reactors designed in Canada will lead to the adoption of this type in many other countries with the creation of a market for heavy water that could be produced competitively in Canada. The possible export of nuclear generating stations, heavy water and uranium fuel is appearing as a new, near-term prospect on a small but significant scale.

### Expanding Capacity

In Canada plans are already taking account of a revolutionary increase in the size of electricity-generating stations. The full-scale, 200,000-kilowatt Douglas Point Nuclear Power Station now under construction has come to seem small. Steam turbines and conventional stations are now appearing in larger capacities and the prospects of long-distance, high-voltage transmission to interconnect centres of load, together with the lower unit-power costs that result from operating on a larger scale, cause utilities to plan generating stations of 2,000,000 kilowatts and more. The Canadian design of nuclear-power reactor appears capable of expansion to keep pace, and will yield even more benefit than the conventional plant in the resulting reduction of unit-power cost.

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*Based on an article by Dr. W.B. Lewis, Vice-President, Research and Development, Atomic Energy of Canada Limited.

It is also significant that, since lower unit-power costs result from larger stations, there is a new incentive for large utilities to export power from their systems, and Canadian policy is changing to allow such export from Canada. Since the planning and construction of major power plants takes many years, these trends are not expected to be extensively realized before the 1970's. The prospect has, however, already had its effect on atomic-energy research and development.

Federal Research Entities

Three Federal Government organizations have the basic responsibilities for atomic energy in Canada:

(1) The Atomic Energy Control Board, responsible for all regulatory matters concerning work in the nuclear field;

(2) Eldorado Mining and Refining Limited, with a double function as a producer of uranium and as the Government's agent for the purchase of uranium from private mining companies;

(3) Atomic Energy of Canada Limited, concerned with nuclear research and development, the design and construction of reactors for nuclear power, and the production of radioactive isotopes and associated equipment, such as Cobalt-60 Beam Therapy units for the treatment of cancer.

The Atomic Energy Control Board does not itself conduct research, but it gives substantial grants to universities to further independent studies and to provide the equipment without which the universities would find it difficult to train the nuclear research workers of tomorrow. In the 1961-62 financial year, its grants totalled $700,000.

Eldorado operates research and development laboratories in Ottawa and uses them to support its uranium mining and processing at Beaverlodge, Saskatchewan, and its refining plant at Port Hope, Ontario. Eldorado co-operates with the Department of Mines and Technical Surveys, which carries out background research on the production and use of uranium, and with the Canadian Uranium Research Foundation, an organization supported by the industry and particularly interested in developing the non-nuclear uses of this metal.

Atomic Energy of Canada Limited (AECL) has an 11-man board of directors, including individuals from private industry, public and private power companies and the universities. The company's major plant is near Chalk River, Ontario, and its head office and Commercial Products Division are in Ottawa. A new research centre is under construction at Whiteshell, Manitoba. The Nuclear Power Plant Division in Toronto directs the engineering of power reactors and nuclear generating stations. The first project was NPD, a nuclear-power demonstration plant to produce 20,000 kw of electricity, now in operation at Rolphton near the Chalk River establishment; its design and construction were carried out in collaboration with the Canadian General Electric Company Limited and the Hydro Electric Power Commission of Ontario.

The Nuclear Power Plant Division of AECL, with the assistance of Ontario Hydro, is also designing and constructing a full-scale nuclear power plant, which will supply 200,000 kw of electricity to the Ontario Hydro system. This plant, which has a reactor known as CANDU, is being built at Douglas Point near Kincardine on Lake Huron. By agreement, Ontario Hydro wil purchase the plant when it is in satisfactory operation. An Advisory Committe on Atomic Power Development keeps all other utilities fully informed of the progress being made. This body, set up by the Federal Government in 1954, m periodically at Chalk River to assess the economic prospects of nuclear power throughout the country.

Because of the great pace of technological development in nuclear power throughout the world, AECL devotes a major effort to collaboration with many organizations. These include industrial firms and the scientific and engineering departments of universities in Canada and, through foreign government agencies and several international organizations, many technical groups in other countries. For example, the Canadian General Electric Company is under contract to design and construct WR-1, an organic-cooled experimental reactor, for the Whiteshell Nuclear Research Establishment. AMF Atomics Division of AMF Canada Limited and CGE are AECL's chief contractors for fuel-element fabrication, and other work related to Canada's nuclear-power programme is carried out in collaboration with Shawinigan Engineering, Orenda Engines Division of Hawker Siddley Canada Limited, the Canadian Westinghouse Company Limited, the Montreal Locomotive Works Limited and the Montreal Engineering Company Limited. In general, AECL's policy is to stimulate the interest of private industry in the development of nuclear power so that these firms can take over construction of power plants when the time arrives, leaving AECL free for fundamental studies and developing new reactor concepts. AECL also lends general support to the nuclear and related studies of Canadian universities and lets contracts to the universities on specific problems.

In the international field, close ties are kept with the United States Atomic Energy Commission and the United Kingdom Atomic Energy Authority, both of which have representatives permanently at Chalk River. There is an agreement with the United States for co-operative work on heavy-water-moderated reactors; it provides for the free exchange of all technical data in this field and a commitment by the USAEC to spend $5 million in the United States on research and development related to reactors of Canadian design. Collaboration has also been established with the International Atomic Energy Agency, the Organization for Economic Co-operation and Development, and Euratom, as well as with Australia, Japan, Pakistan, Sweden, Switzerland, West Germany, and, less formally, with Denmark, France, India and Norway. In India, a major experimental reactor, the Canada-India Reactor, similar to NRX at Chalk River, was constructed and was formally inaugurated in January 1961.

Chalk River Laboratories

At this research and development establishment basic and applied research is carried on by about 200 professional scientists and engineers supported by 300 technicians devoted to research in nuclear physics, nuclear chemistry, radiobiology, reactor physics, radiation chemistry, environmental radioactivity, physics of solids and liquids, and other subjects, using as their primary facilities the two major reactors, NRX and NRU, the auxiliary reactors, ZEEP, PTR and ZED-2, the tandem Van de Graaff accelerator and analytical facilities such as a precision beta-ray spectrometer, mass spectrometers, electron microscopes, multi-channel pulse analyzers, automatic recorders, analogue and digital electronic computers.

Basic research is carried on in many fields, especially that of the structure of atomic nuclei, and of the interactions of neutrons, not only with individual nuclei but also with liquids and crystalline solids, particularly those involving energy transfer. For nuclear-structure studies, the tandem Van de Graaff has made pioneer work possible by providing multiply-charged ions of precisely-known energy and direction. It has proved possible to produce nuclei in specific energy states by different routes and to identify and analyse the states, thereby deducing the spin and other characteristics and discovering, for example, a correlated series of rotational states in the nucleus neon-20. Not only is this important to a basic understanding of nuclear structure, but it also finds application in unravelling the complex of nuclear reactions responsible for the genesis of nuclei in the interior of stars.

Studies of neutron interactions with matter are made possible by the intense beams of neutrons available from the NRU reactor. By monitoring the neutrons in cosmic radiation, it has been possible to find correlations with the occurrence of solar flares and contribute to the recent advances of knowledge of phenomena in interplanetary space. Isotope techniques have brought about revisions in the basic theory of chemical reactions induced by radiation. This basic research may find a useful early application in the technology of using an organic liquid as coolant in nuclear-power reactors.

Since extracted plutonium is no longer required, the fuel in the NRX reactor has been changed from natural uranium metal to a combination of natural uranium oxide and a uranium-235 aluminum alloy. The available neutron flux has been increased thereby, while keeping the power at 42 megawatts. It is planned to revise the fuelling of NRU similarly at the end of 1963.

The research facilities of the NRX and NRU reactors have continued to attract individual scientists as well as teams from other countries. A team of Brookhaven (U.S.A.) and AECL scientists is using a neutron beam with a high-speed chopper and long flight-path for nuclear interaction studies. Another team, with scientists from Harwell (Britain) and other countries, is using another system of choppers for studying details of the slowing-down of neutrons by moderators. Both in NRX and NRU, the exceptional facilities for irradiations in high-temperature water, steam and organic liquids have brought teams from Britain and the United States and individuals from West Germany and Sweden to conduct tests important for the design of future power reactors.

Nuclear Power Prospect

The generation of electricity by nuclear power on a competitive economic basis is expected to be established by the type of reactor now under construction by the Nuclear Power Plant Division of AECL. This promise rests on the attainment of very-low-cost fuelling by an extremely simple system that has proved satisfactory in the Nuclear Power Demonstration Station reactor, where there has been no fuel failure in the first year of operation. The fuel is uranium dioxide specially prepared entirely in Canada from natural uranium. A wide range of tests in hot channels in the NRX and NRU reactors at heat ratings and energy yields in excess of those required has established that this oxide fuel is incomparably more dependable than the uranium metal fuel for which the NRX and NRU reactors were designed. No provision for reprocessing the irradiated fuel is involved, for, by careful attention in the reactor design to minimizing any waste of neutrons, an energy yield of over 9,000 thermal megawatt-days is expected from a ton of uranium before it is discarded. This results in a prospective fuelling cost of about 1 mill (0.1 cent) an electric kilowatt-hour, to be compared with about 3 mills from coal at $8 a short tone.

Canada has access to such an abundance of coal, oil and natural gas that the competitive cost level for electric power is lower than in many other countries. Nuclear-power plants of the types now under construction in Britain and the United States have been assessed as unable to reach a low enough cost level, at least until several successive plants have been built and operated to discover where economies are possible. Plants of the CANDU type do not promise to be significantly cheaper in total initial outlay, but the fuelling cost can be so much less that meeting the competitive target is a very real prospect.

The low fuelling cost derives as much from the details of the design proposed as from the general type of reactor chosen. Some of the important features seem worthy of mention. The full-scale plant will generate 220 megawatts with a steam-cycle efficiency of 33.3 per cent, so the reactor has to supply 660 thermal megawatts to the steam-raising plant. The reactor is essentially a tank of heavy water, 20 feet in diameter and 16.5 feet long, lying horizontally. It is penetrated by 306 fuel channels parallel to the axis on a 9-inch-square lattice. Each channel is a zirconium-alloy pressure tube of 3.25 inches inside diameter and about 0.16 inches thick. The fuel consists of bundles of 19 rods, 0.6 inches in diameter and 19.5 inches long, made of dense uranium dioxide in thin zirconium-alloy tubes. Heat is taken from the fuel directly by heavy water that passes at 560°F. to the steam boiler, where normal water is raised to saturated steam at 483°F. and 38 atomospheres. The heat developed in the heavy-water moderator that is in the tank outside the fuel channels is not directly used and amounts to about 35 thermal megawatts. The overall net plant efficiency is then 29.1 per cent. These details show that the design represents a very considerable advance over that originally conceived in 1956, and the improvement bears promise that continued progress will lead to costs well below the economic target. As examples of the advance, it may be noted that, for the same electric-power output, the reactor power has been brought down from 790 to 700 megawatts and the length of fuel rod from 86 to 30 kilometres. The prospective fuelling cost has dropped from 1.85 mill/kWh to 1.0 mill/kWh. On the other hand, no wholesale reduction has been achieved in the capital-cost estimates, which remain in the range $300 to $400 an electrical kilowatt for the whole plant. No reduction is expected until manufacturing experience has been gained that can be used in future construction, but thereafter appreciable reductions should be possible.

The first plants seem to find economic application in Canada only in the Ontario system, where annual charges on capital are low and coal has to be imported and costs about $8 a short ton. Moreover, the demand for electricity in Ontario is growing at more than 200 megawatts capacity a year. To build reactors for lower powers saves little in the cost, so the cost a kilowatt rises and becomes uneconomical. Now that confidence has been gained from the early plants, higher powers seem possible and designs up to 750 electrical megawatts from one reactor are being studied.

Repair Problems

Operating experience with the NRX and NRU reactors at Chalk River and with the many other types throughout the world has served to emphasize the great difficulty and costliness of making even minor operating repairs in the presence of the extremely high levels of radiation that are encountered around reactors. Directly and indirectly, this is responsible for the current hesitation to construct a number of large plants that for economic power will cost no less than $40 million or $50 million each. With every new design it is necessary to acquire operating experience before the reliability and availability can be effectively estimated. Experience with defective fuel has been deliberately sought at Chalk River, because this is one of the difficulties most likely to be encountered. Appropriate techniques of locating the defective element, removing it and cleaning up the released radioactive fission products have been established and practised; at the same time, fuel designs and ratings that lead to least difficulty in these operations have been studied. Experience of mechanical failures of control rods has lent weight to reactor designs such as NPD, where control rods are not needed. Temperature changes are likely to provoke mechanical failures, so design is aimed at keeping the reactor at power for all essential operations, including refuelling and complete maintenance testing and readjustment of instruments and working parts of the control system.

A study is in progress of the relative merits of four types of large power reactor for which development work is active. All are heavy-water-moderated and would not require any reprocessing of spent fuel. The fuel could be natural uranium or slightly enriched in the form of uranium dioxide or uranium carbide. The differences lie in the coolant and steam cycle. The four coolants are pressurized (perhaps partly boiling) heavy water (as in CANDU), fog or wet steam, ordinary boiling water, and an organic liquid. The fog and boiling-water reactors would pass steam directly to the turbine; the heavy water and organic liquid would raise steam via a heat exchanger. It is apparent that, in large sizes, construction costs would be comparable but the small differences may be significant. A larger difference is in prospect from fuel-fabrication costs. The cost of development of each type, although high, may be justifiable economically by the cost savings in appropriate circumstances. All appear competitive with conventional plants except locally, where fuel is abundant at low cost.

## CANADIAN NUCLEAR REACTORS IN OPERATION, UNDER CONSTRUCTION OR APPROVED FOR CONSTRUCTION

| Name | Location | Date of Start-up | Power | Fuel | Moderator | Coolant | Use |
|---|---|---|---|---|---|---|---|
| Zero Energy Experimental Pile (ZEEP)...... | Chalk River, Ontario | 1945 | 100 w. | Natural uranium metal or oxide | Heavy water | — | Lattice experiments |
| National Research Experimental (NRX)..... | Chalk River, Ontario | 1947 | 42,000 kw. | Natural uranium oxide and enriched uranium alloy | Heavy water | Ordinary water | Research and isotope production |
| National Research Universal (NRU)......... | Chalk River, Ontario | 1957 | 200,000 kw. | Natural uranium metal | Heavy water | Heavy water | Research and plutonium and isotope production |
| Pool Test Reactor (PTR).................... | Chalk River, Ontario | 1957 | 100 w. | Enriched uranium alloy | Ordinary water | Ordinary water | Reactivity and absorption measurements |
| Toronto University Sub-critical Reactor...... | Toronto, Ontario | 1958 | — | Natural uranium metal | Heavy water | — | Research and teaching |
| McMaster Nuclear Reactor (MNR).......... | Hamilton, Ontario | 1959 | 1,000 kw. | Enriched uranium metal | Ordinary water | Ordinary water | Research |
| ZED-2.................................... | Chalk River, Ontario | 1960 | 100 w. | Natural uranium metal or oxide | Heavy water | — | Lattice experiments |
| Canada-India Reactor (CIR)................ | Bombay, India | 1960 | 40,000 kw. | Natural uranium metal | Heavy water | Ordinary water | Research and isotope production |
| Nuclear Power Demonstration (NPD)...... | Rolphton, Ontario | 1962 | 20,000 kw. (electricity) | Natural uranium oxide | Heavy water | Heavy water | Power demonstration |
| Canadian Deuterium-Uranium (CANDU)... | Douglas Point, Ontario | 1964-65 | 200,000 kw. (electricity) | Natural uranium oxide | Heavy water | Heavy water | Power |