NUCLEAR POWER IN THE NEXT DECADE
AND AECL'S PROGRAM TO MEET IT

by

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In order to make the story on the next decade fully meaningful, I'll have to begin with a description of the state of CANDU nuclear power today.

Table I lists the CANDU units which are now operating, under construction or committed for construction.

STATUS OF OPERATING UNITS

NPD

This nuclear power demonstration unit has been operating since 1962. All difficulties experienced for which remedies were practicable have been eliminated. Currently, its most important use is for the training of operating staff. It is also used for the first field trials of development results whenever it can provide an adequately relevant environment. If it were used solely for the generation of power, its operability (or availability) would be not far off an acceptable commercial unit but, because of its small size, it is not an economically competitive source of power.

Douglas Point

This prototype unit first produced power early in 1967. As was the case with NPD, operational difficulties were experienced but most of them were different. With only one or two exceptions, appropriate modifications have been introduced with the result that during the last year the performance of the plant has been about what could be expected of a second generation unit. There are improvements which can yet be made and, of course, there is probably much to be learned from problems yet to be experienced.

Pickering #1

This first fully commercial power unit went into operation early this year. The experience so far has been most encouraging.

TABLE I: CANDU NUCLEAR POWER

<table>
<thead>
<tr>
<th>Unit</th>
<th>Power (MW(e))</th>
<th>Scheduled for Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NPD</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td>Douglas Point</td>
<td>200</td>
<td></td>
</tr>
<tr>
<td>Gentilly</td>
<td>250</td>
<td></td>
</tr>
<tr>
<td>Pickering</td>
<td>500</td>
<td></td>
</tr>
<tr>
<td>Under construction</td>
<td></td>
<td></td>
</tr>
<tr>
<td>KANUPP</td>
<td>130</td>
<td>1971</td>
</tr>
<tr>
<td>RAPP 1</td>
<td>200</td>
<td>1972</td>
</tr>
<tr>
<td>Pickering 2</td>
<td>500</td>
<td>1972</td>
</tr>
<tr>
<td>Pickering 3</td>
<td>500</td>
<td>1972</td>
</tr>
<tr>
<td>Pickering 4</td>
<td>500</td>
<td>1972</td>
</tr>
<tr>
<td>RAPP 2</td>
<td>200</td>
<td>1974</td>
</tr>
<tr>
<td>Bruce 2</td>
<td>750</td>
<td>1974</td>
</tr>
<tr>
<td>Bruce 1</td>
<td>750</td>
<td>1977</td>
</tr>
<tr>
<td>Committed for construction</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Madras 1</td>
<td>200</td>
<td>1975</td>
</tr>
<tr>
<td>Madras 2</td>
<td>200</td>
<td>1976</td>
</tr>
<tr>
<td>Bruce 3</td>
<td>750</td>
<td>1978</td>
</tr>
<tr>
<td>Bruce 4</td>
<td>750</td>
<td>1979</td>
</tr>
</tbody>
</table>

Gentilly

Gentilly differs from the other CANDU (Canadian Deuterium Uranium) reactors in that it is cooled with boiling light water. It first produced power early this year. Again, as with the Douglas Point unit, we have experienced some difficulties with this prototype — the shaft of a main coolant pump has been broken, the main steam line to the turbine was inadequately secured, the zonal control devices were not effective enough at low power levels, we were disappointed with the performance of the latest model of in-core flux detectors and we have had some weld repairs to make on connections to the steam drum. So far, there is no indication that this prototype will not confirm the desirable attributes.
claimed to be inherent in the boiling-light-water-cooled version of CANDU.

COMPARATIVE ECONOMICS

There is no doubt that for unit sizes above 500 MW(e), nuclear power is cheaper for base load purposes than power produced from fossil fuels even though the capital investment required is almost twice as great. Indeed, in general even compared to hydro power the cost of generation and transmission is less for nuclear power over 500 MW(e) when the transmission line distance exceeds about 600 miles.

There are, however, a variety of power needs to be satisfied and more of both fossil fired stations and hydro generating units will be required. But for base load purposes, the only real competition for CANDU will come from other nuclear concepts.

Isolated bits of information coming from the market place sometimes indicate that CANDU has an economic edge and sometimes that one or the other of the American light-water-reactor (LWR) types has shown up better. Indications that CANDU offers better economy are occurring with increasing frequency. Table II indicates what I suggest to be the best guess of the real comparative economy of units which could be committed for construction today.

<table>
<thead>
<tr>
<th>TABLE II: COMPARATIVE ECONOMY</th>
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</thead>
<tbody>
<tr>
<td>Cost Items</td>
</tr>
<tr>
<td>Unit cost of power generation ($/kWh)</td>
</tr>
<tr>
<td>Capital costs ($/kW(e))</td>
</tr>
<tr>
<td>Total initial investments</td>
</tr>
<tr>
<td>Investment excluding D$_2$O and initial fuel inventory</td>
</tr>
<tr>
<td>Annual fuelling costs* ($/year per kWh)</td>
</tr>
</tbody>
</table>

As for comparative economy in the future, most trends likely to occur in the economic factors will result in an increasing advantage to CANDU. Both LWR's and CANDU's will enjoy the economic benefit of technical advances. The speed with which these advances in technology are made and applied will certainly be one of the factors which will principally determine the future competitive position of the CANDU reactor.

FORECAST OF DOMESTIC NUCLEAR INSTALLATION

Figure 1 indicates the nuclear generating capacity expected to be operating in Canada up to 1985. The estimate (not shown) for 1990 is more than double that for 1985. I have shown additionally a conservative estimate of the number of professionals required to carry out all the primary functions—research, development, design, equipment testing, manufacturing, construction commissioning and operation. Of the factor of more than three by which the numbers should increase between 1970 and 1985, 80% is expected to occur in manufacturing and operations, which traditionally have not used professionals with the highest academic qualifications. I have perhaps somewhat underestimated the increase in research and development effort because I am not optimistic that the level of funding for these purposes by government, industry and the utilities will be consistent with the need or with the benefit to be derived from satisfaction of the need.

To provide some measure of the size of the forecast installation program, it is enough to point out that the capacity now operating or planned for operation in Ontario before the end of 1979 is approximately half the present generating capacity of Ontario Hydro, is 2 1/4 times the Canadian share of the Niagara and is 5 times our share of the St. Lawrence development.

FORECAST OF NUCLEAR PLANT EXPORT

Four CANDU power reactors totalling nearly 800 MW(e) are now being constructed outside Canada. Two of these, one in Pakistan and one in India are expected to produce power before next mid-year. Funding for a fourth unit of 200 MW(e) in India has just been authorized, and this will increase the number being constructed outside Canada to five.

Much has been said throughout the country regarding lack of success of CANDU's in the export market. As a matter of fact, no reactor can be said to have been successful in commercial competition. The
only order which might be said ever to have been
placed as a result of international competition was
that for the Atucha plant in Argentina. No order has
yet been placed for any plant for which AECL made
a bid.

With the current generation of CANDU already
being economically competitive and now being
confirmed as a reliable commercial power source, it is
reasonable to expect that some of the great number
of nuclear plants which will be built throughout the
world will be CANDU's. Our marketing group are
confident that this will indeed be achieved and are
forecasting an export business comparable to our
forecast of domestic installation but delayed in time
by about five years. This would mean an order rate of
nearly $200M per year before the end of this decade.

DEVELOPMENT PROGRAM

The nuclear power development program can be
considered to be comprised of two phases.

The first phase with the objective of establishing
competitive nuclear power started in the early 1950's.
Although we have passed the time of peak effort,
there still remains the work of assisting in problem
solving in operating units and of getting improve-
ments where possible out of the lab and into the
designs of committed units which are already on the
drawing boards.

The second phase commenced only a few years
ago and concerns evolution of the CANDU concept,
cost reduction and major improvements. We have not
yet reached the peak of work for this phase. It will
continue at least through the 1970's.

A successful program to meet the challenge
inherent in the forecast of the demand for nuclear
power in the next decade must include more than the
development of technology.

I wish at the least, to make mention of these
other aspects before going on to giving you an overall
picture of the technical program. No amount of
technology has any real worth unless it is applied. So,
along with the development of technology we expect
to develop an export market, promote domestic
installation, assist in the development of public
acceptance of nuclear power, contribute to the
development of increased industrial capability in
Canada and do our share towards establishing the
inventory of experienced manpower necessary for the
execution of all aspects of nuclear enterprise.

Incentive for Technical Advance

Since the primary incentive for making advances
in nuclear power technology is economic, the deve-
lopment program must have as its objectives:
1) reduction of heavy-water cost,
2) increase in power density,
3) increase in net thermal efficiency, and
4) decrease in manufacturing and construction
cost.

To increase plant availability, one must
concentrate on:
1) improvement of the reliability of systems,
equipment and fuel, and
2) reduction of the time required to remedy faults.

The prerequisites to low fuelling cost are
1) low consumption,
2) low failure rate, and
3) low fabrication cost.

To achieve lower operating and maintenance cost
we need to:
1) improve reliability,
2) reduce the man-hours required for remedy of
faults, and
3) reduce $O_2$ loss and the amount of escaping
$O_2$ which requires upgrading.

Our development program covers all of these
objectives to an extent determined by the availability
of funding. More emphasis is placed where the most
benefit is expected to be achieved.

Coolant Options

The three types of CANDU which we can or
expect to be able to offer to prospective customers
before 1980 are
1) CANDU-PHW,
2) CANDU-BLW, and
3) CANDU-OCR (organic-cooled reactor)

Each has comparative advantages.

The CANDU type now being operated and under
construction in Ontario is the PHW. Its primary
advantage is the extent of our experience with it. For
any other type, the predicted advantage has to be
weighed against the possibility of unexpected
difficulties. Further, from a marketing point of view,
the actual performance capability and economics of
the PHW will be sooner known.

The CANDU-BLW type now in operation at
Gentilly promises lower capital cost due to the
elimination of heavy water as coolant and to the
somewhat higher net thermal efficiency achievable. It
also promises lower operating cost due to reduction
in heavy-water losses. The fuelling cost will be higher
than for the PHW though this would be more than
offset by the reduction in capital cost.

The OCR also eliminates the expense of
heavy-water coolant and offers additionally even
higher net thermal efficiency than the BLW. The
unique feature of OCR is the negligible level of
radiation in the boiler room which has been
demonstrated in the WR-1 test reactor at Whiteshell.
This feature would substantially reduce the cost of
maintenance in boiler rooms. For PHW's and BLW's.
the means of reducing these costs is limited primarily to improvement in reliability and simplification of equipment and systems.

The capital cost of any of the three CANDU types may be reduced by enriching the fuel with plutonium or $^{235}U$. When enriched fuel is used, the fuelling cost is somewhat increased unless the reactor is designed specifically for burning enriched fuel. In that case, the fuelling cost is about the same as for natural fuel.

**Fuel Options**

There are also a number of fuel options which are or will be available during this decade:

1) natural $UO_2$,  
2) natural $U_3Si$,  
3) natural UC, and  
4) $UO_2$ enriched with plutonium or $^{235}U$.

We certainly have much more experience in the design, fabrication and use of natural $UO_2$ fuel. However, the development of $U_3Si$ is well advanced and principally because of its higher density it offers both lower consumption and lower fabrication cost.

UC is suited only to use in the organic cooled reactor. It, along with $U_3Si$, has the advantage of higher density compared to $UO_2$. Its development is well advanced.

We've only recently initiated the application of significant effort in the development of enriched fuel (using NRX and NRU), the principal objective being to demonstrate performance and to determine fabrication costs for a fuel which would burn the plutonium being produced in our reactors. In respect of the capital cost reduction which could be achieved by designing future reactors for the burning of plutonium, the greatest advantage would be obtained in the boiling-light-water-cooled type.

**Program Summary**

A boiling-light-water reactor recycling its own plutonium offers the greatest reduction in capital cost. We have chosen this version of CANDU for the reference around which to design the development program for water-cooled reactors. Fortunately, most advances made in a program centred around a self-enriched BLW are also applicable to other types of CANDU. This water-cooled development program is the chief responsibility of Chalk River Nuclear Laboratories (CRNL).

The program at Whiteshell is chiefly concerned with the organic-cooled type which at this time appears to offer a superiority to the other two which cannot for some time yet be fully demonstrated.

The Chalk River and Whiteshell programs can be briefly stated most easily by saying that the emphasis now and for some time to come will concern:

1) capital cost reductions,  
2) improvement in reliability;  
3) development of alternative fuels;  
4) development of sources of nuclear materials and equipment;  
5) performance of materials, equipment and fuels in abnormal conditions;  
6) reduction in the effect of activation of corrosion and wear products; and  
7) increasing ability to assure the public that nuclear plants are acceptably safe and 'clean'.

Although it can now be assumed with confidence that the CANDU type plant can continue to be a success technically and economically, neither the domestic nor any export market is reserved for CANDU's. We have problems yet to be solved and problems yet to be experienced.

The program is one of continuing evolution of heavy-water-moderated reactors with the objective of maintaining and improving their competitive economic position for the safe and 'clean' generation of power.