Early Decisions in the Development of the CANDU Program

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Abstract
This paper identifies about twenty major decisions of the Canadian Nuclear Power Program from its inception in 1942 to maturity – the decision of Ontario Hydro to complete the Pickering Nuclear Power Station and proceed with a major nuclear power installation program. The decisions are discussed briefly.

This paper reflects my views of the early years of the CANDU program to the point of program maturity. I have drawn heavily on the research work of Professor Robert Bothwell – who is writing a book on Atomic Energy of Canada Limited (AECL) – particularly for the period up to the incorporation of AECL, when I became directly involved. I certainly learned much from having access to Bothwell's early drafts of the period 1942 to 1952. I have also found *A History of the Atomic Energy Control Board* (AECB) by Gordon H.E. Sims to be a valuable reference.

C.D. Howe

The first 'key decision' was taken by Prime Minister W.L. Mackenzie King when he appointed C.D. Howe as minister of the Department of Munitions and Supply and, in October 1944, minister of the Department of Reconstruction – he was also the chairman of the Privy Council Committee for Scientific and Industrial Research, which, incidentally, almost never met. Howe, a former professor of engineering and a successful business man, had no trouble understanding nuclear fission, and he was familiar with the management and promotion of large and expensive projects.

His stature in the government and his more-than-persuasive powers allowed the nuclear program to obtain support during its early years, and he was able to keep his finger on the three main areas of importance: uranium, nuclear research and development, and nuclear regulation and control. Eldorado, with its uranium operations; the National Research Council (NRC) and later AECL, with the nuclear development program; and the Atomic Energy Control Board (AECB), the regulatory agency – all reported to Howe.

I need say no more about Howe, but I suspect that without him the nuclear development program would have died in its first few years, and probably have been reborn in the 1950s with, hopefully, but not certainly, heavy water reactors in the program.

One of the earliest actions that produced a key decision resulted from the war in Europe and the fall of France. Both the British and the French were aware in 1939 of the possibility of a nuclear weapon as a result of the work of the Curies and others. Hans von Halban, an Austrian, was working with Frederic Joliot-Curie, along with Lew Kowarski, a Russian, and the French team had advanced to the point of outlining an arrangement of uranium and a moderator that could sustain a chain reaction – a reactor. The team recognized the worth of heavy water and cornered the world's supply that had been produced in Norway, 185.5 kg.

With the invasion of France some of the scientists decided to depart, taking with them their heavy water. Halban and Kowarski arrived in England in 1941, and they were soon part of the British nuclear program. They joined other scientific colleagues at Cambridge University's Cavendish Laboratory. There was no shortage of scientists, both British and from Europe, but Halban and Kowarski were the main proponents of a reactor system using heavy water and uranium. Others were more involved in separating the fissile atom of natural uranium, U-235. They knew about plutonium but seemed to feel that a nuclear weapon was more likely to be achieved, during World War II, with U-235 than with plutonium, and the reactor development program was not of the highest priority.

The entry, by December 1941, of the USA into the war, both in the Japanese and European theatres, changed the tempo of the US nuclear development program. General Leslie Groves led the Manhattan Engineering District, and by the winter of 1942 US nuclear research was leading the way for the allies.

Hans von Halban visited the US in 1942, and recognized that the effort and facilities in the US outclassed those of his group at Cambridge. It was suggested that the British might send Halban's group to the US – or at least some individuals expert in heavy water developments. The British director of their program, Wallace Akers, was not too impressed with the US proposals, due partly to patent rights clauses, and Canada was considered as an alternative. But neither was Akers very attracted to locating the British team in Canada.

When details of the US offer were studied, Halban realized he would only be a part of a US laboratory, with no overall authority. Canada had a small program at NRC, with Dr G.C. Laurence experimenting with uranium and coke – a rudimentary pile – and Halban could expect to be placed in charge of a joint project; this was enough for him to press for a Canadian location, which would still have access to US information and supplies. The outcome was an agreement between the British and Canada, with the support of the US, that moved the British Heavy Water Project from Cambridge to Montreal in late 1942 – a key decision. It was to be headed by Halban, but without Kowarski, and included among its personnel several British, as well as Canadians and some 'refugees' from Europe, which posed a security question mark for the US; and rightly so, as we found out from the Gouzenko affair. This was the start of heavy water-moderated reactor research and development in Canada – an 'Anglo-Canadian Project' with support from the US.

Hans von Halban, as director of the Montreal nuclear laboratory, had some good points to offer the project, but he also had some deficiencies. He was an able scientist from an aristocratic family, and he had strong personal ambitions to lead an important nuclear program. He had a high opinion of his abilities, but it turned out that he lacked the personality and abilities of leadership and management.

Halban was certainly persistent and believed in the heavy water natural uranium system, and knew it was worth fighting for. The project faced severe difficulties in 1943 and 1944. The US and Britain were quarrelling, Groves was dissatisfied with the progress of work at the laboratory, the morale of the staff was very low, and the death of the lab a distinct possibility. Halban's work in France coupled with the work of Kowarski – the foundation for the reactor project – was being questioned by the US Manhattan Engineering District, but stood up under review. Halban's insistence on the merits of the heavy water-moderated natural uranium-fuelled reactor system resulted in its survival, but he was not around to see the first reactor project committed. Some feel that it was Halban's persistence that saved the project, and if so his appointment rates as a key decision. While he created the lab, he was almost the death of it.

The problems of management and program direction at the Montreal laboratory concerned not only the British and Canadians, but the US as well. A reactor design and construction program had been proposed with a price tag of about $50 million. It would be at Canada's expense. The British and Americans were not getting on too well, partly because of Halban and others of the British team in Montreal, but also because of personality conflicts among senior personnel on both sides of the Atlantic.

The British came close to abandoning the project, but instead of pulling out appointed a new director, Professor John Cockcroft, who arrived in April 1944, and things began to change rapidly. This appointment, leading to Cockcroft's arrival in Montreal, was certainly a key decision. He took command and relegated Halban to head of physics. At the same time Groves gave his consent to building a reactor – even though he knew it was obviously not going to contribute to the supply of plutonium for the current war. So the military purpose of the Anglo-Canadian project had disappeared. General relations with the US improved – as they had to.

Halban eventually got himself into trouble by stretching security procedures to report to Juliot-Curie on the progress of work in North America, both Canadian and US. This action disturbed the British, the Canadians, and particularly the US. Halban was denied access to the labs and soon returned to England and a post at Oxford.

Cockcroft was a highly respected scientist and an able leader, quiet but firm. He brought Lew Kowarski to join him.

Following discussions with the US and the laboratory staff it was recommended that a 10 MWt heterogeneous reactor moderated with heavy water, fuelled with natural uranium and cooled with light water be built – NRX (National Research Experiment) – certainly a key decision. The program proceeded with DIL as the engineer and construction manager and Fraser Brace as the contractor, in July 1944.

The selection of Chalk River as the reactor site was a very good one, and some may view it as a key decision – the only 'key' I can see is that it is in the province where Ontario Hydro is located, a utility that might be interested in nuclear power, still a dream in the scientists' minds.

In November of 1945, much to the surprise of C.J. Mackenzie, president of NRC, it was learned from newspaper reports that Cockcroft was being appointed to head the new British Atomic Energy Establishment at Harwell. Attempts were made to keep him in Canada, at least until NRX was operating. He eventually left in September 1946.

The British government had taken a firm decision to have a full-scale nuclear program of reactors, chemical separation facilities, and isotope separation plants, independent of Canada and the US and located in

Britain. This meant that the Anglo-Canadian agreement that was based primarily on the development of a means of producing plutonium for weapons was no longer valid, and that the Anglo-Canadian program would be terminated. Canada would have to proceed alone with minimal help from the British and with possible support from the US. Although this key decision was taken by the British Government, it resulted in the Canadian program for nuclear power development.

Many of the staff returned to the UK, but some stayed on at Chalk River and made major contributions to the Canadian program. Before Cockcroft left he helped arrange for a replacement from Britain, Dr W.B. Lewis, who had had an outstanding career in radar development. His confirmation as Head of the Scientific program at Chalk River was certainly a key decision. He arrived in Chalk River in September 1946 to run the research program.

Dr Wilfrid Bennett Lewis, C.C.

As I have said before, if I had to pick one person who contributed most to the success of the Canadian nuclear power program it would be W.B. Lewis – having said that, let me add that he could not have had the successes he did without the help of scientific colleagues and, more important, some very good engineers translating his ideas into practical plants.

Lewis was undoubtedly a brilliant scientist – he lived for his work, day and night; he carried a large briefcase to and from the workplace and worked late in his study at home and used his slide rule as well as any engineer. He was particularly noted for his reverence for neutrons – one wasted meant another fissile atom had to be added. The preservation of neutrons was a religion to him, and consequently he had many battles with the design engineers or materials development staff, insisting on minimum material in the reactor cores. He did not always win, but he certainly made everyone think seriously of possible ways to reduce neutron-capturing material in the core.

Lewis, as an outstanding scientist, had his own targets and pursued them intensely. I am sure he is considered as having been one of the world's leading nuclear scientists. He received many honorary degrees and awards – the Major Achievement Award in 1963 from the Public Service of Canada, the Atoms for Peace Award from the United Nations in 1967, the Royal Medal from the Royal Society in 1972, and the prestigious Fermi Award from the US Government in 1981 – all indicating the place he held in international science.

There is absolutely no doubt in my mind that Lewis' attitude towards the value of a neutron and his intense commitment to seeing they were not wasted has resulted in a natural uranium-fuelled reactor, moderated and cooled with heavy water, that is about as close to ideal as is possible in a practical reactor: CANDU. It has resulted in extremely low fuel costs for these reactors – an essential element in the success of the plants in operation.

Lewis spent a lot of effort developing an organic-cooled heavy water-moderated reactor system fuelled with thorium. He showed that in a well-designed thermal reactor with enriched fuel to start, he could approach breeding through the production and recycling of U-233. Theoretically, he was probably right, but the cost of a program to prove his case was estimated by some to be $500 million and there was no guarantee of success. CANDU units were performing very well, and Ontario Hydro was not interested in a major role in developing another system, although with thorium as the fuel it would extend fuel reserves for centuries.

Lewis called his system the 'Valubreeder.' He did his best to get the Valubreeder approved, but after much deliberation within the AECL Board and among various government departments in Ottawa, it was decided to terminate the project – certainly a key decision, and a negative one. Lewis was very disturbed, but he settled down to being concerned with the CANDU-BLW system for Gentilly I.

NRX-ZEEP-NRU

The decision taken in Cockcroft's time to build research reactors was a key one, and NRX, followed by NRU, became the backbone of the research and development programs at CRNL. The approval of ZEEP followed NRX, but it was such a simple reactor that it was operating by 22 July 1945. It is rumored that Cockcroft wanted it to keep Kowarski busy, and it was used extensively to check calculations and theories being used for NRX, particularly lattice arrangements. It was the first reactor to go critical outside the US.

NRX was a very solid accomplishment. It was by far the best R&D nuclear facility in the world, with a high neutron flux and a relatively large core. It had excellent neutron beams for basic research and very good facilities in core for fuel and materials research and development. The loops – a small reactor inside a reactor – were particularly valuable and were used extensively by the British and, more particularly, the USAEC and, of course, AECL, particularly for fuel, materials, and coolants development.

NRX went critical in 1947 at 10 MWt and was soon raised to 20 MWt and later to 30 MWt, and was used continuously to December 1952, when we did what we called a very advanced experiment that required a shutdown for about a year. We learned much from the accident, and the rebuilding program, and now have a 40 MWt reactor. It was just recently given an award by the American Nuclear Society as being the oldest reactor in operation today.

NRX produced Pu in the natural uranium metal fuel, and some was sold to the USAEC under contract, and since the life of the reactor was in doubt – some thought perhaps five years – a proposal was put forward for a second reactor of greater power to make money selling Pu and have improved research and development facilities in the reactor. NRU (National Research Universal), a 200 MWt reactor, was approved on 20 December 1950. It went critical on 3 November 1957, and Canada once more had the best research and development reactor in the world. Unfortunately, it did not make much money selling Pu, but did sell isotopes that were distributed throughout the world by AECL, and it proved to be a superb reactor for research, and with its in-pile loops that could really test, at full scale power, reactor fuels and coolants, it advanced the fuel and materials program greatly and was of particular interest to the USAEC for joint programs.

The agreements to sell Pu to the USAEC, the sale of isotopes and the prospects of commercial arrangements with the USAEC to support joint programs centred at CRNL, and the general view that CRNL was getting more commercial led Howe to decide that the existing form of the organization – a division of NRC – was not appropriate for the future, and this resulted in the incorporation of AECL. Certainly a key decision, and a good one.

Atomic Energy Control Board (AECB)

One key decision – and in my view one of the more important ones – was that of the Government of Canada to enact the Atomic Energy Control Act of 31 August 1946, which set up the Atomic Energy Control Board (AECB) to assist the Government and '... to make provision for the control and supervision of development, application and use of atomic energy and to enable Canada to participate effectively in measures of international control of atomic energy.' It should be noted, particularly, that the AECB is a federal agency and its mandate covers the whole of Canada.

The mandate to the AECB to 'control' and to 'supervise development and application' was a very broad one that would require an amendment to the Atomic Energy Control Act within a few years.

In reading Gordon Sims *A History of the Atomic Energy Control Board*, which is recommended to those interested in atomic energy control procedures exercised by the AECB under the Act, I was surprised to learn that the Chalk River Nuclear Laboratories were to be 'controlled' and 'directed' by the AECB, through a Government directive, dated December 1946, to 'assume the control and direction of the Chalk River (NRX) Project.' In actual fact, the AECB requested the National Research Council to take over the operation and management of the project on behalf of the AECB – a sensible decision.

One should note that, during the early years of the AECB, there were only two full-time professional employees: a secretary and legal advisor, and a scientific advisor, both very able people, but hardly an organization to assume control of a project of the size of Chalk River, with major items of equipment and plant, including two chemical separation facilities and a very important research and development program. According to Sims, the AECB advised NRC of the Board's policy 'as to objectives of operation priorities in relation to research and development, capital expenditures, communication of information to the Board.'

The AECB had part-time Board members and a part-time president, Dr C.J. Mackenzie – who was also Acting President of NRC (confirmed in 1948) – until 1961. The fact that Mackenzie was the Chief Executive officer of both NRC and AECB helped make this arrangement possible. There was no doubt about the wording of the Atomic Energy Control Act. The AECB was required to control, to supervise development, application, and use of atomic energy, but had no structural organization really to undertake such responsibility. In fact, as Sims says, very little control and direction was exercised over the Chalk River research project.

However, the AECB did an excellent job of developing regulations relating particularly to health and safety. Being short on staff they resorted to the Advisory Committee formula, and internal staff strength and capability gradually increased after the appointment of Dr G.C. Laurence, with his serious personal interest in reactor safety, as president on a full-time basis. The great majority of the early work was done by the Committees made up of representatives of federal and provincial departments, particularly Health and Welfare, along with experts in the fields of atomic energy from NRC, AECL, universities, industries, and the utilities.

There was a requirement for development of regulations and procedures for handling applications for licenses, ranging from radium treatment applications in medicine, through cobalt sixty beam therapy units, to nuclear electric power stations of varying sizes and complexity. In my view, the AECB have done an excellent and thorough job in this very important area of their responsibility. I must say there were times when those of us who were trying to get nuclear power plants built and into operation wondered why the AECB could be so stubborn, especially when those of us in the business had much more experience. On reflection, I am sure our plants have benefitted from the input of the AECB committees and staff review of our submissions, and, moreover, a safety review by a qualified and responsible independent licensing agency is more acceptable to the public.

The decision to increase AECB staff, started by Laurence and expanded by succeeding presidents, was certainly a key decision, and a good one. As the nuclear power program expanded, the work load on the advisory committees, particularly the Reactor Safety Advisory Committee, became intolerable and the AECB staff had to take on more and more work. By 1980, the staff numbered about 200, with well-qualified, experienced personnel, quite capable of meeting the Board's responsibilities without the use of the RSAC.

Effective 1 April 1952, an agreement was reached *via* the Appropriations Act, authorizing the transfer of the Chalk River establishment from NRC to a crown company, Atomic Energy of Canada Limited (AECL). AECL had been incorporated under Part 1 of the Companies Act 1934, on 14 February 1952, but AECL was set up pursuant to the Atomic Energy Control Act, which allowed the AECB to procure the incorporation of companies to exercise on behalf of the Board such power that had been conferred on the Board.

Although I was appointed General Manager of AECL in 1952, with Chalk River the main project, and with Dr Mackenzie as President (and we had an independent and excellent board of directors), I just realized from reading Sims that AECL was 'set up to administer the project (CRNL) on behalf of the Atomic Energy Control Board.' I have no recollection of AECL reporting to the AECB, although financial estimates were submitted to the Government *via* the AECB. Once again, with a joint-president it was possible to operate with little, if any, friction.

There is no question that AECL was required to report to the Government through the AECB, and Mr Howe stated categorically that AECL '... is a creature of the AECB and AECB is in charge of atomic works in Canada.'

Howe's right-hand man and 'enforcer' for nuclear energy development in Canada was C.J. Mackenzie; as president of AECB, NRC and, for two years, AECL. It was undoubtedly a closed-shop organization, with Howe calling the plays and Mackenzie executing them up to 1953, when he retired as president of AECL. The supposed control and direction of the research and development program for nuclear energy by the AECB was really a myth. The AECB had virtually no staff and no organization to exercise the responsibilities conferred on them by the Act. The arrangement of Howe and Mackenzie, and the positions the latter held, represented one way to move forward with the nuclear program, though haltingly at times.

It became clear that this was not the best organizational structure, particularly when Mackenzie retired and was succeeded by W.J. Bennett, who had been executive assistant to Howe during the war. Some action was indicated.

On 1 April 1954 the Atomic Energy Control Board Act was amended to transfer research and production functions of the AECB to a minister (the chairman of the Privy Council Committee for Scientific and Industrial Research); certainly a key decision that should have been taken sooner. Both crown companies, Eldorado and AECL, were to report to Howe.

Nuclear Power Reactors

Early in the history of the program in Canada, the staff, and others, were discussing the possible use of nuclear energy for electric power production, but the first definitive decision came early in 1953, when C.D. Howe stated in the House of Commons: 'Canada should develop atomic power in this country and discussions are underway to bring about this development. Production of power should rest with the utilities such as Ontario Hydro.'

The Nuclear Power Branch of AECL

This quickly led to another key decision. The AECL Board agreed, late in 1953, to set up a study team in its Nuclear Power Branch to look at a small power reactor. Perhaps the real key decision was the appointment of H.A. Smith of Ontario Hydro in January 1954 as head of the team. The members of the team included not only AECL and Ontario Hydro staff, but representatives of other utilities and Canadian industry, and consulting engineers.

By August 1954 the studies indicated that the design, engineering, and construction of a prototype power reactor should be undertaken – size 10–20 000 kWe – D_2O moderator and coolant using natural uranium fuel with the possible use of some Pu for enrichment.

The AECL Board took a formal decision 30 November 1954 that although AECL was necessary in the role of research and development, AECL should not directly design and construct nuclear electric power plants – it should be the responsibility of the manufacturers and the utilities. Certainly a key decision but one that would not stand the test of time.

The Board also felt that, although the small prototype power reactor was an essential step, a larger unit should be studied to uncover the problems likely to be encountered in commercial-sized power units.

Nuclear Power Demonstration (NPD) Plant

When it was decided to proceed with a demonstration power reactor to be designed and constructed by a manufacturing company, AECL invited seven Canadian corporations to bid on a contract to design and construct the Nuclear Power Demonstration plant. Proposals were to be in by February 1955. AECL undertook several responsibilities, such as supply of D_2O, nuclear data, uranium fuel, and some key personnel to assist the contractor. AECL also assumed responsibility for the operation of the reactor from the nuclear standpoint, but the contractor was to be responsible for mechanical performance.

The AECL Board, at a meeting on 10 March 1955, reviewed the proposals received; they were carefully evaluated and shops inspected to check facilities, experience, and capacity to handle power plant design, supply, and construction. Participation by a utility was also reviewed; two had presented proposals – Ontario Hydro and Nova Scotia Light and Power Company.

The Board recommended that the Canadian General Electric Company Limited be selected to design and construct the demonstration nuclear electric power plant, and that the Ontario Hydro proposal for participation be accepted. The participation of Ontario Hydro was probably the most important key decision.

CANDU – Douglas Point

Following the initial report of the group in the Nuclear Power Branch, which resulted in NPD I, it was decided to extend the work, again under Harold Smith, with seconded representatives from Ontario Hydro and other utilities, and manufacturing companies as the Nuclear Power Group, which relied heavily on AECL staff for advice and guidance in scientific considerations of nuclear systems.

The Nuclear Power Group reported in May 1957 (NPG 10) and recommended that a nuclear power reactor of about 200 MWe be considered, employing pressure tubes to contain the fuel and heavy water coolant. With short-bundle fuel fed from each end of the reactor – on power, bi-directional fuelling – adequate fuel burnup could be achieved with natural uranium. The Group recommended that a program of design, development, and construction of one or more such units could 'reasonably be expected to compete favourably on the basis of safety, reliability and economy – with conventional steam-electric plants for base load applications in Ontario.' With a proper, well-developed program this could be achieved in about ten years.

This report – NPG 10 – was not in itself a key decision, but it certainly led to key decisions taken within the next couple of years.

In February of 1958 AECL published *A Statement of the Nuclear Power Development Program* (AECL No. 561). It was a comprehensive statement covering Canada's need for nuclear power, the status of nuclear power development, AECL's basic policy for development work, the Ontario Hydro proposal for participation, a summary of the program, and the organization to carry out the program.

The statement included a detailed description of the Nuclear Power Plant Division that was to be set up by AECL in Toronto, to meet the requirements of Ontario Hydro for their serious participation in the Canadian program for nuclear power development.

The work of the NPG on CANDU resulted in a very key decision that was not easy to take – to change the basic design of NPD-1. It recommended horizontal pressure tubes in place of the 'pressure vessel' in the NPD I design, to contain the pressurized heavy water coolant and the fuel – which, among other things, eliminated the limitation of size that the pressure vessel design faced – and recommended a new method of fuel loading and unloading that was a major improvement over NPD I. The new design concept looked so promising that a key decision was taken to cancel the pressure vessel supply contract and redesign NPD I along the lines recommended in the CANDU study. This caused a delay in the completion of NPD of about two years, but the change was well warranted and fitted smoothly into the planned program of progressively developing a commercial nuclear power plant that could compete with other sources of thermal electric energy. NPD had some problems, but generally it has been very successful and a major contribution to the Canadian program.

Another key decision came in 1959, with the agreement between the Federal Government, represented by AECL, and the Hydro Electric Power Commission of Ontario (Ontario Hydro) to commit to a program of design, development, construction, and operation of the 200 MWe CANDU power plant subsequently located at Douglas Point.

AECL – Nuclear Power Plant Division (NPPD)

Coincidently, another key decision was taken, to set up, in Toronto, a Nuclear Power Plant Division (NPPD) under the general direction of AECL, assisted substantially by Ontario Hydro staff for reactor design. A joint effort was effectively integrated to cover all aspects of a nuclear power plant from design, through development, construction, and operation – a basic requirement of Ontario Hydro if they were to be a major partner in Douglas Point.

The decision to set up NPPD requires special attention as it was not universally popular at the time, since a manufacturing company had a nuclear power plant design capacity and was actively engaged in the design and supply of NPD, and contemplating export sales and alternative designs. The utilities generally preferred to acquire plant and equipment by competitive tendering, and this was not possible with only one qualified supplier. Some Canadian consulting engineering organizations contemplated putting together a nuclear design team that could be developed into a fully rounded design group, when coupled with their experience in conventional power stations.

On looking at such an arrangement, and at the state of the art of nuclear power, and the very prominent and important position of AECL (with its laboratories and years of experience in the nuclear field from fundamental research, through development and operation of advanced research and development reactors), it became obvious that AECL should take a major role in at least the CANDU 200 MWe Douglas Point station.

H.A. Smith, in a paper presented to the European Nuclear Conference on Nuclear Energy to Maturity, April 1975, stipulated clearly the principles he felt most important in the overall organization and administration of a nuclear power project.

1) To insist that the client-owner of the ultimate facility be heavily involved both financially and administratively.
2) To assign authority and responsibility in relation to the financial risk accepted.
3) To encourage direct participation by consulting engineering and industrial organizations.

4) To restrict the number of development options to be pursued.
5) To minimize duplication of effort, particularly avoiding commercial competition in experimental and developmental assignments.
6) To ensure continuity of, and maximum feedback in successive stages of the program.
7) To maintain strong liaison with other nations developing nuclear power plants, both for information exchange and monitoring.

With Harold Smith appointed General Manager of NPPD, you may be sure these principles were adopted, and the structure of the Agreement between AECL and Ontario Hydro included the NPPD organization, which was the most attractive route to the design and development of the Douglas Point Station.

It is clear to me that this joint arrangement between AECL and Ontario Hydro, with maximum use of consultants and industry was a key decision in Canada's nuclear power program, and an essential one. One can only wonder why other countries, particularly the UK, have not followed suit – except, perhaps, they are reluctant to accept a colonial program that has been successful in such an advanced energy field. A single industrial company as designer and supplier of a nuclear power plant did not fit the principles thought necessary, in a utility like Ontario Hydro, for a program.

AECL and Ontario Hydro reached a formal agreement that resulted in a NPPD of AECL located in Toronto, managed by an Ontario Hydro engineer, H.A. Smith, supported by a member of an engineering consulting firm, J.S. Foster, and surrounded with very capable staff from AECL, Ontario Hydro, and the general engineering community of Canada.

This group, which had in part been together from 1953 through the original NPD I designs and recommended the changes that resulted in NPD II, now started, in 1959, to design and supervise general development of the 200 MWe CANDU at Douglas Point.

The group, of course, continued to look at advances in system designs and to encourage Canadian industry to manufacture products to nuclear standards. They not only designed systems but operated extensive prototype test facilities to ensure satisfactory Canadian equipment to meet the rigorous standards of the heavy water-moderated and cooled power reactors.

Another very significant decision – and a 'gutsy' one – was taken in 1964, prior to the start-up of Douglas Point, to proceed with the first two 540 MWe units at Pickering. Again it was a joint program of AECL, Ontario Hydro, and the Province of Ontario, with AECL taking the responsibility for the supply and performance of the NSSS; Ontario Hydro was responsible for the general construction program and supply of the conventional part of the plant. Ontario Hydro agreed to own and operate the plant, and pay AECL and the Province, on an agreed formula, the difference between the cost of the electric energy sent out and that from a similar coal-fired station at Lambton of generally the same size and vintage. Incidentally, up to the time of the shutdown to change pressure tubes in Pickering I and II, I understand AECL had recovered all its costs including interest.

Following Pickering I and II, Ontario Hydro have proceeded on their own to meet their needs for nuclear electric capacity using the nuclear power plant group in Toronto for design and development. Their key decisions – Pickering completion, Bruce A and B, and Darlington – were major undertakings, and will contribute to continued relatively low-cost electric energy in Ontario for many years.

Nuclear Fuel Supply

The first real inkling we had that we might be able to replace the metal uranium fuel we had for NRX and NRU with an uranium oxide fuel for power reactors, and obtain much higher burn-up, came when Gib James X-rayed an experimental fuel assembly to be irradiated in an NRX loop for the US Nautilus fuel development program, and found, contrary to any information supplied by the USAEC, we were to irradiate enriched UO_2 fuel clad in Zr. This really started Canada on the road to UO_2 fuel for power reactors, probably a key decision that would allow the CANDU reactor system to perform so well. The USAEC claimed we had breached security, but Gib James said 'no one puts anything in the fuel channels of my reactor without an X-ray examination; we have done it from the start.' We survived the investigation and got busy looking at UO_2.

AECL and the Department of Mines and Technical Surveys developed a very good joint in-house program of development of a natural uranium oxide (UO_2) fuel, including manufacturing processes, but it became evident that this was one area where Canadian industry could take over the production and supply of power reactor fuels as a commercial venture and, presumably, develop a profitable line of business. The decision to place the responsibility for the manufacture of nuclear power reactor fuel in the private sector is one real success story and a key decision.

Proposals were invited from Canadian companies, and after some changes the private companies, particularly the Canadian General Electric Company Limited (CGE) and Westinghouse Canada Limited, with equal production capabilities and their own development facilities and competence, have become the main suppliers, on a commercial basis, of UO_2 fuel for all CANDU reactors. The quality of product is very high, with few failures. It is a simple fuel, and one of the keys to very low fuel costs in a neutron-efficient reactor.

Canadian Supply of Heavy Water

The first heavy water production in Canada was at the Consolidated Mining and Smelting Company (CMS) plant at Trail, B.C. The US contracted with CMS to produce heavy water from the deuterium in the hydrogen stream they had for the production of fertilizer. Production started in 1943, and they produced about six tons per year to 1955, when the economics did not match the production costs from the large plants in the US.

As soon as Ontario Hydro and AECL decided, in 1964, to proceed with the Pickering Station, it became evident that the supply of heavy water from any source might be a holding item, and construction of large Canadian heavy water production plants was necessary to ensure an orderly program of nuclear power development.

A contract with Deuterium of Canada Limited (DCL) had been signed in late 1963, but with Pickering underway a second unit was approved to be located in Nova Scotia under a contract with CGE. Both plants had a design capacity of 400 tons / year and both, particularly the DCL plant, had their difficulties.

Although granting authority to enter into contracts for the units in Nova Scotia was a key decision and put Canada on the road to supplying an essential part of the CANDU power reactor program, the lack of early production and the small size of plants became particularly evident when Ontario Hydro announced its decision to proceed with the 3,000 MWe Bruce station. AECL was authorized to build a 400-tons-per-year facility at Bruce using nuclear steam for energy – increased to 800 t / yr in 1969, when it was realized that the DCL plant was not able to supply any product for Bruce. This AECL plant was purchased by Ontario Hydro after having operated successfully.

The first Bruce heavy water production plant went so well that Ontario Hydro took the initiative and proceeded on its own with a major program that led the way to major heavy water production facilities that ensured ample supply for the foreseeable future of this essential material from Canadian sources. The design and construction and early operation of the Bruce I plant, and subsequent plants, benefitted from the start-up and operation of the CGE plant, where many problems were solved and the information passed on to Bruce.

Incidentally, the DCL plant did not produce product, and in 1971 AECL took over the plant for major redesign and rehabilitation – full production was only achieved in 1979. CGE found they could not meet their contract prices, and AECL took over the plant. These earlier 'questionable decisions' were rather disastrous to all concerned, but the plants at Bruce were very successful. All plants are now 'mothballed,' awaiting orders from reactors yet to be committed.

In summary, the decision to contract with DCL to manufacture heavy water and to locate the facility at Glace Bay – which AECL did *not* recommend – was a disaster; the decision to contract with CGE for the Port Hawkesbury plant production was a relatively good decision. The key decision was the decision to build the first large plant at Bruce, designed by Lummus, owned by AECL originally, but built and operated by Ontario Hydro and powered with nuclear steam. It was an essential decision that allowed the nuclear power program to proceed.

CANDU BLW and Organic-cooled Reactors

When the AECL directors decided not to proceed with an organic-cooled reactor system, but felt that some back-up to the CANDU-PHW system was advisable, they selected the boiling light water-cooled version of CANDU. Other countries, particularly Japan, were also considering the same basic system; only the Japanese have continued in a serious manner.

The Gentilly station was committed as a CANDU-BLW, and although it operated it did not prove to be an acceptable unit in the Hydro Quebec system and its operation was terminated.

L.R. Haywood, who was at the centre of engineering development at CRNL during this period, has suggested to me that, if AECL and Hydro Quebec had spent as much time and effort to ensure good initial operation of Gentilly I as we did for Douglas Point, we might have had a successful unit. He may be right; certainly the Japanese have shown the system will work, but economic assessments are not as yet complete.

In the light of experience from the organic-cooled research reactor WR1 at the Whiteshell Nuclear Research Establishment, some of us feel we may have missed the boat in not developing the organic system as the second string to the Canadian bow. So AECL's batting average of key decisions was very high, but we did not bat 1,000.

Altogether, the nuclear power program decisions taken by the Canadian Government, Ontario Hydro, and AECL have generally been successful and satisfying. They rested heavily on decisions taken daily at the engineers' desks and in the scientists' laboratories of AECL, Ontario Hydro, and the suppliers – an input of many hundreds of man-years of good solid advice.