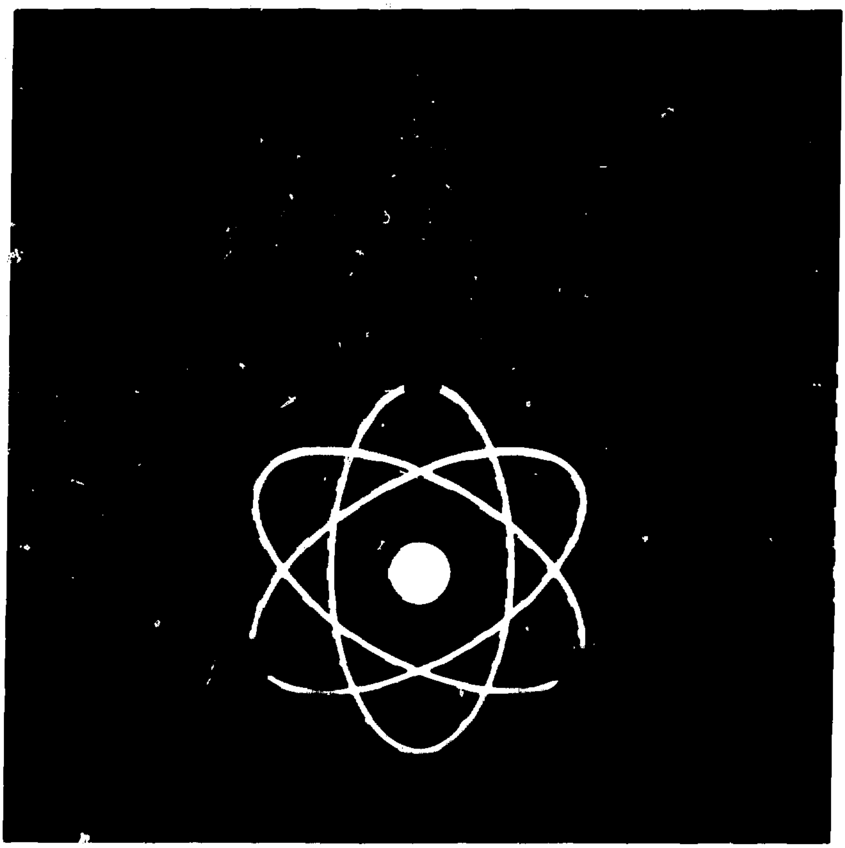
CA8004691

Nuclear Energy in Canada: The CANDU System

by J.A.L. Robertson

AECL - 6328



Nuclear Energy in Canada: The CANDU System

by J.A.L. Robertson

Mr. Robertson is assistant to the head of the Chalk River Nuclear Laboratories. He has had over 25 years' experience in the nuclear energy field, including a number of years engaged on research of fuels and materials. He has authored numerous technical papers and a book on nuclear fuels, and for five years was editor of the Journal of Nuclear Materials.

October 1979 AECL-6328

Nuclear electricity in Canada is generated by CANDU nuclear power stations. The CANDU reactor — a unique Canadian design — is fuelled by natural uranium and moderated by heavy water. The system has consistently outperformed other comparable nuclear power systems in the western world, and has an outstanding record of reliability, safety and economy. As a source of energy it provides the opportunity for decreasing our dependence on dwindling supplies of conventional fossil fuels.

This booklet reviews a number of aspects that are discussed at length in a continuing series of companion reports dealing with various issues relating to nuclear energy in Canada.

L'électricité nucléaire au Canada est produite par les centrales nucléaires CANDU. Le réacteur CANDU — système canadien unique en son genre —est chargé d'uranium naturel et modéré à l'eau lourde. Ce système a surpassé continuellement les autres systèmes nucléaires comparables du monde occidental et a une réputation remarquable du point de vue de la fiabilité, sûreté et économie. Comme source d'énergie, il nous permet de réduire notre dépendance des combustibles fossiles classiques en diminution.

Cette brochure examine un certain nombre d'aspects qui sont longuement passés en revue dans une série continue de rapports du même ordre qui traitent de diverses questions concernant l'énergie nucléaire au Canada.

ENERGY REQUIREMENTS

On average, every man, woman and child in Canada uses daily an amount of energy equivalent to five gallons (23 litres) of oil. About 20 per cent of this is used in the home (for space heating, appliances, etc.) and about 20 per cent for transportation (from the family car to jet aircraft); about 30 per cent and 10 per cent respectively are due to the individual's share in industry (producing materials, manufacturing goods, etc.) and commerce (heating and lighting stores, etc.); the remaining 20 per cent represents losses in conversion and transmission of the energy between its source and where it is used.

The amount of energy used per person has been steadily increasing in Canada, as elsewhere, and is now twice what it was in the early 1960s. With the average income going up, dwellings are larger and better heated while travel is more popular; many features of today's lifestyles consume lots of energy — clothes dryers, colour television, air-conditioning, power boats and other recreational vehicles. Also, any material possession requires energy for its manufacture. Improved services such as education and health care also add to energy consumption. Another reason for the energy demand increasing for Canada as a whole is that there are more people every year. The combination of population growth and the increase in energy consumption per person, resulted in an average annual increase in demand of about 5 per cent from 1960 to 1973.

The trend — more people living more secure and productive lives — will act to keep energy demand growing. Even without population growth the trend would remain because many Canadians are poorer, and consume less energy that the more fortunate. The growth rate can be slowed by energy conservation, that is, by using energy more efficiently while pursuing our goals. Energy conservation will take time to have full effect. Some measures, such as turning down a thermostat or installing attic insulation, provide immediate savings, but others must await replacement of existing buildings, cars and industrial equipment.

Meanwhile, conventional oil resources — which supply about half our energy requirements — are dwindling. New energy sources are needed to substitute for oil as well as to provide for any additional demand. Thus all energy sectors, including conservation, that can save or supply energy economically, safely and acceptably must do their best if we are to avoid serious harm to our economy and society. It is not a question of conservation versus coal, or renewables versus non-renewables: all will be needed, each in its appropriate place.

NUCLEAR ENERGY

Nuclear energy has already been proved to be an economic source of electricity. A Canadian nuclear industry has been established, and is capable of expansion to match needs. Strictly, nuclear energy involves the consumption of uranium (or other nuclear fuels) and is therefore a non-renewable resource. However, the world has enough uranium, if used wisely, to provide energy for centuries. This period would allow an orderly transition to a sustainable energy system that does not depend on oil.

For all practical purposes nuclear energy is produced as heat. This heat results from a physical process, *nuclear fission* *(see box page 2)*, rather than the more familiar chemical process of combustion, but thereafter is just the same as any other heat. A companion report[1] describes how the heat can be used directly, for instance in district heating or as industrial process heat, but, for many years to come nuclear energy's main contribution will continue to be through the large-scale generation of electricity.

ELECTRICITY GENERATION

In a conventional generating station combustion of coal, oil or natural gas boils water into steam, which turns a turbine that drives a generator (Figure 1). In the nuclear plant, fission heat from a nuclear reactor boils the water, and the rest is the same as the conventional plant.

Figures 2a and 2b show two of Ontario Hydro's generating stations. Each consists of four separate turbo-generator units which together produce about 2000 megawatts of electricity (MW(e)), sufficient for the needs of a city of about two million people. Both were built in the early 1970s; the one at Lambton, near Sarnia, is coal-fired while the Pickering Nuclear Generating Station, near Toronto, uses uranium. The coal piles and the smoke stacks show which is Lambton.

Both stations are located near plentiful supplies of cooling water, since the conversion of heat to electricity involves the inevitable discharge of large amounts of waste heat. Nuclear stations discharge more heat to the lake or river than do coal-fired plants of the same capacity, but none direct to the atmosphere as they have no smoke stacks. In the future some of this waste heat could be used, for instance to warm greenhouses or in fish farms[1]. At Pickering the cooling water is taken from well below the surface of Lake Ontario, where the water is relatively cold, and is returned to the surface of the lake after having been heated by no more than 10°C

THE BASICS OF FISSION

All solids, liquids and gases are composed of less than one hundred different chemical *elements* such as carbon, oxygen, iron and aluminum. The smallest unit of each element that still retains the characteristic properties of that element is an *atom*. Atoms are so small that a single airborne dust particle, that could be seen only under a powerful microscope, contains over a trillion atoms. Hydrogen, the lightest atom, and uranium, the heaviest that exists naturally to any appreciable extent, are both very important to nuclear energy.

Not all atoms of a given element are identical. For instance, hydrogen can exist as three *isotopes*, ordinary hydrogen, *deuterium* and *tritium* with respective masses of one, two and three atomic units. The different isotopes of other elements do not have distinct names but are identified by their masses. Thus the hydrogen isotopes would be hydrogen-1, hydrogen-2 and hydrogen-3. Uranium, as found in nature, consists of 99.28 per cent of uranium-238 and 0.71 per cent of uranium-235, with only very small amounts of other isotopes.

Differences in mass between the isotopes have virtually no effect on the atoms' chemical properties. For example, all three hydrogen isotopes burn in air to form water. Some small differences in common physical properties can be detected, but these are generally of little consequence. A given volume of water produced from deuterium is about ten per cent heavier than the same volume of water from ordinary hydrogen, and is therefore known as *heavy water* compared with the ordinary *light water*. The weight difference between the uranium isotopes is only about one per cent, so that there is little noticeable effect on most physical properties. However, there can be very marked differences between isotopes in their nuclear properties, which determine how they behave in a nuclear reactor.

When an atom of uranium-235 is hit by a *neutron* (a sub-atomic particle that is one of the components of all atoms) there is a high probability of a violent reaction, but if the atom is one of uranium-238 the probability is very low. The reaction is known as *nuclear fission* or splitting of the atom, because the uranium atom splits into two lighter atoms, releasing energy. The two light atoms, the *fission products*, can be any one of about twenty atom pairs, such as iodine and silver. The uranium-235 is said to be *fissile* (or *fissionable*).

Two or three neutrons are emitted when an atom fissions. If one of these causes fission in another fissile atom more neutrons are emitted, one of which could possibly cause a further fission, and so on in a *chain reaction*. If a neutron hits a uranium-238 atom it is unlikely to cause fission. Instead, the two will probably combine and subsequently transform spontaneously into an isotope of another element, plutonium-239. Although uranium-238 is not fissile, plutonium-239 is, so uranium-238 is said to be *fertile*.

However mucn naturally occurring uranium (*natural uranium*) is heaped up it will not generate useful energy because there are not enough fissile atoms present to sustain a chain reaction. The few neutrons produced are either captured by, or pass through, the much more abundant fertile atoms and so are unavailable to cause further fission.

The brute-force solution to this problem is to increase the proportion of fissile atoms artificially. One way is to *enrich* the uranium with uranium-235 in large *enrichment plants* that exploit the small differences in physical properties between the two uranium isotopes.

A more subtle solution is to divide up the uranium into small packets which are surrounded by a *moderator*, a material that slows down the neutrons, which are travelling very fast when first emitted from a fissioning atom, before they hit the next packet of uranium. The reason that this solution works is that slow neutrons are much more likely to cause fission in uranium-235 than faster ones. Generally, elements with light atoms are good moderators. Ordinary water (a compound of ordinary hydrogen and oxygen) is good, but not good enough to sustain a chain reaction with natural uranium. Very pure graphite (carbon) is better, but the best is heavy water (a compound of deuterium and oxygen). Deuterium is present in all naturally occurring hydrogen, e.g., in ordinary water, to the extent of about one part in ten thousand. Heavy water is produced by *enriching* the deuterium content of natural water in large *heavy water plants*, described in Reference (11).

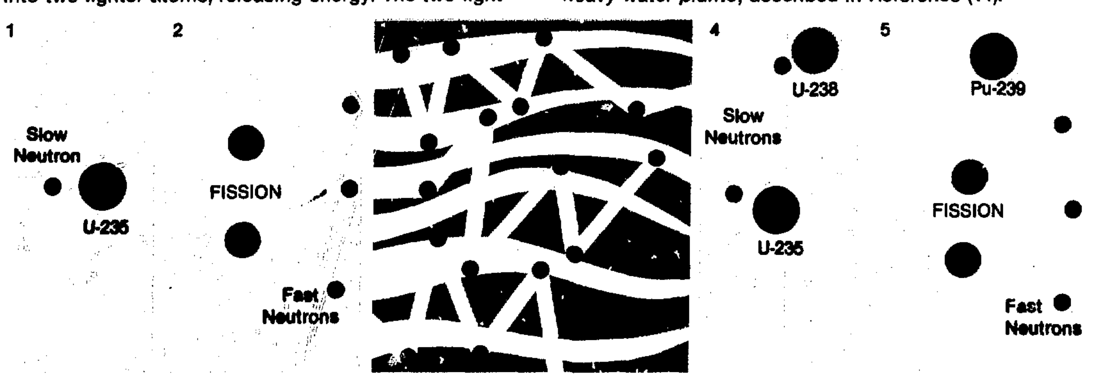
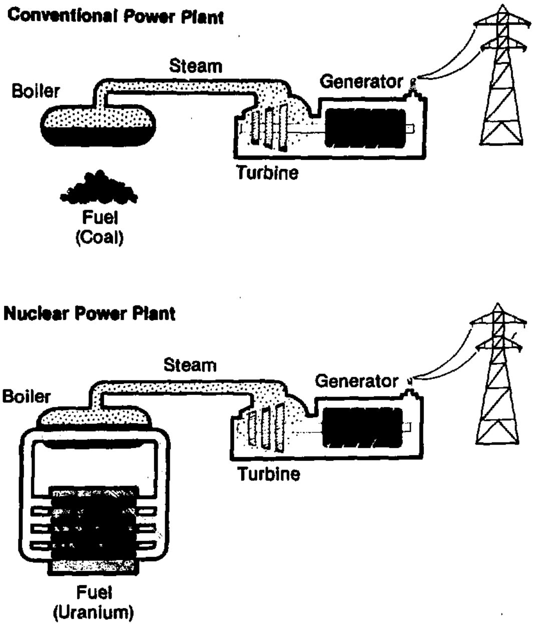


Figure 1 Principles of conventional and nuclear generating stations



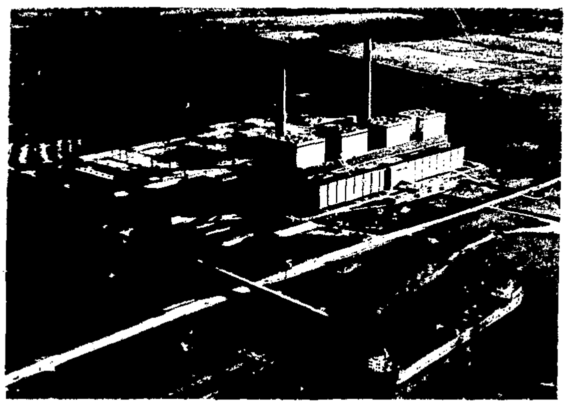


Figure 2a Lambton (Coal-Fired) Generating Station

(18°F). As a result, the discharge is sometimes actually *colder* than the surrounding surface water. Generally, the warmer discharge has some local effects — for example, it attracts species of fish that prefer warm water — but no resulting harm to the ecology has been detected.

The efficiency of converting heat to electricity increases as the temperature of the cooling water is lowered. Therefore Canada's abundant supplies of cold water constitute a valuable resource that indirectly helps to conserve energy. Eventually, if Canadian waterways were to approach their heat removal capacity, other means of cooling could be introduced, such as cooling ponds or cooling towers. This stage has already been reached for some rivers passing through highly industrialized regions of the USA and Europe, explaining why the phenomenon is often called *thermal pollution.* However, it will be several decades before these alternative cooling means, which cost more, need be used to avoid undesirable effects in most parts of Canada.

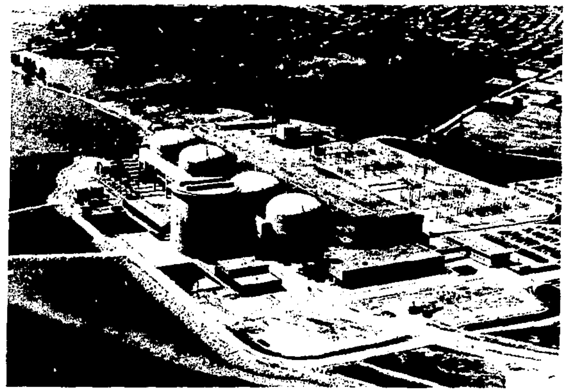


Figure 2b Pickering (Nuclear) Generating Station

NUCLEAR REACTORS

Uranium is the fuel for all current nuclear power reactors. Uranium ores are mined and then refined to produce uranium-oxide powder, which is pressed and fired to form hard, insoluble ceramic pellets (Figure 3). These are sealed into metal tubes which are assembled into bundles ready for insertion in the Canadian design of power reactors, known as CANDU reactors.

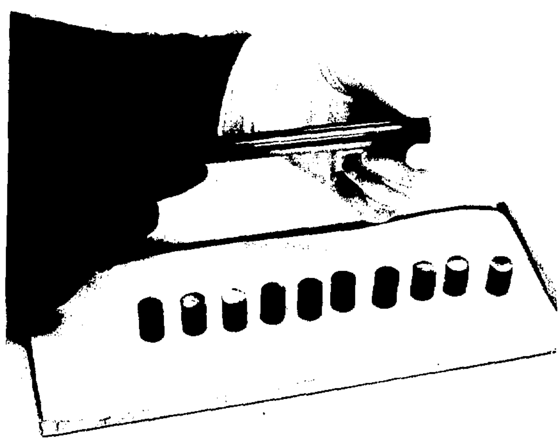


Figure 3 Initial stage of fuel bundle assembly

Figure 4 CANDU fuel bundle

Uranium is a very concentrated source of energy. A single fuel bundle (Figure 4) is 50 cm (20 in) long by 10 cm (4 in) diameter and weighs only 22 kg (50 lbs). Thus it could be carried in an overnight bag, but in a CANDU reactor such as those at Pickering, it can produce as much heat as burning 400 Mg (400 tons) of coal or 1700 barrels of oil. This heat produces enough electricity to supply more than 100 average homes for a year.

Twelve of these bundles are placed end-to-end in each *fuel channel* (Figure 5) of the reactor, in a tube 10 cm diameter that also contains flowing water to cool the fuel and remove the heat. The water is at nearly 300°C (570°F) and so develops a pressure about one hundred times the normal atmospheric pressure. The tube is made strong enough to contain this pressure and is called a *pressure tube*. To change fuel that has delivered its energy, after one to two years in the reactor, two *fuelling machines* connect to the pressure tube, one at each end. Fresh fuel bundles from one machine are pushed into the tube, forcing out used fuel bundles into the other machine which, when disconnected, removes these bundles to storage.

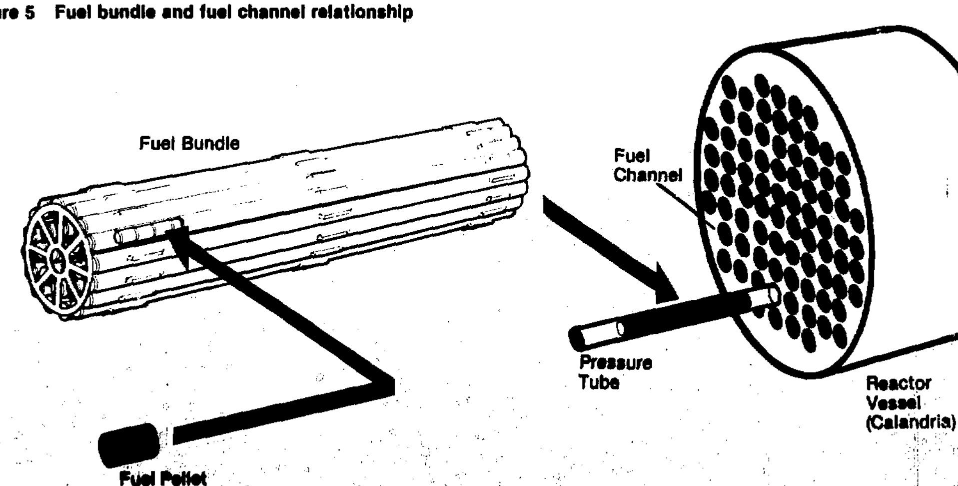
Fission, and hence heating, can occur in ordinary (or *natural*) uranium only if three conditions are simultaneously satisfied:

- There must be sufficient uranium present, many megagrams or tons.
- The uranium must be surrounded by a special material, called a *moderator*, in a highly purified form.
- The tubes containing the uranium must be stacked in a carefully calculated arrangement, neither too close together nor too far apart.

These requirements can contribute to the safety of the reactor. If the station were to be seriously damaged, either accidentally or deliberately, one or other of these requirements would probably be affected, hence shutting off the fission process automatically.

The most efficient moderator is *heavy water* (deuterium oxide), which is used in CANDU reactors. By using this highly efficient moderator CANDU reactors

Figure 5 Fuel bundle and fuel channel relationship



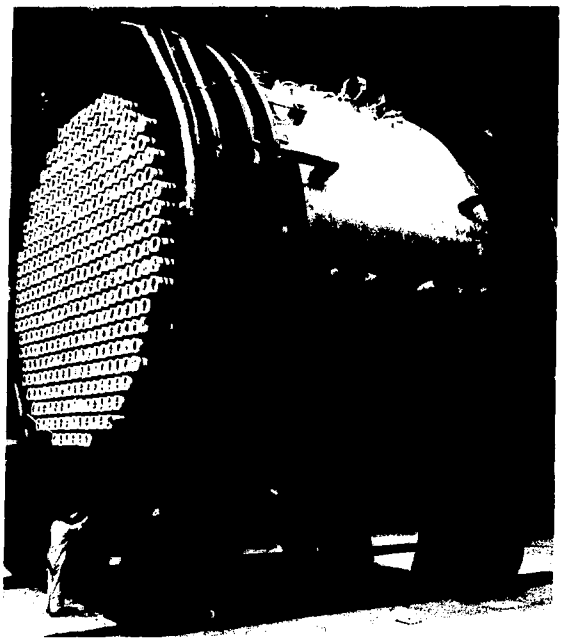


Figure 6 The calandria during construction

are able to "burn" natural uranium without any special treatment beyond normal refining and fabrication. (For a discussion of some differences from US reactors to which this statement does not apply see Reference (2).) This important characteristic is summarized in the acronym CANDU, which stands for CANada Deuterium Uranium.

In practice, a CANDU reactor consists of a large tank of heavy water (the *calandria*), penetrated by several hundred fuel channels (Figure 6). Cooling water from the fuel channels (heavy water like the moderator) is taken to the *steam generator (boiler)*, which produces steam in a separate circuit to drive the turbines (Figure 1). Further engineering details of the reactor, together with its control and safety systems, are described in Reference (3).

HEALTH PROTECTION AND SAFETY

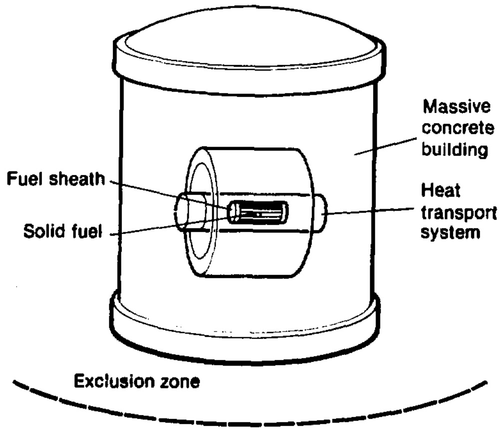
In generating heat, the fuel becomes highly radioactive, due to the production of *fission products* which emit *ionizing radiation.* The radiation from fuel is similar to that from medical X-ray equipment (and that from outer space and many natural objects around us) in that it can cause biological damage, including the initiation of cancer and hereditary defects. Even though these effects have been observed only after comparatively high radiation exposures, as a prudent measure it is assumed that any amount of radiation, however little, can cause some harm. The biological effects of radiation are discussed more fully in a companion report[4].

Any equipment that emits ionizing radiation should be designed and operated so that resulting human exposures are as low as can be reasonably achieved. Certainly nuclear reactors are designed and operated that way. Radiation is absorbed in passing through matter, with dense materials absorbing it in the shortest distance. To protect the operators from radiation, the reactor and its primary coolant circuits are shielded behind concrete walls, about a metre thick, in just the same way as the operators of medical X-ray equipment are protected by metal shielding. The same principle is used to protect people from the fuel after it is discharged from the reactor, and from any other part of the reactor that may become radioactive in service.

The hazard of nuclear power is, in essence, that radioactive materials might be released in significant amounts to the human environment, as the result of some accident. It is worth stressing that there is *no* risk of a reactor exploding like a nuclear bomb; that is physically impossible.

Reactors are built to be safe in the event of human or equipment failure, or even of coincidental failures. Designers know that components fail, that humans are fallible, and that acts of God occur, and therefore design the reactors accordingly. One principle employed to give protection is "defence in depth", or multiple containment (Figure 7). More than 90 per cent of the radioactivity is locked into the fuel pellets. These, together with any fission products released from the pellets in service, are sealed in the metal tubes, which are enclosed in the leak-tight, shielded circuit for the primary coolant. This, in turn, is within a gas-tight containment building which is surrounded by an exclusion

Figure 7 The principle of "defence in depth"



zone of roughly one kilometre (half a mile) radius which would allow dispersion and dilution of any released radioactivity before it reached an inhabited area.

These and other safety measures are discussed more fully in a companion report[5], which also explains why the present excellent safety record can be expected to be maintained.

The operation of nuclear generating stations results in release of radioactivity to the environment in small amounts that are strictly controlled and monitored by regulatory agencies such as the Atomic Energy Control Board. A hypothetical individual who spent his whole life at the limits of the exclusion zone, drinking water from the reactors' effluent and eating fish from the same effluent, would increase his exposure to radiation by only a few per cent of the inevitable dose from naturally occurring radiation. By moving away from the reactor site he might avoid this small extra dose only to receive a larger dose. For example, if he were to move into a brick house or relocate in an area a hundred metres (300 feet) higher above sea level he would increase his total radiation exposure. A single jet flight from Halifax to Vancouver would expose him to more radiation than he would have received from the nuclear generating station during a year at its boundary. The average individual, of course, receives far less radiation from the generation of nuclear energy than would this hypothetical individual.

Paradoxically for a relatively new energy source, more is known of the biological effects of radiation than those of pollutants from most other energy sources. Burning fuels such as coal, oil, wood or even garbage, produces chemical agents with the same potential as radiation for causing cancer and genetic defects. Although this much is well established, the quantitative effects of the chemicals are less well known than those of radiation. The available information on the effects of radiation has been summarized and applied to estimate the resulting risks to both workers within the industry and members of the public[4]. These comparisons with what is known for coal-fired plants show that using coal rather than uranium to generate electricity would almost certainly cause greater health harm to society.

NUCLEAR WASTES

The concern over nuclear wastes is essentially the same as for operating reactors, that a significant amount of radioactivity might be released to the human environment. More than 99 per cent of this radioactivity, as fission products, is sealed within the fuel bundles, which come out of the reactor looking much the same as they did when they went in. This simple fact gives nuclear energy a tremendous advantage in pollution control over burning coal, etc. *Nuclear wastes are contained from the start and need never be dispersed.* A second advantage is the very small volume of the wastes. A year's fuel for the Pickering Nuclear Generating Station could be packed into an average house. Consequently, elaborate means can be afforded for disposal of the highly radioactive wastes.

The objective of nuclear waste management is to keep the wastes away from mankind for as long as they constitute a hazard — unlike many non-radioactive pollutants, their hazard diminishes with time — and to do it so that there is no burden of responsibility on future generations. The favored solution is to place the wastes deep underground in a stable rock formation, having first put them in a form that is as insoluble as the rock itself. Details of this method for disposal, which again has the advantage of "defence in depth", are provided in a companion report[6], which also explains the proposed program for demonstrating this solution. In some ways, however, geological disposal has already been demonstrated by Nature itself with its many examples of protecting mankind from dangerous materials such as lead, mercury, arsenic, and huge quantities of naturally radioactive material by burying them in the earth's crust in the form of insoluble ores.

Getting the wastes from the reactor to the geological vault for disposal requires that they be safely transported. Just how this is accomplished is described in a companion report[7].

Provision must also be made for decommissioning the station at the end of its useful life, which will probably be considerably longer than the amortization period of 30 years for repayment of the capital investment. Eventually, the radioactive parts of the station, about five per cent of the volume of the reactor buildings seen in Figure 2b, must be disposed of with other wastes. Some decommissioning options, including restoring the site to its original condition have been described in a companion report[8] together with estimates of time and cost involvement

All the necessary waste management operations, including transportation and reactor decommissioning, can be achieved without costing more than a few per cent of the cost of the electricity produced. In Canada, responsibility has been assigned to Atomic Energy of Canada Limited for development and operation of waste management facilities. Like all other aspects of nuclear energy, waste management is subject to regulation by the Atomic Energy Control Board.

FUEL SUPPLY AND FUEL CYCLES

The current fuel for CANDU reactors is uranium, with which Canada is well endowed, having about one quarter of total world reserves (excluding the Soviet bloc and China, for which data are not available).

Government policy controlling uranium exports assures Canadian utilities of at least a 30-year reserve of uranium for all existing, committed and planned reactors in any 10-year forward period. Beyond that, existing uranium reserves are sufficient for Canadian requirements well into the next century while, as a result of accelerated exploration, the reserves have increased by nearly 30 per cent over the past three years. However, uranium is a non-renewable resource and Canada is under increasing pressure to export uranium. Consequently it is desirable to examine possible ways of using the available uranium more efficiently in alternative fuel cycles. This is done in a companion report[9], which also provides more details on existing reserves and future commitments.

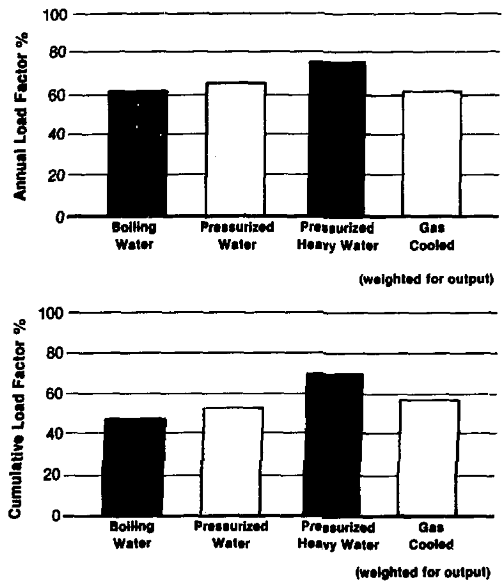
The present "once-through" fuelling of nuclear power reactors consumes only about one per cent of the uranium. The used fuel contains substantial amounts of fissile materials that could produce more energy. Simply recovering and recycling the fissile materials with fresh uranium would roughly double the amount of energy that could be extracted from a given amount of uranium. If instead the fissile material is recycled with thorium, another potential nuclear fuel that is even more abundant than uranium, our nuclear resources can be extended to last for centuries.

Commercial introduction of these alternative fuel cycles would require large chemical plants to reprocess the used fuel and recover its contained plutonium and other fissile materials. This would cost more, but the additional amount would probably be less than 25 per cent of current costs for nuclear electricity. Thus the CANDU system offers the prospect of continuing to supply energy at competitive costs for the indefinite future, by adjusting fuel cycles when uranium becomes more expensive. In the meantime, while uranium remains relatively plentiful and inexpensive, the present once-through, natural-uranium arrangement is the simplest possible and gives CANDU reactors the advantage of the lowest fuelling costs.

PERFORMANCE AND COSTS

Reliability is judged by *net capacity factor,* which is the ratio of the energy actually produced to the amount that would have been produced if the plant had operated at its maximum output for the whole period, usually expressed as a percentage. Because of inevitable shutdowns for inspection and maintenance, no plant achieves 100 per cent, and 80 per cent is normally regarded as a practical if challenging target. An independent survey[10] of the performance of power reactors shows the heavy water reactors, mostly the Canadian CANDU type, leading the rest of the world (Figure 8).

Figure 8 World power reactor performance 1978[10]



Ontario Hydro's operating experience with strictly comparable generating stations shows that nuclear energy is providing electricity at just over half the cost of that from coal-fired plants (Figure 9). Plants fuelled by oil or natural gas are more expensive still. Ontario

Figure 9 Cost comparison for coal-fired and nuclear generated electricity — 1978

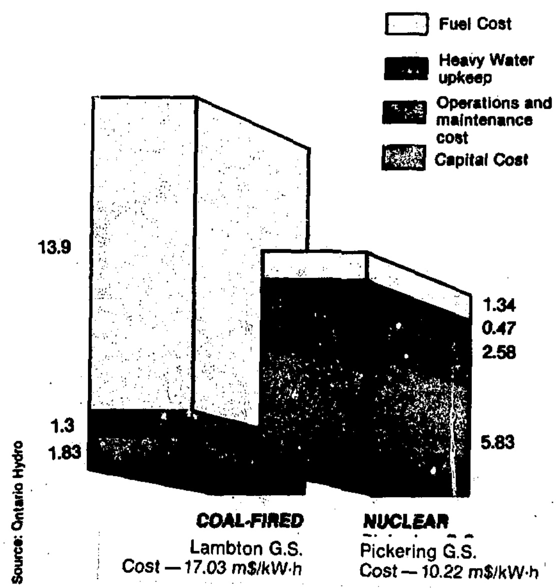
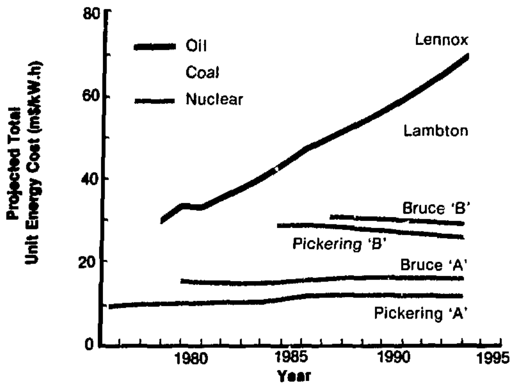


Figure 10 Projected cost of electricity from three different fuels



Hydro's estimates for the future (Figure 10) indicate that nuclear energy is expected to continue costing less.

CONCLUSION

In the CANDU nuclear system Canada has acquired the capability for technological sovereignty and resource security in the vital area of electricity supply. This position has been achieved in competition with other countries and major international corporations. The Canadian nuclear industry already employs more than 30 000 people with an output of more than one billion dollars per year. As a result about one third of Ontario's electricity is obtained from nuclear energy, with an exceptional record for reliability, safety and economy.

For the rest of this century and into the next, nuclear energy provides the opportunity for decreasing our dependence on dwindling supplies of conventional fossil fuels. The electrical sector, with a demonstrated capacity to grow at a rate of about 7 per cent per year, is in a better position than most energy sectors to substitute for rapidly dwindling stocks of conventional oil and gas; and through the use of nuclear fuels it can do so without fear of fuel shortages. In Canada, the extent to which nuclear energy is exploited for this purpose is the responsibility of provincial authorities.

When compared with available alternatives for electricity generation, continued use of nuclear energy offers security of fuel supply, decreased vulnerability to foreign suppliers, employment opportunities and improved balance of trade for the nation, as well as cash savings for the utilities' customers. The environmental effects of nuclear energy are probably less than for any of the alternatives.

For the longer term, nuclear energy represents one of the few dependable options to supply energy indefinitely at a reasonable cost.

The CANDU nuclear system, as operated by Ontario Hydro and soon to be used by other utilities, is a major Canadian achievement that has aroused worldwide admiration and even envy. Some of the reasons are:

- through its use of heavy water as moderator it burns natural uranium, thus yielding the world's lowest fuelling costs and making Canada independent of foreign sources of enriched uranium.
- on-power fuelling has contributed to exceptionally high availability for power generation.
- the bulk of the reactor components and the fuel can be fabricated by an established, domestic industry.
- the absence of fuel enrichment simplifies both fuel supply and safeguarding nuclear facilities.
- retrievable storage of spent fuel had been planned from the start, allowing sufficient time to develop and demonstrate safe and responsible disposal of the wastes.
- the system is capable of operating on advanced fuel cycles which can ensure fuel supplies for centuries, *without the need to introduce a drastically new type of reactor.*

CANDU technology offers immediate benefits and the prospect for gradual evolution rather than obsolescence.

REFERENCES

(1) **G.J. Phillips,** *Future Developments in Nuclear Power.* Atomic Energy of Canada Limited, Report AECL-6335 (December 1978).

(2) **J.A.L. Robertson,** *The CANDU Reactor System: An Appropriate Technology.* Science, Volume 199, p. 657 (February 1978).

(3) **L.R. Haywood,** *The CANDU Power Plant.* Atomic Energy of Canada Limited, Report AECL-5321 (1976).

(4) **H.B. Newcombe,** *Public Health Aspects of Radiation.* Atomic Energy of Canada Limited Report AECL-6330 (December 1978)

(5) **V.G. Snell,** *Safety of CANDU Nuclear Power Stations.* Atomic Energy of Canada Limited, Report AECL-6329 (November 1978).

(6) **E.R. Frech,** *Management of Nuclear Waste.* Atomic Energy of Canada Limited, Report AECL-6333 (1979).

(7) **D.R. Prowse,** *Transportation of Nuclear Fuel.* Atomic Energy of Canada Limited, Report AECL-6331 (January 1979).

(8) **G.N. Unsworth,** *Decommissioning of CANDU Nuclear Power Stations.* Atomic Energy of Canada Limited, Report AECL-6332 (April 1979).

(9) **S.R. Hatcher,** *Prospects for Future CANDU Fuel Cycles.* Atomic Energy of Canada Limited, Report AECL-6334 (February 1979).

(10) *Nuclear Station Achievement: Annual Review -1978,* Nuclear Engineering International, p. 66 (March 1979).

(11) *Heavy Water.* Atomic Energy of Canada Limited, Report AECL-3866, (1971).

Copies of this publication are
available from:

Atomic Energy of Canada Limited
Public Affairs Office
Sheridan Park Research Community
Mississauga, Ontario L5K 1B2

Atomic Energy of Canada Limited
L'Énergie Atomique du Canada, Limitée

AECL-6328
October 1979

La présente publication est également disponible en français

Printed in Canada