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"NRX to Pickering" by Dr. Lorne G. McConnell (R-1)

Introduction

The prime achievement of the Nuclear Power Demonstrator (NPD) is that it was a vital first step which led to the commercial highly successful CANDU type nuclear-electric generating units in Canada and overseas.

The commercial CANDU units were highly successful because they achieved high performance in regard to the five basic objectives:
- low cost of electricity produced;
- high reliability of electricity produced;
- excellent safety of generating station workers;
- excellent safety of the general public; and
- excellent low environmental and biosphere impact (zero greenhouse gas emissions).

The commercial CANDU units were also highly successful because of the high Canadian content (jobs) associated with all costs:
- initial capital;
- operations and maintenance;
- fuelling;
- capital modifications;
- decommissioning; and
- repository.

With regard to achievements, my comments will be limited to a few highlights during the period from 1943 to 1989. Because I retired in 1989, I am not qualified to talk about the period from 1990 to 2012. I will emphasize nuclear-electric generation in Canada with a focus on the Ontario Hydro nuclear-electric generation program. In the 20 minutes allocated to me, I will not have time to also focus on the important Canadian Programs in Manitoba, Quebec, New Brunswick and Overseas.

First, I will present a few highlights about the **nuclear technology foundation** period from 1943 to 1954;

Second, I will briefly review the 1950 **Ontario Hydro Driving Force** to develop economic nuclear-electric generating stations in Ontario;

Third, I will highlight the Canadian **3 step plan to develop economic nuclear-generation** in Canada;

Fourth , I will focus on the **first development step**, and talk about the Nuclear Power Demonstrator (NPD1) from 1955 to 1957;

Fifth, I will review the cancellation of NPD1 in 1957 and the **commitment of NPD 2, the first CANDU demonstration unit committed in 1958.**

Sixth, I will review the **major change in Canada Acquisition Policy made in 1957.**

That is the policy change from
'competing Canada nuclear design organizations and competing supply organizations' to

'a single Canada nuclear design organization, competing supply organizations, and high Canadian jobs content'.
Seventh, I will present a few **highlights about NPD2** which produced first electricity in Canada in 1962.
Eighth, **I will briefly review the evidence of the success of the Ontario Hydro Commercial nuclear electric program from 1962 to 1989. I will emphasize how Ontario electricity rates in Ontario were maintained much lower than USA electricity rates during the period up to1989 thereby achieving the 1950 Ontario Hydro goal to help maintain competitive manufacturing in Ontario;**
Ninth, I will briefly express my opinion of **9 major reasons the Canada/Ontario Hydro nuclear-electric program from 1950 to 1989. was so economically successful**; and
Tenth, I shall make a few closing remarks.

1. Nuclear Technology Foundation Period from 1943 to 1954.

During World War 2 the USA, Britain and Canada decided to proceed with the development of atomic bombs. The major program in the USA with Canadian support was (a) the development of atomic plutonium bombs using graphite moderated reactors and (b) the development of atomic uranium bombs using U235 separated from natural uranium. Canada was also given the back-up task of producing plutonium using high-flux heavy-water reactors. A Canadian Team, with British and French involvement, committed in 1944 the design and construction of NRX (National Research eXperimental), the first high flux 20 MWt (MegaWatts thermal) nuclear reactor in the world. This heavy water moderated reactor conceived in the Canadian Montreal Laboratory by Canada's NRC (National Research Council with British and French support) and designed by Defence Industries Limited in Montreal, Quebec, was constructed at Chalk River, Ontario by Fraser Brace Company, and was commissioned and operated by Defence Industries Limited (DIL). Research was conducted by the Canadian National Research Council (NRC). This NRX high flux unit went into service in 1947. This reactor at Chalk River featured excellent research and development facilities which rapidly advanced Canada's nuclear knowledge both qualitatively and quantitatively prior to the commitment of the Canada Nuclear Power Demonstrator (NPD1) in 1955.
The following are a few examples:
- measurements were made of how much heat energy could be obtained from a kilogram of natural uranium in a heavy water moderated reactor;
- effective chemical controls of light water and heavy water moderator systems and high temperature water heat transport systems were established;
- methods of managing dimensional changes in materials such as graphite, pressure tubes, etc., as a result of radiation were established;
- processes to extract plutonium from irradiated uranium and uranium 233 from irradiated thorium were established;
- low-cost minimization of heavy-water dissociation with ion-exchange units was developed;
- effective management of worker radiation exposure was developed;
- the mathematics and management of xenon poisoning as a result of reactor shutdowns was

developed;

- the pros and cons of optional heat transport fluids and gases, fuels, and moderators such as graphite, light water, and sodium-potassium were established;
- the pros and cons of pressure vessels versus pressure tubes and alternative reactor orientations (horizontal vs. vertical) were developed;
- a set of reactor safety principles following a significant safety incident in 1952.was developed and implemented;
- these are just a few examples of the extensive knowhow acquired at Chalk River between 1944 and 1954 - this knowhow was vital to the development of economic nuclear-electric generating stations in Canada.

A higher power 200 MWt combined production and research reactor called NRU was committed in 1948. This unit did not start up prior to the commitment of the Nuclear Power Demonstrator (NPD1) in 1955. However, it did provide technology for on-power fuelling which later became a feature of NPD2 committed in 1958.

The technology required for a nuclear-electric program was further advanced by high temperature loops in NRX which operated at high pressure and high temperature.

The NRX reactor was also utilized to perform experiments and tests for other countries. Canada also benefited from technology exchange with several countries such as USA, Britain, France, Germany, Italy, Sweden, and Japan.

2. Ontario Hydro Driving Force to Develop Economic Nuclear-Electric Generating Stations in Ontario;

In the period from 1906 to 1950, the Ontario manufacturing industry flourished and depended on the low electricity cost from hydro-electric generating stations. Ontario Hydro wanted to maintain this cost advantage in Ontario but only limited additional low cost hydro resources were available to meet an expected large increase in post-World-War-2 electricity demand. There were no significant fossil resources in Ontario. Transportation costs of coal from eastern and western Canada was expensive to transport. Low cost coal was available from the USA but this did not provide jobs for Canada. However, Ontario had extensive deposits of uranium. If low-cost nuclear-electric generating stations could be developed, Ontario could continue to maintain a manufacturing advantage while most jobs for nuclear-electric stations would be in Canada.

3. The AECL Nuclear Power Group (NPG) Established the Canadian 3 Step Nuclear-Electric Development Plan

In 1950, Canada decided to focus its nuclear program on the development of nuclear energy for **peaceful purposes**. Atomic Energy of Canada (AECL) was created by the Canadian Parliament in 1952 and took over all organizations at Chalk River, Ontario. This peaceful program was to focus on production of electricity from nuclear fuel and produce radioisotopes for medical therapy and other peaceful uses. Canada was one of several countries in the world that decided to proceed with the development of nuclear-electric generation.

A **Nuclear Power Study Group (NPG)** was created by AECL at Chalk River in 1953 which included representatives from Canadian Utilities and Canadian corporations and was managed by a representative from Ontario Hydro. Canada proposed to establish competing nuclear design organizations in Canada and utilize competing component manufacturing organizations (both Canadian and Non-Canadian suppliers with emphasis on establishing competitive Canadian suppliers).

A Canadian 3-step program was conceived by the Nuclear Power Study Group (NPG) and subsequently committed:

Step 1 - A nuclear power demonstrator (the first Nuclear Power Demonstrator (NPD1) was committed in 1955 and cancelled in 1957 and then a second Nuclear Power Demonstrator (NPD2) was committed in 1958 and completed in 1962).

Step 2 - A prototype nuclear-electric station (the Douglas Point Nuclear Generating Station) and

Step 3 - A first commercial nuclear-electric station (Pickering Nuclear Generating Station A).

Proposals were solicited from private enterprise and public utilities to participate in the first step, a 20 MWe Nuclear-Electric Unit (later called NPD1).

4. The First Development Step, the Nuclear Power Demonstrator (NPD1) 1955 to 1957.

The design and construction of the Nuclear Power Demonstrator (NPD), later called NPD1, commenced in 1955. The nuclear part of NPD1 was to be designed by a private company, Canadian General Company. The conventional part of the station was to be designed by an electrical utility, Ontario Hydro. NPD1 was to be commissioned and operated by Ontario Hydro. AECL was to be the owner of the nuclear part of the station (steam generation). Ontario Hydro was to be the owner of the conventional part of the station (turbine-generator, electric transformer, and site). Bechtel was selected to construct the station under CGE project management.

This commitment featured a heavy water moderator and heat transport, a vertical pressure vessel, natural uranium oxide fuel and off power re-fuelling. **This concept was not expected to be an economic concept.**

In 1955, the AECL Nuclear Power Study Group (NPG) at Chalk River continued with a Ontario Hydro manager with the objective of formulating a heavy-water-moderated nuclear-electric concept which promised to be economic - that is to have a lower electricity cost than coal, oil, and gas, etc., for base load application in Canada.

The design and construction of NPD1 at Rolphton, Ontario on the Ottawa River, proceeded rapidly. However, the forecast cost of completion was over double the original cost estimate (33 M$ compared with 15M$).

5. The Cancellation of NPD1 in 1957 and the Commitment of NPD 2, the first CANDU unit Committed in 1958 and Started in 1962 - the Promise of Economic Commercial Nuclear Electricity.

Between 1955 and 1957, the **Nuclear Power Study Group formulated a new concept called CANDU** which featured a heavy water moderated horizontal reactor, pressure tubes rather than a pressure vessel, natural uranium fuel, heavy water heat transport, and on-power bi-directional fuelling. The Chairman of this study group suggested that this concept could be commercially competitive by the second commercial station. This design promised a very high Canadian content for most expenditures (more than 75%).

In 1957, the design and construction of NPD1 was suspended and subsequently terminated in 1958 - an agonizing decision. In 1958, NPD2 was committed based upon the CANDU concept.

6. Major Change in 1957 - Canada Nuclear Design and Supply Policy .

By 1957, utilities throughout the world recognized that very large coal, oil and gas electric generating units from 100 to 1000 MWe capacity would have a much lower cost than the 15 to 30 MWe fossil-fired units built before World War 2. To further lower costs, Ontario Hydro planned to build a small number of standardized large fossil and nuclear multi-unit stations (four to eight 500 MWe and larger units per station) on the shores of the Great Lakes. If nuclear generation units in Ontario were to have lower base load costs than fossil generation units, very few generating stations would be required to meet the large expected demand in electricity in Ontario (in 1950, the Ontario electricity demand expected to more than double by 1975.)

Ontario Hydro proposed and AECL agreed to a decision in 1958 that Canada was too small (population) to support more than one nuclear design organization. The 1957 Ontario forecast indicated very few large multi-unit nuclear generating stations would be required in Ontario between 1957 and 2000. Also very few nuclear-electric generating stations were expected to be built in other provinces in Canada during this time frame. The majority of station capital cost would continue to be expended through competitive private enterprise providing most of the station components and competitive private enterprise would provide all of the nuclear fuel in Canada. The choice of natural uranium meant that most of the fuel cost would be provided by the mines, refineries and manufacturers in Canada. and no enrichment facilities would be required in Canada. Although very disappointing to Canadian General Electric, the one nuclear design organization was to be a Federal public organization and AECL Nuclear Power Projects Division was created. However, in 1958, CGE would continue to be the nuclear designer for NPD2. Also in 1958, the AECL Power Projects Division proceeded with the second step, the design and construction of a 200 MWe Douglas Point Prototype Nuclear-Electric Generating Station.

7. NPD2 First Step - Vital to Success of CANDU

NPD2, based upon the CANDU concept was designed, built, and commissioned in 4 years between 1958 and 1962. As was expected, many problems were encountered in the early operation of this demonstrator. Most of these problems were resolved by the Ontario Hydro operators in co-operation with the CGE designers, Ontario Hydro designers, and the component suppliers. Some problems were solved using the R&D services at Chalk River, CGE, and Ontario Hydro Research Division.

Although NPD2 did not achieve high capacity factor performance, it was an outstanding success. The feasibility of the CANDU concept was demonstrated and NPD2 experience was vital to the later high performance of CANDU commercial units of Ontario Hydro and other Canadian units and Canadian units built overseas.

NPD2 was also vital in the training of large numbers of operating and maintenance staff required for commercial generating units in Canada and Overseas. NPD2 operations led the world in reducing the key worker positions in steam generating stations from more than 10 positions down to 3 primary positions (operators, mechanical maintainers, & control maintainers) thereby reducing the previous extensive job jurisdiction disputes.

8. Prime Evidence - Cost success - Ontario Hydro Commercial Nuclear Program 1962 to 1989

The knowledge and experience gained from the Demonstrator, NPD2, and the Prototype Douglas Point Generating Station were both vital to the later success of the Commercial CANDU stations built in Canada and Overseas.

The Ontario Hydro base-load nuclear-electric program included 5 multi-unit generating stations located on 3 sites at Pickering, Bruce and Darlington which provided about one half the electricity energy in Ontario. In the period from 1971 to 1989, the Ontario Hydro electricity cost of nuclear energy was the lowest in the world. as determined in 1989 by ONCI (Ontario Nuclear Cost Inquiry) established by the Provincial Government of Ontario. ONCI included one Canadian (not from Ontario), one member from France, and one member from USA and several analysts. The worker safety, public safety, and environmental protection was also outstanding. Note: The author of this article retired in 1989 and is not qualified to talk about nuclear performance in Ontario from 1990 to 2012. The large multi-unit stations in Ontario which burned USA coal to meet peak load requirements in Ontario, also had lower generating costs than the USA. The costs associated with the Ontario hydro-electric units continued to have low costs compared with other hydro-electric units in the USA and Canada in the period up to 1989.

The final and non-disputable evidence of the hydro-electric, nuclear-electric and fossil-electric success in Ontario from 1906 to 1989 is as follows:

The low electricity rates in Ontario, contributed to the manufacturing success in Ontario from 1906 to 1989. In the period from 1972 to 1988, 16 large nuclear-electric units were brought into service. The actual average annual electricity rates in the USA varied from 38% to 80% higher than in Ontario (see Figure 4 attached). Ontario electricity rates were somewhat higher than rates in Quebec, Manitoba and British Columbia which enjoyed a high percentage of hydro-electric generation.

Carbon dioxide emission from coal, oil, and gas fired generating stations was not a global issue during the period from 1950 to 1989. As of 1990, the carbon dioxide emissions from electric generation became a major issue. Without the Ontario nuclear-electric program, the emissions from electric generation in Ontario would have been about triple the actual emissions in 1989.

9. Nine Major Reasons the Canada/Ontario Hydro Nuclear-Electric Program was so Economically Successful from 1950 to 1989.

It is the author's judgement, based upon the information and judgements of many other persons, the following are nine major reasons for the outstanding success of the Canada/Ontario Hydro nuclear-electric program:

1. Soundness of the CANDU concept.

2. Within limits large nuclear units are more cost effective than smaller units.
3. High level of standardization of design and operation.
4. Very large Ontario commercial nuclear program.
5. Acquisition process for new nuclear units tailored to Canada's ability.
6. High competitive acquisition of components and fuel for nuclear-generating stations.
7. Effective Ontario Hydro funding process.
8. Excellence in operations (supervisors, operators, and maintainers) recruitment and training.
9. High utility performance in design, construction, research, and operations.

10. Closing Remarks

In closing, I would I would like to acknowledge that the major achievements of NPD2 were accomplished through the Canadian teamwork which included:
- the AECL Canadian Nuclear Power Group that conceived the CANDU concept,
- the Canadian General Electric designers, developers, and project managers;
- the Ontario Hydro designers and operations & maintenance staff,
- the Atomic Energy of Canada research staff, and last but not least
- the many Canadian manufacturers and the few non-Canadian manufactures that manufactured the NPD2 components and materials.
- I would also like to acknowledge the important foreign contributions which included the USA, UK and Sweden and
- I would also like to acknowledge the staff of the Canadian Atomic Energy Control Board that performed their function independently and professionally (with a smile let me say logically most of the time).

I would like to express my thanks to the Canadian Nuclear Society for this opportunity to speak to you about NPD.

It is indeed a pleasure for me to have this opportunity to meet with some of the 50-year survivors who are here today.