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ATOMIC RESEARCH IN CANADA

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A number of large nuclear electricity-generating stations are being brought into operation in Canada, Pakistan, and India, all stemming from the "heavy-water-moderated" type of nuclear reactor introduced and developed by Atomic Energy of Canada Limited (AECL). A brief review of them and other large-scale engineering activities will serve to show how closely the research and development work of AECL is linked to activities that form an important part of the national economy.

Heavy water (deuterium oxide) had been chosen for slowing or "moderating" the neutrons from nuclear fission to maintain the fission chain reaction in the experimental NRX reactor at Chalk River. The virtue of heavy water in permitting high-power density had been demonstrated in the operation of NRX from 1947 to 1952, when a thermal power of 30,000 kilowatts was attained using less than ten tons of natural uranium fuel. The power was raised to 40,000 kilowatts in 1954. The 200,000-kilowatt experimental NRU reactor designed and constructed from 1950 to 1957 uses heavy water for both coolant and moderator and its fuel is changed with the reactor at power without shutting down. In the NRX and NRU reactors, the temperature of the coolant was too low to generate steam for power, but in 1951 it became clear that a heavy-water power reactor could be designed that would have a very low fuelling cost compared to coal. The first design employed a pressure vessel to contain the hot coolant, but in 1956 the promising performance of zirconium alloys allowed the preliminary design of the power reactors now coming into large-scale use. This design, given the name CANDU (CANada-Deuterium-Uranium), retains the desired fuelling economy and makes it the only type yet in operation anywhere in the world that can claim the designation of "near-breeder" and "advanced converter" with an expectation that the type will remain economically competitive for the foreseeable future. Moreover, it could meet the power needs of the whole world for many hundreds, and possibly thousands, of years if operated with fuel recycling on enriched uranium and thorium as fuel. All the reactors so far built have been designed to operate on natural uranium fuel, but fuel recycling is possible.

By virtue of its success with nuclear generating stations, Canada was able to make a strong presentation at the fourth United Nations International Conference on the Peaceful Uses of Atomic Energy in September 1971. During the month of July, 8 per cent of the electricity supplied by the

Ontario Hydro system was generated by nuclear energy from the 200,000-kilowatt Douglas Point station and the first 540,000-kilowatt unit at the Pickering station near Toronto. Moreover, the Gentilly 250,000-kilowatt station being commissioned for Hydro Quebec had reached 45 per cent of its designed output. The second 540,000-kilowatt unit at Pickering also started up during the Conference. All four reactors are of the CANDU type.

The heavy-water moderatory is held at low pressure in a tank threaded by separate channels containing the nuclear fuel in the form of bundles of small, short rods. The heat is transferred from the fuel by a heat-transport fluid or *caloporteur*, which in the Ontario Hydro reactors is heavy water under pressure and in the Hydro Quebec reactor is ordinary or "light" water that boils. A third caloporteur, a specially-developed type of hydrocarbon oil or organic liquid, has given outstanding performance at higher temperatures (e.g., 400°C or 750°F) in an experimental CANDU reactor developing 40,000 thermal kilowatts; this, the WR-1 reactor, is located at AECL's Whiteshell Nuclear Research Establishment in Manitoba. This organic liquid, in conjunction with thorium fuel and enriched uranium, promises to allow a reactor to operate at more than three times the power density of existing installations and so reduce its capital cost. Moreover, the operating costs are expected to be much lower, for, after five years operation of WR-1, the caloporteur-circulating pumps and piping show negligible radiation levels and allow easy maintenance.

In addition, 1971 saw the successful start-up of KANUPP, a generating station using a CANDU reactor of 125,000 kilowatts rating designed and built by the Canadian General Electric Company in Pakistan near Karachi. Four more 200,000-kilowatt CANDU reactors are under construction by the Department of Atomic Energy in India.

Operating difficulties initially experienced with the Douglas Point generating station have been largely overcome and fuel has been changed routinely with the reactor at power since March 1970.

The success of these operating reactors has not lessened the demand on AECL for supporting work of many kinds. In particular, a shortage of heavy water for new reactors is foreseen, resulting from the failure of a production plant commissioned from private industry. AECL has now been assigned responsibility for rebuilding and commissioning this plant. Meanwhile AECL is building a larger plant at Bruce, close to Douglas Point, Ontario.

The large-scale engineering work undertaken by AECL has also included the construction of a high-voltage DC transmission-line to bring power from the Nelson River in northern Manitoba to Winnipeg. This line has been successfully built but manufacturing problems have delayed much of the power-conversion equipment.

AECL has continued to expand its production of radioactive cobalt-60, used throughout the world in radiation teletherapy units for cancer treatment and also in industrial plants for the sterilization of packaged medical supplies and similar purposes.

The very small low-energy nuclear reactor -- SLOWPOKE -- brought into operation at Chalk River in 1970 has been moved to the University of Toronto for use principally in the neutron-activation analysis of materials at low levels of concentration, such as mercury in foods. A second SLOWPOKE, with some refinements, has been brought into operation at AECL Commercial Products in Ottawa.

The aluminum vessel forming the core of the NRX reactor at Chalk River since 1954 had corroded in some areas and was replaced at the end of 1970 in an operation that was most satisfactorily completed in 130 days. Preparations have been made for replacing the reactor vessel in the larger NRU reactor at Chalk River, which has operated since 1957.

Over the past few years there has been growing public concern about pollution of the environment. For many years AECL has had an environmental research branch at Chalk River, and has been able to study the problems of radioactive-waste management in a secluded area. This area is on bedrock that forms a basin with only one water outlet, a small creek that is monitored to assure that the outflow meets the radiation levels permissible for drinking water. Should such levels be approached, it is possible to raise the weir level to increase the dilution or to process the whole stream. Glass blocks containing high levels of strontium-90 and caesium-137 were buried there in 1959 and the levels of activity in the surrounding ground-water have been followed and found to be satisfactorily low. Such a method of managing wastes appears preferable to any disposal in an area at a distance from an operating plant. Radiation levels are far below those at which biological effects can be expected, but by the use of sensitive detectors it is possible to follow any movement of radioactivity within the management area. It seems likely that the CANDU reactors will be easily managed without imposing any burden on the environment. In order to obtain independent monitoring, AECL many years ago passed over to the Department of National Health and Welfare responsibility for the radioactive monitoring of public water supplies, discharges into rivers, and radioactivity from the atmosphere that may enter milk supplies by settling on vegetation.

Fundamental research has always been, and must remain, the basis of AECL's development. AECL's primary research tools are the reactors. The three large reactors, NRX, NRU and WR-1, are major research installations providing facilities in their cores for irradiation of materials over extended periods. Special isolated fuel channels, or loops, are provided for the "in-reactor" testing of different types of fuel and coolant systems -- this testing being fundamental to further development of the Canadian power-reactor program. Additionally, horizontal holes through the reactor shielding allow intense neutron beams to be directed to various test rigs. One such rig (in NRU) includes a fast-beam "chopper", allowing time-of-flight studies on neutron interactions with matter. In-reactor loops at CRNL and WNRE are complemented by out-of-reactor test rigs, which, apart from the radiation field, simulate reactor fuel-channel conditions.

Commissioning of a new out-of-reactor research facility designed specifically for investigation of the BLW and the Advanced BLW reactor concepts was completed in 1971. This test rig uses Freon as a coolant, and is designed to simulate a variety of power-reactor conditions. With three full-size test sections, the loop will provide realistic test facilities for any CANDU type of fuel configuration at present envisaged. The use of Freon (with its low vapour pressure) as a modelling fluid to simulate water provides a considerable saving in both construction and power costs.

A further major research tool at Chalk River is the 10-megavolt "MP" Tandem Van de Graaff Accelerator. Among its many uses are precise studies of the structure and excited states of heavy atomic nuclei. Data acquisition and analysis equipment associated with the accelerator is on-line to powerful data-processing systems. The accelerator is undergoing modifications to uprate the machine to 13 megavolts, which will provide higher particle energies and considerably increase its research potential.

In the field of technical information, the introduction of mechanized systems is progressing. The main CRNL library -- Canada's national repository of nuclear literature -- has successfully introduced computer control of book circulation and periodical renewal and budgeting. Experimental operation of a computerized current-awareness service has started -- initially serving AECL staff but later to be extended on a national basis. Additional technical information activities included the co-ordination of the 17 Canadian papers presented at the fourth United Nations Conference on the Peaceful Uses of Atomic Energy, and preparation of supplementary material for this conference.

As previously mentioned, the Whiteshell Nuclear Research Establishment is specifically oriented toward investigation of materials for advanced reactors. The establishment's research reactor, the organic-cooled WR-1, is undergoing modification to replace its stainless-steel fuel channels with channels of Ozhennite -- 0.5. The comparative "transparency" to neutrons of zirconium will permit a reduction in fuel enrichment and a 50 percent increase in neutron flux. Additionally, the reactor core is being increased in size from 37 fuel sites to 54, improving the flexibility and capacity of the reactor to deal with experimental programs. Two in-reactor organic loops have been commissioned in WR-1, both of which, at 4.5 megawatts each, are of higher power than the existing water-cooled loop. A fourth loop is under construction.

Out-of-reactor loop work at WNRE has been devoted to investigation of liquid-metal coolants, which offer higher temperatures than the organic liquid. Three lead-bismuth loops (one at 630°C, the others at 800°C) have provided much information on liquid metal heat-transport systems, and a fourth facility using molten lithium is being commissioned.

A terminal unit and data-link at Whiteshell, installed in 1971, now provide the WNRE with direct access to CRNL's powerful CDC 6600 computer system. A similar link serves power projects.

Other projects at Whiteshell include work on radiation-field measurement techniques in confined spaces (such as inside reactor cores), investigation into fundamental biological mechanisms and the effect of radiation (especially low-dose exposure) on them, and materials research -- particularly oriented toward fibre-reinforced ceramics.

Radioisotopes made in the Chalk River reactors are marketed through Commercial Products for use in medical applications for diagnosis, therapy and research. Radioactive tracers are also used significantly in agricultural research by a number of groups throughout Canada.

The Commercial Products group, well established as a world leader in the design of cancer-therapy equipment, introduced a new cobalt-60 therapy machine, known as the Brachytron. This instrument can remotely locate up to three small cobalt-60 sources in body cavities for internal radiation therapy and represents a great advance over the existing treatment techniques using manually positioned external sources.

Under a contract with the Task Force on Oil Pollution, measurements of the trace elements in oil samples from known sources are being made. It is hoped that this could lead to the setting up of a file of distinctive features, enabling identification of oil-pollution sources. Commercial Products has also introduced a trace-element analysis service for government and industry. Employing neutron-activation analysis techniques, the service can identify elements and their quantities in submitted samples. This service has special application in the determination, for example, of various contaminants in food sources and human tissue.

The transportation of radioactive materials is subject to specific regulations, and many developments have been made over the years to ensure that these can be met.

The advent of the Nuclear Weapons Non-Proliferation Treaty and the safeguards against fissile-material diversion, inspected by the International Atomic Energy Agency, has led to special developments of instruments and procedures.

Despite the increasing load of development work, a high quality of active research has been maintained, as has collaboration with other laboratories in universities and research institutes in Canada and abroad.

Relations with Other Organizations

A strong feature of the Canadian organization for atomic energy is that the regulatory body -- the Atomic Energy Control Board (AECB) -- is separate from the chief executive agency (AECL). This does not, however, preclude close working relations. The President of AECL is, *ex officio*, a member of the Control Board and AECL staff are members of several AECB advisory committees.

AECL shares with the Department of Industry, Trade and Commerce a desire to increase the participation of Canadian industry in the developing nuclear market and AECL's many overseas interests involve relations with the Department of External Affairs and the Export Development Corporation.

While AECL does not make grants to universities, research contracts are negotiated in many cases where the university has the necessary facilities and expertise. Some 20 Canadian universities undertake such work for AECL. However, the close relations that have been built up with universities are mainly the result of personal contacts. During the summer, many graduates and undergraduates of Canadian universities work at AECL establishments. A number of professors also use AECL facilities for research projects, a service which, owing to the demand, is now available throughout the year under the aegis (at CRNL) of the Experiments Advisory Committee, a joint universities and CRNL committee. It is also noteworthy that some 60 former AECL employees now hold staff positions at Canadian universities.

AECL has encouraged and fostered Canadian industrial participation in many aspects of its program by the award of research and development contracts and the employment of professional and consulting services. Development contracts have contributed materially in qualifying Canadian companies to supply services, materials and equipment to the exacting standards required in the nuclear industry. As a result, two Canadian companies are now established as qualified and competitive suppliers of nuclear fuels. In other cases, qualification results from trial orders, supported by the provision of a prototype or samples, specifications and assistance from the laboratories and technical staff.

International Relations

International relations have always been an important feature of Canada's nuclear program. Many irradiations in the NRX, NRU and WR-1 reactors have been made for several countries at their expense or on a shared-cost basis, notably for the United States, Britain and Euratom. In exchange for information on the Canadian power-reactor program, the United States carried out an agreed research program in support of AECL's work. Technical meetings and the exchange of reports have maintained contact between the British steam-generating heavy-water power-reactor project and the Canadian program. Informal exchanges of visits and information with France and Italy have taken place for many years. Italian relations have been strengthened and put on a more formal basis recently with the maintenance at CRNL of a full-time Italian liaison office. Close relations also exist between AECL and the Department of Atomic Energy (DAE) in India, the first Canadian-designed research reactor to be built outside Canada (CIRUS) having been set up near Bombay in a co-operative program partly supported by the Colombo Plan. AECL also designed India's first heavy-water nuclear-power station, the Rajasthan Atomic Power Project (RAPP), now under construction in a co-operative program. This will consist of two 200-megawatt reactors, each very similar to Canada's Douglas Point station.

Additionally, formal arrangements for information exchange have been established with Australia, the Federal Republic of Germany, Japan, Romania, Spain, Sweden, Switzerland and the Soviet Union.

AECL is represented on numerous international organizations and committees. Its Senior Vice-President, Science, represents Canada on the United Nations Scientific Advisory Committee to the Secretary-General, and is also a member of the International Atomic Energy Agency (IAEA) Scientific Advisory Committee. Canada is a member of the Board of Governors of the IAEA and participates in advisory panels, conferences and symposia arranged by this organization, and also plays an important part in the development of the International Nuclear Information System (INIS), which is providing a world-wide nuclear-information service. Canada is a major participant in the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), as well as other *ad hoc* United Nations committees. AECL also contributes to the activities of the International Commission for Radiological Protection, the International Nuclear Data Committee, the European Nuclear Energy Agency and the International Council of Scientific Unions.

The fourth United Nations Conference on the Peaceful Uses of Atomic Energy, attended by 4,000 delegates and observers from 79 countries, has profound significance. First, it has served to emphasize the extremely rapid rate of progress being made in nuclear science -- it is, after all, less than 40 years since Rutherford and his research team were investigating the structure of the atom and now nuclear-power reactors with outputs of the order of hundreds of millions of watts are operating. Even more significant, the tremendous potential of nuclear power has proved to be a major force in promoting true internationalism; in no other activity has the world seen such a high degree of international co-operation. The necessity for such co-operation is becoming increasingly obvious -- the prospect looms of a world population of 15,000,000,000. Applications of radiation and radioisotopes to agriculture and medicine are beginning to provide some of the answers that will help the world support its millions and provide them with the fundamental amenities, but the major problem remains one of power supply. It has been estimated that a 15,000,000,000 population would require 300,000 gigawatts (1 gigawatt = 10^9 watts) of energy. Canada's presentation at the Geneva Conference indicated that the CANDU reactor system had reached the stage from which it could make a major contribution. Not only is the system advanced in development, but resources of uranium and thorium are more than sufficient for the foreseeable future.

CHRONOLOGY OF NUCLEAR POWER IN CANADA

1942-43 Research scientists from Cavendish Laboratories, England, arrived in Montreal to continue work on atomic bomb project.

1944 Under auspices of National Research Council (NRC), work started on Chalk River Nuclear Laboratories (CRNL).

1945 First working reactor, ZEEP (Zero Energy Experimental Pile), outside of the United States attained criticality at CRNL.

1947 NRX (National Research Experimental) reactor came into operation at CRNL. Initial power 38 megawatts (thermal).

1952 Formation of Atomic Energy of Canada Limited as a Crown corporation. Commercial Products transferred from Eldorado Corporation to AECL.

1957 NRU (National Research Universal) reactor came into operation. Design power 200 megawatts (th).

1962 NPD (Nuclear Power Demonstration) generating station started operations at Rolphton, Ont. Power 22 megawatts (electrical).

1964 WR-1 reactor came into operation at Whiteshell Nuclear Research Establishment, Man., using mixture of organic fluids as coolant -- Canada's first organic cooled reactor. Initial power 40 megawatts (thermal).

1965 First Canadian full-scale prototype power reactor started up at Douglas Point. Heavy-water-moderated, heavy-water-cooled reactor, with output of 208 megawatts (electrical).

1970 Gentilly boiling light-water-cooled power reactor attained criticality near Trois-Rivières, Que. Power output to be 250 megawatts (electrical).

1971 Pickering I came into operation. Power output 540 megawatts (electrical). Pickering II attains criticality.

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