CANADA

CANADA, THE CANDU AND THE FUTURE

by J. L. GRAY, President, Atomic Energy of Canada Limited

I am honoured to have been among those asked to contribute to this issue of the IAEA Bulletin commemorating the 30th anniversary of the first man-made self-sustaining nuclear chain reaction.

I also welcome the opportunity to congratulate and commend the IAEA for the great deal of good work it has done in promoting and fostering peaceful uses of atomic energy throughout the world. Much of the progress that has been made in nuclear development has been due to co-operation between and among nations, and in this area the IAEA has taken the lead and has set for us all a splendid example.

We have, all of us, nuclear programs which are national in character, and are so identified. Canada, for instance, is known for having pursued an independent course in nuclear power and in the process produced the CANDU series of reactors. Nevertheless, even though we have gone our own way, we have benefited considerably from co-operative agreements with other countries and information that has come to us through the open literature. Conversely, others, I am sure, have benefited from research and development done in Canada.

From the outset, Canada has concentrated on the design and development of reactors employing heavy water as the moderating material. Initially the choice was circumstantial, but subsequently it was deliberate, being a result largely of experience gained and success achieved in the operation of large, heavy water-moderated research reactors. From this experience evolved the basic CANDU nuclear power system – heavy water moderator and natural uranium fuel in a pressure tube reactor. To these features may be added a fourth, on-power refuelling.

Canada's first nuclear power reactor, called Nuclear Power Demonstration, with a net capacity of 22 electrical megawatts, was started up in 1962. Now, ten years later, operating nuclear capacity in Canada is 2 000 megawatts, or about 100 times that of NPD.

Of the many milestones that have marked our progress to the present, I would say that the one inscribed "Pickering, 1971-72" stands out the most. For it has been the highly successful performance of three 500-megawatt units of Pickering Generating Station, since starting up successively in 1971-72, that has firmly established commercial nuclear power in Canada and the viability of the CANDU system.

The fourth Pickering unit is due to be completed and come on line in 1973. Then at yearly intervals between 1976 and 1979, the four 750-megawatt reactors of the Bruce Generating Station, now under construction, will begin producing power. So another 3500 megawatts of operating nuclear capacity are to be added in the Ontario Hydro system, and with the installation of a 600-megawatt unit in the Hydro-Quebec system, for operation in 1979, total nuclear capacity in Canada will reach 6100 megawatts by 1980.

According to one forecast, Canada's nuclear power capacity 20 years hence, in 1992, will be in the neighbourhood of 44 000 megawatts. This is a 22-fold increase over the present output and presages the installation of two units or more a year, in sizes of 750 megawatts and larger, during the latter half of the period.

We foresee the present conceptual reactor designs persisting into the 1980s. The CANDU-PHW system, in which a CANDU reactor is cooled with pressurized heavy water, has established itself at Pickering and our utilities are unlikely to opt for any radical design changes unless they are clearly proven to be better. Our first emphsis will be on effecting refinements to known designs, with the object of reducing costs and improving reliability and performance.

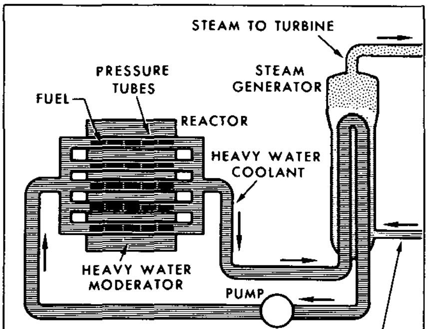
The Bruce heavy water plant,
with a design capacity of 800 tons a year. Its first production is scheduled shortly.

And, as we gain more experience in the operation of nuclear plants, so do we find more places where improvements can be made.

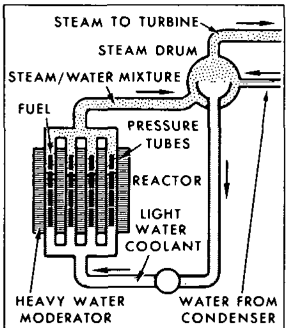
While basic designs may not change appreciably, unit sizes are expected to increase, to 1200 megawatts and possibly larger. We may also go in the other direction. It is commonly held that nuclear power plants are not competitive in sizes of less than 500 or 600 megawatts. However, the minimum size is decreasing, as fossil fuel prices increase, and we may well see nuclear plants as small as 200 megawatts chosen to supply power for areas of low demand, in Canada and elsewhere in the world. This is an intriguing prospect and one to which we are giving some attention.

A notable feature of the CANDU system is its flexibility and its capacity to lend itself to step-by-step, evolutionary improvements. Thus, although we expect PHW reactors to be the main commercial line in Canada for many years to come, we have under way two major programs directed toward the development of coolants alternative to pressurized heavy water.

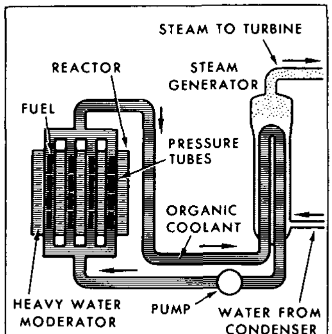
One is boiling light water and it is being tested in a prototype power station (CANDU-BLW) that has been in operation since 1970. If the station, Gentilly, continues to establish a good performance record, I see the possibility of a commercial BLW breaking the PHW monopoly in the next 10 or 15 years. The main attraction of boiling light water is its promise of lower capital costs and continued low fuel costs.



PHW
(Pressurized Heavy Water)



BLW
(Boiling Light Water)



OCR
(Organic Cooled Reactor)

The other coolant to which we are giving serious attention is an organic, oil-like substance. Many of the problems predicted for this material have been overcome in the operation of the organic-cooled research reactor, WR-1, and we are making a detailed engineering study of a 500-megawatt plant to obtain an accurate picture of the advantages of a CANDU-OCR. Proven features of the organic are high temperature leading to higher thermal efficiency, low pressure in the coolant circuit and an absence of activity in the heat transport system, making for easy access to many reactor systems for maintenance and repairs during operation.

Whatever the coolant, the heavy water moderated CANDU reactor is distinguished by its high nuclear efficiency -- its economical use of neutrons -- resulting in the ability to burn natural uranium fuel, in fuelling costs that are appreciably lower than those of other systems, and in a simple throw-away fuel cycle. Spent fuel processing is not a current requirement, so we are not faced with the cost and complications of reprocessing and associated waste management.

Future CANDUs may well use fuels other than natural uranium, or in combination with natural uranium, if the economics dictate. Here again the system has great flexibility, for it can be adapted readily to a variety of fuelling regimes.

Plutonium, of which CANDU is a relatively prolific producer, is a potential future fuel, with particular application to CANDU-BLW reactors. Realizing that we shall have a sizeable plutonium inventory by 1980 or so, we have under way a program that has progressed to where we have produced some uranium-plutonium oxide fuel bundles for testing over a period of two or three years in the NPD reactor.

An organic-cooled reactor fuelled with natural uranium requires a fuel with greater density than UO_2. Uranium carbide is the prime candidate and the WR-1 reactor is to be loaded next year with uranium carbide fuel, with the object of obtaining the experience and data needed to establish an economic fuel fabrication process. Uranium metal also has its attractions, and experiments with uranium metal will be continued in loops associated with WR-1. In the longer term, we see the introduction of thorium into the CANDU fuel cycle, thereby extending indefinitely the availability of nuclear fuel.

The fast breeder is one area where we have not expended any effort. For one thing, we could not have afforded it. And in any event, we do not feel in Canada the same pressure to develop breeders that there is in countries whose reactors are more extravagant in the use of uranium. We expect that CANDUs, in one variant or another, will serve Canada well for many years to come, with a distinct possibility of their being adopted in other countries as their advantages, features and performance record become better recognized.

Our opinion is that the Canadian series of heavy water reactors will evolve to a system that is generally equivalent in resource economy to fast reactors (particularly during the next few decades, when power generation is expanding), that is equal or lower in power costs and is technically much simpler. Moreover, we see CANDU becoming complementary to rather than competitive with the fast reactors. Plutonium from thermal reactors will be required to meet the needs of an expanding system of breeders, and in the longer term the CANDU thorium burner will be a companion system to the uranium-burning breeder.

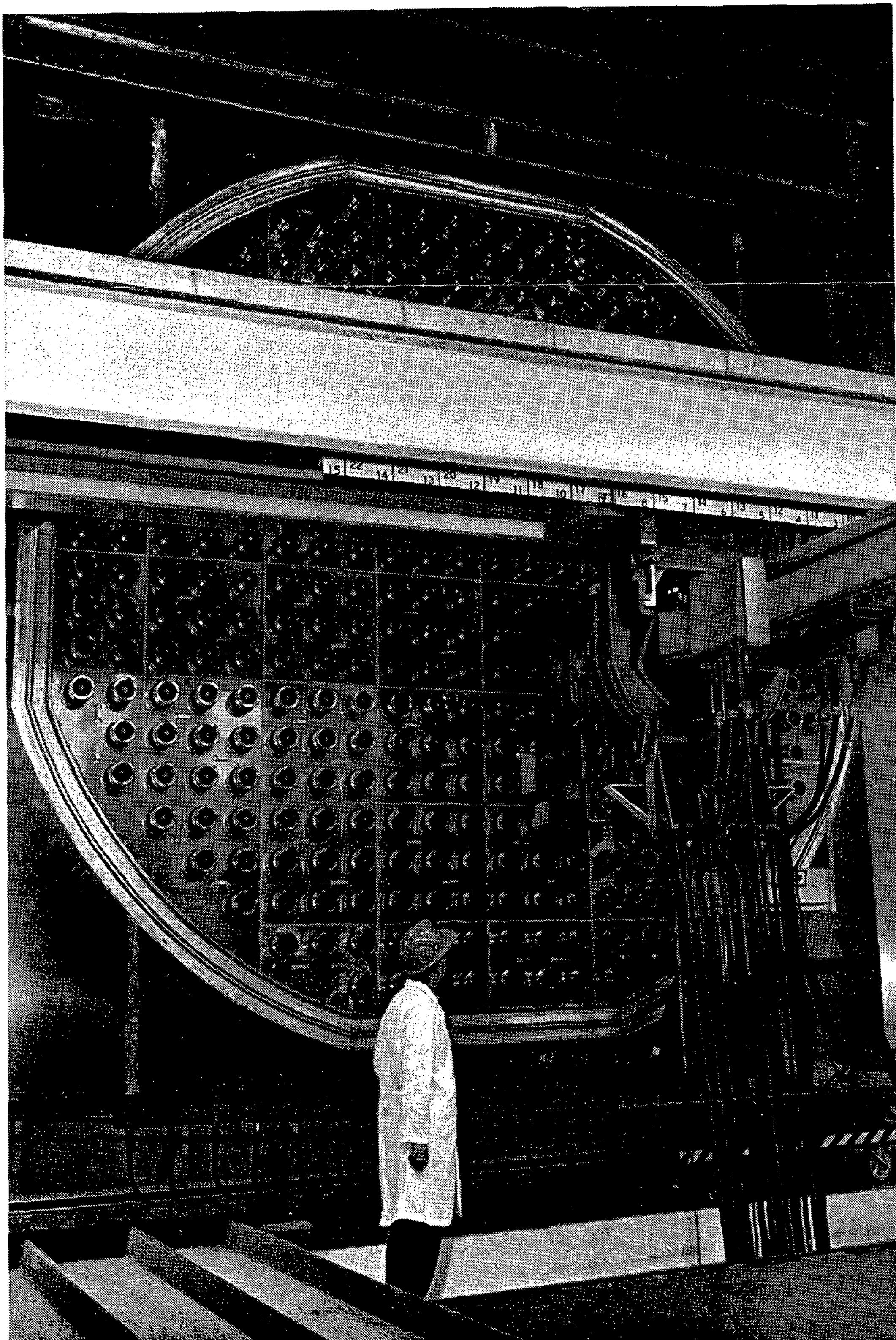
In the realization that neutrons are the currency of nuclear power, we are studying the possiblity of developing an accelerator, or accelerators, that will produce neutrons cheaply and in quantity for injection into the CANDU system. These electrically-produced neutrons might be used, for example, to produce fissile materials to feed the thorium fuel cycle. While we are reasonably sure the process is feasible, at the present time it is not economic. However, advances in accelerator technology that are under way or in prospect may well make the electronuclear process look very attractive 20 years or so from now.

In addition to its long-term objective, our work on accelerators encompasses other more immediate applications, in medicine, industry and research. Medical accelerators, machines for the treatment of waste water or the sterilization of wood chips, and microwave power for the drying of wood are examples.

For more than 20 years, Canada has been in the forefront in the production of radioisotopes and the development of radioisotope applications. It was in Canada, in 1951, that a cancer patient was treated for the first time with a cobalt-60 teletherapy machine, and since then we have seen this form of treatment become commonplace throughout the world.

Mankind has benefited from the use of cobalt-60 in the treatment of cancer and we expect these benefits to continue and expand. At the same time, we anticipate that parallel benefits will be available from particle accelerators designed for therapeutic uses. New cancer treatment techniques involving neutron generators will also emerge and may find an important position as better and less expensive equipment is developed.

Gamma radiation from cobalt-60 has been used for more than seven years in the sterilization of commercial quantities of medical disposables. The positive results and low-cost aspects indicate a much broader application in the field, particularly as hospitals move increasingly to the use of sterile medical packs for specific uses. Cobalt-60 is already available in quantities large enough to satisfy demands for these uses and production from power reactors permits essentially unlimited supply.



Pickering reactor face and fuelling machine

Radionuclides coupled with thermo-electric conversion are now finding use in radioisotope power generators. Canada's geographic features – thousands of miles of rugged coastline, long overland distances in sparsely populated regions, and navigable Arctic passageways – have spurred the development of long-lived reliable electric power sources using radio-cobalt to operate automatic navigation beacons, for the support of weather stations and for individual links in long-distance microwave communication networks. Prototype units are in operation and their performance indicates extensive use of this practical and versatile power source.

The use of activation analysis employing neutron sources with higher fluxes has already demonstrated sensitivities from 0.04 to 50 000 ppm on a continuous basis. Spot and continuous process control using this convenient and accurate tool will expand. Canada has developed a small, self-regulating, fail-safe, low-cost reactor admirably suited to such applications.

Plant growth stimulation resulting in early maturity and higher yields has already been demonstrated. This will have particular application in short-growing season areas but should also win commercial acceptance in others. Field tests on sweet corn, lettuce, tomatoes, cucumbers and other products show promising results. Small, inexpensive cobalt irradiators could become standard equipment in the agricultural industry.

The treatment of foods to increase shelf-life has been progressing slowly, although the scientific and technical results are encouraging. Potato and onion sprouting can be easily controlled, greatly enhancing storage capabilities. Shelf-life of fresh fruits can be extended, allowing longer shipping and processing periods. Irradiation of meats offers real benefits where storage is a factor. The economics of all these "benefits" vary with circumstances and the approvals by the relevant authorities for human consumption of irradiated foods have been slow. However, one cannot help but predict that within a decade irradiated food and grain will be on the market and within the present century we could easily find this to be a very large business with tremendous benefit to a hungry world.

Another application with potential is the use of radiation in the initiation of chemical reactions. The production and use of wood-polymer combinations is of considerable interest in Canada, with its important forest products industry. The improvement of textile properties by radiation grafting of selcected molecules onto the existing fibres allows selective improvement in properties such as moisture uptake, stain resistance, resistance to wear, dyeability and ultra-violet stability. Gamma radiation requiring no chemical catalyst and operating at normal temperatures and pressures will be used in processes to manufacture superior materials within the decade.

The atomic energy program in Canada had its beginning at about the same time that Fermi and his associates initiated the chain reaction beneath the stadium at Stagg Field. In that winter of 1942-43, scientists came to Canada from the United Kingdom, to establish with Canadian colleagues an Anglo-Canadian nuclear laboratory. The team from Britain included eminent scientists from many countries, giving the Canadian program at its inception a truly international flavour.

In 1945 the ZEEP reactor was completed and became the first reactor to be brought into operation outside the United States. Then in 1947 the powerful and versatile NRX was started up. Since then the Canadian program has steadily expanded, with the Canadian government giving generous support throughout the period.

In nuclear power, the policy from the outset has been to involve the utilities and industry to the fullest possible extent. As a result, we now see one utility, Canada's largest, heavily committed to nuclear power and possessing a strong nuclear competence; a second large utility heading in that direction, and a sound and widespread industrial base capable of meeting the stringent demands of the nuclear program.

Looking back, we can see we have come a long way in 30 years. Looking ahead, we can see how far we still have to go.