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ATOMIC RESEARCH IN CANADA

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The first major fruits of Canadian atomic energy research now appear close at hand. The Hydro-Electric Power Commission of Ontario is constructing a multi-unit nuclear electric generating station at Pickering, near Toronto. Each unit will generate 500 megawatts (1 megawatt = 1,000 kilowatts), and it is planned to bring two units into operation in 1970-71. Estimates indicate that the power will be generated for less than 4 mill/kwh (0.4 cents a kilowatt hour) and will be competitive with that from other available types of thermal-generating stations. The Quebec Hydro-Electric Commission is also entering the nuclear field with a 250-megawatt prototype nuclear-generating station of advanced design. Like the earlier CANDU (Canadian Deuterium Uranium) reactors, the design employs natural uranium as the fuel and heavy water as the moderator but the heat will be carried from the fuel by boiling ordinary water instead of by heavy water at a pressure sufficient to prevent boiling. The design is distinguished by the title CANDU-BLW-250 (Canadian Deuterium Uranium-Boiling Light Water-250 megawatts).

The first nuclear-power demonstration (NPD) reactor, CANDU-PHW-20 (pressurized heavy water-20 megawatts), at Rolphton, Ontario, gave very good service in 1964, achieving a capacity factor of 82 per cent, exceeding the target of 80 per cent. Moreover, in December 1964 and January 1965, when the target was 96 per cent, a capacity factor of 98 per cent was achieved. In December 1965 and January 1966, the figure was still above target (96.5 per cent). The reactor at the 200-megawatt station at Douglas Point on Lake Huron went into operation November 15, 1966.

Canadian heavy-water power reactors are also under construction in India and Pakistan. To meet the prospective large demand for heavy water, two production plants are being constructed in Nova Scotia by private industries and the purchase of a total of 2,500 tons of heavy water has been underwritten by the Federal Government.

Although nuclear power is expected to restore the world market for uranium, the major build-up is expected in the 1970s. The high energy yield from the fission of uranium is the key to economic nuclear 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 is 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 economy of nuclear-power systems is reactor-plant construction and a minor component, 10 per cent to 15 per cent, is fuel fabrication.

In the past, the major atomic energy activity in Canada was uranium mining and refining for export in support of military uses. Circumstances have changed so greatly that the Government has announced a policy of no further exports for nuclear weapons but encourages export for peaceful purposes such as nuclear power.

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 to interconnect centres of load by high-voltage transmission, even over long distances. All users of electricity also benefit from the new trend to lower rates the greater the demand.

The Canadian designs of nuclear-power reactor appear capable of adapting to the largest capacities desired and of taking advantage of changes in the market value of natural uranium and of reprocessed fuel to reach even lower power costs as the scale of operations increases.

Organizational Arrangements

Three federal 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: and (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, and large installations for the sterilization of medical supplies and other uses.

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 they would find it difficult to train the nuclear research workers of tomorrow. The National Research Council also has made grants in the atomic energy field. In 1964-65 the total of these grants was $2,450,000.

Eldorado operates research and development laboratories in Ottawa and uses them to support its uranium mining and processing at Beaverlodge in northern 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.

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, the Chalk River Nuclear Laboratories, is near Chalk River, Ontario, and a second plant, the Whiteshell Nuclear Research Establishment, is near Pinawa in Manitoba. The company's head office and AECL Commercial Products are in Ottawa. AECL Power Projects in Toronto directs the engineering of power reactors and nuclear-generating stations and operates as consulting nuclear engineers. The design and construction of NPD, the demonstration plant, was carried out by collaboration between AECL, the Canadian General Electric Company Limited and Ontario Hydro. Power Projects, with the assistance of Ontario Hydro, designed and constructed the Douglas Point station. By agreement, Ontario Hydro will purchase the plant when it is in satisfactory operation. The large units of the Pickering station are being built by Ontario Hydro, using Power Projects as consulting nuclear engineers. An Advisory Committee on Atomic Power Development keeps all other utilities fully informed of the progress being made. This body, which was set up by the Federal Government in 1954, meets periodically 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 has designed and constructed WR-1, an organic-cooled experimental reactor, for the Whiteshell Nuclear Research Establishment, on a fixed-price negotiated contract. The Canadian General Electric and Canadian Westinghouse Companies 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 Limited, Dilworth, Secord, Meagher and Associates, Atlas Steel Limited and 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 ideas. For some years AECL expects to continue a consulting engineering role in the design of nuclear generating stations. AECL also lends general support to the nuclear and related studies of Canadian universities and lets contracts to the universities on specific problems.

To support their activities in this field, both industry and universities need ready access to information. This was one reason why industry set up the Canadian Nuclear Association, a body that has held a highly successful series of annual conferences at which both progress and the prospects for the future are reviewed. A commercially-published magazine, <u>Canadian Nuclear Technology</u>, maintains the flow of general information and opinion. Detailed technical information is available principally from the library of the Chalk River Nuclear Laboratories, which lends about 500 items a month from its comprehensive collection of the world's nuclear literature. Information is also distributed from extensive depository collections of the libraries of the University of British Columbia, McMaster University and the National Research Council, and from seven smaller collections located across Canada.

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. 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, West Germany, India, Italy, Japan, Pakistan, Spain, Sweden, Switzerland, the U.S.S.R. and, less formally, with Denmark, France 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.

A 200-megawatt plant similar to that at Douglas Point is being constructed in India in a co-operative programme known as the Rajasthan Atomic Power Project (RAPP). Pakistan has entered into an agreement to purchase from the Canadian General Electric Company a 130-megawatt station for the Karachi area.

Research and Research Facilities

At the Chalk River Nuclear Laboratories, 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, multichannel pulse analysers, automatic recorders, and 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, three 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 application in the technology of using an organic liquid as coolant in nuclear power reactors.

The research facilities of the NRX and NRU reactors have continued to attract individual scientists as well as teams from universities and from other countries. The international study on the scattering and slowing of neutrons by moderators and other materials of interest at high and low temperatures is drawing successfully to a close. More facilities for studying radiation damage under closely-controlled conditions are coming into use. These include devices for measuring creep of metals under stress and fast neutron bombardment at controlled temperatures.

The first major installation at the Whiteshell Nuclear Research Establishment (WNRE) is the organic liquid-cooled, heavy-water-moderated experimental reactor WR-1, commissioned in 1965. The facilities are specially suited for development work roward large reactors of a similar type. The facilities of WR-1 are quite extensive and can be applied to development work also with other coolants such as boiling water and super-heated steam. Laboratory facilities at WNRE are specially suited to studies of the effects of radiation and a wide programme from molecular biology to radiation chemistry and reactor engineering is under way.

Nuclear Power Development

Much of the success of CANDU series of reactors is attributable to the engineered design of the fuel tested in many experimental irradiations under conditions that are more exacting than normal service. The fuel is uranium dioxide specially prepared from natural uranium entirely in Canada. Strings of pellets of sintered oxide are charged into thin-walled zirconium alloy tubes. The tubes deform slightly in service in a determined manner that has proved satisfactory. The migration of the fission product atoms, especially the gases, has been extensively studied and satisfactory operating conditions established for the full energy yield of 9,000 megawatt-days per ton of uranium and more. This energy yield is so great that there is no need to make provision for processing the spent fuel and the prospective fuelling cost is less than one mill (0.1 cent) per kilowatt hour of electricity. This cost may be compared to about three mills from coal at $8 a ton. The low fuelling cost is most important because 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 countries.

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. At Douglas Point, the first full-scale plant generates 220 megawatts with a steam-cycle efficiency of 33.3 per cent, so that 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 lattice nine inches square. Each channel is a zirconium-alloy pressure tube of 3.25 inches inside diameter and about 0.16 inch 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 atmospheres.. These details show that the design represents a 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 total heat production of the reactor has been brought down from 790 to 700 megawatts, the efficiency of the steam cycle itself has risen from 27.9 per cent to 33.3 per cent, and the length of fuel rod has been reduced from 86 to 30 kilometers. The prospective fuelling cost has dropped from 1.85 mill/kwh to 1.0 mill/kwh. On the other hand, no general reduction has been achieved in the capital-cost estimates, which remain in the range of $300 to $400 an electrical kilowatt for the whole plant. However, a reduction is expected now that manufacturing experience has been gained that can be used in future construction. Even greater reductions in unit power cost will result at Pickering from the increase in the capacity of the reactor to 500 megawatts of electricity and the incorporation of several such units in a large generating-station.

An evaluation was presented at the third United Nations Conference on the Peaceful Uses of Atomic Energy at Geneva in September 1964 of cost estimates of several preliminary designs of large power reactors using heavy water as moderator. These designs represented types for which development work was well advanced. The differences lie in the choice of heat-transfer fluid or "coolant" and the steam cycle. Basically, there are three coolants: heavy water, ordinary or light water, and an organic liquid. The heavy water can be under pressure to prevent boiling or to allow some boiling. Light water must boil or must be in the form of "fog" or "wet steam". The organic liquid must not boil. All types have excellent economic promise and it was decided to develop the boiling light-water type, chiefly for two reasons: (1) By taking the steam direct to the turbine a boiler or heat-exchanger is eliminated and the efficiency is raised. (2) The second advantage is a relaxation of the strictness of control of leaks needed with hot heavy water, both because of its cost and because of the toxicity of the tritium it contains. Some development of the organic liquid system continues under a new agreement with the United States in support of its programme to develop such a system for water desalination as well as for power.

Most of this development work centres on establishing the properties of materials for the arduous environment of high temperatures, and radiation effects affecting the solids and the fluids. In ordinary engineering, the three parameters of stress, temperatures and time lead to complex analyses, especially when corrosion and atomic diffusion are active. In reactors, irradiation is a fourth and major parameter. Thus, materials development still calls for a major scientific and engineering programme of studies.

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