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ATOMIC ENERGY OF CANADA LIMITED

L'ÉNERGIE ATOMIQUE DU CANADA LIMITÉE

THE FUTURE FOR CANDU

by

J.S. FOSTER

Presented at the

Canadian Nuclear Association 17th Annual International Conference

Montreal, 5-8 June 1977

Chalk River Nuclear Laboratories

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Perspectives d'avenir des centrales CANDU*

par

Dr J.S. Foster

Président

L'Energie Atomique du Canada, Limitée

Résumé

En plus de confirmer le bien-fondé de la filière CANDU (CANada Deutérium Uranium), la performance remarquable de la centrale Pickering a également démontré la capacité industrielle du Canada et la compétence du personnel oeuvrant dans le domaine du génie nucléaire. En fait, sans faire de nouveaux plans, et en n'ayant qu'à consolider sa base industrielle existante, le Canada pourrait avoir 60 000 MW(e) de capacité installée pour la production d'électricité d'origine nucléaire en l'an 2000 et il pourrait exporter des centrales produisant 5 000 autres MW(e).

Bien que le réacteur CANDU puisse être facilement extrapolé pour avoir des unités de plus grande taille, son véritable potentiel se trouve dans la plus grande efficacité qui pourrait être obtenue en utilisant d'autres cycles de combustible. Par exemple, le cycle de combustible à base de thorium-uranium-233 permettrait d'obtenir un facteur de conversion égal à l'unité ou un peu supérieur à l'unité en étant alimenté par du thorium pur dans un réacteur CANDU substantiellement inchangé. Etant donné que le thorium est environ quatre fois plus abondant que l'uranium et qu'il ne serait consommé qu'à environ 1% du taux où l'uranium l'est, dans le cycle actuel d'uranium à passe unique, il offre la possibilité d'un approvisionnement de combustible virtuellement illimité. D'autres développements, comme la spallation, offrent le moyen de convertir des matières fertiles en matières fissiles afin de constituer des stocks de matières fissiles pour une filière en pleine expansion.

Le programme nucléaire canadien va probablement être touché pendant plusieurs années par le débat public actuel sur l'énergie nucléaire et par la réaction du gouvernement face à ce débat. Cependant, la coincidence des pénuries auxquelles on s'attend dans les approvisionnements énergétiques d'autres sources et de la bonne expérience acquise dans le domaine nucléaire devrait favoriser un climat permettant le développement accéléré de l'énergie nucléaire.

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L'Energie Atomique du Canada, Limitée
Laboratoires Nucléaires de Chalk River
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Dr. J. S. Foster
President
Atomic Energy of Canada Limited

ABSTRACT

The outstanding performance of the Pickering Generating Station, besides confirming the soundness of the CANDU (Canada Deuterium Uranium) design, has also demonstrated Canada's industrial capacity and competence in the nuclear engineering field. Indeed, with no re-design and little more than a consolidation of its existing industrial base, Canada could have 60,000 MW(e) of installed nuclear-electric generating capacity by the year 2000 and have exported the plant to generate a further 5,000 MW(e).

While the CANDU reactor can readily be scaled up to larger unit sizes, its real potential lies in the even greater efficiency that can be obtained by using alternative fuel cycles. The thorium - uranium-233 fuel cycle for instance, makes it possible to attain a conversion factor of unity, or a little better, on a feed of pure thorium in a substantially unmodified CANDU reactor. Since thorium is about four times as abundant as uranium and would be consumed at about 1% of the rate at which uranium is consumed in the present once-through uranium cycle, it offers the prospect of a virtually unlimited fuel supply. Further developments, such as spallation, offer means of converting fertile to fissile material to provide a fissile inventory for an expanding system.

The Canadian nuclear program is likely to continue to be affected for several years by the current public debate on nuclear power and government reaction to it. However, the coincidence of expected future shortages of other energy supplies with continuing good experience in the nuclear field should assist in creating a climate that will permit accelerated nuclear power development.

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THE FUTURE FOR CANDU*

Present Status

Today Canada has the designs for single 600 MW(e) CANDU-PHW** nuclear-electric generating units and for stations composed of multiple 500 MW(e) and 800 MW(e) units of the same type. The very successful operation of the Pickering station, backed by the long experience with the NPD (Nuclear Power Demonstration) and Douglas Point prototypes, has demonstrated that the CANDU system is capable of safe, dependable, economic performance. Early experience with the first two units in the Bruce station is tending to confirm this for these larger units. From my knowledge of the design of the 600 MW(e) units, I expect them to be as good as these earlier designs.

The good performance of Pickering, besides confirming the soundness of the CANDU design, has also demonstrated Canada's industrial competence in this field and the ability to build and operate these plants in an effective way in at least one part of the country. This competence is already extending to other areas and there is every reason to be hopeful that experience in these areas will be similar.

Relative to her own needs, Canada is one of the best endowed countries in the world with respect to domestic uranium resources. Domestic production of uranium is half a dozen times current domestic consumption and has been as high as the likely domestic consumption rate at the end of this century. There are two fully operational CANDU fuel manufacturing plants in Canada, a third in partial operation and a fourth in immediate prospect. These provide the number of centres for growth and the desirable diversity to underpin what is inherently the highest growth sector of the nuclear power industry.

The highly successful operation of the Bruce heavy water plant and the resumption of good performance at Port Hawkesbury indicate that the heavy water necessary for a CANDU program can be assured. Heavy water plants in early operation or under construction will increase the production capacity to a level sufficient to commission 3,000 MW(e) of new nuclear-electric generating capacity annually.

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**600 MW electrical Canada Deuterium Uranium-Pressurized Heavy Water.

The production of zirconium alloy mill products now embraces the finishing of pressure tubes as well as the fabrication of calandria tubes, and expansion of activities into other parts of this business is in prospect.

Industrial capacity for the manufacture of components for CANDU nuclear steam supply systems is now sufficient to manufacture about 2,000 MW(e) of new CANDU nuclear-electric generating capacity each year. I do not think there is any question that it can expand to match the expansion of the national heavy water production capacity so that in a few years Canada will have the industrial capability to commission 3,000 MW(e) of new nuclear-electric capacity each year.

With no new basic designs and with little more than consolidation of the industrial base, Canada could have 60,000 MW(e) of nuclear-electric generating capacity installed by 2000 and could have exported another 5,000 MW(e) of plant by the same date. This is a kind of base case. It indicates what could be done with the present state of the art and with the manufacturing capacity for pertinent major capital goods that is now in place or under construction provided the power plants were installed at a uniform rate. It is not a projection. I have presented it simply to convey an idea of the present capacity in this country.

Promise

In order to better gauge what might in fact transpire over the next quarter century let us now turn to the other end of the scale and look at the promise of the CANDU system. Promise is essential if a line of endeavour is to endure, for promise invites development and development maintains vitality.

On the simplest plane the CANDU system lends itself very readily to scaling up, and survey type studies carried out by AECL (Atomic Energy of Canada Limited) indicate no impediments to this in units up to at least 2,000 MW(e) capacity. A preliminary design for a unit of 1,250 MW(e) for application on the Ontario Hydro system is already well advanced, and relevant development work is in progress. Units of this size will undoubtedly be in service in Canada in the nineties and perhaps before.

The real promise of CANDU, however, lies in its efficiency. The same efficiency which enables CANDU reactors to operate with natural uranium fuel and, in doing so, to extract substantially more energy from the raw uranium than can contemporary alternatives makes it possible to derive many times the amount of energy that is available from a given quantity of uranium with the current simple fuel cycle. This is achieved through the thorium - uranium-233 fuel cycle. The combination of heavy water, the most efficient moderator, with uranium-233, the most efficient fuel in a thermal reactor, makes it possible to attain a conversion ratio of unity or a little better. In this way a CANDU reactor, supplied with the appropriate amount of fissile material to begin with, could operate on a feed of pure thorium and derive all the energy available from fission of the total thorium feed. The starting fissile material must come, in one way or another, from uranium for the only natural fissile isotope is uranium-235. To start operation of a CANDU reactor on the thorium - uranium-233 fuel cycle it is necessary to employ uranium-235 separated from natural uranium or plutonium generated by neutron irradiation of the uranium. The reactor and fuel cycle can be designed to operate at any level of efficiency up to self-sufficiency on pure thorium feed with varying effect on the amount of energy that can be realized from a given quantity of uranium. The consumption of thorium is not important except for the most efficient system over a time measured in centuries.

At this point it is probably advisable to point out just what the thorium - uranium-233 cycle can do and what it cannot do. What it can do is to make the energy available from uranium virtually limitless since a certain generating capacity once started on the cycle can operate on a consumption of thorium that is only about 1% of the consumption of uranium on the present once-through natural uranium fuel cycle. Thorium is nearly four times as abundant as uranium and therefore it is reasonable to think that its availability will be at least as great. What the thorium - uranium-233 cycle cannot do is to make a corresponding amount of power available. In fact, the amount of power that can be generated is only about three times that which can be generated with the current once-through natural uranium fuel cycle. This is a consequence of the requirement of uranium for the starting fissile material.

Immediate advantages to the use of the cycle are that it provides assurance of virtually unlimited fuel supply with insensitivity to the cost of that supply, and it does so without having to change from the same thermal reactor used for the once-through natural uranium fuel cycle. As far as can be seen changes to the reactor to accommodate the thorium - uranium-233 fuel cycle will be minimal.

It does not, however, materially reduce total uranium requirements during periods of fast power system growth (and the same thing is true for the fast breeder reactor) because of the dependence upon uranium for initial fissile material. That is with today's technology: isotope separation processes and fission reactors. There are, however, other routes to fissile material and other ways besides the fission process to produce neutrons to convert fertile materials to fissile. One way might be to use the neutrons from the fusion process. Another is to use the spallation process. Spallation is a process that will be understood by all the civil engineers in the audience. The word comes from spall and is the name of a nuclear reaction in which a chip is spalled off the nucleus of an atom as opposed to the fission reaction in which the atom splits into two relatively large chunks. Nuclei of atoms consist of neutrons and protons. Fission results when an extra neutron is crammed into the nucleus of certain heavy elements. Spallation results when an extra proton is crammed into the nuclei of certain heavy elements. Whereas a neutron can simply wander into a nucleus because it does not carry any electrical charge, a proton has to be impelled into it because, bearing a positive charge, it is repelled by all the other protons already happily inside that nucleus.

The spallation process produces about 50 neutrons as opposed to the 2 or 3 produced by fission so it is very attractive as a neutron source for producing fissile material. The initiating protons need to be accelerated to 1 GeV to have a reasonable probability of entering the nucleus. The reaction, however, yields 4 GeV so it is at least conceivable that the process could produce enough energy to drive itself.

AECL is doing research related to this process and neutron yield experiments are being performed in the TRIUMF experiment in Vancouver.

Today's CANDU reactors operating on the once-through natural uranium fuel cycle provide access to a whole new energy resource. The thorium - uranium-233 fuel cycle removes any practical limit on the energy available from that resource. The spallation process could provide access to that energy at a rate that is not limited by the availability of uranium.

This expansion in access to energy is clearly the most important strategic line of development relative to application of the CANDU reactor.

It cannot, however, detract from more immediate research and development (R & D) requirements in the field of nuclear power, notably the R & D related to maintaining and improving the good performance of the current line of power reactors. Nor should it preclude developments of a more tactical nature when the time for them is right. For instance, some day it may very well be desirable, assuming it is practical, to develop the organic-cooled CANDU system to make feasible reactors for nuclear-electric generating units with thousands of megawatts capacity and to reduce the size of the associated turbines. A logical development application along the way might be the provision of steam for in situ extraction of the Athabasca tar sands.

A CANDU reactor already provides steam for heavy water production. Heavy oil extraction from tar sands is only one more possible process application for energy from nuclear power. Such uses will multiply, and either directly, or indirectly through the expanded use of electricity, nuclear power will assume an increasingly important share of total energy supply.

External Factors

The present status of nuclear power in Canada and the promise of the CANDU system are only two of many determinants of the "Future for CANDU". External factors are just as important as inherent qualities in determining the future for anything.

The most important external factors in relation to the future of CANDU are unquestionably the concerns about nuclear power and the social and political reactions to those concerns and the general state of energy supply and demand. I will start with the concerns about nuclear power and the resultant reactions.

The concerns about nuclear power have to do with safety, effects on the environment, disposal of wastes, misuse by criminal elements and proliferation of nuclear weaponry. I am not going to discuss these. All kinds of views of them are getting a continual airing. I have enumerated them because they are at the root of the objections by sincere opponents of nuclear power, are used by all opponents of nuclear power, and are the matters addressed by governments and politicians in trying to meet energy imperatives while endeavouring to remain on popular ground.

Effects are not determined by qualitative possibilities; they are determined by quantitative practicalities. Good information and continual dialogue are essential but relief of the concerns mentioned does not lie in dialectic. It lies in good experience and familiarity with the experience.

I already sense some diminution in the concern about nuclear power on the grounds of reactor safety because of the accumulating good experience in this regard.

The concerns about waste disposal and diversion of material can only be relieved through a similar route - demonstration.

Disposal of wastes is not a problem; it is a task. It will pose some difficulties but it is simply a job to be done and an easier job than many that have already been done in this business. Governments want to see this proceed in order to maintain the nuclear energy option but are worried about local reactions to waste disposal of any kind and to radioactive wastes in particular.

The waste disposal question, the possibility of misuse by criminal elements, and proliferation of weaponry are, unfortunately, all interrelated in a complex way. Irradiated fuel, because of its content of fissile material, is a valuable energy resource; it should not be treated as a waste. Reprocessing, however, makes fissile material somewhat more susceptible to theft and is a useful route to the production of nuclear explosives.

There are no simple answers because an entirely good result depends upon unmitigated goodness in men. Unfortunately, such is not reality and consequently there is a recurring search for some way of living at ease with both nuclear energy and human nature. Some propose the barren expedient: no nuclear power. Even if acceptable for other reasons this is no answer to the concerns because sufficient knowledge is now sufficiently available that turning our back cannot prevent powerful groups bent on doing so from misusing nuclear energy. There is a tremendous range of other views. President Carter's recent statements indicate a certain set of views. These seem to be that if at this stage commercial reprocessing were not undertaken by countries uncommitted to it and suspended by those who are, to set an example, the access to fissile materials for weaponry by those who do not now have such weapons would at least be delayed. At the same time this view embraces the necessity for more efficient fuel cycles than the current once-through fuel cycle. There is the hope that some fairly efficient cycle can be found which will not entail nearly the degree of availability of fissile material inherent in the production of fast reactor fuels. It is a new look at old ideas but with new emphasis - emphasis on control of fissile material. There can, however, be no magic answers, only variations by degree.

This new direction in thinking has stimulated American interest in the CANDU reactor in several different contexts and as a result we look forward to enhanced collaboration in the field of nuclear power. Contrary to some hasty impressions, Canadian development of the thorium - uranium-233 fuel cycle would not be at variance with the American stance.

Besides making available a means to better resource utilization in the next century the development would entail an enterprise employing several hundred people that should make association with closing the fuel cycle attractive to a number of communities.

We are at a stage in the development of nuclear power that is going to require an unusual degree of understanding between the technical and political elements. The technical element, immersed in the subject, and anxious to do the job that it feels society needs and which it is capable of providing is frustrated by any apparently avoidable delays. The political element, on the other hand, is much more sensitive to trends in public opinion. Political power rests on public perceptions.

At this juncture a large part of the populace is just becoming aware of the important role that nuclear power is beginning to play and is adjusting to it or trying to in a welter of information, misinformation, rhetoric and polemic. In this environment the natural inclination is to move cautiosly and political leaders are responsive to this attitude. Until a large part of the population has grown accustomed to nuclear power and has at least some intuitive appreciation of its character as regards safety and effects on the environment and until some clear personal sense of need for it emerges, nuclear power development will be inhibited to some degree. In certain other countries such as, for example, Sweden, Switzerland, Denmark and the United States this has been quite serious. It has not been serious in Canada and I am very optimistic that it will not be in the future but some protraction of programs is inevitable.

The other external factor that is, of course, crucial with respect to the future of CANDU is the state of energy supply and demand. There are two important aspects of this in relation to nuclear energy. One is the resultant real demand for nuclear energy; the other is the public impression. The first is fundamentally more important but it is dealt with so frequently that I do not intend to devote much time to it. Very briefly, Ontario has determined that the major part of the province's electrical energy will in future come from nuclear power. Quebec speaks of having an additional 15,000 MW(e) of hydro-electric potential that can be economically developed after Baie James and thereafter envisages a major nuclear power program. The hydro-electric resources could probably carry the province until the mid-nineties. However, at that time annual increments would be about 3,000 MW(e) so that a sudden switch from one energy form to another would entail a virtual metamorphosis in parts of the utility's organization and a major staff development task. It is more likely that a more gradual transition will be adopted with earlier expansion of nuclear power capacity; but a clearer picture of the form of the development must await the definition of policy expected this fall. The Maritime Provinces have already begun the transition to nuclear power and although it is possible that tidal power or thermal power based on coal may affect the rate of installation for a short period, the long-term trend is clear. Manitoba's position is very similar to that of Quebec and Manitoba Hydro has already begun preparation for the transition from hydro to nuclear. The other Western provinces are better endowed with alternative energy resources and their adoption of nuclear power will be somewhat later. By the end of the century, however, probably all provinces will be relying to some degree on nuclear power generation. The Department of Energy, Mines and Resources mean estimate, and our own survey of the utilities supports it, is that nuclear-electric generating capacity in Canada in 2000 will be 80,000 MW(e).

The other aspect of energy demand and supply that can and probably will affect the nuclear power program is the public impression of the energy situation. The Department of Energy, Mines and Resources supported by many knowledgeable sources in the petroleum industry is predicting a substantial shortfall in domestic Canadian oil supplies by the mid-eighties and increasing reliance on imported oil. This is likely to create monetary strains and high prices, and periodic dislocations of supply can be expected. Although there will be very little that nuclear power will be able to do to relieve the situation, my suspicion is that this situation will create a mood that will facilitate installation of nuclear power plants.

It will be ironic that if these problems with oil supply do materialize it will be in the face of major established tar sands resources extractable with current techniques. It is too late to forestall the problems entirely and it would require a joint federal-provincial policy to ensure success, but I suspect the most important thing Canada can do in energy development at the present time would be a major program of development of the tar sands. The country is fortunate that they are there and that they are no more easily exploitable than they are. This has preserved them until a time when the country can most benefit from them.

Summary

Summing up, Canada has domestic technology and an industrial base that can rise to meet the likely demand for the rest of this century. The CANDU system holds promise for increases in scale and improvements in thermal characteristics but, more important, for long-term evolutionary development to make increasingly better use of the nuclear energy available in the heavy elements. This promise should attract the development that is essential for vitality in the program. The application of CANDU reactors is on a clearly upward trend but is likely to continue to be subject to cyclical forces. For the next few years, as a larger part of the population becomes aware of the importance of nuclear power and adjusts to it and as governments react to apparent popular opinions, the development of all facets of nuclear power will be somewhat inhibited. Subsequently, the coincidence of shortages of other energy supplies with culmination of a large measure of the adjustment of the population to nuclear power will probably create a mood that will accelerate nuclear power development.

I have not said anything about the application of CANDU reactors in other countries. Despite AECL's very substantial loss on the company's first firm-price overseas contract, the company's embarrassment over agents' fees, and increasing difficulty in trade in nuclear reactors because of the mixed feelings about such trade and the effect this has on government policy and official practice, I am sure the trade will continue. Perhaps paradoxically I believe it is one of the essentials for a continued relatively peaceful existence on this planet.

Provided we all do our part, CANDU reactors will play an important role in Canada and other countries for a long time to come.

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