University. Of the older accelerators the cyclotron at McGill University in recent years has been used extensively for nuclear physics and nuclear chemistry and among the results obtained was the discovery of several nuclei that emit protons in their radioactive decay. The nuclear reactor at McMaster is used extensively in a wide range of research.

Nuclear Power Development.—Much of the success of the 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 studied extensively and satisfactory operating conditions have been 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 0.8 mill (0.08 cent) per kilowatt hour of electricity. This cost may be compared with about three mills from coal at $8 per 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 thermal power is lower than in many other countries.

An evaluation was presented at the third United Nations Conference on the Peaceful Uses of Atomic Energy held 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 could be under pressure to prevent boiling or to allow some boiling. Light water would have to boil or 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. By taking the steam direct to the turbine a boiler or heat-exchanger is eliminated and the efficiency is raised. 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.

The low fuelling cost derives as much from the details of the designs proposed as from the choice of heavy water as the moderator. Extensive development has been applied to reduce the fabrication cost of the fuel; a recent $9,000,000 order at a price including the uranium and zirconium of $44 per kilogram of uranium fulfills the predicted estimates while leaving still further promise of lowering the cost as the scale of production increases. Particular attention is paid in reactor design to minimize the wastage of neutrons by reducing the amount of absorbing structural material. For example, in the NPD reactor the tubes forming the fuel channels have 3.25 inches inside diameter and walls 0.163 inches thick whereas the four-inch diameter tubes in the Gentilly reactor will be of an improved zirconium alloy and only 0.095 inches thick. The capital cost per kilowatt is also being reduced by building reactors and turbines of larger capacity, by simplification and repetition of designs as well as by increased fuel ratings. The cost of heavy water is also falling as modern plants of large capacity come into production.

Most of the 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, temperature 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 program of studies.