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# THE EARLY IDEAS ON NUCLEAR POWER REACTORS OF WILFRID BENNETT LEWIS*

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Canada's initial involvement in the field of nuclear energy grew out of wartime cooperation with the United States and Great Britain. But after the end of the war, Canada concentrated on developing the so-called peaceful aspects of the atom--the use of nuclear reactors for generating power. This note will focus on the views of one man, Dr W.B. Lewis, who throughout this period was in charge of Research and Development at the Chalk River Nuclear Laboratories. His early ideas on power reactors were remarkably advanced; in fact, as it turned out, too advanced. But further experimentation and discussion led to more practicable ideas for power reactors and cooperation between Atomic Energy of Canada Limited and Ontario Hydro culminated in the design and construction of a pilot power reactor. Many of the distinctive traits of the future CANDU reactor were introduced in the pilot reactor, NPD. In looking at these early ideas on power reactors, we can see the basis for what has become one of Canada's most significant scientific and technical accomplishments.

Canadians learned that their country had collaborated with the United States and Great Britain in developing the atomic bomb shortly after the first bomb was used to destroy the Japanese city of Hiroshima. First in Montreal and then at Chalk River, Ontario, a multi-national research team had been helping to solve selected problems in nuclear physics. Canadians were also introduced shortly after the end of the war to the idea that the energy within the atom could also be used as a source of power. In a Toronto newspaper, E.F. Burton, head of the Department of Physics at the University of Toronto, predicted that '[w]ithin 25 years [atomic power] will probably be our source of all energy. It will supplant coal and steam and oil and electricity. It is the beginning of a new era.'[1] Carried away by the excitement of the moment he went on to predict that soon a three-day week and a six-hour day would be the norm. However, Burton had not been involved in the nuclear energy project; scientists at work at the nuclear laboratories near Chalk River quickly realized that there were many difficulties involved in obtaining power from nuclear fission.

* An earlier version was read at the 4th Kingston Conference, Queen's University, October 1985.

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These made the time scale of Burton's predictions seem very optimistic. In fact, it would not be until 1962 that any nuclear-generated electricity would enter Ontario's power grid, and a great deal of scientific and engineering work and discussion led up to that significant event.

After the end of the war, many foreign scientists made plans to leave the project at Chalk River to return home to jobs they had abandoned in favour of war work. In particular, British scientists led by John Cockcroft, the director of the project at Chalk River, were anxious to return home to initiate an atomic energy programme there. To replace Cockcroft, the British suggested Wilfrid Bennett Lewis, and after considerable hesitation, he was appointed. In 1946 Lewis was only thirty-eight years old but had already had an impressive scientific career. Lewis received his doctorate in 1934 from Cambridge University. He had worked with Rutherford in radioactivity and after graduating stayed on at Cambridge to work with Cockcroft on nuclear disintegrations. After the outbreak of war in 1939, Lewis was asked by the British air ministry to work on the development of radar. He remained with this work until, in 1946, he accepted the position of director of the Atomic Energy Division of the National Research Council at Chalk River.[2]

A great deal of fundamental nuclear research was ongoing at Chalk River. Shortly after the end of the war, in September 1945, Canada's first reactor, ZEEP, had gone critical. Two years later a much more powerful experimental reactor, NRX, was successfully completed. Lewis was involved in every aspect of scientific life at Chalk River, and at the same time he was planning for the future. It was around this time that he first recorded his ideas on the possibilities of constructing a power-producing reactor.

Lewis quickly recognized the many problems inherent in obtaining power from a nuclear reactor. In December 1946, a few months after assuming his position, he wrote to his predecessor, Cockcroft, that '[i]t is the difficulty of releasing energy from nuclear fuel, keeping under control the rate of release and the disposal of fission products, which is the key to the economic development and application of nuclear power.'[3] In another memo he foresaw the many problems involved in removing the heat from the pile, the unknown behaviour of various component materials under high temperatures and high neutron flux and the difficulties introduced by the presence of radioactive fission products.[4] Even this substantial list did not cover the challenges facing the Chalk River group, but Lewis firmly believed that not only could these physical problems be solved but that in time nuclear power would also prove to be an economic source of usable energy.

In his early reports, Lewis was anxious to emphasize the enormous potential of nuclear fission in terms of power production. Charts abounded showing the greater power reserves within one ton of fissile material as compared to one ton of coal. He also argued that reserves of coal and oil were limited and therefore fissile material should replace them as a fuel in feasible situations. For example, since nuclear fuel could not provide land locomotive power, he argued that coal and oil should be reserved for this function. On the other hand, nuclear power could easily displace coal and oil in areas without water power where large electrical generating stations were needed. Also cited as an advantage of nuclear fuel was the ease with which it could be transported; this opened up possibilities of providing power in remote parts of Canada.[5]

Although to Lewis the many fascinating scientific problems inherent in the development of nuclear energy alone justified its study, he recognized that for the programme to advance and be successful it would have to be economically viable. This, it was argued, could only be achieved by building very large plants producing in the range of one hundred thousand to one million kilowatts of power. The cost of such a plant was estimated in 1947 to be between $100,000,000 and $300,000,000.[6] The high capital cost of a power plant could be attributed to many factors but the most significant was the high cost of the fissile material used as fuel. There were a number of methods of obtaining fissile material. The most straightforward was to separate the fissile isotopes Uranium 235 and Uranium 233 from natural uranium. In the early postwar years, however, a perceived shortage of uranium made it necessary to find other methods of obtaining fissile isotopes. One method was to 'breed' fissile material from other more abundant elements such as thorium. When a nucleus of thorium absorbs a neutron, it passes through a number of changes eventually transforming into the fissile isotope U233. Lewis advocated the construction of a 'breeding pile' in a director's report written in 1947.[7] A 'breeding pile' was envisaged as a fissile core surrounded by a moderating substance. Neutrons released from the core would be slowed to thermal speed by the moderator at which time they would enter the surrounding blanket of thorium and the reactions noted above would occur. It order for this process to occur successfully, it was important that no neutrons be wasted. The importance of neutron economy was a theme throughout Lewis' reports, for if too many neutrons were wasted, a chain reaction would not be possible. Fission product 'poisoning' was another serious problem to be solved. When the nuclear reaction occurs, certain fission products begin to form which themselves absorb neutrons. Thus, to keep the reaction going, they must be removed at definite intervals. The method for doing so was not well defined but was difficult because of the high levels of radioactivity of the fission products. Lewis' interest in breeder reactors lay in their ability to produce valuable fissile material from abundant elements. This material could then be used to fuel a 'secondary' reactor, that is a reactor that only produced power. He did, however, suggest at the end of the report the possibility that a breeder reactor could also produce useful power but did not expand on this idea.[8]

Although Lewis recognized the many difficulties involved in obtaining power from a nuclear reaction, he felt that despite the uncertainty about the form a nuclear reactor would take, there was a demand for power which necessitated fundamental research towards achieving that goal. This research was undertaken at Chalk River with the result that Lewis grew more confident in later reports that the goal of economic power from nuclear fission could be reached. In these early reports it is apparent that he was lacking experimental data to back his claims. But by the early 1950s, the two reactors at Chalk River, NRX and NRU, had provided Lewis with data to strengthen his case for the development of nuclear power. At that time Lewis argued that three major advances had been made which, in his ever-optimistic opinion, brought the possibility of economic nuclear power closer.[6] First, through experience with the NRX reactor, it was found that uranium could be irradiated for much longer than previously expected without any reprocessing. It had been believed earlier that because of a rise in neutron absorption, fission products reprocessing would be needed following a much lower irradiation. As reprocessing was a very expensive process, this discovery meant a considerable economic difference. Lewis argued that with the current prices of uranium, coal and oil, the larger irradiation time meant that uranium was three to four times cheaper as a fuel. This brought natural uranium reactors and coal-fired reactors on a competitive level.

The second advance outlined by Lewis in his 1951 report was that through the design of NRU it had been shown that it was possible to operate a reactor continuously at high output. This made it possible for fuel rods to be changed without shutting the reactor down. Finally, through further experimentation, it had proven possible to operate the system at high levels of irradiation, high temperatures and high pressures--all three of which were necessary for economic power. Note also that the type of reactor under consideration had changed. Although the breeder was still discussed seriously, it was not the only reactor type advanced as in earlier papers. Lewis was obviously concerned about both the difficult technical problems involved in chemical processing as well as expense incurred. The theme running throughout Lewis' papers was economics. Unless the cost of nuclear power was comparable to that of conventional forms of power, he realized that the future of nuclear power was uncertain. This attempt from the beginning to link technology and economics is significant.

The idea of selling plutonium produced in the reactor in a further attempt to reduce costs had been suggested by Lewis in his earlier papers. Plutonium was one of the possible fuels to be used in a breeder reactor but becuase of its military importance, it was difficult to obtain it in sufficient amounts, and the United States was secretive about processes used to separate it. But the fact that plutonium could be used in a bomb made it a valuable commodity in the postwar years, and Lewis was not averse to cashing in on this advantage. Although it would mean shortening the fuel radiation time, Lewis was willing to process the fuel for plutonium if it meant a lowering of the cost of nuclear power. But he realized the difficulties involved. Foremost were the technical and scientific problems of separating the plutonium from the highly radioactive fuel. Then there was the complication of having an uncertain price for plutonium. He mentioned prices ranging from $6/g. to $120/g; obviously, this would be a crucial consideration in deciding whether to attempt to process the fuel. To Lewis, plutonium was of interest only insofar as it could help lower the cost of a nuclear power reactor.[10]

Discussions about nuclear power reactors--possible types, costs, engineering and scientific difficulties--had been ongoing since 1947, but in 1953 Lewis stated clearly that a pilot plant must be built and outlined the stages involved. He wanted general specifications listing the limits within which the scientists and engineers would have to work. This was to be followed by a feasibility study which would provide a tentative design, specifying major components so as to provide an estimate accurate to twenty percent. Finally, a detailed design and construction would follow. Obviously, this type of planning would require a great deal of work, and it was suggested that Ontario Hydro cooperate with AECL to accomplish this programme. The partnership was necessary as AECL staff were simply not available to work on the project full time.[11]

The goals in mind at this time were, in retrospect, overly optimistic. In 1954 Lewis wrote that the plan was to have the small pilot power reactor built by mid-1958, a mere four years in the future. But of still greater optimism was the goal of commissioning two 100 MW stations by the end of 1961. In the end, NDP--the pilot scale plant--did not begin operating until 1962. This gives one an idea of the difficulties which lay ahead.

Lewis was adamant about building a small pilot-scale reactor. He argued that the feasibility and design studies should be kept very flexible so that beneficial changes could easily be incorporated into them. The design and construction of a pilot reactor would provide invaluable knowledge and experience to the engineers who would move on to the construction of a full-scale plant. With his usual concern for the economics of power reactors, Lewis pointed out that the mistakes made on a small scale would be less costly and could be avoided for the large-scale reactors.[12]

Lewis' arguments for building a small-scale power reactor were to prove sound. Although a great deal of knowledge and experience had been gained from the design, construction and operation of NRX and NRU, there were still many unknowns involved in the construction of a power reactor. Lewis insisted on a high degree of flexibility during construction, sometimes at considerable cost. Such was his prestige that AECL accepted stopping work in 1957 on the pilot plant to allow time for a study on whether a pressure tube design was more desirable than the pressure vessel design under construction. The recent success in making zircalloy pressure tubes had precipitated this study, and the decision was reached to use pressure tubes. This has become a distinctive feature of the CANDU reactors. In 1956 the method of bidirectional fuelling was developed. This required horizontal pressure tubes in the reactor core with fuel moving across the reactor until by the time it reached the other side, it would be fully irradiated. These delays ooncerning design and the difficulty of the work postponed construction of the reactor, and it was not until 1962 that it came on line, feeding the first nuclear-generated electricity into the Ontario power grid.

Lewis' involvement in these developments in nuclear power plants was crucial, but he was not acting alone. W.J. Bennett, who succeeded C.J. Mackenzie as president of AECL in 1953, supported Lewis' power proposal in 1954 and backed his redesign in 1957. Lewis also received the backing of Bennett's successor as president, J.L. Gray, throughout the 1950s. Finally, Harold Smith of Ontario Hydro used Lewis' concepts and turned them into workable reactors. The cooperation among these men, two of whom were engineers, made the development of nuclear power possible in Canada.

From the beginning of his studies into the possibilities of generating economic nuclear power, Lewis had recognized that there would be a great many difficulties involved. As he noted in one memo in 1953, '[t]here is no hope of tumbling crude nuclear fuel into a pot and getting almost free heat.'[13] But the number and the size of the physical and technical difficulties encountered had not been accurately predicted. It was the gradual realization of these that forced Lewis to move from the more complicated breeder reactor design to a simpler heavy-water natural uranium reactor. It was this type of reactor which was built on a pilot scale and which has since been further developed to become the CANDU reactor.

NOTES

1. *Toronto Daily Star*, 7 August 1945.

2. *Modern Scientists and Engineers* (New York, 1980), vol. 2, 225-7.

3. W.B. Lewis to J. Cockcroft, 10 December 1946. Chalk River Nuclear Laboratories (CRNL), Wilfrid Bennett Lewis Papers--Miscellaneous.

4. Minutes of Meeting, 9 December 1946. *Ibid.*

5. CRNL, Scientific Documents Distribution Office (SDDO), Director's Report-1 (25 March 1947).

6. *Ibid.*

7. *Ibid.* Note that Lewis used the term 'pile' to mean reactor.

8. *Ibid.*

9. *Ibid.*, 18 (27 August 1951).

10. *Ibid.*, 22 (7 January 1957).

11. Report by Lewis, 3 November 1953. CRNL, W.B. Lewis Papers-Miscellaneous.

12. Minutes of Meeting, 26 July 1954. *Ibid.*

13. CRNL, SDDO, Director's Lecture--12 (September 1953).