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By F. C. Boyd

Nuclear power is more than a promise; it is already very much a reality. In most developed countries a significant amount of electricity is now being generated from power stations using nuclear reactors, and more than 50 per cent of new electrical generating plants in the United States and Western Europe are nuclear. Although Canada has large reserves of oil and gas and still has some undeveloped hydro-electric potential, most of the new electric generating stations in Ontario will be nuclear and other provinces will soon add nuclear power stations. The reason for this rapid growth of nuclear generating capacity is that nuclear reactors have proven to be an economical and safe source of energy. As our demands increase the use of oil, gas and coal their availability goes down and the cost goes up. On the other hand there are very large deposits of relatively low cost uranium in Canada and in several parts of the world which provide an economical alternative to the fossil fuels.

Various forms of nuclear reactors have been developed in different countries. In Britain the most predominant form has been graphite-moderated reactors cooled with carbon dioxide gas. France previously concentrated on graphite reactors but now like many other countries has adopted the light water reactors designed originally in the U.S.

In Canada we have developed our own unique CANDU system using heavy water as the moderator, i.e. the material to slow down the neutrons produced in the fission reaction. A major advantage of the heavy water reactor is that it can employ natural uranium as fuel and does not require enriched uranium as do the light water reactors. Only one part in 140 of natural uranium is composed of the easily-fissioned isotope U-235. To separate this from the predominant U-238 requires enormous diffusion plants which have been built in the U.S., U.K., France, U.S.S.R. and China as part of their nuclear weapons programs.

The practical proof of the Canadian heavy water concept can be found in the Pickering Generating Station near Toronto which is the first full scale nuclear power station in Canada. The plant was built very close to the original time schedule and three of the four units are already producing electricity at lower cost than fossil fuel plants of the same period.

Another distinguishing feature of the CANDU-type nuclear reactor is the use of pressure tubes for the fuel channels in

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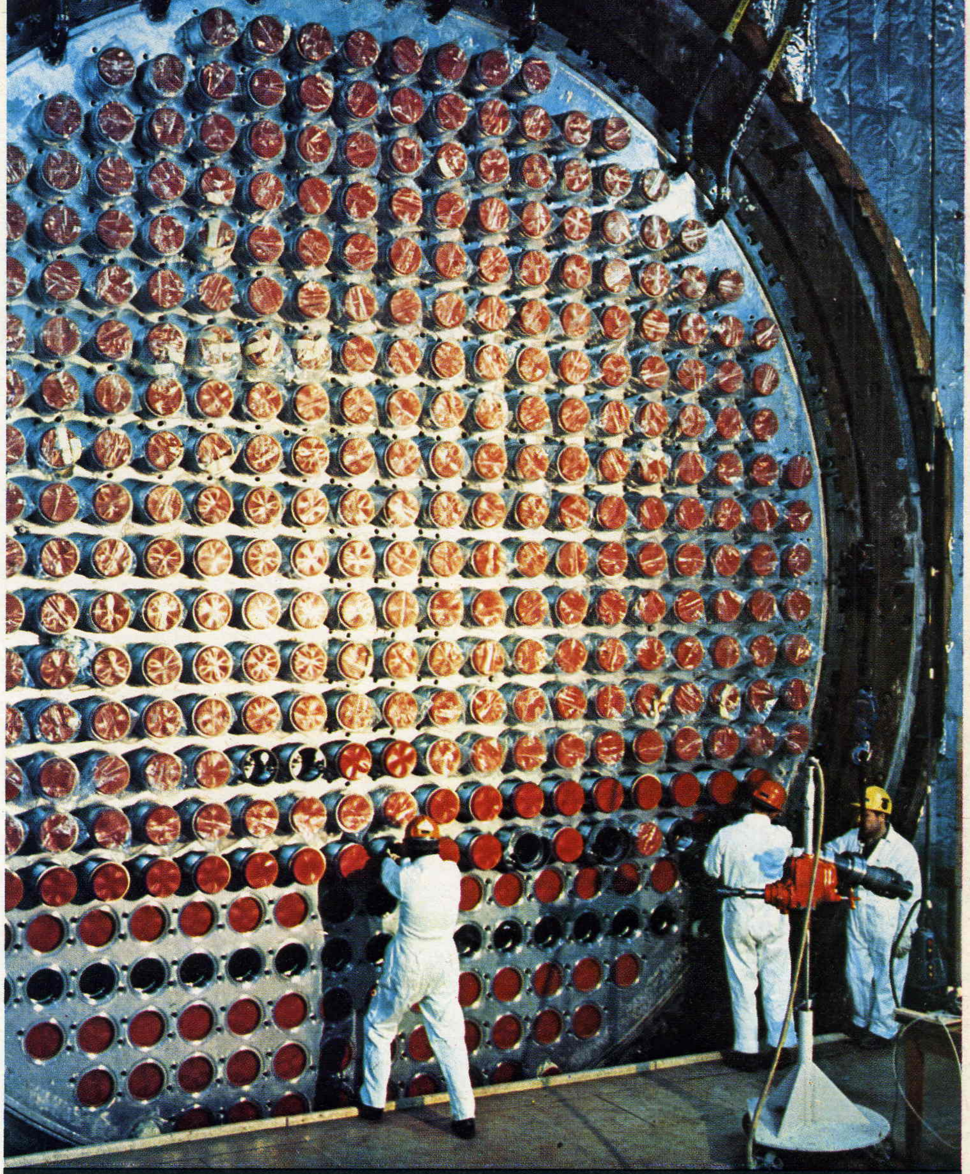

CANADA PLANS FOR SAFE NUCLEAR POWER

The Atomic Energy Board checks out all nuclear installations such as the fuelling channel bellows being fitted in the picture above at the reactor face of Unit One at the Pickering station.

contrast to the large pressure vessel used for a light water reactor. This aspect has many advantages ranging from the possibility of mass production of the channels in Canadian industries to greater safety by eliminating the concern about the consequences of a failure of the large pressure vessel.

The safety of nuclear power has been uppermost in the minds of those developing and designing nuclear power plants since the very beginning. Perhaps the fact that nuclear power followed after nuclear weapons development underlined the need for very careful evaluation. Although no nuclear power plant can explode like a bomb, reactors do produce large quantities of radioactive material which if released could be very dangerous. Because of this concern and awareness of the potential dangers, the development of nuclear power in all countries has been accompanied with a regulatory process somewhat unique in modern industrial methods. Most countries require prior evaluation of the safety implications and environmental impact before permitting a nuclear power plant to be constructed. In Canada this control is exercised by the Atomic Energy Control Board which administers the Atomic Energy Control Act.

The Board was established in 1946 when the Act was proclaimed but its staff remained extremely small until the 1960's. Since then it has grown to a present complement of 50 people. The Board has five members one of whom is the President who is also the Board's chief executive officer. The Act empowers the Board to make regulations covering the development of all aspects of atomic energy, to disseminate and control information and to offer grants to promote research in the atomic energy field. The Minister of Energy, Mines and Resources is the designated minister through whom the Atomic Energy Control Board reports.

The Act also authorizes the designated minister of the government to establish companies in the name of the government, for research and development of atomic energy. The crown corporation, Atomic Energy of Canada Ltd., was formed in 1952 to take over the nuclear research centre at Chalk River, which had been set up in 1945 by the National Research Council, and to carry on with research, development and exploitation of atomic energy. The company now operates another research centre near Pinawa, Manitoba, an engineering office near Toronto and a radioisotope facility in Ottawa.

The Atomic Energy Control Board exercises formal control over the development and building of nuclear power plants in Canada through a system of construction and operating licences. In addition semiformal discussions are held at the site selection stage at which questions of potential environmental impact are raised. During these early discussions concerning site approval, when only the general nature of the plant may be known, interest is centred on characteristics of the site such as the size, geology, usage of the surrounding land, population, density, meteorology and water consumption. This is also the time when the relevant federal and provincial government departments having an interest in these factors are first brought into the picture.

To obtain a construction licence an applicant must submit to the Board a description of the proposed design together with analyses of possible malfunctions and any hazards arising therefrom. The design and analyses are reviewed by the technical staff of the Board together with an expert Reactor Safety Advisory Committee. During this review, meetings are held with the designers to obtain additional information that might be required for a proper assessment of the safety of the proposed nuclear plant.

Depending upon the circumstances, the Board, through the advice of its Committee and staff may require substantial changes in a design before granting a construction licence. An example is the case of the Pickering Generating Station where the construction licence was withheld until the unique vacuum containment system was developed to a point which the Board and its committee felt was acceptable. In this system the four buildings housing the four nuclear reactors are connected to a large cylindrical structure held at very low pressure. In the event of a failure of the cooling system of any of the reactors the released hot pressurized water which flashes to steam and any attendant released radioactive material would be expelled into the large vacuum building, collected by a falling water stream, and the liquid held there for safety.

Since the design is typically not completed at the time when construction begins the construction licence may contain several conditions restricting certain aspects of the installation of equipment or further construction until further details are designed or further analyses have been submitted and accepted. Whether or not such conditions are explicitly stated in the licence, the committee and staff meet with the designers frequently during the construction progress to consider details of design as they are developed.

When construction is completed the various systems of the nuclear power plant must be tested to ensure that they function as intended. These tests are observed or overseen by members of the Board staff resident at the reactor site during the final construction, testing and commissioning phases. The Committee and staff review the final design, the results of tests and the plans for operation. When they determine that the plant has been designed, constructed, tested and staffed adequately and can be operated safely they will recommend to the Board that the operating licence be granted.

In addition to the design details of the plant, the qualifications and experience of the key operating staff of a nuclear plant are examined by a special committee established by the Board. Certain key operating people such as the shift supervisors and control room operators must write examinations that cover both the theoretical and practical aspects of operating the plant and give emphasis to protection of both people and the environment.

Despite the care exercised and the strict regulatory process employed there have been numerous public complaints and criticisms throughout the world of the safety of the nuclear programs. This has been especially so in the U.S. where the questioning has centred on four points: (1) the conflict of interest within the United States Atomic Energy Commission between regulation and promotion; (2) the possible unreliability of emergency core cooling systems; (3) the effect of thermal discharges; and (4) the adequacy of radiation dose limitations.

"the safety of nuclear power has been uppermost"

In the U.S. the licensing of nuclear power plants is conducted by a group within the United States Atomic Energy Commission, the same organization which develops nuclear weapons and which has been the main promotional body for the development of peaceful nuclear energy. Although the USAEC has made great efforts to keep the licensing group separate from the rest of the organization, critics continue to point to the potential, if not actual, conflict of interest. As indicated earlier, the situation is different in Canada where the Atomic Energy Control Board is a separate governmental agency whose prime responsibility is the regulation of the atomic energy field for safety and security.

The emergency core cooling controversy in the U.S. concerns one of the major safety devices which is typically incorporated in a nuclear power plant. In the event that one of the main pipes of the cooling system of the nuclear reactor should fail and the coolant were to be lost it is possible that even though the reactor was automatically shut down the fuel would overheat due to its contained radioactive material, then melt and disperse some radioactive material. All nuclear reactors operating at elevated temperatures and pressures have emergency cooling systems attached to them to cool the fuel in the remote possibility of a gross failure. The controversy in the U.S. developed in 1971 with the release of data from small scale tests on emergency core cooling systems made at the nuclear reactor testing station in Idaho. These showed that in several cases the coolant did not refill the test pressure vessel and therefore would not cool the fuel. The USAEC held a series of public meetings in 1972 to review this situation and has issued more restrictive interim criteria for the design of emergency cooling systems. In the Canadian system with the pressure tube concept it is easier to ensure that the emergency cooling is directed onto the fuel. Although several model tests have been done to demonstrate the inherent safety of the CANDU emergency cooling system, a review of the process is currently being conducted under the direction of the Atomic Energy Control Board.

Because of materials limitations, nuclear power plants operate at a somewhat lower thermal efficiency than current fossil fuel plants. In addition all the waste heat is rejected to the cooling water of the turbine, while much waste heat from a fossil-fuelled plant goes up the smoke stack. Consequently the waste heat to the cooling water from a nuclear power plant is about 50 per cent greater than that from a comparable size fossil fuel plant. Although studies commissioned by E.M.R. show that the total heat from all industrial and power plants on the Great Lakes to the year 2000 will still be a very small addition to the heat from the sun, this waste heat (sometimes termed thermal pollution) can have significant local effects. Because most of our lakes and rivers are relatively cold this thermal pollution problem is not considered to be a major immediate problem in Canada.

The question of the adequacy of the radiation exposure regulations is a complex one. All countries have adopted as general criteria the recommendations of the International Commission on Radiological Protection, a non-governmental body working in this area since the 1920's. At the levels of radiation dose recommended by the ICRP for atomic energy workers and for the general public, no deleterious effect has ever been observed. However, laboratory experiments with animals indicate that with significant radiation dosage various forms of cancer and other damaging effects can occur.

While most of these experiments have not demonstrated that there is a threshold to this effect, some experiments do suggest this. Using the pessimistic assumption that the effect of radiation exposure is linear (from the observed effects at relatively high doses down to the extremely low doses which might be received around nuclear power plants) critics have predicted that there would be significant effects in the total population if everyone was exposed to the allowed limits. While no country has yet felt it justified to lower the limits, the USAEC has published guidelines for the operation of nuclear power plants which set the design limit for the radiation exposure to individuals near a light water reactor nuclear power plant at 100 times lower than the general radiation exposure regulations. In Canada different guidelines have been used for the last seven years which ensure that the exposure to a significant number of people is extremely low. This has resulted in designs where the radiation dose to the general public from the operation of nuclear power plants is as low or lower than that from American plants.

The possibility of an accident which could release significant quantities of radioactive material has been the major concern in the licensing review of nuclear power plants. Every effort is made to ensure that the likelihood of any major release of radioactive material is so small as to be considered impossible in ordinary terms. The first line of defence in ensuring the low probability of accidents is a requirement for thoroughness and extremely high quality in the design and construction of the plant. Next, separate safety systems must be provided to cope with any failure in the basic operating equipment of the plant. These safety systems must be independent of the operating systems, must be independent of each other, must be testable and must have a very high reliability. Finally, to protect against the unlikely event of a major failure in the reactor systems and a concurrent failure of these safety systems, the plant is typically housed in a special containment structure which will contain any radioactive material which might be released from the reactor system.

Over the past few years more and more concern has been expressed over the handling of the radioactive waste from nuclear power plants. Again although the basic problems are worldwide the specific problems of radioactive waste in Canada are quite different at present from those in most other countries developing nuclear power because the spent fuel is not chemically processed. Well over 99 per cent of the radioactive material discharged from a reactor is in the nuclear fuel. If this fuel is processed to reclaim the remaining fissionable material the radioactive isotopes end up in acid solutions with obvious storage problems. With the efficient natural uranium cycle which is possible with the CANDU reactors there is no current economic incentive to reprocess the spent fuel. Therefore in Canada at present the spent fuel is stored in water-filled bays at the nuclear power plants. However the spent fuel from Canadian heavy water reactors does contain valuable plutonium which can be recycled, and processing is likely to take place in the future.

Because of the long lifetime of some of the radioactive products in the fuel, safe storage is required for a very long period of time. In other countries methods have been proposed for long term or permanent disposal of high level radioactive waste. For example in the U.S. a great deal of effort has been spent studying permanent disposal in geological structures such as salt mines. The Canadian approach is to put the spent fuel at first into a simple water-filled pool. After several years, when the radioactive decay heat has decreased to a low level, it is planned to store the fuel bundles in air within an engineered storage facility which would require a minimum of surveillance and where they would be safe for more than a century. If at the end of life of this storage facility a safe permanent and more economic disposal method has not yet been proven, the fuel could be retrieved and placed in a similar storage facility for a further period.

When fuel processing becomes economical and part of the Canadian program it will introduce additional problems of waste management. While the plutonium, one of the most hazardous components of the spent fuel, will be recycled back to further reactors, the other fission products would come from the processing in aqueous solution. These would likely be converted to a solid form at an early date since long term safe storage of liquid radioactive waste is difficult.

The present and planned methods of storage of radioactive material are suitable for the immediate future and for much longer periods if necessary. Meanwhile methods of more permanent disposal are under study in Canada and in many parts of the world. It seems quite certain that satisfactory solutions will be found and that a legacy of hazardous waste will not be left to future generations.

In summary, the design and development of nuclear power plants have been focussed on safety, as well as, economics. The approach of those responsible in the nuclear industry when coupled with the thorough licensing process of the Atomic Energy Control Board ensures that any nuclear plant, waste management site, or any other nuclear facility, will be very safe and will have negligible effect on the environment. ☐