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# CANDU - CANADIAN EXPERIENCE AND EXPECTATIONS WITH THE HEAVY-WATER REACTOR

by

J.S. FOSTER, S.H. RUSSELL

Paper IAEA-CN-36/179 presented at the IAEA International Conference on Nuclear Power and its Fuel Cycle, Salzburg, Austria, 2-13 May 1977

Chalk River Nuclear Laboratories
Chalk River, Ontario
May 1977

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# CANDU - Expérience canadienne et ce que l'on peut attendre du réacteur à eau lourde*

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## Résumé

Une fois que les deux premières unités de 750 MWe de la centrale Bruce de la Commission électrique ontarienne seront en service, il y aura au Canada neuf unités électronucléaires dont la capacité totale atteindra 4000 MWe. Cette capacité constituera près de 6% de la capacité totale des centrales électriques implantées au Canada. Cinq unités semblables ont été vendues à d'autres pays. Toutes ces unités comportent un réacteur CANDU à tubes de force dont le combustible est de l'uranium naturel et le modérateur de l'eau lourde. Grâce au rapport de modération élevé de l'eau lourde les réacteurs CANDU sont très efficaces avec les cycles de combustible à passe unique employés aujourd'hui et moyennant peu ou pas de changement ces réacteurs pourraient tirer grand parti des éléments lourds au moyen de cycles de combustible comportant le recyclage de matières fissiles. Ce mémoire décrit l'évolution des centrales CANDU, particulièrement en ce qui concerne: les objectifs de sécurité, de fiabilité et d'économie; le développement d'une capacité industrielle pour la fourniture de combustible, de composants et d'eau lourde; et le développement éventuel de cycles de combustible avancés, y compris les résultats escomptés. Par ailleurs, ce mémoire passe en revue les questions suivantes: rayonnements, émanations et expositions à l'intérieur et à l'extérieur des centrales; facteur de disponibilité, facteur de capacité et autres données relatives à la performance des centrales; aspects économiques de l'exploitation des centrales nucléaires au Canada; fabrication du combustible et des composants; données relatives à la fabrication de l'eau lourde du point de vue sécurité, fiabilité et économie; prévision de la performance de réacteurs CANDU fonctionnant avec un cycle de thorium-U233, y compris le développement requis pour établir ce cycle; et intentions concernant la gestion du combustible irradié et le stockage des déchets radioactifs. Le développement du réacteur CANDU, d'une industrie nucléaire associée et du cycle de combustible avancé thorium-U233 forme un programme évolutif et intégré qui permet d'employer de plus en plus efficacement en éléments lourds au moyen de la technologie des réacteurs thermiques.

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## ABSTRACT

With the commissioning of the first two 750 MWe units of the Bruce generating station of Ontario Hydro there will be 9 nuclear-electric units with a total capacity of 4000 MWe operating in Canada. They represent about 6 per cent of the total installed electric generating capacity in the country and will supply about 8 per cent of the electrical energy consumed. Five similar units have been sold to other countries. All of these units employ CANDU natural-uranium-fuelled heavy-water-moderated pressure-tube reactors. Because of the high moderating efficiency of heavy water, reactors of this type are not only efficient units for operation on today's once-through fuel cycles but promise, with little or no alteration, to make very effective use of heavy-element resources through fuel cycles entailing the recycling of fissile material. The paper describes the evolution of the CANDU nuclear-power plants with particular reference to the objectives of safety, reliability and economy; the development of industrial capacity for the supply of fuel, components and heavy water; and the prospective development of advanced fuel cycles and the projected results. It provides data on radiation, releases, and exposures, internal and external to the power plants; plant availability, capacity factors and other performance data; economic data for operating plants in Canada; fuel and component manufacturing data; heavy water production data with reference to safety, reliability, and economics; projections of the performance of CANDU reactors operating on a thorium - U-233 cycle and the development required to establish this cycle; and intent with respect to spent-fuel management and radioactive-waste storage. The development of the CANDU reactor, of the associated supply industry, and of the thorium - U-233 advanced fuel cycle is seen as an integrated, evolutionary program, permitting increasingly efficient use of the world's heavy-element resources with thermal reactor technology.

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# CANDU - CANADIAN EXPERIENCE AND EXPECTATIONS WITH THE HEAVY WATER REACTOR[*]

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## General

The 3,000 megawatt Bruce Generating Station situated on the eastern shore of Lake Huron is now being commissioned. The first of its four 750 MWe units was started up in September 1976. The second unit, scheduled to commence operation in 1977, will be the ninth nuclear-electric generating unit in Canada and will bring the total nuclear-electric generating capacity in the country to 4,000 megawatts (Table I). This represents about 6 per cent of the total Canadian electrical generating capacity which is sufficient to supply about 8 per cent of the nation's electrical energy.

All units employ CANDU[1] natural-uranium heavy-water pressure-tube reactors based on the design pioneered in the 25 MWe NPD[2] plant that went into service in 1962. After further development in the 200 MWe Douglas Point station, which began operation in 1967, the CANDU system was demonstrated to be an economical power source in the 500 MWe units of Ontario Hydro's Pickering Generating Station. This was Canada's first multiple-unit nuclear-electric generating station and the progressively shorter commissioning times for the units, which went into service between 1971 and 1973, attested to the merits of multiple unit construction. Additional units, now under construction or committed for construction, will bring the total installed capacity in Canada to about 15,000 MWe by 1988.

Besides the domestic applications, 600 MWe CANDU units are under construction in Argentina and the Republic of Korea. These follow in the footsteps of the first overseas CANDU units: the 137 MWe unit at Karachi in Pakistan and the two 200 MWe units near Kota in India. These last two units are the forerunners of a program of this type of reactor which India is pursuing with her own resources.

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[1] Canada Deuterium Uranium

[2] Nuclear Power Demonstration

## Table I

## CANDU REACTORS IN OPERATION, UNDER CONSTRUCTION, COMMITTED AND PLANNED

| Name[a] | Location | Power MWe Net | Nuclear Designer[b] | Date of First Power |
|---|---|---|---|---|
| NPD | Ontario | 22 | AECL & CGE | 1962 |
| Douglas Point | Ontario | 208 | AECL | 1967 |
| Pickering A | Ontario | 514 x 4 | AECL | 1971-73 |
| Gentilly 1 | Quebec | 250 | AECL | 1971 |
| KANUPP | Pakistan | 125 | CGE | 1971 |
| RAPP 1 | India | 203 | AECL | 1972 |
| RAPP 2 | India | 203 | AECL | - |
| Bruce A | Ontario | 745 x 4 | AECL | 1976-79 |
| Gentilly 2 | Quebec | 600 | AECL | 1979 |
| *Point Lepreau* | *New Brunswick* | 600 | AECL | 1980 |
| Cordoba | Argentina | 600 | AECL | 1980 |
| Pickering B | Ontario | 514 x 4 | AECL | 1981-83 |
| Wolsung 1 | Korea | 600 | AECL | 1981 |
| Bruce B | Ontario | 750 x 4 | AECL | 1983-86 |
| Darlington | Ontario | 800 x 4 | AECL | 1986-88 |
| | Total | 16,703 | | |

| | |
|---|---|
| [a]NPD | Nuclear Power Demonstration |
| KANUPP | Karachi Nuclear Power Project |
| RAPP | Rajasthan Atomic Power Project |

| | |
|---|---|
| [b]AECL | Atomic Energy of Canada Limited |
| CGE | Canadian General Electric Company Limited |

The CANDU reactor will probably remain the preferred type of reactor in Canada for a very long time. There are several reasons for this:

1. The effectiveness of the CANDU system has been established by the performance of the NPD demonstration plant, the Douglas Point prototype unit and the first commercial units in the Pickering station.

2. The CANDU reactor has a very simple and economical fuel design and fuel cycle.

3. With heavy water now being produced by the Bruce, Port Hawkesbury and Glace Bay plants, Canada has established a domestic heavy-water production industry.

4. Perhaps in the long run, the most important reason of all is that the CANDU reactor can be developed to operate on thorium fuel. Uranium will be needed to provide the first fuel charge of each reactor designed to burn thorium but it is possible to design the reactor so that only thorium would be required for refuelling.

For the conservation of nuclear fuel resources, the development of the thorium-burning CANDU reactor is a simpler development than that of the fast-breeder reactor being pursued elsewhere.

Furthermore, thorium is a more abundant resource than uranium and, until much of the world is employing reactors that use it, its price will not be affected by the same demand pressure that will be exerted on the price of uranium.

The remainder of this paper will review Canadian experience and expectations with CANDU heavy water reactors from these points of view.

## Effectiveness of CANDU

The characteristic most commonly accepted as a measure of the technical performance of a nuclear generating unit is its annual net capacity factor (NCF). Those for Douglas Point and the Pickering units are shown in Table II.

Table II

ANNUAL NET CAPACITY FACTORS

| | DOUGLAS POINT | PICKERING | | | |
|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 |
| 1971 | 52.7 | 78.8 | - | - | - |
| 1972 | 16.9 | 72.3 | 82.2 | 91.3 | - |
| 1973 | 56.8 | 92.5 | 69.0 | 85.1 | 90.1 |
| 1974 | 62.5 | 72.0 | 88.4 | 42.7 | 93.9 |
| 1975 | 70.9 | 80.2 | 86.0 | 57.5 | 23.8 |

Douglas Point's NCF in 1972 and 1973 suffered major reductions when, due to a shortage of heavy water in Canada, its heavy water was transferred to the Pickering station to allow the startup of units there. Its performance has improved steadily since that time and it is now performing reliably in its dual role of supplying electricity to the Ontario Hydro grid and process steam to the Bruce Heavy Water Plant Unit A.

The data shown for Pickering exclude a 4-month period in 1972 when, by management decision, the Pickering units were shut down during a strike of Ontario Hydro operators.

The major causes of lost production at Pickering during 1974 and 1975 were the replacement of 69 pressure tubes in Units 3 and 4 which took a total of eighteen months to complete for both units, and a six-week outage to replace generator conductors and to modify the conducting end bracing on Unit 3.

In spite of these difficulties, the units have provided reliable and economic service.

From their in-service dates to the beginning of June 1976, lifetime net capacity factors for each unit were:

| Unit 1 | Unit 2 | Unit 3 | Unit 4 |
|---|---|---|---|
| 81.0% | 81.5% | 67.6% | 60.0% |

The weighted average for the station, representing more than 15 unit-years, was 73.8%. In broad terms, about 60% of lost production can be attributed to nuclear steam-supply system problems and 40% to problems in the so-called conventional portion of the plant.

Operating performance of CANDU fuel, as described in another paper at this Conference [1], has been excellent. Of the 110 bundles which developed defects while under irradiation in Pickering, only 19 have done so since 1 November 1972 when, as a result of a thorough investigation into the causes of fuel defects, the problem was overcome by changes to fuel management and reactor operating procedures.

The excellent performance of the fuel when combined with its simple and economic design lead to very low fuelling costs. Actual fuelling costs for Pickering, which do not take any credit for the value of the plutonium that might be recovered from the irradiated fuel, have been:

| 1973 | 1974 | 1975 |
|---|---|---|
| 0.91 m$/kWh | 0.88 m$/kWh | 0.95 m$/kWh |

The fuel handling system performance has also been satisfactory. To date more than 9,000 on-load refuelling operations have been performed at the NPD, Douglas Point and Pickering stations. At Pickering, about 6.3% of lost production during the lifetime of that station has been attributed to fuel handling systems. This is higher than we consider desirable and improvements are being introduced. As a result, in 1975 lost production caused by fuel handling systems was reduced to about one-fifth of the lifetime annual average.

The cost of heavy-water upkeep is a measurement of performance that is unique to CANDU reactors. In calculating this cost, we take into account both the cost of replacing heavy water permanently lost from the station plus the cost of upgrading heavy water that leaks from the various reactor systems and is recovered at concentrations below those considered acceptable for use in the reactor. At Pickering, the cost of heavy-water upkeep has been about 4% of the total energy cost.

The ultimate test of the economic performance of an electrical generating unit is its total unit energy cost (TUEC).

Actual total unit energy costs experienced to date at Pickering (including all corporate overheads and training costs) have been:

| 1973 | 1974 | 1975 |
|---|---|---|
| 7.1 m$/kWh | 8.2 m$/kWh | 9.8 m$/kWh |

The individual components of this energy cost are also of interest. For 1975, these were:

| | |
|---|---|
| Capital | 6.18 m$/kWh |
| O and M | 2.30 m$/kWh |
| Heavy-water upkeep | 0.39 m$/kWh |
| Fuelling | 0.95 m$/kWh |
| Total | 9.82 m$/kWh |

This TUEC was achieved in spite of the fact that the net capacity factor at Pickering in 1975 was only 61.9%, because (as mentioned earlier) almost one unit-year of production was lost while replacing pressure tubes on Units 3 and 4 and repairing the generator on Unit 3.

Even this high value of total unit energy cost is lower than the fuelling cost alone of Ontario Hydro's coal-fired generating stations, the most efficient of which had a fuelling cost of 12.7 m$/kWh in 1975.

## Health and Environmental Performance

The effects of reactor operations on human health and the environment are as important as technical and economic criteria in evaluating the performance of nuclear reactor systems.

In the early years of operation of Douglas Point, annual radiation doses to the operating and maintenance staff were increasing at an unacceptable rate. After detailed study of various alternatives, it was decided that one of the solutions to the problem lay in reactor decontamination. Conventional methods based on the use of strong concentrations of organic acids were ruled out due to the possible downgrading of heavy water and corrosion of the many sealing surfaces in the reactor components. Eventually, a technique was evolved of cycling the operating conditions of the reactor coolant while passing an increased flow through a newly enlarged purification circuit. This technique proved very effective in reducing the radiation fields around the Douglas Point boiler cabinets (Figure 1) and in maintaining them at this reduced level for over four years. The technique was not so effective at NPD where a different material was used for the boiler tubing.

Development then began on a decontamination procedure now known as the CAN-DECON[3] process which involves the addition of dilute organic acids to the coolant [2]. This process seems ideally suitable for performing mild decontamination at regular intervals (say, one to two years as required by the growth rate of radiation fields) so that these fields are never permitted to become very high.

As a result, considerable improvement has been achieved in the radiation exposures of operating and maintenance staff.

We have found that tritium accounts for about 25% of the total annual exposure at each station. This is being reduced by improvements in equipment

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[3] CANDU Decontamination

design to reduce leakage and spillage; by improved ventilation of areas where high tritium concentrations are expected; and by development of better tritium monitors and protective clothing. In addition, we are studying possible methods of removing tritium from heavy water, using knowledge acquired in our studies of heavy-water production processes.

The control of radioactive effluent releases from CANDU stations has also proved excellent. Canadian standards for permissible radiation exposures are based on the recommendations of the International Commission on Radiological Protection. For each reactor site, release limits which will ensure compliance with the radiation exposure limits are derived from various radionuclide groups taking into account possible emission paths, general population densities around a given site and local meteorological conditions. Such release limits are not considered design targets but rather as maximum limits that must not be exceeded. As an operational target, a limit of 1% of the derived release limits has been set. Pickering operation has demonstrated that this target can be met.

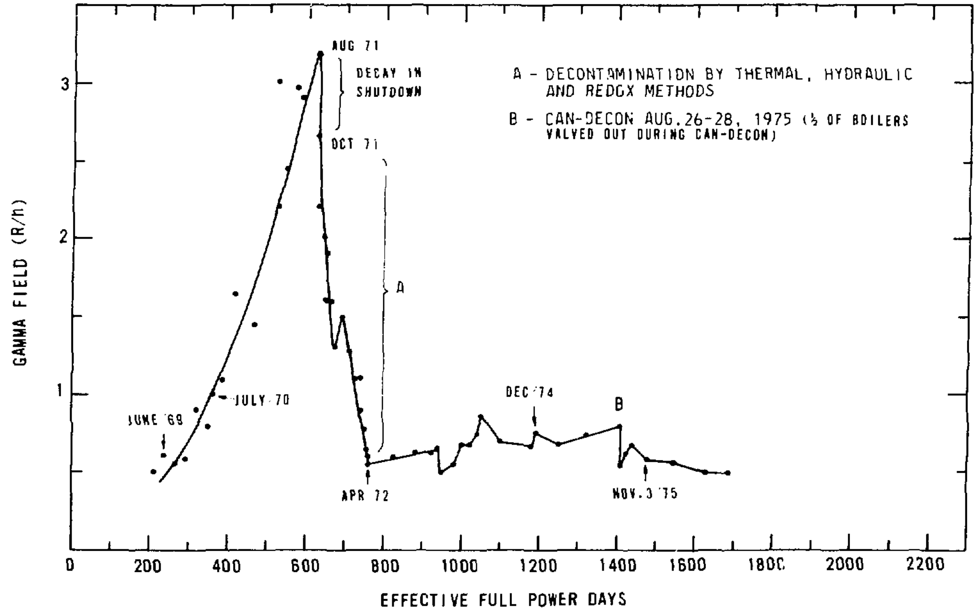

Fig.1. Douglas Point G.S. Boiler Room Fields.
Average of 8 Boiler Cabinet Sides Measured 24h After Shutdown

## Heavy-Water Production

Another paper at this Conference describes in detail the status of our heavy-water production program [3].

By 1983, when all plants now under construction are expected to be in full operation, Canada will have a nominal heavy-water production capacity of about 4,000 megagrams per annum which will support a program of 3,000 MWe per annum of new CANDU nuclear-electric generating capacity.

Health and environmental impacts from those plants now in operation have been minimal. In spite of the large quantities of hydrogen sulphide gas used in the production processes, no operating staff have been seriously injured nor have residents around these plants been harmed in any way. Environmental impacts are being monitored closely and such impacts as have been detected to date are well within acceptable limits. These results can be attributed to the strictness of the codes and standards used for the design, construction and operation of these plants.

## Nuclear Industry

AECL has continued to encourage participation by Canadian industry in Canada's nuclear power program. As a result, it is estimated we have now achieved an average level of 75% Canadian content in manufactured components for the nuclear steam-supply system. These include the calandria [illegible] reactor vessel, the fittings that go on the end of the pressure tubes and related components, the on-load refuelling machines, the reactivity control devices, boilers, pumps and certain computing-centre equipment.

It is expected that Canadian production of items not previously available in Canada will become established as the domestic market expands. This has already happened for certain items. Several years ago, a Canadian company began to produce calandria tubes from imported zirconium alloy strip. More recently, another company has begun to produce special alloy boiler tubing with the intention to move into the production of zirconium alloy tubing for fuel sheaths as the market and its expertise increase. Another company has begun to produce finished zirconium alloy pressure tubes from imported extruded stock and will gradually undertake more of the production processes over the next few years.

## Advanced Fuel Cycles in CANDU Reactors

Over the last few years AECL has carried out studies of advanced fuel cycles in CANDU reactors. These show that it is feasible to use these cycles in the existing CANDU-PHW design with no degradation in safety and with few, if any, modifications. Thus, development of a new reactor type would not be required. Some $ThO_2$ fuel development and fuel testing would be needed, as would extensions of procedures and computational methods for fuel management and control.

Two general types of advanced cycles are of interest--uranium cycles with plutonium recycling and thorium cycles with uranium recycling. Detailed characteristics for various CANDU reactors, using many variations of the two basic advanced cycles, have been derived [4]. For thorium cycles in CANDU-PHWs of proven design, these include using either enriched uranium (U-235) or plutonium (from a CANDU-PHW operating on a once-through uranium cycle) as the external feed of fissile material, and different additions of external fissile material to the recycle fuel (and hence different burnups per pass and conversion ratios).

The uranium needs for these various fuel cycles have also been derived. Determining these needs for a typical nuclear power system can be simplified by classifying the requirements as being either for equilibrium feed or "inventory". The existence of these two classifications means that the system's annual uranium requirements per unit energy output are a function of the system's growth rate. Typical values for various CANDU-PHW systems and growth rates [5] are shown in Table III.

### Table III

### ANNUAL URANIUM REQUIREMENTS FOR CANDU-PHW SYSTEMS AT VARIOUS GROWTH RATES

| System | Annual Uranium Requirements Per GWe at 80% Load Factor - MgU/a (System Growth Rates per annum) 0% | 3.33% | 6% |
|---|---|---|---|
| Once-through, Natural U CANDU-PHW only | 133 | 138 | 141 |
| Plutonium Recycling with Natural U Feed (CANDU-PHW) | 56 | 62 | 68 |
| Natural U CANDU-PHWs Feeding Plutonium to: | | | |
| "High Burnup" Th Cycle CANDU-PHWs | 36 | 58 | 70 |
| "Intermediate" Th Cycle CANDU-PHWs | 17 | 47 | 63 |
| "Self-Sufficient" Th Cycle CANDU-PHWs | 0 | 43 | 64 |
| Enriched Uranium (U-235) Feed to: | | | |
| "High Burnup" Th Cycle CANDU-PHWs | 26 | 49 | 67 |
| "Intermediate" Th Cycle CANDU-PHWs | 10 | 34 | 53 |
| "Self-Sufficient" Th Cycle CANDU-PHWs | 0 | 29 | 52 |

Note that the annual uranium requirements for once-through uranium cycles can be reduced by more than a factor of two by employing plutonium recycling. At the growth rates shown, the uranium requirements for systems using any of the range of thorium cycles are essentially as low or lower than the requirements of either uranium cycle.

From the point of view of instilling confidence in the adequacy of uranium resources to provide large amounts of nuclear energy, thorium cycles can play an even larger role. Figure 2 [6] shows estimates of the nuclear power capacity as a function of time (and hence energy production) which can be supported by $3 \times 10^5$ Mg of uranium (the amount we know at present is available in Canada) using various cycles. The values of total electrical energy produced are proportional to the areas under the curves and are listed below.

Natural uranium once-through cycle: 1,800 GWe years
Plutonium recycling : 3,500 "
Th cycle - high burnup : 6,900 "
Th cycle - intermediate : 17,000 "
Th cycle - self-sufficient : 79,000 "
(limited only by Th supply which
is assumed equal to the U supply)

AECL is now embarking on an orderly, 20 to 25 year program with the objective of developing and demonstrating the technology, in Canada, for recycling of fissile material in CANDU reactors. It is essential that we understand all the implications of the fuel cycles including technical, economic, safety, health and security aspects as a prerequisite to any future decision for their commercial-scale use.

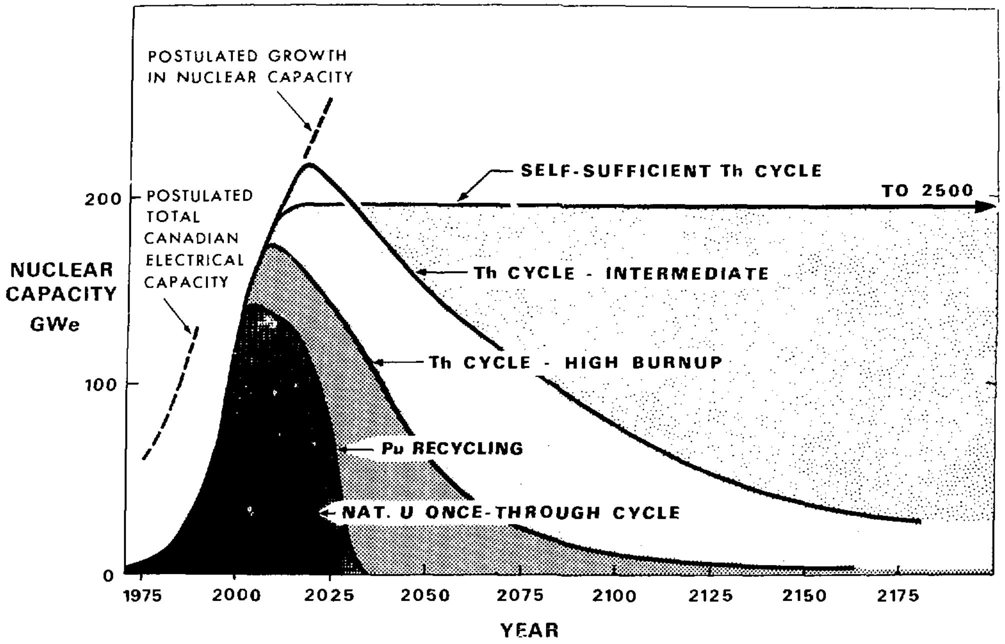

Fig.2. Energy from 3 x $10^5$ Mg Uranium with Various CANDU cycles

## Radioactive Waste Management

No description of a power reactor program would be complete without a discussion of the management of radioactive wastes.

In Canada the plan for the management of spent fuel involves storing the fuel in water-filled storage bays at each reactor site for a period of about five years. After this, the fuel will be transferred to an interim spent-fuel storage facility where it will be stored in a retrievable manner until such time as a decision is made on recycling of plutonium.

Two concepts are under consideration for this interim central storage. The first, of course, is to build additional water-filled bays. No new technology is required. The second is to place the spent fuel in steel cans which are then stacked inside large concrete canisters which can be sealed. Cooling is provided by conduction of heat through the walls to the surrounding air. A demonstration of this concept is now in progress at the Whiteshell Nuclear Research Establishment.

If the decision is made to proceed with fuel reprocessing, the plan is to immobilize the separated fission products and the actinides remaining with them in an essentially insoluble glass or ceramic matrix which would then be placed in an ultimate disposal facility. Should the decision be not to proceed with fuel recycling, the spent fuel would be packaged intact in a form suitable for ultimate disposal.

For ultimate disposal, we plan to place the radioactive wastes, immobilized as described above, deep underground in a suitable geologic formation. Work to date has concentrated on two types of rock-bedded salt and granitic plutons, which are large bubbles of igneous rock found in abundance throughout the Canadian Shield. We are at present engaged in identifying suitable sites with a view to having a site selected by 1980 and a demonstration facility in operation by 1986. A highly desirable occurrence would be to find a site suitable not only for ultimate disposal but also for central interim storage, fuel reprocessing and recycled-fuel fabrication.

## Conclusions

The development of the CANDU reactor and of the associated supply industry has been an integrated, evolutionary program which has provided Canada and the world with an efficient, low-cost source of electrical energy.

For the future, the development of advanced fuel cycles will make it possible to derive energy from thorium as well as uranium, thus assuring economic power to mankind into the foreseeable future.

## REFERENCES

[1] FANJOY, G.R., BAIN, A.S., "CANDU Fuel - Fifteen Years of Power Reactor Experience", paper 184 at this Conference.

[2] LE SURF, J., WATSON, D.A., WILSON, R., VIVIAN, G.A., "Radiation Dose Reduction Programs for CANDU Nuclear Power Stations", paper for the World Energy Conference, Istanbul, 1977, to be published.

[3] DAHLINGER, A., RAE, H.K., LOCKERBY, W.F., "Canadian Heavy Water Production", paper 183 at this Conference.

[4] FOSTER, J.S., CRITOPH, E., "The Status of the Canadian Nuclear Power Program and Possible Future Strategies", Ann. Nuc. Energy 2 11/12 (1975) 689.

[5] CRITOPH, E., "The Thorium Cycle in Water-Moderated Reactor Systems", paper 177 at this Conference.

[6] FOSTER, J.S., CRITOPH, E., "Advanced Fuel Cycles in Heavy Water Reactors", paper for the Conference on World Nuclear Energy, Washington, D.C., Nov. 14-19, 1976, to be published.

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