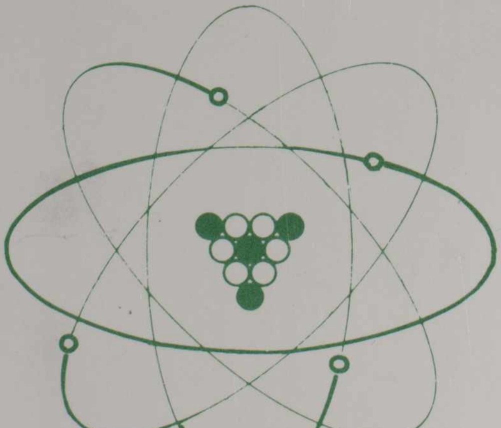
NUCLEAR ENERGY
UNMASKING
THE MYSTERY



Barbara J. Sparrow
Chairman
August 1988

Tenth Report
Standing Committee on
Energy, Mines and Resources

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Chairman: Barbara Sparrow

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Consideration of a draft report

Second Session of the
Thirty-third Parliament, 1986-87-88

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Présidente: Barbara Sparrow

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De l'Énergie, des Mines et des Ressources

CONCERNANT:

Considération de l'ébauche d'un rapport

Deuxième session de la
trente-troisième législature, 1986-1987-1988

Members of the Standing Committee on Energy, Mines and Resources

Chairman: **Barbara Sparrow, M.P.** — Calgary South

Vice–Chairman: **Aurèle Gervais, M.P.** — Timmins–Chapleau

Paul Gagnon, M.P. — Calgary North
Len Gustafson, M.P. — Assiniboia
Russell MacLellan, M.P. — Cape Breton–The Sydneys
Lorne Nystrom, M.P. — Yorkton–Melville
Bob Porter, M.P. — Medicine Hat

Clerk of the Committee

Eugene Morawski

Consultants to the Committee

Dean N. Clay
Lawrence Harris

Second Session of the Thirty-third Parliament

The Standing Committee on Energy, Mines and Resources has the honour to present its

TENTH REPORT

Pursuant to Standing Order 96(2), the Standing Committee on Energy, Mines and Resources undertook a study of the economics of nuclear power in Canada. After hearing evidence, the Committee has agreed to report to the House as follows.

Members of the Standing Committee on Energy, Mines and Resources

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Foreword

In September of 1987, this Committee issued a report entitled *Oil – Scarcity or Security?* (Canada, House of Commons, Standing Committee on Energy, Mines and Resources, 1987) which presented the results of a year-long study of the future availability of conventional light crude oil. The report observed that Canada's output of conventional light oil will fall substantially in the future, with that decline to be offset either by rising imports of light crude or by a costly investment in the extraction and upgrading facilities needed to exploit Canada's large bitumen resource contained in the oil sands of Alberta. The development of frontier Canadian oil deposits was seen as offsetting only part of the decline in Western Canadian light crude production.

The study documented the growing shortfall in U.S. crude oil production relative to domestic consumption, a shortfall which raises serious concerns about U.S. national security. The report also examined the global distribution of recoverable petroleum resources, observing that the easily and inexpensively produced light hydrocarbons – light crude oil and natural gas – are concentrated in the Eastern Hemisphere (crude oil in the Persian Gulf and natural gas in the Soviet Union) while the hard to produce and costly to upgrade heavy hydrocarbon resources – heavy crude oil, bitumen and shale oil – are concentrated in the Western Hemisphere (heavy oil in Venezuela, bitumen in Canada and shale oil in the United States). Almost all of the world's current 10 million barrels/day surplus in oil-producing capacity is in OPEC and two-thirds of that surplus is in turn held by Persian Gulf producers. The principal finding of this study was that the stage is being set for yet another, more profound disruption in the international supply of light crude oil some years in the future.

In view of this finding and given rising concern about the environmental impact of fossil fuel use, the Committee decided to investigate a component of Canada's energy system which has attracted public debate but no comprehensive review by Parliament. Committee members agreed that a retrospective and prospective look at nuclear power development in Canada was warranted. This report presents the results of that examination.

Over the last 45 years, the scientific and engineering achievement of harnessing the nuclear chain reaction has been transformed in Canada into a unique reactor system with the world's best lifetime operating record. Despite this engineering success, Canada's nuclear power program continues to be challenged on various grounds. Public concern about reactor safety and environmental contamination was sharpened first by the 1979 Three Mile Island incident in the United States and then by the 1986 Chernobyl accident in the Soviet Union. Questions regarding the economic viability of nuclear-electric power generation are regularly raised. The Standing Committee on Energy, Mines and Resources therefore adopted the following mandate under Standing Order 96(2):

That the Committee conduct an examination of the economics of Canadian nuclear power and any matters pertaining thereto.

The study was begun in November 1987 with public hearings in Ottawa. The Committee soon realized that hearings alone would provide an insufficient basis on which to make recommendations in this complex field. Accordingly, the Committee supplemented its public meetings with visits to selected nuclear installations in Canada and with travel to Sweden, West Germany, France and the United States to examine the nuclear power programs of those nations in more detail. The cooperation which the Committee received during this travel allowed it to assemble information and gain impressions which would not otherwise have been available to it.

The Committee concentrated its investigation on the technical and economic aspects of Canadian nuclear development, including the nuclear-electric power program, the production of radionuclides for both medical and industrial applications, and the development of certain related technologies. These activities are interrelated and the Committee decided that they should be considered as aspects of the same issue. Other committees of the House of Commons have primary responsibility for studying environmental and health matters, so these elements of the nuclear question are referred to in less detail in this report.

The Committee presents 14 recommendations arising from its study. These are included in the section entitled Summary and Recommendations, which follows this Foreword. Dissenting statements by two of the Committee members are presented in Appendix A.

Many individuals and organizations assisted the Committee in its work, both within Canada and in the four countries visited by the Committee as part of this study. To those who shared their time and views with Committee members and staff, we are particularly grateful. Witnesses who appeared in public hearings are listed in Appendix B; those who contributed to the Committee's investigation during its travel are listed in Appendix C. The Department of External Affairs did a remarkable job of arranging the foreign travel on short notice.

The Committee also depended upon the abilities of its staff: on Dean Clay and Lawrence Harris of Dean Clay Associates for their consulting work; on the Committee Clerk, Eugene Morawski, and other staff from the House of Commons; on Diane Gagnon-Beaupré, Lucie S. Pilon and Georges Royer who prepared the French manuscript; and on the translators, who were faced with a demanding job.

Given the technical nature of nuclear development and the specialized terminology used by its practitioners, a list of abbreviations and acronyms is contained in Appendix D and a glossary in Appendix E. The report is extensively referenced because the subject of nuclear power is complex and because unfamiliar foreign sources of information were used in its preparation.

Summary and Recommendations

In the closing years of the twentieth century, global society has reached what one author has described as the "hinge of history". The increasing human population (estimated to have surpassed five billion in 1987), the massive shift to an urbanized pattern of human settlement and the continuing demand by all peoples for a higher standard of living are placing unprecedented stresses on our planet. Examples of environmental degradation have become so commonplace that reaction is difficult. What are the priorities for action? What are the consequences of not acting? What are the costs of remedial action? How can society better anticipate the environmental impact of various forms of development?

This Committee believes that some of the most profoundly disturbing aspects of environmental contamination are linked to society's growing exploitation of the Earth's energy resources. The emission of acid gases and of carbon dioxide to the atmosphere – both a product of the combustion of fossil fuels – are prime examples of contamination which is exceedingly difficult and costly to prevent. (1)

What society does in the remainder of this century to address these issues will fundamentally affect the quality of life that mankind will experience in the next century. Energy plays a pivotal role in determining this outcome – it is both part of the problem and part of the solution. All human activity depends upon the availability of energy in its various forms; all human exploitation of energy comes with its particular set of environmental consequences.

Although this study of nuclear development in Canada has had technical and economic issues as its primary focus, these broader environmental and social issues have coloured the Committee's thinking about the future contribution of nuclear power, within Canada and abroad.

The Committee wishes to make its position clear from the beginning: **maintaining the nuclear power option is vital to Canada's interests**, as it is vital to the interests of society in general. There is a compelling case to be made in support of continued nuclear development, a case based upon the future inadequacy of conventional petroleum resources and upon the environmental degradation arising from burning coal in progressively greater quantities for electricity generation. Unfortunately, in Canada neither the federal government nor the nuclear industry has articulated that case very well over the years and the public attitude has become ambivalent.

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(1) When this report speaks of environmental contamination, it is referring to man-made contaminants, not to natural geochemical cycles which may already involve the same substances. Volcanic eruptions can inject sulphur dioxide into the atmosphere, for example, and carbon dioxide is a natural constituent of air. Of concern here is that society's activities have reached a scale where natural chemical cycles are being modified so extensively that the welfare of the human race is threatened.

The Committee's support for nuclear development is not uncritical – there are shortcomings in the Canadian nuclear program and there are problems inherent in the application of atomic energy. These must be weighed against the consequences of other forms of energy development, development which must satisfy diverse economic, social, environmental, strategic and technical ends. It is essential that such decisions and trade-offs be made by a well-informed public.

The onus of explaining nuclear power does not lie only with its proponents – opponents of nuclear power must also address difficult questions. Will the public and the environment be better protected by irretrievably dispersing huge quantities of sulphur dioxide, nitrogen oxides, carbon dioxide and other contaminants into the atmosphere, or by isolating relatively small quantities of radioactive wastes underground? What are the longer-term energy options open to society if nuclear fission is not exploited? How does one justify abandoning the huge investment in nuclear power and where will the resources come from to replace it with another form of generating capacity? What would Ontario substitute for the 50% of its electricity that it already derives from nuclear reactors?

The nuclear debate has been too narrowly focussed in Canada. It is not simply a question of whether to continue generating electricity with nuclear reactors. It is also a question of diminishing alternatives in electricity production, of the environmental consequences of not using atomic energy, of national energy security, of acquired scientific and engineering expertise, of spin-off technologies, and of employment for many Canadians.

As conventional oil and gas reserves are depleted and as the prime remaining sites for hydro-electric development are exploited, atomic energy will be increasingly looked to as an alternative means of producing electricity. The 1973-74 oil embargo educated Eastern Canadians about the danger of depending too heavily on imported oil for such purposes as electrical generation. Nuclear power is an economically attractive way of generating electricity today in certain parts of Canada, and in numerous countries which lack Canada's diversity in energy resources.

The environmental impact of burning larger amounts of fossil fuel, especially coal, to generate electricity has become alarming. Research is revealing the magnitude of the public health hazard, the enormous economic costs and the environmental destruction resulting from acid gas emissions from fossil-fuelled power plants. The implications of carbon dioxide accumulation in the Earth's atmosphere – an unavoidable accompaniment to fossil fuel combustion – are being studied intensively and the potential for disruptive climatic change is evident. Set against these concerns, the Committee finds nuclear power to be an environmentally appealing technology.

Nuclear power improves the security of energy supply in Canada, as most elements of our nuclear power program can be domestically supplied. Moreover, a substantial portion of Canada's research and development (R&D) capability is associated with the nuclear enterprise. Canada is not so well endowed with scientific and engineering resources that it can afford to lose the pool of talent and the R&D facilities represented by our nuclear institutions.

There is an industry of almost 30,000 people whose employment is a direct consequence of Canadian nuclear development. This industry supports a domestically developed reactor system whose operating record continues to set the international standard among all reactor systems. Canada is the world leader in applying radionuclides to medical therapy; radiotherapy has prolonged the lives of millions of people in countries around the world. Canada is also in the forefront of radiation technology for industrial applications and in extending this technology to food irradiation, to wastewater treatment and to the sterilization of sludges containing disease-producing organisms. The Canadian nuclear program has also created technologies with application in non-nuclear fields, from screening individuals for their susceptibility to cancer to designing new O-rings for the U.S. shuttle launch vehicle. Quality assurance and quality control standards which Canadian manufacturers have had to develop as suppliers to the nuclear program have carried over to other product lines and strengthened the competitive position of Canadian companies.

Maintaining the nuclear option means ensuring that all parts of the enterprise are kept healthy – the federal component, led by Atomic Energy of Canada Limited (AECL) and the Atomic Energy Control Board (AECB); the provincial electric utilities that employ nuclear power generation; the private sector which provides the mining, processing, manufacturing and other support; and Canadian universities and colleges which supply professional and skilled personnel.

AECL is the federal crown corporation that promotes the use of nuclear energy. This corporation is composed of four divisions: (1) The Research Company which performs research, development and demonstration (R,D&D); (2) CANDU Operations which designs, constructs and markets CANDU nuclear reactors and which provides engineering services; (3) the Radiochemical Company which produces radionuclides for medical and industrial applications, and manufactures commercial and industrial irradiation equipment; and (4) the Medical Products Division which produces radiotherapy equipment.

AECB is the federal regulatory agency that controls the development, application and use of atomic energy in Canada, from the generation of electricity at power reactors through industrial radiography to the use of cobalt–60 in cancer treatment. AECB also participates on behalf of Canada in international measures of control. These measures include programs to prevent the proliferation of nuclear weapons through the diversion of nuclear materials.

Three provincial utilities operate power reactors today. They are Ontario Hydro in a program that now accounts for half of all the electricity generated in the province, Hydro-Québec and the New Brunswick Electric Power Commission. Despite this incorporation of nuclear generation into three electrical utility systems of central and eastern Canada, nuclear power is not economically competitive with coal-fired or hydro-electric generation in all circumstances and in all regions of the country. In Alberta, for example, coal-fired generating plants located beside open-pit coal mines can produce electricity at a cost which nuclear plants simply cannot match. Given that coal firing will continue in some regions for the foreseeable future, it is particularly important that coal combustion technologies such as those described to the Committee by TransAlta Utilities be commercially deployed as rapidly as feasible, to minimize the environmental impact.

Canada holds extensive reserves of uranium and Saskatchewan's deposits are among the richest found anywhere. Uranium is mined in Ontario and Saskatchewan, and Canada exports more of this commodity than any other country. With uranium processing and reactor fuel fabrication also done domestically, Canada has established all of the steps in the nuclear fuel cycle needed to support the CANDU reactor system.

Despite this prominent position in the world nuclear industry, an adequate supply of professional and technical workers for the nuclear industry is not assured in Canada, as enrollment in nuclear-related educational programs continues to decline.

While supporting Canadian nuclear development in general, the Committee recognizes that there are deficiencies in specific aspects of that development. This report identifies a number of those deficiencies and makes recommendations addressing them. These recommendations are presented in the remainder of this section.

One of the Committee's foremost concerns is with the domestic program of radioactive waste management. Intensely radioactive materials are created in the course of nuclear-electric power production. In Canada, these high-level radioactive wastes take the form of irradiated uranium fuel bundles, currently being stored at each reactor site. Although storing spent fuel in water-filled concrete bays is quite satisfactory for a period of decades, the spent fuel must ultimately be disposed of in some final repository. This also applies to reprocessing wastes should Canada decide to recycle its irradiated fuel into new reactor fuel.

The Committee concludes that the concept of siting a final repository deep within a stable geological formation is an appropriate approach for Canada to take. Comparable work being carried out in other countries, especially in Sweden where the disposal program has many parallels with that of Canada, reinforces this conclusion. Yet public concern over radioactive waste management is perhaps the greatest single threat to the Canadian nuclear program. The public is not reassured when the deadline for concept verification is allowed to slip by a decade since the joint federal-Ontario radioactive waste management program was launched in 1978.

In the Committee's opinion, the schedule for the disposal component of the radioactive waste management program – which is a federal responsibility – must be advanced in Canada, not because the present methods of storing high-level radioactive wastes are inadequate or inappropriate or unsafe, but to strengthen public confidence that the longer-term issue of disposal is being satisfactorily resolved. In particular, the disposal program through the concept verification and site selection/acquisition phases must be completed more quickly so that the public can be assured that both a means and a location for waste disposal have been identified. The Committee recognizes that expediting the high-level waste management program requires increased levels of funding in the short run. This is a modest price to pay for establishing such a critical component of the Canadian nuclear power program.

1. **The Committee recommends that the complete schedule for establishing a commercial, high-level radioactive waste repository be advanced, and that the additional funds necessary to expedite the program be made available by the Government of Canada.**

To monitor progress on this matter, the Committee directs the Atomic Energy Control Board to appear before it no later than June 30, 1989 and, in public testimony, present a revised timetable for establishing a disposal facility and a thorough description of the parameters by which the suitability of a site for the facility will be judged and the design and construction of the facility licensed. The Committee acknowledges that Atomic Energy of Canada Limited has established this timetable in the past but concludes that the program scheduling in future should be overseen by the regulatory agency. AECB must, of course, consult with AECL to ensure that the accelerated program is technically feasible. AECB must also allow sufficient time for the recently-announced Federal Environmental Assessment Review Panel to complete its comprehensive review of long-term nuclear fuel waste management. The Committee is convinced that a highly visible and vigorous program of radioactive waste management is crucial to maintaining public confidence in Canada's nuclear power program.

2. **The Committee directs the Atomic Energy Control Board to appear before it in public hearings, no later than June 30, 1989, to present an accelerated schedule for establishing a commercial disposal facility, together with a description of all the parameters which the Board will apply in licensing the site and the facility. The Atomic Energy Control Board will consult with AECL to ensure that the new schedule is technically feasible.**

The technical problems of radioactive waste management are not insurmountable: the Committee concludes that these wastes can be safely handled, stored, transported and disposed of providing the political will is there.

Canada's power reactors have been examined in several safety studies, most recently in the Ontario Nuclear Safety Review conducted by Dr. F. Kenneth Hare. In each case, the reactors have been judged to be acceptably safe. As Hare puts it, "The Ontario Hydro reactors are being operated safely and at high standards of technical performance...The risk of accidents serious enough to affect the public adversely can never be zero, but is very remote" (Ontario, Nuclear Safety Review, 1988c, p. i-ii).

The safety engineering of the CANDU reactor and the design concept of "defence in depth" provide assurance that this reactor system can be operated in Canada with a minimal level of risk both to utility personnel and to the public at large. Nothing the Committee learned in its testimony and travel seriously questions this judgement.

Nonetheless, the Committee has concluded that the limits of public liability on Canadian nuclear facilities are inadequate and must be raised. The current maximum liability on the part of the utility – $75 million for a multi-unit nuclear generating station such as Pickering A/B or Bruce B – is simply not sufficient. Nuclear suppliers have no public liability at all. While the Committee is not prepared to specify what those increased limits of public liability should be, it observes that today's coverage is neither realistic in terms of what the Three Mile Island and Chernobyl accidents cost (the liability claims arising from Three Mile Island have passed the billion-dollar mark and damages arising from Chernobyl are reportedly well in excess of two billion dollars), nor does it even approach the liability limits set in countries like West Germany and the United States. The fact that a serious accident which releases dangerous quantities of radioactivity to the environment is considered to be a very remote possibility does not mean that Canada should be unprepared to handle such an event.

3. **The Committee recommends that the basic insurance coverage on Canada's nuclear facilities be raised substantially.**

The lead agency for Canadian nuclear development is Atomic Energy of Canada Limited. AECL has provided and will continue to provide most of the R&D which underlies Canadian reactor design, development and safety. This crown corporation also markets Canadian reactor technology abroad and, in company with other international vendors, has been financially squeezed by the worldwide downturn in new power reactor construction. At the same time, the federal government is in the process of reducing AECL's funding in stages by a total of $100 million per year.

It is not appropriate, however, for the federal government to be reducing its financial support of AECL at this time. As the Committee heard in testimony and as Dr. Hare reported in his study, this reduction in funding is impairing AECL's ability to provide the R&D support required by Canada's nuclear-equipped utilities to continue the safe and reliable operation of their power reactors. This support is necessarily a continuing function for as long as the reactors operate. There is the prospect of greater financial self-sufficiency at AECL in the future, and the electric utilities which have benefitted so much from AECL's work may be in a position to increase their financial support. Even so, the federal level of funding should not be reduced. The Committee concludes that federal funding of AECL's operations should be increased and maintained at a higher level for at least the next five to ten years, giving this crown corporation an assurance of financial stability while it works to commercialize its various products and become more self-supporting. In no circumstances should a lack of funding be allowed to compromise the integrity of the existing reactor program.

4. **The Committee recommends that the Government of Canada increase its financial support of Atomic Energy of Canada Limited and guarantee that level of support for a minimum of five years.**

AECL is the premier institution for "big science" in Canada. Its scientific, engineering and technical skills are a national resource developed over a period of more than four decades. Atomic Energy of Canada Limited should be encouraged to continue its diversification into new areas of science and technology, accompanied by a program of public awareness to convey the significance of what it is doing.

5. **Atomic Energy of Canada Limited should be encouraged by the Government of Canada to expand its research and development activities, including non-nuclear R&D, as one of the primary scientific institutions in the country.**

AECL has nonetheless been slow to respond to a declining domestic and international market for reactor sales. Although AECL is now making major efforts to diversify its activities within the nuclear sector, valuable time has been lost. It is evident from the Committee's studies that future reactor sales in the international market will be much less frequent for some time to come, and intensely fought for by AECL, Framatome, Westinghouse, General Electric, Kraftwerk Union and other vendors. AECL cannot survive on the reactor business alone, but must diversify, and should be encouraged by the federal government to accomplish this as rapidly as feasible.

Because of the large front-end investment in money and time needed to construct nuclear reactors, uncertainty in predicting future demand for electricity causes utilities to be extremely wary about building new plants. Given the high carrying costs associated with delays in construction, it is imperative that future reactors be built in much less time (as is routinely achieved in France and Japan, for example). Means to expedite the design-licensing-construction process must be found. The standardized design of the CANDU reactor system should have been an important advantage in marketing. The Committee does not understand why that advantage has not been better exploited. Standardized designs have been used successfully in the French and West German reactor programs and allow for generic licensing by regulatory agencies.

The Committee encourages the Governments of Canada and New Brunswick to reach an agreement on the construction of a new CANDU 300 reactor at Point Lepreau. This project could be used as an opportunity to demonstrate the time savings of "up-front" licensing. This will be very difficult, however, unless the AECB's current manpower shortage is rectified.

The federal government proposes to privatize two divisions of AECL in the near future: the Radiochemical Company (RCC) and the Medical Products Division (AECL Medical). RCC produces radionuclides and irradiators for medical and industrial use and AECL Medical markets radiotherapy equipment. The Committee supports the objective of privatization but is concerned that AECL will be left with a core of basic and applied research which cannot become self-sustaining. Coupled with declining federal funding for nuclear research and development, this would in the Committee's view cripple the research effort needed to sustain Canadian nuclear power development and to produce the next generation of reactor technology. Important R&D advances such as Chalk River's cancer-screening research might not find another home.

The Committee therefore recommends that AECL retain a minority interest in the Radiochemical Company, in the Medical Products Division and in the various Business Units as they are privatized. This provides for a modest but continuing income for AECL on the one hand; on the other, it provides the new entity with an R&D link to an internationally recognized corporation which should be valuable in future product development. The Committee further recommends measures that would restrict foreign ownership in these companies to a minority interest.

6. **The Committee recommends that the legislative mandate of Atomic Energy of Canada Limited allow the Corporation to hold a minority interest in any component of AECL which is privatized.**
7. **The Committee further recommends that any new entity created by privatization from Atomic Energy of Canada Limited be required to remain under Canadian control, although a minority foreign interest should be allowed.**

The Atomic Energy Control Board, which regulates nuclear activities in Canada, clearly lacks the manpower and financial resources to carry out its present responsibilities, let alone perform an expanded role. It is essential that nuclear power and the associated radionuclide business be well regulated to ensure their safe operation and that these activities be seen by the general public to be well regulated.

The Committee recommends that the Board's implementing legislation be modified to allow it to practice some measure of cost recovery, especially in its licensing operations. To the extent that cost recovery does not provide sufficient funds for the Board to fully discharge its responsibilities, the Committee also recommends that AECB's Parliamentary appropriation be adjusted to make up the shortfall. Increased support of the AECB would reduce delays being experienced in reviewing licence applications, and allow the Board to examine more thoroughly the submissions of licensees. The AECB also needs larger resources to expand its program of regulatory research. The Committee observes in this context that the U.S. Nuclear Regulatory Commission has been mandated by Congress to recover 45% of its $US 392.8 million 1988/89 budget through user fees. [The Parliamentary appropriation for the AECB in fiscal year 1988/89 is $24.4 million.]

8. **The Committee recommends that the *Atomic Energy Control Act* be altered to allow the Atomic Energy Control Board to practice cost recovery through licensing fees and charges for other user services as appropriate, provided that such fees do not unduly interfere with the Board's public dissemination of information.**

Testimony from the AECB itself, the recently-completed study by Dr. Hare on reactor safety in Ontario and other sources all suggest that the Board is substantially deficient in money and manpower. The Committee accepts this evidence and doubts that cost recovery alone can fund expanded operations by the Board.

9. **The Committee further recommends that, to the extent the cost recovery measures instituted by the Atomic Energy Control Board fail to offset its cost of operations, the Board's Parliamentary appropriation be increased to ensure that all of its reponsibilities are fully and promptly discharged.**

Other aspects of the AECB's operations require attention. The Committee recommends that the AECB have its complement of full-time Board membership raised from one to five. This would allow more areas of specialization to be represented on the Board and better equip it to handle an increased volume of work. The Committee recommends that the Board adopt a higher public profile, opening all of its hearings to the public as one example. The Committee agrees with Dr. Hare's recommendation that AECB's advisory committees also be strengthened. To make the AECB more readily distinguishable by the public from AECL, the Committee further recommends that the AECB have its name changed, perhaps to the Nuclear Regulatory Board.

10. **The Committee recommends that Board membership at the AECB be increased from one full-time member to five full-time members, while maintaining the four part-time positions on the Board.**

11. **The Committee recommends that the Atomic Energy Control Board adopt a more public style of operation, including holding its hearings in public.**

12. **The Committee also recommends that the name of the Atomic Energy Control Board – AECB – be changed so that it is more readily distinguished by the public from that of AECL.**

There is an obvious need to educate the Canadian public about the benefits and costs of nuclear power. Much of the public debate about nuclear development is ill-informed and it serves everyone's interests that this situation be changed. The Committee believes that this task should be vested in a federal agency that is knowledgeable about the subject but removed from its promotion. The Committee sees the AECB as that agency.

13. **The Committee recommends that the Atomic Energy Control Board be directed to establish an office of public education dedicated to informing the Canadian public in an objective manner about the facts of nuclear development. The Government of Canada should ensure that this function receives adequate funding for the AECB to perform the task effectively.**

The cost of regulating the nuclear enterprise is comparatively high even in Canada, where nuclear regulation is far less obtrusive and prescriptive than in the United States. The reason is the unique standards applied by society to the generation of nuclear power and to the management of radioactive wastes. These standards are much more rigorous than those applied to the operation of other energy systems and to the handling of other toxic materials, but are necessary to reassure the public. Nonetheless, an appropriate balance between regulation and regulatory costs should be sought. Opportunities to apply technology developed for radioactive waste management to the management of other toxic materials should be pursued by AECL.

Energy conservation/electricity demand modification has its place in utility planning, but in the longer run will not address all of the increase in electricity demand. Conservation and demand modification ease the pressure to construct new generating facilities, and should therefore be widely practiced, but are not in themselves a complete solution. The federal government should promote the more efficient use of electricity in those circumstances where the measures are cost effective and provide a positive economic return to all parties, but it should not be assumed that such efforts can entirely supplant the need for new generating capacity.

14. The Committee recommends that the federal and provincial governments cooperate more closely to identify opportunities where more efficient use of electricity could be achieved, and to promote those measures which can attain the greatest economic efficiency.

Private power generation is another approach to reducing the burden on utilities of financing new generating facilities. Given the mounting long-term debt being carried by Canada's electric utilities – almost $50 billion owed in total by Canada's two largest utilities – the way should be cleared of all unnecessary barriers to private power development, so that these producers can compete on economic terms. Whether or not private power generation will play a substantial role is very much a function of each utility's circumstances, but in principle the Committee supports the increasing contribution of electricity from this source.

The Committee notes the bid by the Government of Ontario for the province to become the location of the International Thermonuclear Experimental Reactor. This is a proposed collaboration by the United States, the Soviet Union, the European Community and Japan to build a large fusion test reactor, said to be the next major developmental step in fusion technology. Ontario has a strong case to make in support of its bid. The Bruce Nuclear Generating Station on Lake Huron provides both an excellent site and a source of electricity to operate a fusion reactor. Ontario Hydro's capability to supply tritium as a fuel for the fusion process is another enticement. The R&D, engineering and construction benefits would in turn be very welcome in Canada. Finland and West Germany are reported to have also bid for the project.

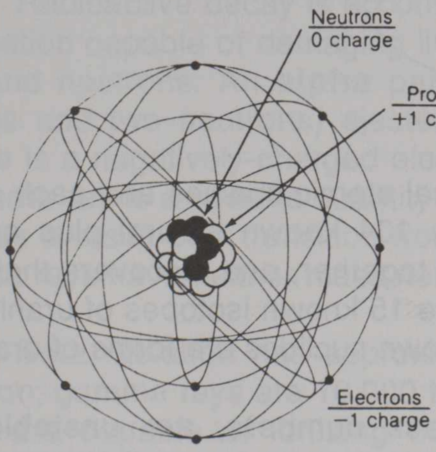
Atomic energy is not the evil genie in the bottle. Treated with respect and properly managed, it is a source of energy holding great promise for society's future. Canada's nuclear power program is well conceived and well run. With proper attention to the shortcomings noted by the Committee, nuclear power appears certain to play a larger role in Canada's energy system of the twenty-first century.

Reactor Systems

A. A Note on Atomic Physics

All matter – solid, liquid or gas – is composed of **atoms**, tiny "particles" that move around in perpetual motion. Most atoms are less than 2×10^{-8} centimetres (0.00000002 centimetres) in radius. The unit of measurement equal to 10^{-8} cm is called the angstrom, so atoms are typically less than 2 angstroms in radius. If an apple were magnified to the size of the Earth, then the atoms in the apple would be about the size of the original apple.

Once scientists established that all matter is composed of these particles or atoms, it was natural to ask, how many kinds of particles – **elements** – are there in nature? Ninety-one elements up to atomic number 94 (three elements in this sequence do not occur naturally) have been discovered. Hydrogen (H) is the simplest atom and is assigned the atomic number 1. Uranium (U), the element central to the nuclear power enterprise, has atomic number 92. To the naturally occurring elements, science has added another dozen or so artificially through nuclear reactions. All of these man-made elements are unstable and will sooner or later revert to a lighter, stable element.



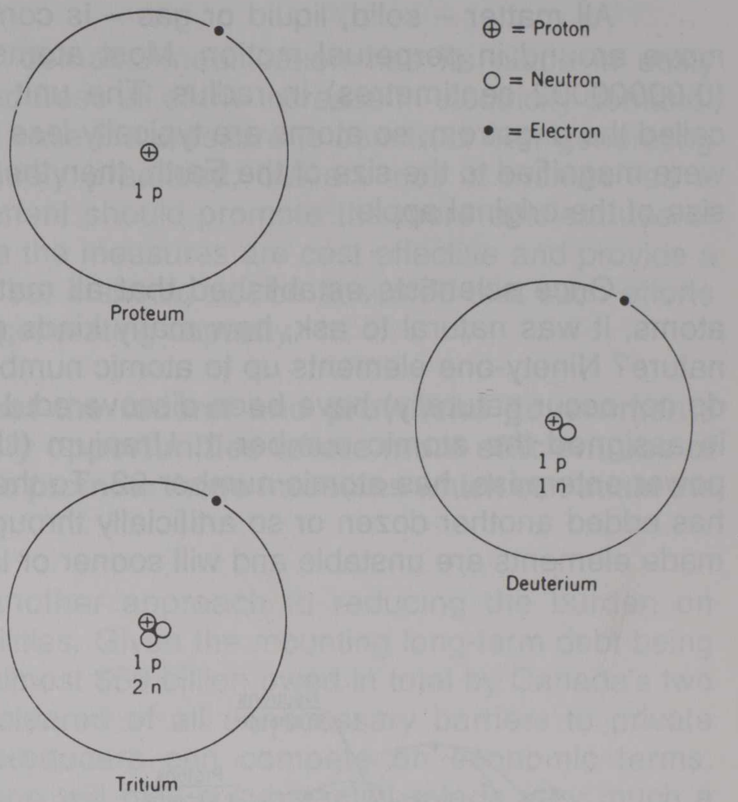
Atoms are in turn composed of three more fundamental particles: protons, neutrons and electrons. A tiny nucleus at the centre of the atom contains positively charged **protons** and electrically neutral **neutrons**. Protons and neutrons are much heavier than the third type of particle, negatively charged **electrons** which may be visualized as circling the nucleus in a spherical cloud. The nucleus represents only about 10^{-15} of the volume of the atom but almost all of its mass, like the sun in our solar system.

The sum of the number of protons and the number of neutrons in an atom is known as its **mass number**.

In their basic state, atoms contain equal numbers of protons and electrons and hence have a net electrical charge of zero. Under certain circumstances, atoms can gain or lose electrons, leaving them with a positive or negative electrical charge. Such atoms are said to be ionized. Radiation capable of stripping electrons from atoms is called **ionizing radiation**.

The number of protons determines the **atomic number** of the element and fixes its place in the Periodic Table. An atom with only one proton is always hydrogen; with eight protons is oxygen; and an atom with 79 protons is gold. Each element may vary, however, in the number of neutrons that it contains in the nucleus, and these differing versions of the same element are known as isotopes.

Hydrogen usually has one proton and no neutrons in its nucleus, and in this form is called protium. Less commonly, hydrogen contains one proton and one neutron, and is then known as deuterium. If the hydrogen nucleus contains one proton and two neutrons, it is in the unstable form called tritium. **Isotopes** are atoms with the same atomic number but a different mass number. The isotopes of hydrogen can be differentiated by writing them as hydrogen–1 (H–1), H–2 and H–3, giving the name of the element followed by its mass number. U–235 is the isotope of uranium used as the initial fuel in a nuclear reactor.



Each isotope of each element is an individual atomic species and each atomic species is known as a **nuclide**. There are some 104 known natural plus artificial elements but when all of their isotopes are added together, one discovers that there are more than 1,700 nuclides. To illustrate, there are 15 known isotopes of uranium (of which three occur naturally), so 15 of the 1,700+ known nuclides are forms of uranium.

Some elements, typically with large mass numbers, are unstable and disintegrate or "decay" naturally. **Radioactivity** is the spontaneous disintegration or fissioning of the nucleus of an unstable atom, accompanied by the release of energy. This spontaneous decay is not random – it proceeds at a specific rate characteristic of the radioactive nuclide (radionuclide) concerned. A unit for measuring radioactivity ("activity") is needed and that unit is the becquerel. One becquerel (abbreviated Bq) is one radioactive disintegration per second. (1)

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(1) The becquerel has replaced the curie as the measure of radioactivity. A curie is defined as the radioactivity of one gram of radium and equals 3.7 x 10^{10} disintegrations per second. Since the becquerel is defined as one disintegration or decay per second, the correspondence between the units is: one curie = 37 billion becquerels, or one becquerel = 2.7 x 10^{-11} curie.

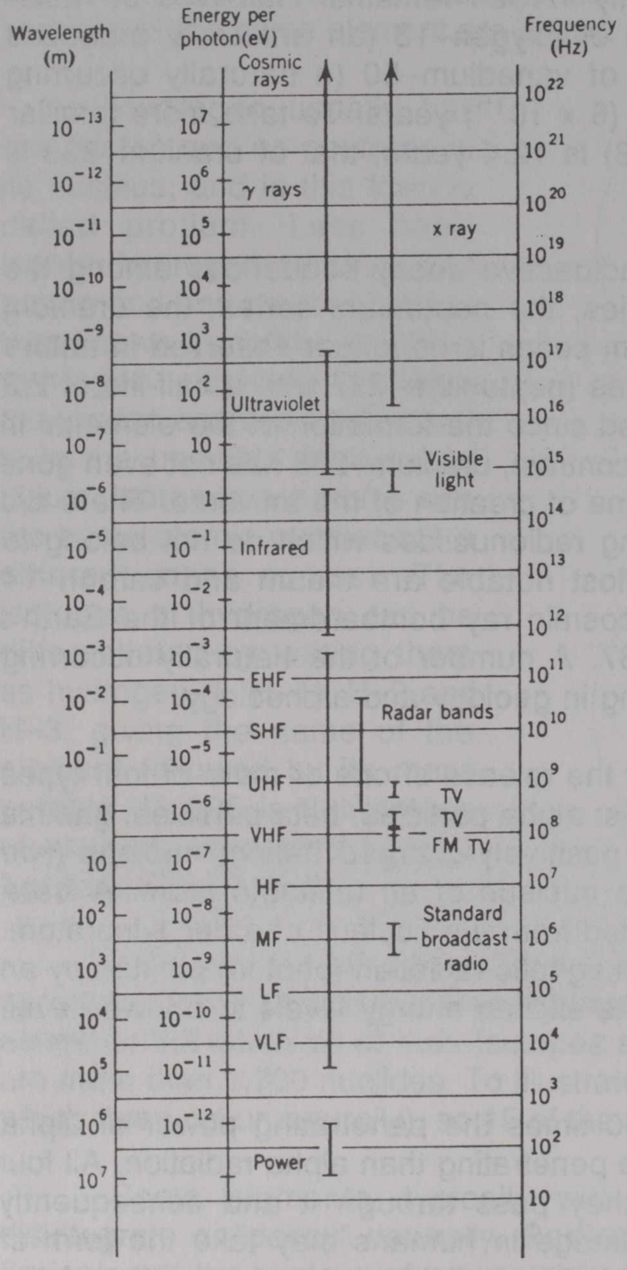
The **half-life** of a radionuclide is the time required for the activity (and thus the number of undecayed atoms) to decrease by 50%. After one half-life, one-half of the original substance and one-half of its original radioactivity remain; after two half-lives only one-quarter; and after 10 half-lives only 1/1024 remains. Half-lives of radionuclides can vary enormously. The half-life of oxygen–13 (an artificially produced radionuclide) is 0.0087 seconds while that of vanadium–50 (a naturally occurring radionuclide) is on the order of 6 quadrillion (6 x 10^{15}) years. To take more familiar examples, the half-life of tritium (hydrogen–3) is 12.4 years; that of uranium–238 is 4.51 billion years.

There are four naturally occurring radioactive decay sequences among the heavy elements, known as the thorium series, the neptunium series, the uranium series and the actinium series. The neptunium series is no longer observed in nature because the longest-lived element in the series (neptunium–237 with a half-life of 2.2 million years) has virtually completely decayed since the formation of the elements in the universe perhaps 15 billion years ago. In contrast, uranium–238 has not even gone through four half-lives since the calculated time of creation of the universe. There are also a number of isolated, naturally occurring radionuclides which do not belong to one of the heavy-element decay chains. Most notable are tritium and carbon–14 (which are continuously being created by cosmic ray bombardment of the Earth's atmosphere), potassium–40 and rubidium–87. A number of the naturally occurring radionuclides have been utilized for age-dating in geology and archeology.

Radioactive decay is accompanied by the release of one or more of four types of radiation capable of damaging living tissues: alpha particles, beta particles, gamma rays and neutrons. An **alpha** particle is a positively-charged helium nucleus (two protons and two neutrons) ejected from the nucleus of an unstable atom. A **beta** particle is a negatively-charged electron emitted from the nucleus of a decaying atom. A **gamma** ray is a specific quantity of electromagnetic radiation (photon) emitted by an atom as a result of a transition from one of its excited energy levels to a lower level. Gamma rays have neither mass nor charge.

Beta radiation has approximately 100 times the penetrating power of alpha radiation; gamma rays are 10,000 times more penetrating than alpha radiation. All four forms are capable of ionizing matter as they pass through it and consequently represent a biological hazard. Biological damage in humans may take the form of somatic effects – physical effects apparent in the individual who has suffered the radiation exposure – or genetic effects – effects which appear in the offspring of the exposed individual. Alpha emitters such as plutonium and radon gas are most hazardous when ingested or inhaled. Beta and gamma emitters, because of their greater penetrating power, are hazardous to humans both internally and externally. Exposure to high-energy neutrons is normally only a hazard in certain working environments around a reactor. All four types of radiation can be absorbed (as heat) in shielding materials like lead, concrete or water.

Figure 1: The Electromagnetic Spectrum



Source: Eisberg, Robert and Robert Resnick, *Quantum Physics of Atoms, Molecules, Solids, Nuclei, and Particles*, John Wiley & Sons, Toronto, 1974, p. 38.

Electromagnetic radiation refers to the emission or transfer of energy in the form of electromagnetic waves or particles. The electromagnetic spectrum extends from the longest radio waves to the shortest gamma rays, distinguished by their frequency of vibration. Society uses the electromagnetic spectrum for many purposes: sending electricity along transmission lines at a typical frequency of 50 or 60 cycles per second (50 or 60 hertz), broadcasting radio and television, radar, X–rays in cancer treatment and even solar radiation for skin tanning (with its risk of inducing skin cancers). The visible light detected by our eyes is part of this spectrum, bracketed by ultraviolet radiation at a higher frequency and infrared radiation at a lower frequency.

Figure 1 illustrates the electromagnetic spectrum and uses made of various bands in this energy spectrum.

Artificial radionuclides are created in nuclear reactors and particle accelerators when atoms are bombarded with highly energetic particles. They exhibit the same physical behaviour as those which occur naturally. For example, when plutonium–239 is created in a reactor, it begins to decay with its own characteristic half-life, which happens to be about 24,360 years. The sequence of nuclear changes which leads to the formation of plutonium within the reactor is:

uranium–238 + neutron —> uranium–239 + gamma ray

uranium–239 —> neptunium–239 + beta particle

neptunium–239 —> plutonium–239 + beta particle

The plutonium subsequently emits an alpha particle when it undergoes radioactive decay, and ends up as a stable isotope of lead.

The nuclei of atoms are held together by powerful electrical forces. When these nuclear forces are released, the energy involved is tremendous. **Fission** is a nuclear reaction in which a heavy nucleus splits into two parts (occasionally three) accompanied by the release of energy and two or more neutrons. Fission may be spontaneous, as in the decay of radioactive substances, or it may be induced by the capture of bombarding particles such as neutrons, the process exploited in a nuclear reactor. The fissioning of one kilogram of uranium–235 in a nuclear reactor releases approximately as much energy as can be obtained in burning 2,800 tonnes of coal. Atomic energy is the result of changes within the nucleus of the atom itself, while the heat liberated by burning the coal is the product of chemical changes only involving electrons on the outside of the atom.

A typical fission reaction can be represented in words in the following manner:

Neutron + Fissionable nucleus —> Fission-product nuclei + Neutrons + Beta electrons
+ Gamma photons.

For the purposes of this discussion, a fissionable isotope will be one in which the fission reaction can be caused by neutrons.

In the design of power reactors, the process of central importance is the **chain reaction**. The possibility of using nuclear fission to produce power in a reactor arises from the fact that 2.5 neutrons are emitted, on average, in each uranium–235 fission process. Plutonium–239 fission releases three neutrons on average per fission process. The reaction becomes self-sustaining if at least one neutron can be captured by another atom, leading to another fissioning and the maintenance of the chain reaction.

B. Elements of Reactor Design and Use

A nuclear **reactor** is an assembly of fissionable material in which nuclear fission can be maintained as a self-supporting, controlled chain reaction. The reactor core within which this assembly is contained may be thought of as a furnace in which the fissionable material is consumed, accompanied by the regulated release of thermal energy. The first self-sustained chain reaction was achieved in a graphite-moderated natural uranium assembly at the University of Chicago on December 2, 1942. Although nuclear weapons and nuclear reactors both exploit the principle of the chain reaction for their operation, the excess reactivity of a nuclear weapon is enormous, allowing it to release a huge amount of energy in an extremely short period of time. To achieve this condition, the bomb requires a high-purity fissionable material and a trigger to force the subcritical mass elements together. A neutron injection device is employed to boost reactivity even further. A reactor cannot suffer a nuclear explosion because of the geometry of the core, the low level of enrichment of the reactor fuel (or lack of enrichment, as in CANDU), and the presence of neutron-absorbing materials such as the uranium–238 in the fuel elements.

Neutrons are expelled from fissioning atoms at high velocity. For the reaction to propagate within a nuclear reactor, the neutrons must be slowed so that they can be captured by other fissionable atoms. The function of the **moderator** is to slow "fast" neutrons without absorbing them (that is, the moderator must have a "low neutron-capture cross section"). When the neutrons are slowed to near-thermal kinetic energies, the neutron-capture cross section of the fissionable material becomes much larger and a chain reaction can then be sustained by the "slow" neutrons. (1) The best moderator is "heavy hydrogen" or deuterium – an isotope of hydrogen with a neutron as well as a proton in its nucleus. Since hydrogen is difficult to handle in its elemental form (recall the explosion of the German dirigible *Hindenburg* in 1937), water is usually used as the moderator, oxygen also having a small cross section. Heavy water (D_2O), regular water (H_2O) and the solids carbon (in the form of graphite) and beryllium have been the preferred moderators.

The release of energy by fission produces large quantities of heat. Therefore, a medium called a **coolant** must be circulated through the reactor core to carry the heat away. The coolant also serves as the heat transfer medium in a reactor used for electric power production, carrying the thermal energy to a heat exchanger where it is passed to circulating steam which in turn drives a turbine to generate electricity. Since the coolant passes through the reactor core, it must withstand high temperatures and radiation damage. Good coolants are water (light and heavy), certain organic liquids (particularly a class of light oils known as aromatic terphenyls), certain liquid metals (particularly sodium), and the gases carbon dioxide and helium.

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(1) A **fissile isotope** in this context means one in which the fission process can be caused by slow or low-energy neutrons. There are only three important fissile isotopes: the naturally occurring uranium–235, and the man-made isotopes plutonium–239 and uranium–233.

The rate of nuclear fission must be precisely controlled within the reactor to maintain the chain reaction: too low a rate of fissioning causes the chain reaction to terminate; too high a rate releases more energy than the circulating coolant can carry away. If the number of fissions is increasing, the power is rising and the reactor is said to be **supercritical**. If the number of fissions is decreasing, the reactor is **subcritical**. The rate of fissioning and the power level remain constant when the reactor is just **critical**. **Reactivity** is a measure of the departure of a reactor from criticality. Positive reactivity means the neutron flux in the reactor core is increasing and the power level is rising; negative reactivity means the neutron flux is decreasing and the power level is falling.

Control rods made of a neutron-absorbing material such as cadmium are used to vary the rate of the reaction. Moving the control rods in or out of the reactor core alters the number of neutrons available to sustain the chain reaction. The control rods can be fully inserted to shut down the nuclear reaction. A reactor may also be equipped with a system to introduce a **poison** into the core. A poison is any non-fissile substance having a high capacity to capture neutrons and thereby decrease reactivity (suppress the chain reaction).

In some circumstances, such as a serious loss-of-coolant accident, normal reactor control systems may not be capable of handling the situation. For these infrequent events, additional safety systems such as **emergency core cooling** and reactor **containment** can be called upon to reduce the consequences of an accident. Emergency core cooling usually takes the form of a system designed to inject large quantities of cool water into the heat transport system following a major loss of coolant. Primary containment is the reinforced concrete structure housing the reactor and its closely related systems. Its function is to contain radioactivity if the reactor core is breached in a major accident.

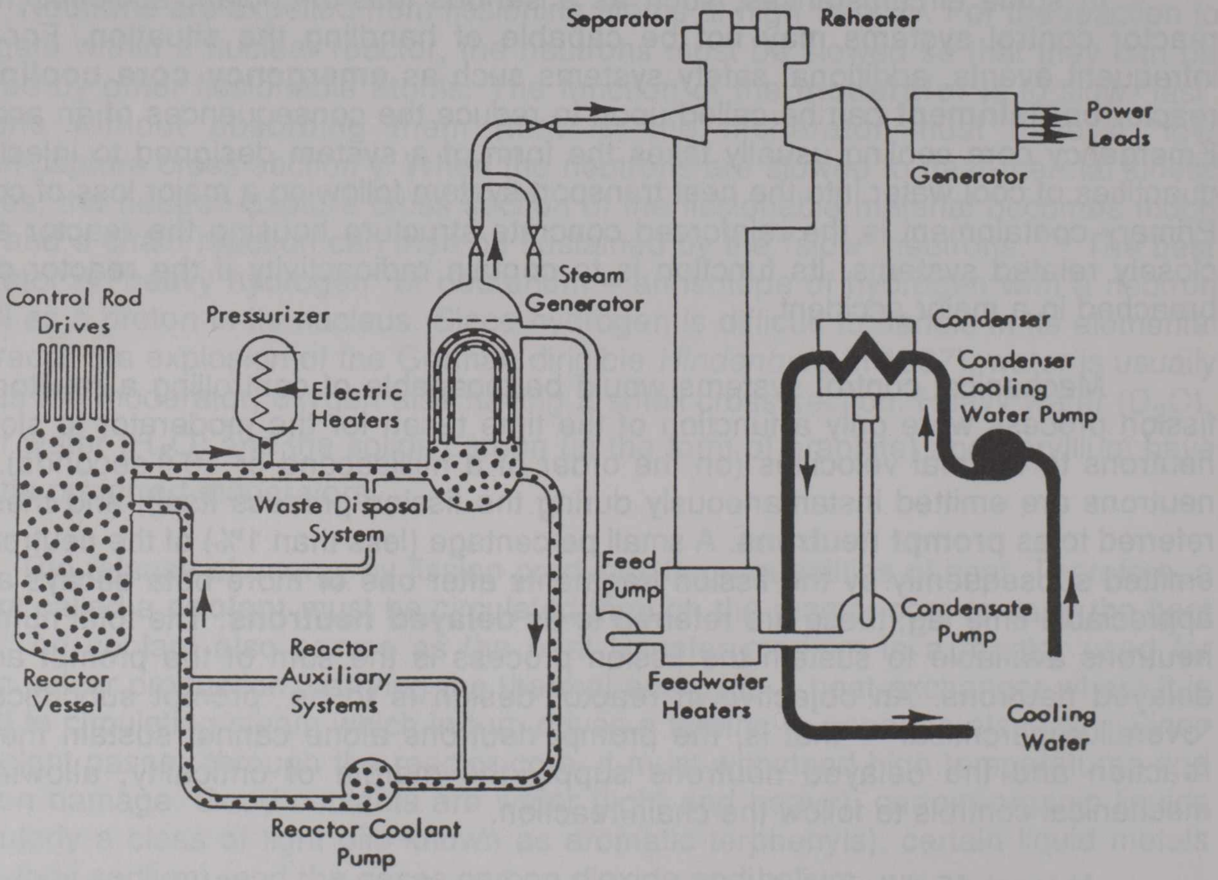
Mechanical control systems would be incapable of controlling a reactor if the fission process were only a function of the time taken for the moderator to slow fast neutrons to thermal velocities (on the order of a millisecond or 10^{-3} seconds). Most neutrons are emitted instantaneously during the fission process itself, and these are referred to as **prompt neutrons**. A small percentage (less than 1%) of the neutrons are emitted subsequently by the fission fragments after one or more beta decays and an appreciable time lag; these are referred to as **delayed neutrons**. The total number of neutrons available to sustain the fission process is the sum of the prompt and the delayed neutrons. An objective in reactor design is to be "prompt subcritical" but "overall supercritical" – that is, the prompt neutrons alone cannot sustain the chain reaction and the delayed neutrons supply the margin of criticality, allowing the mechanical controls to follow the chain reaction.

At least 45 different delayed-neutron precursor isotopes (fission fragments that subsequently decay via delayed neutron emission) are produced in a fission chain reaction. These precursors may be classified into groups with half-lives ranging from about 0.2 to 55 seconds. Their overall average half-life of approximately six seconds provides the margin for normal reactor control.

Liquid-cooled reactors exhibit either a **positive** or a **negative void reactivity coefficient**. A positive coefficient means that any event which leads to boiling of the primary coolant will cause a rise in reactivity and a surge in reactor power. CANDU reactors have a positive void reactivity coefficient and therefore their shut-down systems have to be carefully designed and computer controlled for rapid reactor shut-down. A negative coefficient, characteristic of light water reactors, means that boiling of the primary coolant will lower reactivity and depress reactor power.

About 4% of the fission energy released appears as heat generated by the decay of radioactive fission products. This decay heat continues to be produced after a reactor is shut down. Removal of decay heat during shutdown must be provided for, or the reactor core temperature will rise causing fuel element melting and failure.

Figure 2: Schematic Representation of a Pressurized Light Water Reactor



Source: Tong, L.S. and Joel Weisman, *Thermal Analysis of Pressurized Water Reactors*, Second Edition, American Nuclear Society, 1979, p. 2.

The reactor type displayed in Figure 2 is the pressurized light-water reactor, the most commonly used design abroad. A primary cooling system, operating under high pressure to keep the coolant from boiling, removes heat from the reactor core and carries it to the steam generators. A secondary cooling system operating at lower pressure extracts heat from the primary coolant and transfers steam produced in the steam generators to turbine/generator sets for generating electricity. A third cooling system uses water from an external source such as a river or lake to condense the steam leaving the turbines. In this configuration, the primary cooling system is isolated both from the external cooling water and from the turbines. Light water serves as both coolant and moderator in this design.

Three isotopes of uranium occur naturally: uranium–238 with an abundance of 99.283%, uranium–235 (0.711%) and uranium–234 (0.006%). Uranium–234 may be disregarded because of its low abundance. The importance of U–235 lies in its being the only one of several hundred naturally-occurring isotopes which is spontaneously fissionable by the capture of slow neutrons. Uranium–235 is necessarily the initial fuel for all reactor operation and, if fission power is to become a long-term contributor to society's energy needs, then breeder reactors are part of that developmental path.

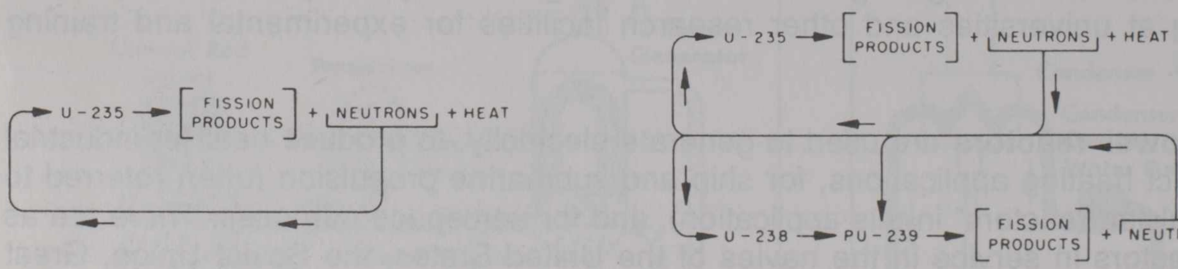
Most reactors belong to one of three types: research reactors, power reactors and breeder reactors. **Research reactors** typically serve as a source of neutrons for experimental purposes. They are used to make physical and chemical measurements, to study the effects of neutrons on biological and nonbiological systems, to produce radionuclides used in medical and industrial applications, for neutron activation studies, and for investigating new reactor designs. Many low-power reactors are operating at universities and other research facilities for experimental and training purposes.

Power reactors are used to generate electricity, to produce heat for industrial and district heating applications, for ship and submarine propulsion (often referred to as "propulsion reactors" in this application), and for aerospace purposes. There are as many reactors in service in the navies of the United States, the Soviet Union, Great Britain, France and China as there are reactors generating electricity in the 26 countries of the world which have developed nuclear-electricity. The United States, West Germany and Japan each built a merchant vessel equipped with nuclear propulsion (the American *Savannah* commissioned in 1962, the German *Otto Hahn* commissioned in 1968 and the Japanese *Mutsu-Maru* commissioned in 1973), but all three were subsequently taken out of service due to doubtful profitability and the difficulty experienced in gaining permission to put into various ports. The Soviet Union has constructed a series of the world's largest and most powerful icebreakers, powered by nuclear reactors. Small reactors have been used to provide electrical power on board satellites and spacecraft. In 1978, Canada had to clean up radioactive debris from the atomic-powered Soviet Cosmos satellite which came down over the Northwest Territories. A small power reactor was formerly operated at a U.S. research station in Antarctica.

Breeder reactors convert the fertile isotopes(1) thorium–232 and uranium–238 into the (man-made) fissile isotopes uranium–233 and plutonium–239 respectively; that is, they "breed" new reactor fuels in greater quantities than the fuel they consume in their own operation. Reactors with a breeding ratio less than one but which nonetheless create significant quantities of fissile material are often referred to as "converter" reactors. CANDU is a converter reactor, creating plutonium–239 from uranium–238 during its operation. CANDU could also be made to operate as a near-breeder on a thorium fuel cycle. Reactors which create only small quantities of new fissile material are sometimes referred to as "burner" reactors. Light water reactors tend to have relatively low breeding ratios. Since breeder reactors are also employed as power reactors, we shall consider breeders to form a subset of the power reactor group.

The difference between the uranium–235 fission power reaction and the uranium–238 breeder reaction is shown schematically in Figure 3.

Figure 3: Schematic Representation of the U–235 Fission Power Reaction and the U–238 Breeder Reaction



Schematic representation of the U–235 fission power reaction:

Schematic representation of the U–238 breeder reaction:

Source: Hubbert, M. King, "Energy Resources" in *Resources and Man*, National Academy of Sciences-National Research Council, Committee on Resources and Man, W.H. Freeman and Company, San Francisco, 1969, p. 220-221.

Most power reactors in turn belong to one of the six main types described in the following list, although there are numerous variants of these basic designs (Leclercq, 1986, p. 71).

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(1) A **fertile isotope** is one capable of being converted into a fissile isotope. Uranium–238 and thorium–232, not in themselves fissionable, can be converted through the absorption of neutrons into the previously nonexistent isotopes plutonium–239 and uranium–233, respectively.

(1) **Gas-cooled reactors (GCR)** use graphite as the moderator; either natural or enriched uranium as fuel; and carbon dioxide gas as coolant. Most of the early GCRs were of the British Magnox type or the French UNGG (Uranium Naturel, Graphite Gaz) type; a more recent version deployed by the British is known as the **advanced gas-cooled reactor (AGR)**.

(2) **Heavy water reactors (HWR)** use heavy water as the moderator; natural uranium, enriched uranium or plutonium as fuel; and pressurized heavy water, carbon dioxide gas or boiling light water as coolant. Most of the reactors in this category are of the CANDU design, employing pressurized heavy water as the coolant and natural uranium as the fuel. They are known as **pressurized heavy water reactors (PHWR)**. The CANDU design itself is usually designated as CANDU–PHWR.

(3) **Pressurized water reactors (PWR)** use light water as the moderator; enriched uranium as fuel; and pressurized light water as coolant. The PWR operates at sufficiently high coolant pressures that the water is kept in the liquid state and passes to a steam generator, creating steam in a secondary system to drive a turbine. In the Soviet Union this type is known as the VVER (Vode Vodjanie Energitcheskie Reactor); in France as the REP (Réacteur à Eau sous Pression).

(4) **Boiling water reactors (BWR)** use light water as the moderator; enriched uranium as fuel; and boiling light water as coolant. The BWR operates at low coolant pressures, with steam being allowed to form in the primary cooling circuit and passing directly to a turbine. The BWR is a simpler, less costly design than the PWR because steam generators are not required, but the PWR isolates the turbine on a secondary circuit and thus radioactivity escaping from the fuel elements does not contaminate the turbine.

The term **light water reactor (LWR)** is used to refer collectively to PWRs and BWRs.

(5) **Light-water graphite reactors (LWGR)** use graphite as the moderator; enriched uranium as fuel; and boiling light water as coolant. The LWGRs are Soviet power reactors, designated as RBMK (Reactor Bolche Molchnastie Kipiache). The Chernobyl units belong to this class.

(6) **Fast breeder reactors (FBR)** have no moderator (hence the name "fast" breeder since the neutron velocities are not moderated); use enriched uranium or plutonium as fuel; and liquid sodium as coolant. The principal design type in this category has been the liquid-metal cooled, fast breeder reactor, LMFBR, based on the uranium–238/plutonium–239 cycle. With the discovery in recent years that the world's uranium–235 reserves are much larger than had been thought, the sense of urgency has disappeared from the breeder reactor program.

The United States, the Soviet Union, France and Japan have led the world in adopting the PWR type for power production. [The Soviet Union operates 23 graphite-moderated reactors of the RBMK type as well as its 29 PWRs, but the majority of the

Soviet power reactors under construction today are PWRs.] As statistics compiled in the *World Nuclear Industry Handbook 1988* (NEI, 1988, p. 10ff) reveal, the PWR represented 60% of the 308,166 million watts (308,166 megawatts or 308.2 gigawatts) in generating capacity installed in 418 reactors operable worldwide as of July 31, 1987. PWRs are even more dominant in the group of reactors under construction, where they represent 75.5% of the 118.6 gigawatts (GW) of generating capacity being built in 130 new units.

The BWR type holds second place among operable reactors with 23.5% of installed capacity, but represents only 7.4% of capacity of reactors under construction.

Another line of reactor development, main advocate of which has been the United Kingdom, is the GCR, known as the Magnox in earlier British versions and as the AGR in more recent form. ["Magnox" refers to the magnesium oxide alloy used to sheath the fuel elements.] The gas-cooled reactor design suffers from the poor performance of both older and newer units: Magnox reactors have a disappointing 57.9% capacity-weighted load factor over their operating lives (as of end-June 1987) and the newer AGRs are doing even more poorly at 34.8%. In contrast, the PWR design averages 62.7% over its lifetime and the BWR 61.4%. The GCR accounts for 5% of operable reactor capacity and only 2.2% of reactor capacity under construction.

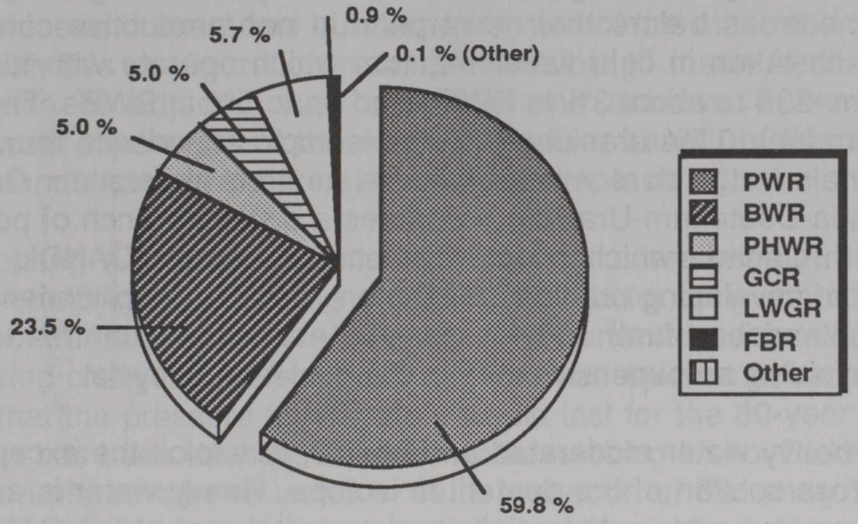
The heavy water reactor, in the PHWR variant pioneered by Canada, accounts for 5% of operable reactor capacity and 7.8% of capacity under construction. The PHWR exhibits the superior operating record, with a 75.5% capacity-weighted load factor through mid-1987. Despite its operating success, the PHWR type has achieved only limited penetration of the world reactor market when compared with the light water design. In terms of planned capacity, the PHWR accounts for just 2% of 141 GW planned in 149 units. This reflects the fact that only one new CANDU reactor was being planned by a Canadian utility when the survey was taken (and that remains to be confirmed), and only six PHWR reactors were being planned in other countries (five units in India, in which Canada has no involvement, and one unit in Turkey).

The LWGR design claims 5.7% of operable generating capacity and 5.9% of capacity under construction. The LWGR's share of reactor construction is represented entirely by six large RBMK units being built in the U.S.S.R.

The fast breeder claims only 0.9% of operable generating capacity and 1.2% of capacity under construction, but will account for a rising share of generating capacity in the future as fission power evolves.

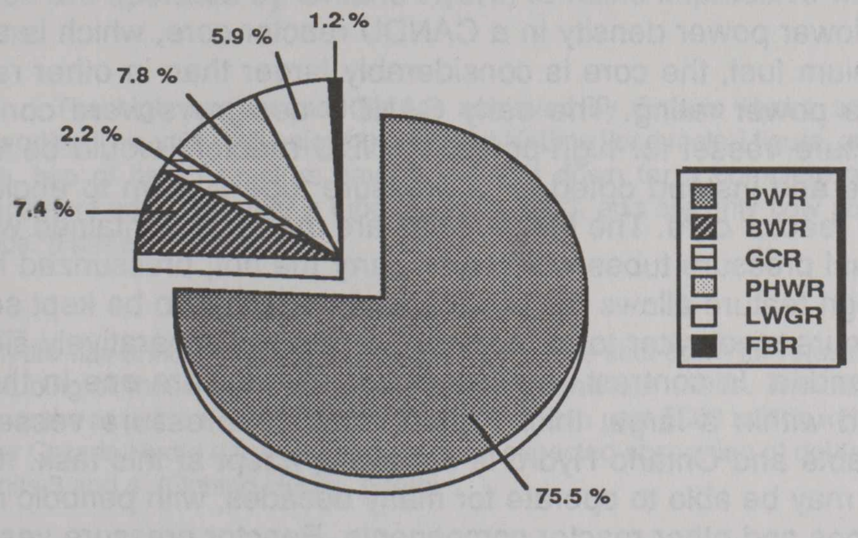
Figures 4 and 5 summarize the shares held at mid-1987 by the principal design types, for operable reactors and for reactors under construction, respectively. The dominance of the PWR design is evident.

Figure 4: Operable Reactors Worldwide at July 31, 1987, by Reactor Type



Source: Nuclear Engineering International, "Reactor Statistics", *World Nuclear Industry Handbook 1988*, Reed Business Publishing, Sutton, England, 1988, p. 10.

Figure 5: Reactors under Construction Worldwide at July 31, 1987, by Reactor Type



Source: Nuclear Engineering International, "Reactor Statistics", *World Nuclear Industry Handbook 1988*, Reed Business Publishing, Sutton, England, 1988, p. 10.

C. The CANDU System

There are two fundamental approaches to designing a reactor to sustain a chain reaction. One is to increase the concentration of fissile atoms within the fuel elements, accomplished by enriching the fuel and thereby increasing the probability of fissile capture of neutrons before their absorption in non-productive core materials. This is the approach taken in light water reactors which operate with fuel elements enriched in uranium–235 to about 3% in PWRs and up to 5% in BWRs. The other is to use natural uranium fuel (0.7% uranium–235, the isotopic abundance found in nature) and employ materials in the core which minimize neutron absorption. CANDU – an acronym for CANada-Deuterium-Uranium – denotes a distinct branch of power reactor design pioneered in Canada which adopts the latter approach. CANDU thus avoids the additional cost of developing uranium enrichment facilities (or of depending upon a foreign supplier for enriched fuel) and lessens the economic incentive to reprocess spent fuel, again avoiding an expensive step in the nuclear fuel cycle.

CANDU is heavy water moderated and cooled, to exploit the exceptionally low neutron-capture cross section of the deuterium isotope. Heavy water is an expensive commodity, however, and adds substantially to the capital cost of the CANDU reactor. There is also a heavy water make-up cost because small quantities are lost under normal operating conditions. A loss rate of less than 1% of the heavy water inventory per year has been achieved, overcoming the early fear that heavy water losses might prove to be uneconomically high. The heavy water inventory in older CANDUs is about 1 tonne per megawatt of generating capacity; in newer and larger units about 0.8 tonne per megawatt. Zirconium alloys, which absorb far fewer neutrons than steel, are used to fabricate structural components and to sheath the fuel elements, adding to the neutron economy of the CANDU design.

Given the lower power density in a CANDU reactor core, which is an aspect of using natural uranium fuel, the core is considerably larger than in other reactor types with a comparable power rating. The early CANDU designers were concerned that fabricating a pressure vessel for high-power CANDU reactors would be very difficult because of its size and instead opted for a pressure tube system to enclose the fuel bundles within the reactor core. The fuel bundles are therefore contained within a large number of individual pressure tubes which also carry the hot, pressurized heavy-water coolant. This design feature allows the coolant and moderator to be kept separate and the cool, low-pressure moderator to be enclosed within a comparatively simple vessel known as the calandria. In contrast, coolant and moderator are one in the LWR and must be contained within a large, thick-walled, complex pressure vessel. Pressure tubes are replaceable and Ontario Hydro is becoming adept at this task. It is possible that CANDU units may be able to operate for many decades, with periodic replacement of the pressure tubes and other reactor components. Reactor pressure vessels are not replaceable and impose a more restricted lifetime on other reactor designs.

The use of a pressure tube design confers a major operating advantage on CANDU: on-power refuelling. Whereas other reactors have to be shut down for refuelling, CANDU can continue to operate at full power while remotely controlled refuelling machines move fuel bundles in and out of the core. Failed fuel elements can also be removed while the reactor continues to operate. Much of CANDU's superior operating record can be traced to on-power refuelling. The pressure tubes are horizontal so that new fuel bundles can be simply pushed into one end of the tube by a fuelling machine and spent fuel bundles taken out of the other end by another fuelling machine. With this configuration it is also possible to insert fresh fuel bundles from opposite ends of adjacent fuel channels and achieve a more uniform power distribution over the length of the reactor. Another benefit of this approach is that it allows the manufacture of short fuel bundles of simple design.

Adopting a pressure tube design has not come without its drawbacks. The much more complicated plumbing of a CANDU reactor core contributes to the higher capital cost of building this type of reactor, an important consideration in an era of high capital carrying charges and frequently delayed construction schedules. Moreover, the early hope that the pressure tube system would last for the 30-year life then attributed to the reactor has been dashed. The premature retubing first of Pickering 1 and 2 in the wake of the ruptured tube at unit 2 in 1983 and soon of Pickering 3 and 4,(1) despite the use of a more advanced zirconium-niobium alloy in the tubing, has been a costly disappointment. The direct cost of materials, labour and equipment needed to remove and replace the pressure tubes, and of recommissioning units 1 and 2, has recently been estimated by Ontario Hydro at $402 million. The cost of replacement power for the lost nuclear-electric output was about $200,000 to $250,000 per unit per day, depending upon the type of replacement energy (coal-fired generation at Ontario Hydro stations or purchased power from other utilities). (Ontario Hydro, 1987a, p. 121-122) Thus the economic penalty of having two reactors shut down for several years for retubing has been large.(2) Even so, the performance of CANDU reactors, most of which are operated by Ontario Hydro, remains impressive when compared with other designs.

> The high performance figures achieved by Ontario Hydro are particularly noteworthy. This utility still enjoys the highest lifetime [load factor] figure, and yet for four years, two of its 15 reactors have been shut down for a complete pressure tube replacement operation after a tube failure in 1983, and are only now going back into service. (Howles, 1988, p. 22)

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(1) Ontario Hydro has announced that Pickering unit 3 will be shut down for retubing in 1989 and unit 4 in 1991. Retubing of these units had been planned for the late 1990s. The utility expects retubing to take 23 months at unit 3 and 19 months at unit 4, and to cost $500 million in total. The decision was taken after Ontario Hydro discovered higher than expected absorption of deuterium in pressure tubes of both units 3 and 4. (Ontario Hydro, 1988c)

(2) The cost of retubing and of providing replacement energy is being approximately equally shared by Ontario Hydro, the Province of Ontario and AECL as the joint owners of Pickering units 1 and 2. The Nuclear Payback Agreement which applies to these two reactors is discussed in the later section on The Economics of Nuclear Power.

Figure 6 illustrates the principal features of the CANDU reactor, the primary coolant circuit and the steam generators.

Figure 6: The Principal Design Features of the CANDU Reactor System

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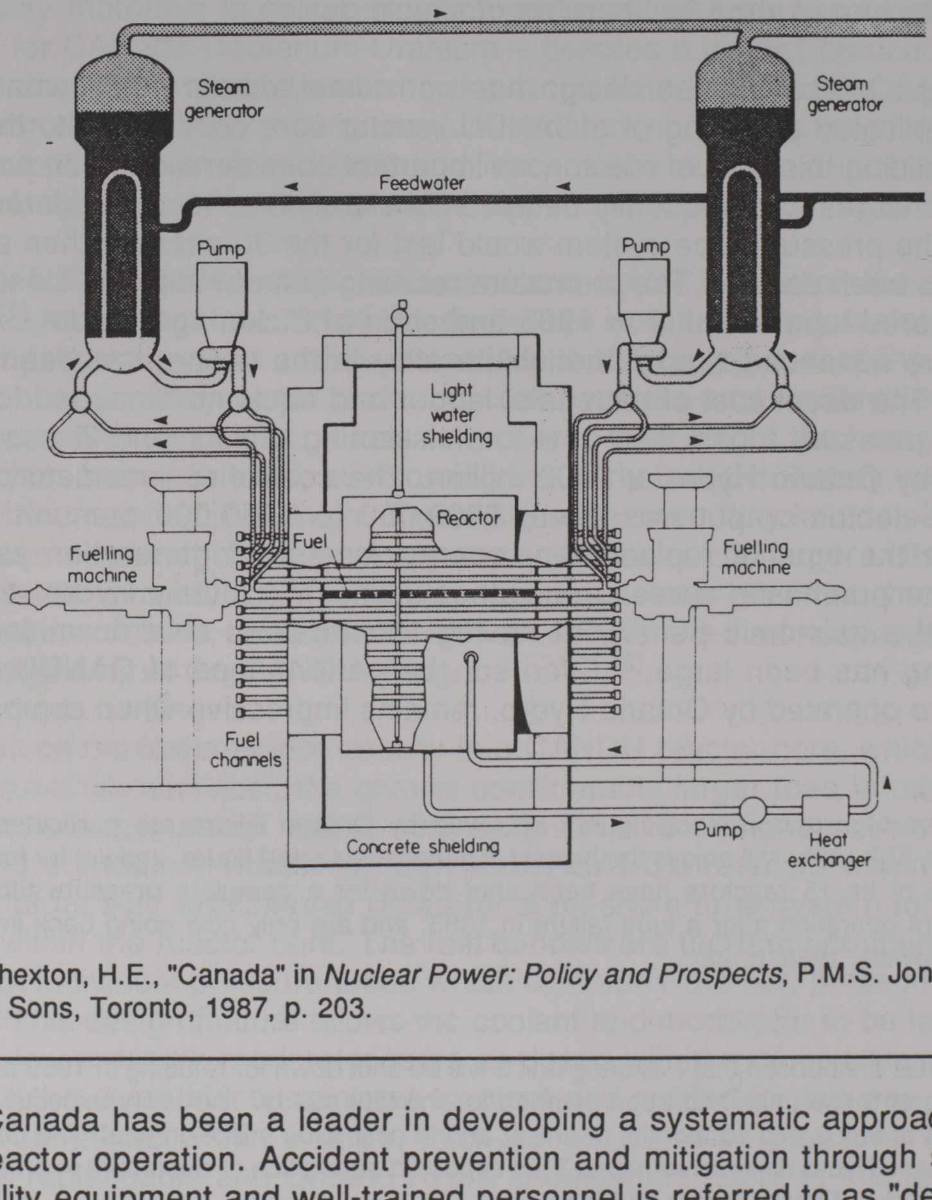

Source: Thexton, H.E., "Canada" in *Nuclear Power: Policy and Prospects*, P.M.S. Jones (ed.), John Wiley & Sons, Toronto, 1987, p. 203.

Canada has been a leader in developing a systematic approach to minimizing risk in reactor operation. Accident prevention and mitigation through superior design, high-quality equipment and well-trained personnel is referred to as "defence-in-depth". This concern with safety is one of the legacies of the 1952 NRX reactor accident at Chalk River. Defence-in-depth assumes that reactor design will have occasional imperfections, that equipment will sometimes fail, and that reactor operators will occasionally make mistakes. The intent is to minimize the probability of an accident occurring and to minimize the consequences of an accident, should it occur.

As described by Ontario Hydro, the concept of defence-in-depth rests on five factors (Ontario Hydro, 1987a, p. 101-104).

(1) High-quality station equipment built to strict engineering specifications is the first line of defence.

(2) In the event of failure in a major reactor system, independent safety systems are activated to compensate for or offset the failure. These safety systems are designed wherever possible to incorporate certain principles of operation. **Separation** means that a failure in one location or system will not affect components in other locations or systems. **Diversity** means that there is more than one way of achieving a result or condition, such as shutting down the reactor. **Redundancy** means that more than one component is available for a given task or operation, such as connecting two pumps in parallel when only one is required. **Independence** means that systems or components operate independently of each other; one example is having independent power supplies for separate systems. **Fail-safe** means that the failure of a component or system automatically causes that component or system to assume a safe condition. For example, shut-off rods may be held above the reactor by electromagnetic clamps; a power failure causes the rods to be released and drop into the reactor, shutting it down.

CANDU reactors have two general classes of safety systems: **reactor shutdown systems** and an **emergency core cooling system** (ECCS). Every CANDU unit has two independent shutdown systems, of the three types of shutdown system that have been designed for CANDU reactors. All CANDU reactors have **shut-off rods** made of neutron-absorbing cadmium. Rapid insertion of the shut-off rods terminates the chain reaction because there are not enough neutrons available to sustain it. Some CANDU reactors are equipped with a **moderator dump**, a system which rapidly drops the moderator into a holding tank beneath the reactor. Loss of the moderator means that fast neutrons are not slowed to cause further fissioning and the chain reaction is again terminated. Other CANDU reactors have a **poison injection** system, in which a liquid with neutron-absorbing properties can be injected under pressure into the moderator. The injected liquid absorbs large numbers of neutrons and "poisons" the chain reaction.

The ECCS is activated if cooling of the reactor core fails, as in a major break in the primary cooling system. Water stored in a reservoir is injected under pressure through the emergency cooling system to flow over the fuel and carry away the heat.

(3) The third factor is barriers designed to contain or to minimize any release of radioactivity. The philosophy has been to create a series of physical barriers to the release of radioactivity during either normal operation or an emergency. The first barrier is the fuel itself which, barring failure of the fuel pellet, will contain 99% of the radioactivity created during normal reactor operation. CANDU fuel is fabricated

as ceramic pellets of uranium dioxide (UO_2) with a melting point of 2800°C. Fuel pellets are in turn contained within sealed zircaloy metal tubes, constituting another barrier to the escape of radioactivity. The fuel bundles are located in pressure tubes within the closed, primary cooling system. The reactor and its main supporting systems are housed within a thick-walled concrete building and, in the case of multi-unit Ontario Hydro stations, connected to a vacuum building by a large duct with pressure-relief valves. If a major break occurs in the primary cooling system, escaping coolant will rapidly form steam and cause the pressure-relief valves to open. The vacuum building is maintained at about one-tenth of atmospheric pressure and the radioactive steam is sucked into it. A dousing system in the vacuum building will condense the steam, minimizing leakage of radioactivity from the containment system to the environment. The final barrier is a one-kilometre exclusion zone at the plant boundary which provides for some dilution before escaping radioactivity reaches any residential area.

(4) A particularly important factor is operator training. As reactor accidents in the past have shown, serious events almost invariably have a substantial or even dominant component of operator error. Ontario Hydro personnel receive at least eight years of training and must pass a series of examinations set by the utility and by the AECB before being licensed as reactor operators.

(5) The final factor is fault detection and correction. A continuous program of testing and inspection, coupled with automatic fault detection systems, is used to ensure the reactor is operating properly and to correct faults that are detected.

Not all reactor accidents are anticipated or are accorded the correct probability of occurrence before the fact. For example, it had been thought that a pressure tube failure in a CANDU reactor would be signalled first by a leaking condition, the so-called "leak-before-break" assumption. In the event, the failure of the pressure tube at Pickering 2 was abrupt – the tube ruptured with no warning of impending failure. Nonetheless, operators responded correctly and reactor operation was stopped with the normal shutdown system (no recourse to emergency systems was needed) in the most serious accident yet in a CANDU reactor. The Pickering 2 pressure tube failure, despite its economic consequences, demonstrated the ability of the CANDU system to cope with a major loss-of-coolant accident.

The CANDU reactor requires substantial amounts of heavy water (deuterium oxide, D_2O) for use both as moderator and coolant. Canada has invested heavily in heavy water production facilities in a program that first suffered from an insufficient supply of heavy water and later from too much as reactor sales failed to materialize.

The heavy water production process is based on the behaviour of deuterium in a mixture of water and hydrogen sulphide. When liquid water and gaseous hydrogen sulphide are mixed, deuterium atoms will move freely between the liquid and the gas – toward the gas at higher temperature and toward the liquid at lower temperature. The first and second stages of a heavy water plant consist of exchange towers operated with a cold (32°C) top section and a hot (128°C) bottom section. Hydrogen sulphide gas circulates upward through the tower and water circulates downward, with mixing promoted by a series of perforated trays. The result is an enrichment of deuterium in the central section of the tower.

Hydrogen sulphide gas enriched in deuterium is extracted from the central section of the first tower in the train and passes to the second tower for the next stage of enrichment. The first stage enriches the hydrogen sulphide gas from 0.015% deuterium to 0.07%; the second stage to about 0.35%. A third stage of enrichment yields a product containing 10-30% heavy water. The final step is a distillation process to finish the output to "reactor grade" heavy water with a purity of 99.75% deuterium oxide. The heavy water production process requires that very large volumes of water be treated: approximately 340,000 tonnes for every tonne of heavy water extracted. (Ontario Hydro, *Heavy Water*, undated)

The cost of operating a heavy water plant is largely insensitive to the rate of production; that is, very little saving is achieved by running the plant at less than full capacity. Thus the unit cost of producing heavy water rises sharply as throughput falls. Information on Ontario Hydro's cost of heavy water production and on the federal investment in Canadian heavy water development is provided in the section on The Economics of Nuclear Power.

Safety is a central concern at heavy water plants because hydrogen sulphide is a colourless, toxic gas that is slightly heavier than air. Plant personnel and nearby communities must be protected from dangerous concentrations of this gas.

AECL has dismantled its Glace Bay and Port Hawkesbury heavy water plants in Nova Scotia. Of the four 800 tonnes/year heavy water plants planned by Ontario Hydro at the Bruce site, only Bruce Heavy Water Plant (HWP) B is operating. Each Darlington reactor will require about one year's output from Bruce HWP B for its initial charge of heavy water. Bruce HWP A and D are mothballed; unit C was not constructed. The 800 tonnes/year LaPrade HWP at Gentilly is also mothballed. AECL is carrying a costly inventory of unsold heavy water that it attempts to market in competition with Ontario Hydro.

Table 1 summarizes the major differences between the CANDU pressurized heavy-water reactor system (CANDU–PHWR) and the pressurized light-water reactor system (PWR).

Table 1: Differences Between the CANDU–PHWR and the PWR

CANDU–PHWR	PWR
• Natural uranium fuel (0.7% U–235)	• Enriched uranium fuel (1-3% U–235)
• D_2O cooled and moderated	• H_2O cooled and moderated
• On-power refuelling – higher load capacity factor – higher fuel burn-up – on-power failed fuel removal	• Batch refuelling during shut-down
• Pressure tubes	• Pressure vessel
• Larger core size with lower power density	• Smaller core size with higher power density
• Comparatively higher capital cost	• Comparatively higher operating cost
• More complicated plumbing	• Less complicated plumbing
• Vacuum building at multi-unit stations	• Various pressure suppression methods
• Higher leak-rate containment	• Lower leak-rate containment
• Positive void reactivity coefficient	• Negative void reactivity coefficient
• Relatively high tritium and carbon–14 production and emissions	• Low tritium and carbon–14 production and emissions
• Shared containment at Ontario Hydro stations	• Separate containment systems
• Easily adapted to thorium fuel cycle	• Not applicable

Canadian Nuclear Development

A. The Power Reactor Program

Heavy water, D_2O, was discovered in 1930 and its properties as a neutron moderator were soon recognized. Heavy water became a strategic commodity during World War II, as both the Allies and the Third Reich laboured to produce the atomic bomb. France had bought up world stocks of heavy water on the eve of the war and some of these stocks were transferred first to England and then to Canada, where Canadian and British research teams worked to construct the first heavy-water-moderated reactor. In the meantime, Allied sabotage prevented the Germans from getting enough heavy water from the world's only production plant in Norway to continue their nuclear research efforts using D_2O.

Canada's first nuclear reactor was ZEEP – the Zero Energy Experimental Pile. ZEEP was built in Chalk River in eastern Ontario, and became the first functional reactor outside of the United States with its startup in September of 1945. Its purpose was to confirm design parameters for a larger reactor and to perform tests on a heavy-water moderated reactor system. (Thexton, 1987)

ZEEP was followed by the 20 thermal-megawatt (MWt) NRX (Nuclear Research Experimental) reactor which began operation at Chalk River in 1947. This heavy-water-moderated research reactor was intended to be a plutonium production unit but proved to be an excellent test bed for nuclear fuels and materials research, because of its large size and high neutron flux. In December 1952, the NRX reactor was badly damaged in an accident caused by operating errors combined with mechanical defects in shut-off rods. NRX had no independent fast shut-down system and no containment system. Before the chain reaction could be stopped by dumping the moderator, extensive damage to structural components and fuel elements occurred, causing the release of radioactivity. It took 14 months to rehabilitate the reactor, which re-entered service at an upgraded rating of 40 MWt. The NRX accident, Canada's first and most serious nuclear mishap, had a major influence on the safety engineering of later power reactors. (Thexton, 1987; Ontario, Nuclear Safety Review, 1988d, p. 42)

The 200 MWt NRU (National Research Universal) research reactor began operation in 1957 at Chalk River. The reactor's vertical core was loaded at the top, using a 240-ton transfer flask which allowed on-power refuelling. In May 1958, a fuel rod broke apart during unloading of the reactor and the resulting contamination caused it to be shut down for six months. Unlike NRX which was largely designed by British scientists working at Chalk River, NRU was a Canadian-designed, heavy-water-moderated reactor. NRX and NRU attracted researchers from several countries. A fortuitous aspect of this collaboration was Canada's early access to the use of a new zirconium alloy, zircaloy, developed by Westinghouse for the U.S. nuclear submarine program. Zirconium alloys were to make possible the construction of a pressure tube reactor. (Thexton, 1987; Bothwell, 1988)

The next step was construction of a prototype power reactor. AECL, Ontario Hydro and Canadian General Electric joined forces to design and build the 22 MWe (net) (1) NPD (Nuclear Power Demonstration) unit at Rolphton, Ontario, near Chalk River. NPD was owned by AECL and operated by Ontario Hydro. This reactor entered service in 1962 and operated until 1987. It is now undergoing decommissioning. NPD was designed as a pressure vessel reactor with a vertical core, although Canadian engineers were worried that it would prove impracticable to build a pressure vessel large enough to contain the core of a commercially-sized, heavy-water-moderated reactor. The vessel had already been ordered from Babcock & Wilcox in Scotland when zircaloy became available and the design of a pressure tube reactor became feasible. Work stopped on the pressure vessel design and NPD was re-engineered as a pressure tube reactor. NPD also served as the model for the 125 MWe (net) KANUPP station near Karachi, Pakistan. (Thexton, 1987; Bothwell, 1988; Ontario, Nuclear Safety Review, 1988a)

Ontario Hydro and AECL next collaborated in scaling up the NPD design, constructing the 206 MWe (net) Douglas Point demonstration reactor on the east shore of Lake Huron, north of Kincardine. This site was later to become the location of the eight-unit Bruce Nuclear Generating Station. The decision to build was made in 1959 and the target date for start-up was 1964. Douglas Point was in fact not commissioned until 1967, but Ontario Hydro was sufficiently confident in the design that it began work on the multi-unit Pickering A station before Douglas Point entered service. This reactor also aided Canada in reactor export, serving as the model for the 203 MWe (net) RAPP–1 and –2 units, committed in 1963 at Rajasthan, India.

Because of a shortage in the Canadian supply of heavy water, Douglas Point was taken out of service from April to December of 1972, when its inventory of D_2O was used for Pickering reactor commissioning. The Douglas Point reactor operated until May 1984 at which time its owner, AECL, offered the unit for sale to the operator, Ontario Hydro. Hydro decided that the reactor's small size, its need for pressure tube replacement, and the lack of adequate transmission capacity from the Bruce site made continued operation uneconomic. AECL then put the reactor into a permanent shutdown condition in January 1985. Douglas Point became the first CANDU–PHWR to be placed in a "storage with surveillance" state, a 30-year delay period to be followed by reactor dismantling and entombment. The entire inventory of irradiated fuel has been placed into concrete canisters for interim, on-site dry storage. This storage program is described in the section Radioactive Waste Management in Canada. (Canada, AECL, CANDU Operations, "The Douglas Point Story", 1984; Broad, 1986)

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(1) Net generating capacity = gross generating capacity – station service. The net capacity represents the electricity available to the grid after the electrical demand and losses of the generating station itself have been accounted for.

A variant of the heavy-water-moderated reactor system, known as the CANDU–BLW, was built by AECL for Hydro-Québec at Gentilly on the St. Lawrence River. This 250 MWe (net), commercially-sized prototype power reactor, designated Gentilly 1, was moderated by heavy water and cooled by boiling light water. It was a back-up design to the CANDU–PHWR in case heavy water coolant losses at Douglas Point and Pickering A proved to be uneconomically high. Gentilly 1 retained the pressure tube design within a vertical core. By allowing the light water coolant to boil within the pressure tubes, reducing its mass and neutron absorption characteristics, the reactor could still operate on natural uranium fuel. The reactor control system proved to be highly complex, however, and Gentilly 1 experienced a series of design and commissioning problems. From entering service in 1972 until its removal from commercial operation in 1977, Gentilly 1 ran at full power for a total of only a few weeks. The reactor was used for training purposes until 1979, when the decision was taken to mothball the station. In 1983, AECL decided to decommission Gentilly 1. The spent fuel has been transferred to concrete canisters for interim, dry storage within the turbine building. Fortunately for the PHWR design, heavy water losses at Douglas Point and Pickering proved to be quite low and interest in the CANDU–BLW type disappeared. (Thexton, 1987; Denault and De, 1985)

Another design approach was embodied in the 40 MWt WR–1 experimental reactor constructed at the Whiteshell Nuclear Research Establishment in Manitoba. This reactor type was designated CANDU–OCR to indicate that it combined a heavy water moderator with an organically-cooled system, using a specially designed light oil as coolant. The organic liquid functioned as a more efficient heat transport medium, allowing the reactor to operate at higher coolant temperature and achieve a better thermodynamic efficiency than the standard CANDU. The organic coolant had the additional advantage of developing lower radiation levels than does heavy water during reactor operation. This experimental reactor, which ran on an enriched uranium carbide fuel, achieved full power in 1965 and operated until 1985. Although the organically cooled reactor was considered to be a promising line of development and extensive studies were conducted by AECL into the 1970s, the success of Pickering A kept interest centred on CANDU–PHWR.

Ontario Hydro began building the first of its multi-unit stations, Pickering A, on Lake Ontario east of Toronto. Four 515 MWe (net) reactors at Pickering A entered commercial service from 1971 through 1973. They were followed by four 740 MWe (net) units at Bruce A on Lake Huron (1977-79). Four 516 MWe (net) units were then added at Pickering B (1983-85) and four 756 MWe (net) reactors at Bruce B (1984-87). The Pickering and Bruce Nuclear Generating Stations rank among the largest nuclear generating complexes in the world. Four 881 MWe (net) reactors are under construction today at the new Darlington site on Lake Ontario. These units will enter service from 1989 through 1992. In 1987, Ontario derived almost half of its electricity supply from nuclear units; in 1992, with the completion of Darlington, this share will rise to almost two-thirds.

A notable feature of the larger CANDU units is their conservative design rating.

The Bruce A units have already been raised from 740 MWe to 769 MWe (or to a net capacity of 848 MW when credit is made for the process steam which these units supply to the Bruce Heavy Water Plant). The Bruce B units are being rerated to 875 MWe in net output. (Ontario Hydro, 1986b, p. 5)

AECL's next design initiative was the CANDU 600 reactor. This unit combines the best elements of the established Pickering and Bruce reactor designs and incorporates a number of technological improvements. The CANDU 600 is engineered as an individual unit with a conventional containment building, distinct from Ontario Hydro's four-unit stations which share a vacuum containment system. Quebec and New Brunswick each elected to build one of the CANDU 600 series reactors, Hydro-Québec locating its 638 MWe (net) unit at Gentilly and the New Brunswick Electric Power Commission (NBEPC) siting its 633 MWe (net) reactor at Point Lepreau on the Atlantic coast. Point Lepreau has established an exceptionally good operating record with a lifetime capacity factor of 92%.

At the time that NBEPC completed Lepreau 1, it represented about a 25% addition in generating capacity to the New Brunswick Power system. Electrical utilities don't normally add generating capacity in increments much larger than about 10% of existing system capacity, because of problems in replacing that capacity when the unit is down. New Brunswick's extensive system interties with Quebec, Nova Scotia and New England allowed it to circumvent this guideline, although not without an increased risk to the stability of the New Brunswick grid.

Three Canadian provinces have thus invested in nuclear-electric generation. Ontario will soon be home to 20 operating power reactors: the eight-unit Pickering station, the eight-unit Bruce station and the four-unit Darlington station. The Douglas Point reactor and the NPD reactor are shut down and decommissioning in Ontario. Quebec has built two units at Gentilly: the Gentilly 1 experimental boiling water reactor, now decommissioning, and the Gentilly 2 CANDU 600 reactor. New Brunswick has the one CANDU 600 unit at Point Lepreau. Since 1962, 21 power reactors have been commissioned in Canada, three of which are now being decommissioned, and four reactors are under construction. No additional reactor development is committed at this time. Table 2 summarizes Canada's domestic history of power reactor development.

The 18 operating power reactors in Ontario, Quebec and New Brunswick have a total net generating capacity of 11,971 MWe (including the uprating of the Bruce B units to 875 MWe, which is underway at the time of writing, but not including any credit for process steam supplied by the Bruce A units). The four units under construction at Darlington will add 3,524 MWe (net) of generating capacity, giving Canada a total nuclear-electric generating capacity of 15,495 MWe (net) in 1992.

For the Ontario multi-unit stations, the capacities are: (1) Pickering A Nuclear Generating Station (NGS) = 2,060 MWe; (2) Pickering B NGS = 2,064 MWe; (3) Bruce A NGS = 3,076 MWe; (4) Bruce B NGS = 3,500 MWe (upon completion of the uprating); and (5) Darlington A NGS = 3,524 MWe.

Table 2: Canada's History of Power Reactor Development

Unit	Location	Type	Capacity (MWe net)	Operator	Commercial Operation	Status
NPD	Rolphton, Ont.	PHWR	22	Ont. Hydro	1962	Shut down 1987
Douglas Point	Tiverton, Ont.	PHWR	206	Ont. Hydro	1968	Shut down 1984
Pickering 1	Pickering, Ont.	PHWR	515	Ont. Hydro	1971	Operating
Pickering 2	Pickering, Ont.	PHWR	515	Ont. Hydro	1971	Operating
Pickering 3	Pickering, Ont.	PHWR	515	Ont. Hydro	1972	Operating
Pickering 4	Pickering, Ont.	PHWR	515	Ont. Hydro	1973	Operating
Gentilly 1	Gentilly, Que.	BLW	250	Hydro-Qué.	1972	Shut down 1978
Gentilly 2	Gentilly, Que.	PHWR	638	Hydro-Qué.	1983	Operating
Bruce 1 (a)	Tiverton, Ont.	PHWR	740	Ont. Hydro	1977	Operating
Bruce 2 (a)	Tiverton, Ont.	PHWR	740	Ont. Hydro	1977	Operating
Bruce 3 (a)	Tiverton, Ont.	PHWR	740	Ont. Hydro	1978	Operating
Bruce 4 (a)	Tiverton, Ont.	PHWR	740	Ont. Hydro	1979	Operating
Pt. Lepreau	Pt. Lepreau, N.B.	PHWR	633	NBEPC	1983	Operating
Pickering 5	Pickering, Ont.	PHWR	516	Ont. Hydro	1983	Operating
Pickering 6	Pickering, Ont.	PHWR	516	Ont. Hydro	1984	Operating
Pickering 7	Pickering, Ont.	PHWR	516	Ont. Hydro	1985	Operating
Pickering 8	Pickering, Ont.	PHWR	516	Ont. Hydro	1985	Operating
Bruce 6 (b)	Tiverton, Ont.	PHWR	756	Ont. Hydro	1984	Operating
Bruce 5 (b)	Tiverton, Ont.	PHWR	756	Ont. Hydro	1985	Operating
Bruce 7 (b)	Tiverton, Ont.	PHWR	756	Ont. Hydro	1986	Operating
Bruce 8 (b)	Tiverton, Ont.	PHWR	756	Ont. Hydro	1987	Operating
Darlington 2	Darlington, Ont.	PHWR	881	Ont. Hydro	1989	Construction
Darlington 1	Darlington, Ont.	PHWR	881	Ont. Hydro	1989	Construction
Darlington 3	Darlington, Ont.	PHWR	881	Ont. Hydro	1991	Construction
Darlington 4	Darlington, Ont.	PHWR	881	Ont. Hydro	1992	Construction

(a) The Bruce A units have been rerated to 769 MWe (including credit for process steam supplied to the Bruce Heavy Water Plant, they have a net capacity of 848 MW).

(b) The Bruce B units are currently being rerated to 875 MWe.

Source: Canada, AECL, *Nuclear Sector Focus*, Corporate Public Affairs, Ottawa, September 1987, p. G-4 and G-5; Ontario, Nuclear Safety Review, *The Safety of Ontario's Nuclear Reactors: A Scientific and Technical Review. A Submission to the Ontario Nuclear Safety Review by Atomic Energy of Canada Limited*, Toronto, 29 February 1988, Fig. 2-2.

In Ontario in 1987, nuclear-electric generation supplied 47.5% of the electricity required to meet customer demand. Fossil-fuelled generation accounted for 23.9% and hydro-electric generation for 23.8%. Burning fossil fuels (mostly coal) last year to generate electricity caused Ontario Hydro to release about 400,000 tonnes of acid gases – sulphur dioxide and nitrogen oxides – to the atmosphere. Although Hydro's total acid gas emissions in 1987 were considerably below the peak value of 531,000 tonnes in 1982, they were nonetheless up sharply from 1986 as a result of dry weather and low water levels which depressed hydraulic generation by about 15% and caused coal consumption to be almost 50% higher than forecast for 1987. Under new and stricter provincial regulations announced in 1985, the utility must lower its acid gas emissions to a limit of 215,000 tonnes in 1994. (Ontario Hydro, 1988a)

Nuclear generation plays a major part in reducing acid gas emissions in Ontario. Nuclear power displaced about two-thirds of the acid gases that Ontario Hydro would otherwise have released to the atmosphere in 1987 by burning coal instead; total acid gas emissions within Ontario were reduced by approximately one-quarter.

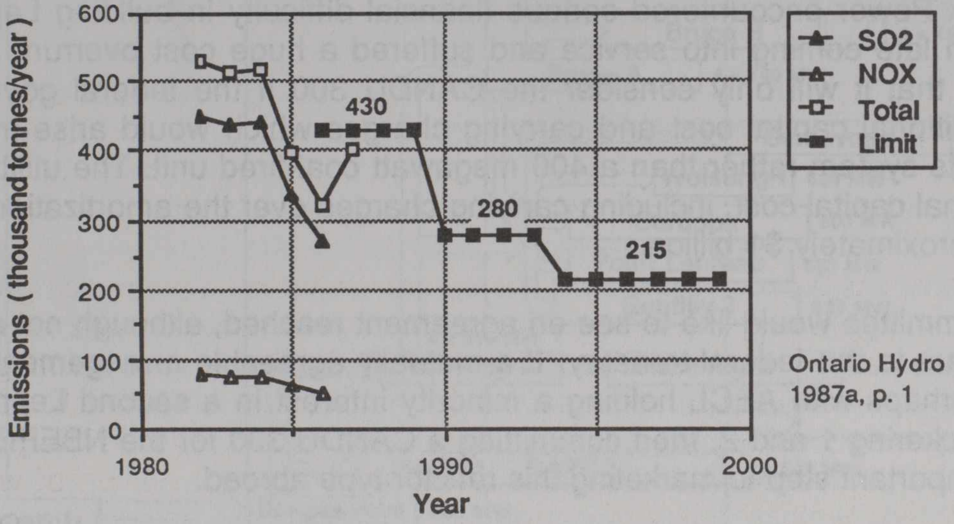
After many years of international development in which reactor size grew more or less continuously, it was recognized by AECL that there is also a need for a smaller unit. Smaller units carry a lower total price tag (although a higher cost per megawatt of installed capacity), thereby representing less of a financial burden and risk. Such units can more readily be accommodated in the systems of smaller utilities. The product of this approach by AECL to reactor evolution is the CANDU 300, design of which will soon be completed. Smaller utility systems, particularly in the developing countries, are seen as the market for CANDU 300.

AECL has simplified the CANDU 300 design in comparison with earlier CANDUs. For example, the use of data highways and multiplexers in the CANDU 300 control systems reduces instrumentation wiring by 80% relative to the CANDU 600. Whereas CANDU 600 (which will have a nominal net power output of 750 MW in new stations) has four steam generators and four primary coolant pumps, the 300 (with its nominal net power output of 450 MW) has two steam generators and two main coolant pumps. CANDU 300 will use one refuelling machine instead of the two built into the 600. Key components such as steam generators, coolant pumps, pressure tubes and fuelling machines will be identical to those already proven in service at operating CANDU stations. (Brooks and Hart, 1988; Canada, AECL, CANDU Operations, undated)

AECL is responding to a global trend confirmed in a 1985 study by the International Atomic Energy Agency (IAEA). The IAEA found that additions to generating capacity in the non-Communist world, over the 5-year period 1985-89, would most commonly be coal-fired units approximately 400 MW in size. This is the market targetted by the CANDU 300, with its nominal net output of 450 MWe. In terms of generating capacity, the IAEA review indicated that 39.3% of the additional capacity would be nuclear-electric, 38.6% would be coal-fired, 6.4% would be oil-fired and 6.3% would be hydro-electric. (Brooks and Hart, 1988)

Ontario Hydro and Acid Gas Emissions

Ontario Hydro estimates that its coal-fired stations account for about 20% of Ontario's total acid gas emissions – sulphur dioxide (SO_2) and nitrogen oxides (NO_x) – or 1% of total North American emissions. The chart shows Ontario Hydro emissions for 1982-86 and the emission limits being applied by the Province of Ontario to the utility (430,000 tonnes of total acid gas emissions for 1986-89; 280,000 tonnes for 1990-93; and 215,000 tonnes from 1994 on).



Ontario Hydro 1987a, p. 1

To decrease emissions, Ontario Hydro has: increased nuclear generation; reduced the sulphur content of the coal burned; bought hydro-electricity from Quebec and Manitoba; and tested low-NO_x burners. Each Pickering reactor displaces about 50,000 tonnes/year of acid gas emissions and each Bruce unit about 75,000 tonnes/year. Each new Darlington reactor will avoid about 90,000 tonnes/year. Without Pickering and Bruce, Hydro's acid gas emissions would be three times current levels. Blending low-sulphur Western Canadian coal with higher-sulphur U.S. coal avoids about 90,000 tonnes of emissions annually but costs Hydro an extra $60 million per year. Washing most of its purchased U.S. coal reduces the sulphur content of the coal by roughly 20%. Low-NO_x burner nozzles tested at the coal-fired Nanticoke station appear to reduce emissions of nitrogen oxides by about 35%. (Ontario Hydro, 1987a, p. 2-3)

These strategies will not, however, meet the tougher 1994 limit as the demand for electricity increases. Ontario Hydro announced in February 1988 that it is seeking government approval to install "scrubbers" (flue gas desulphurization units) at its three largest coal-fired generating stations. The 2,286 MW Lakeview, the 4,336 MW Nanticoke and the 2,100 MW Lambton Generating Stations collectively account for more than 90% of Hydro's coal-fired generation. Four different technologies for flue gas desulphurization have been assessed and the merits of each described in an environmental assessment submitted by Hydro to Environment Minister James Bradley. The scrubbers would be installed in pairs to serve each generating unit and would cost approximately $220 million (1987 dollars) per pair. Ontario Hydro may have to retrofit as many as eight 500 MW coal-fired generating units at the three stations between 1994 and 2000. Each pair of scrubbers will cost up to $12 million to operate per year and a permanent staff of between 50 and 120 people will be needed at each station to operate and maintain the scrubbers. (Ontario Hydro, 1988b)

To reduce the capital cost of the CANDU 300, AECL has worked out a 35-month construction schedule – from first concrete poured to full power operation – for the first unit on a site and a schedule as short as 30 months for subsequent units. This is expected to be achieved through a modular design which limits the weight of individual modules to about 300 tonnes (within the capacity of a very-heavy-lift crane) and by employing advanced construction techniques.

AECL has been trying to obtain a domestic sale of a CANDU 300 to NBEPC, to demonstrate the viability of the design. Although negotiations are continuing, AECL has to date been unable to obtain a commitment from NBEPC to build a CANDU 300. New Brunswick Power encountered serious financial difficulty in building Lepreau 1, which was both late coming into service and suffered a huge cost overrun, and has publicly stated that it will only consider the CANDU 300 if the federal government covers the additional capital cost and carrying charges which would arise in adding such a unit to its system rather than a 400 megawatt coal-fired unit. The utility claims that the additional capital cost, including carrying charges over the amortization period, amounts to approximately $1 billion.

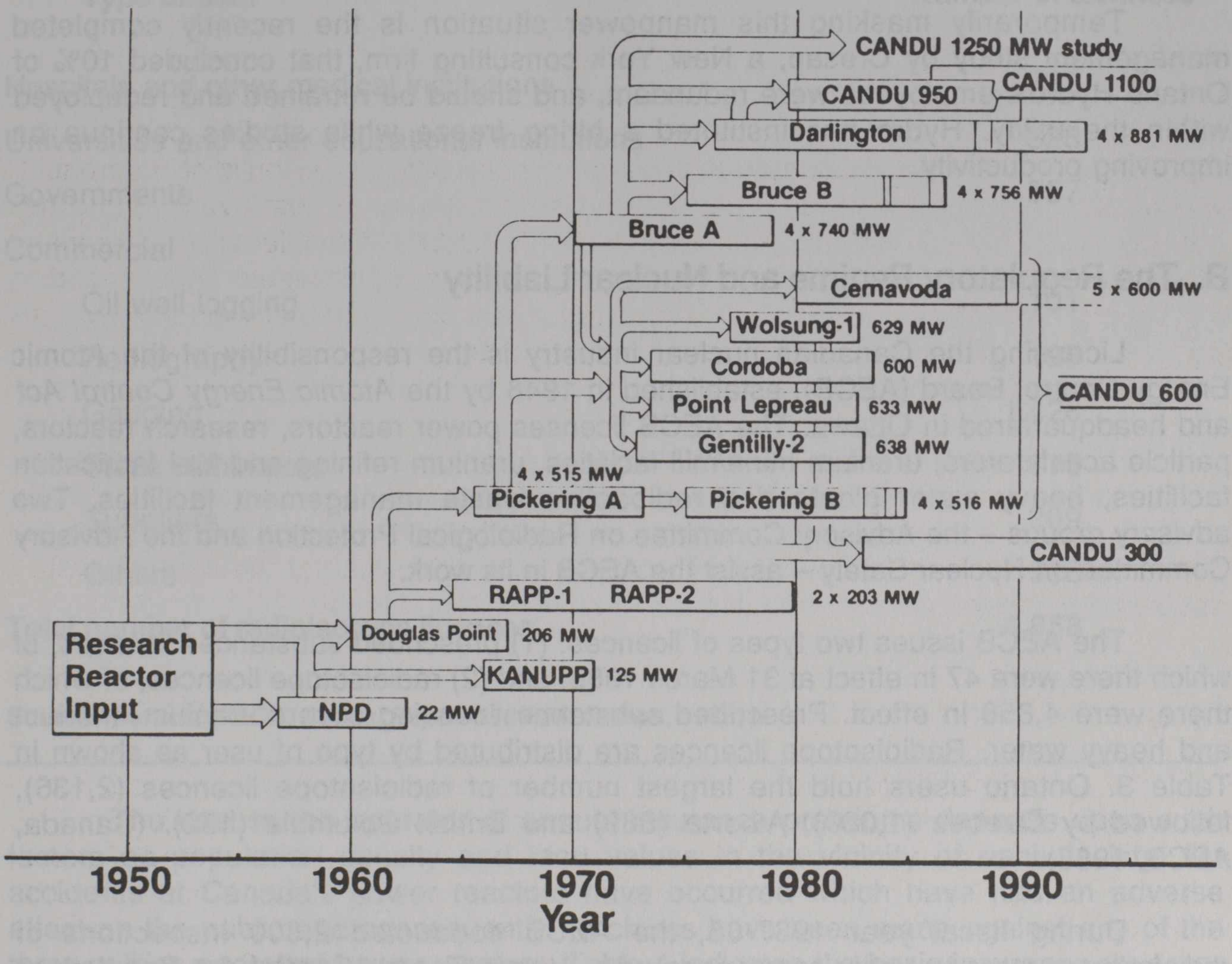
The Committee would like to see an agreement reached, although not at a cost of a billion dollars to the federal treasury. If a mutually agreeable arrangement can be established, perhaps with AECL holding a minority interest in a second Lepreau unit as it does in Pickering 1 and 2, then committing a CANDU 300 for the NBEPC system should be an important step to marketing this reactor type abroad.

Figure 7 outlines the genealogy of the CANDU design, beginning with the prototype NPD reactor and carrying through to the study of a 1,250 MW CANDU unit.

A number of CANDU units have been built in other countries. The sequence of design began with the 125 MWe (net) Kanupp unit built near Karachi, Pakistan. This reactor went on power in 1971. Two 203 MWe (net) units, Rapp–1 and Rapp–2, followed near Delhi in India. Rapp–1 entered service in 1972; Rapp–2 not until 1980. This delay reflects Canada's termination of nuclear cooperation with India after it detonated a nuclear device in May of 1974. Although cut off from Canadian nuclear assistance, India continued to build the CANDU–PHWR system on its own. Since Canada ended its nuclear cooperation, India has also completed the Mapp 1 and 2 and the Narora 1 and 2 units, all similar in output to the Rapp units (and to Douglas Point from which these reactors are derived).

AECL has been successful in selling a series of the CANDU 600 reactors abroad. Two of these units are already operating: the 600 MWe Cordoba unit at Embalse in Argentina and the 629 MWe Wolsung unit in South Korea. Five CANDU 600 units are being built in Romania, Cernavoda units 1–5. The Romanian program is falling behind schedule because of that country's insistence on domestic content. Romanian manufacturing has been unable to fabricate nuclear components of consistently high quality and the rejection rate has been excessive.

Figure 7: The Development Sequence of the CANDU Reactor System



Source: Meneley, Daniel A., "Ontario Hydro's CANDU Nuclear Stations: An Outline of Safety-related Design Aspects" in Ontario, Nuclear Safety Review, *The Safety of Ontario's Nuclear Power Reactors: A Scientific and Technical Review. Vol. 2 Appendices*, Appendix I, Toronto, 29 February 1988, p. I/2.

A manpower problem is developing largely unremarked in the Canadian nuclear program. There is a growing shortage of professional and technical personnel in the nuclear field – Ontario Hydro, AECL and industry are all experiencing increasing difficulty in staffing. Highly trained personnel sense a loss of purpose in the nuclear program and see dwindling opportunities for advancement as the power program contracts; some are already leaving the field for employment elsewhere. Added to this is the normal attrition in the workforce through retirement and career changes. Canadian universities and technical schools are not producing the next generation of professional and technical people in the numbers required to maintain the nuclear program in its present form. Once again, Canada is facing the prospect of importing this expertise, as it did in the early years of domestic nuclear development.

Temporarily masking this manpower situation is the recently completed management study by Cresap, a New York consulting firm, that concluded 10% of Ontario Hydro's employees were redundant, and should be retrained and redeployed within the utility. Hydro has instituted a hiring freeze while studies continue on improving productivity.

B. The Regulatory Regime and Nuclear Liability

Licensing the Canadian nuclear industry is the responsibility of the Atomic Energy Control Board (AECB), established in 1946 by the *Atomic Energy Control Act* and headquartered in Ottawa. The AECB licenses power reactors, research reactors, particle accelerators, uranium mine/mill facilities, uranium refining and fuel fabrication facilities, heavy water plants and radioactive waste management facilities. Two advisory groups – the Advisory Committee on Radiological Protection and the Advisory Committee on Nuclear Safety – assist the AECB in its work.

The AECB issues two types of licences: (1) prescribed substances licences, of which there were 47 in effect at 31 March 1988; and (2) radioisotope licences, of which there were 4,858 in effect. Prescribed substance licensing covers uranium, thorium and heavy water. Radioisotope licences are distributed by type of user as shown in Table 3. Ontario users hold the largest number of radioisotope licences (2,136), followed by Quebec (1,060), Alberta (589) and British Columbia (452). (Canada, AECB, 1988)

During fiscal year 1987-88, the AECB conducted 2,800 inspections of radioisotope users to verify compliance with *Atomic Energy Control Act* Regulations and licence conditions. Thus many licence holders are inspected less frequently than yearly. Devices such as smoke detectors are exempt from licensing because the quantity of radioactivity is very small and the detector is desgned to contain it safely.

The AECB is also responsible for administering the *Nuclear Liability Act* of 1970. The Board designates nuclear installations and, with the approval of Treasury Board, prescribes the amount of basic public liability insurance to be maintained by the operator of each facility. This coverage is intended to meet claims by the public in the event of a nuclear accident – it cannot be used to repair the operator's damaged facilities. The Nuclear Insurance Association of Canada (NIAC), a consortium of insurance companies licensed to do business in Canada, is the only approved commercial source from which the operator of a designated nuclear facility can obtain liability insurance.

Table 3: Radioisotope Licences in Effect in Canada by Type of User on 31 March 1988

Type of User	Number of Licences
Hospitals and other medical institutions	732
Universities and other educational institutions	328
Governments	557
Commercial	
Oil well logging	101
Radiography	190
Gauging	1,428
Static eliminators	775
Suppliers	209
Others	538
Total number of radioisotope licences	**4,858**

Source: Canada, AECB, *Annual Report 1987-88*, Ottawa, 1988, p. 6.

The cost to the operator of annual insurance premiums depends upon such factors as population density and land values in the vicinity of each facility. No accidents at Canada's power reactors have occurred which have had an adverse effect on the public and consequently no claims have been made against any of the three utilities operating power reactors. Table 4 indicates the basic insurance coverage for each designated nuclear installation in Canada.

In 1986, Ontario Hydro paid $1.733 million in premiums to provide the liability coverage for its power reactors. In 1987, the premiums totalled $1.7 million, reflecting the return of the Douglas Point reactor to AECL in October of 1986. The 1987 premiums were distributed as follows (Ontario Hydro, 1987a, p. 96):

Pickering A and B Generating Station –	$1,064,000
Bruce A and B Generating Stations –	$603,000
NPD Generating Station (recovered from AECL) –	$33,000

Table 4: Basic Liability Insurance Coverage on Canadian Nuclear Facilities, as of 31 March 1988

Installation	Basic Insurance
Bruce A Generating Station (4 units)	$75.0 million
Bruce B Generating Station (4 units)	$75.0 million
Gentilly 2 Nuclear Power Station (1 unit)	$75.0 million
NPD Generating Station (1 unit)	$23.4 million
Pickering A and B Generating Stations (8 units)	$75.0 million
Point Lepreau Generating Station (1 unit)	$75.0 million
University of Alberta SLOWPOKE Reactor	$0.5 million
Dalhousie University SLOWPOKE Reactor	$0.5 million
McMaster University Research Reactor	$1.5 million
École polytechnique SLOWPOKE Reactor	$0.5 million
Saskatchewan Research Council SLOWPOKE Reactor	$0.5 million
University of Toronto SLOWPOKE Reactor	$0.5 million
Eldorado Resources Limited Port Hope Refinery	$4.0 million
Zircatec Precision Industries Inc. Port Hope Fuel Fabrication Plant	$2.0 million

Note: In the case of power reactors, a nuclear facility is considered to include all of the reactors sharing a containment system. Thus Lepreau 1 is one facility, as are the eight reactors at Pickering which are all connected to one common containment system. Bruce consists of two facilities for the purposes of the Act since each set of four units shares a containment system.

Source: Canada, AECB, *Annual Report 1987-88*, Ottawa, 1988, p. 24.

NIAC does not provide all of the insurance coverage for nuclear facilities that is required under the Act and the federal government therefore maintains a Nuclear Liability Reinsurance Account, forming part of the Consolidated Revenue Fund. As of 31 March 1988, the supplementary insurance coverage provided by the Government of Canada under the *Nuclear Liability Act* is $641.6 million. This reinsurance extends the coverage on each nuclear facility to $75 million as required by the Act (thus a SLOWPOKE research reactor or a fuel fabrication plant is covered to the limit of $75 million by the federal reinsurance). The federal reinsurance coverage also includes risks which have been excluded by NIAC as the principal insurer. NIAC will not cover damages arising from normal operating emissions at nuclear facilities, and will not insure the difference between bodily injury and personal injury (which means that claims for mental or psychological injury are excluded from NIAC coverage). The Government of Canada assumes these risks through its supplementary coverage. (Personal communication: Bob Blackburn, AECB, 11 July 1988) There have been no claims to date against the Nuclear Liability Reinsurance Account.

In the event of a nuclear accident in which public liability claims are expected to exceed the prescribed limits, the *Nuclear Liability Act* specifies that a Nuclear Damage Claims Commission be established to settle all claims arising from the accident. If the settlements exceed the liability coverage, Parliament must authorize any additional payments. Under Canadian law, all liability claims are directed at the operator of the facility. Neither the public nor the operator may sue a supplier for liability arising from a nuclear accident (although an operator can sue a supplier on other grounds). The claimant must prove that damage or injury was caused by the nuclear accident at the operator's facility. This is not necessarily a straightforward matter, since radiation-induced cancers may not appear until 20 or 30 years after exposure (there is a 10-year time limit in the Act for applying for compensation) and it may be difficult or impossible to establish cause and effect.

In April 1987, Energy Probe launched a legal challenge to the *Nuclear Liability Act* in the Ontario Supreme Court, arguing that the Act violates certain provisions of the *Canadian Charter of Rights and Freedoms*. Specifically, Energy Probe claimed that the time allowed under the Act for an individual to bring an action is unreasonably short; that the Act limits the total amount of compensation available to individuals suffering personal injury or property damage; that the Act shields nuclear suppliers and designers of equipment and products from any liability caused by a nuclear accident for which they may be responsible due to neglect or willful wrongdoing; and the Act removes the threat of greater liability as an incentive for suppliers and operators to reduce the risk of occurrence of nuclear accidents. In September 1987, an Ontario Supreme Court judge ruled that the court action was premature and based on a hypothetical argument, and that Energy Probe lacked the status required to pursue the action. Energy Probe has in turn appealed the case to the Court of Appeal of the Supreme Court of Ontario, where the matter awaits resolution. (Ontario Hydro, 1987a)

The Committee also has concerns about the provision of nuclear liability insurance in Canada, and has concluded that the current coverage is inadequate. In view of the claims arising from the Three Mile Island reactor accident (for which the Committee has been advised that liability claims now exceed $US 1 billion) and the Chernobyl accident (for which reports suggest damages approaching $US 3 billion), a maximum liability in Canada of $75 million does not accord with experience in dealing with such events. West Germany, which has never had a serious accident in its nuclear power program, has a limit on operator (utility) liability approximately ten times that of Canada. In the United States, a shared total liability carried by the operators of all American power reactors under the *Price-Anderson Act* will be raised to about $US 7 billion, once Congress renews the Act (which expired in August 1987). Each reactor operator will be liable for an amount of up to $US 60-63 million per reactor, to be paid in annual post-accident installments of $US 10-12 million into a compensation fund following an accident causing public harm (the amounts depending on the version of the bill adopted). Private insurance covers the first $US 160 million of public liability.

The Committee is not prepared to recommend what the increased level of Canadian public liability should be for operators of designated nuclear facilities, beyond observing that current limits are inadequate. The Committee was advised that an Interdepartmental Working Group has completed a review of the *Nuclear Liability Act*, including the adequacy of the prescribed insurance levels, and will be reporting its findings soon to the President of the AECB. The Committee hopes that the result of this review will be a greater degree of financial protection for the public, in the unlikely event of a serious accident at a Canadian facility.

Among its other responsibilities, the Atomic Energy Control Board ensures that Canada adheres to international protocols on nuclear safeguards. Canada is a signatory of the *Treaty on the Non-Proliferation of Nuclear Weapons* (usually referred to as the Non-Proliferation Treaty or NPT) and as such is a party to a safeguards agreement with the International Atomic Energy Agency. AECB, jointly with AECL, administers the Canadian Safeguards Support Program which assists the IAEA in improving safeguards approaches and techniques. Recent work under this Program has concentrated on improving the reliability of safeguards equipment installed at the four CANDU 600 reactors and completing the development of other safeguards equipment for these reactors. (Canada, AECB, 1988)

The Committee is disturbed, however, by reports from various quarters that the Atomic Energy Control Board lacks the financial and manpower resources to discharge its responsibilities fully. The AECB, appearing before this Committee in regard to its 1988-89 Main Estimates, stated that it needs a 50% larger budget if it is to fully carry out its present set of responsibilities. [About five years would be required for the AECB to absorb an increase in funding and related staffing of this size.] The AECB has fallen behind on its nuclear safeguard commitments to the IAEA because it lacks the resources to institute the programs and install the monitoring equipment which Canada has agreed to (a problem compounded by the recent funding cuts to AECL which administers this program jointly with AECB). The AECB has been unable to perform the independent R&D which it considered appropriate in regard to the metallurgical problems encountered in the pressure tubes of certain CANDU reactors.

The Committee has also learned that staff shortages at the Board are causing licensing and other delays. AECL has requested that the AECB study the generic licensing of the CANDU 300 reactor system, an important marketing consideration for AECL. AECB has a large amount of work to do for the Darlington start-up, however, and a "paper reactor" study does not have the same priority so the CANDU 300 licensing study has not begun. In another example, the University of Sherbrooke will be applying to the AECB to build a SLOWPOKE reactor. This application will also face delay because the Board's work on power reactor applications takes precedence.

The Committee concludes that this shortage in resources at the AECB is intolerable in view of the importance of its regulatory function. The Committee believes that there are two steps to be taken to rectify this situation. First, the implementing legislation for the AECB should be altered to allow the Board to recover part of the costs of its licensing activities. [Although the Committee would prefer to see the AECB recover the greatest share possible of its costs through cost-recovery mechanisms, it does not believe that any useful purpose is served by arbitrarily stating that the Board must achieve full cost recovery.] If partial cost recovery alone does not provide sufficient additional funds, then the Parliamentary appropriation for the Board should be increased such that the AECB can fully discharge all of its responsibilities.

The Committee agrees with the view that both AECL and the nuclear industry have in the past not done a particularly effective job of educating the public about nuclear power. The advertisements and information kit recently produced by the Canadian Nuclear Association are a step in this direction, but the Committee believes that much more remains to be done if the public is to become well informed about Canada's nuclear power program. The Committee sees a role for the AECB to play in an objective public education program and recommends that such a function be established at the Atomic Energy Control Board.

C. The Radionuclide Business

The use of radioactive materials in medical applications dates back to the late 19th century. Wilhelm Roentgen discovered X–rays in 1895 and Henri Becquerel detected radioactivity in a sample of pitchblende in 1896. Pierre and Marie Curie achieved the chemical separation of radium from pitchblende, and for the first time a concentrated source of radioactivity became available.

Radiotherapy began in the closing years of the 1890s, when it was realized that radiation had biological effects. Superficial cancers were treated with radium before the turn of the century, but ignorance of the dangers of radiation led to the overexposure of both patients and practitioners during diagnostic and therapeutic work.

Scientists soon learned that there were at least three different types of radiation released by radioactive elements. These were called alpha, beta and gamma rays, corresponding to the first three letters in the Greek alphabet. Alpha radiation is the least penetrating, beta radiation is somewhat more penetrating, while gamma radiation is highly penetrating and requires the greatest amount of shielding for protection.

It was recognized that radiotherapy required the application of carefully controlled doses of radiation and, with the development of the X–ray tube in the 1920s, it became possible to design machines that possessed the required degree of flexibility and control. World War II development of microwave technology and high-power radiofrequency generators led to the successful operation of microwave linear accelerators and their application to medical and industrial uses.

In Canada, a Commercial Products group was formed in 1946 within Eldorado Mining and Refining Ltd. to sell radium as a by-product of Eldorado's uranium business. Radium is very limited in supply, however, and it quickly became apparent that new products would be required for the burgeoning radiotherapy business. In 1947, the NRX research reactor was completed at Chalk River. This reactor, with its high neutron flux, allowed the production of a variety of radionuclides at activity levels higher than available elsewhere. In particular, the production of cobalt–60 provided the Commercial Products group with the new product required to replace radium. In 1949, Commercial Products began marketing radioisotopes produced by the NRX reactor. When Atomic Energy of Canada Limited was formed in 1952, Commercial Products was transferred from Eldorado to AECL.

In 1951, the group produced the first commercial unit to house cobalt–60 for cancer therapy. AECL has continued to develop its line of cobalt–60 machines, most recently adding the Theratron–C therapy unit. The company has introduced a fully integrated and computerized radiotherapy planning system (marketed as THERAPLAN) and a three-dimensional dosimetry unit for radiation beam analysis (marketed as THERASCAN). Today, there are more than 3,000 units in use for cancer treatment around the world. AECL Medical has designed and built the majority of these machines, as the world's largest manufacturer of cobalt–60 radiotherapy machines. As of May 1988, AECL Medical had installed 1,675 cobalt–60 units. These units had treated approximately 9.2 million patients and had added an estimated 13.8 million years of life to the 50% of the patients for whom treatment was deemed successful (adding an average of three years to the survival of these patients).

Canada is the world's largest supplier of cobalt–60, providing about 80% of this man-made radioisotope. Cobalt–60 is produced by irradiating natural cobalt–59 in a reactor and Ontario Hydro is AECL's principal supplier. The cobalt is sealed in zircaloy tubes which are vertically suspended in the CANDU reactors. The cobalt is irradiated for about one year during normal reactor operation and removed from the reactor during planned maintenance outages. Ontario Hydro then ships the cobalt to the Radiochemical Company.

Most cobalt–60 is used in the treatment of cancer but Ontario Hydro estimates that about 5% of the current market for this radionuclide is represented by food irradiation. Food irradiation is not done commercially in either Canada or the United States at this time but the technology is being applied in China, Japan and some European countries. Among its uses in this field are the elimination of salmonella in poultry and seafoods, the inhibition of fruit ripening and the elimination of the parasite *Trichinella spiralis* in pork. (Ontario Hydro, 1987a)

The need for self-contained irradiation units to conduct experimental work on the effects of gamma radiation on various materials was recognized more than 30 years ago. A prototype gamma irradiation cell – the Gammacell 220 – was exhibited in New York in 1956 and was the precursor of both research irradiators and gamma irradiation processing on an industrial scale. As of early 1986, there were 132 industrial gamma irradiators operating in 39 countries. By far the largest supplier of these units was AECL Radiochemical Company, with 71 units installed in 29 countries. The closest competitors were the Soviet Union with 11 in domestic use, Marsh of England with nine units (four operating in the United Kingdom and five abroad), Commissariat à l'Énergie Atomique (CEA) of France with five units (three domestic and two abroad), and Radiation Sterilizers of the United States with five units in domestic service. (Canada, AECL, RCC, 1986)

Another area of application of irradiation is in radiation processing, which refers to the use of ionizing radiation from electron beam and gamma ray sources to initiate chemical changes in polymeric material or to destroy harmful microorganisms. The three main applications of radiation processing are:

1. sterilization of medical goods and preservation of food products;
2. treatment of polymers; and
3. curing of surface coatings.

There has been an enormous increase in the use of radiation to sterilize medical disposable goods since 1960. Gamma irradiation is preferred for thicker materials, where deep penetration is required, and electron beam equipment is preferred where the product is relatively thin. Food irradiation to inhibit sprouting, kill insects or enhance preservation is a controversial but promising application with a huge potential. Similarly, the treatment of wastewater and sludges by irradiation to kill pathogens is another potentially large area of application.

Polyethylene, polyvinylchloride, polyester and fluoropolymers are some of the plastics which can be used in irradiated products. Most natural and synthetic rubbers can be vulcanized by radiation. Radiation curable coatings – inks, adhesives, fillers and top coats – are finding progressively wider use in manufacturing.

The road to the present for AECL's Radiochemical Company was not uneventful. In the 1960s, a new technology – the linear accelerator or "linac" as it is sometimes termed – began to challenge cobalt–60 as the preferred means of treating cancers. By 1972, RCC had concluded that it needed to develop accelerators if it was to remain in the forefront of radiotherapy. Using profits from other parts of its operations, RCC worked on an advanced linear accelerator which it named the Therac 25 (T–25). The T–25 was supposed to become the new standard in linacs, being smaller, more powerful and less expensive than other accelerators on the market. Unfortunately, T–25 turned out to be a financial drain, drawing in profits from other operations as the design proved to be much more difficult than expected to perfect. The cost of the T–25 rose to a million dollars a unit, which meant that it could only reach a limited market. As one observer described the situation, "The T–25 was a technological marvel and an economic nightmare."

In the early 1980s, the Radiochemical Company reached a crisis. The solution embarked upon was to create a new division, AECL Medical Products, which contained the money-losing accelerator work, cobalt therapy, medical simulators, treatment planning and manufacturing. RCC would remain the home of the profitable radioisotope business. AECL would withdraw from accelerator development. The Medical Products division came into existence in January 1985 and was in effect given one year to prosper. In a remarkable combined effort by the AECL board, management, union leaders, professionals and unorganized employees, AECL Medical did just that, although at the cost of trimming half of its former staff.

AECL Medical established the feasibility of a simple and inexpensive yet high-quality cobalt therapy unit for use in developing countries and in rural hospitals. Named the Phoenix to symbolize the hoped-for revival, a prototype was produced in just eight weeks. Another group of employees streamlined the existing cobalt therapy business, cutting costs and improving service. Excess capacity in AECL Medical's manufacturing capability began to be contracted out. As its advertising brochure states: "The Medical Division of Atomic Energy of Canada Limited is proud to offer a complete range of modern manufacturing facilities for your products or components through sub-contracting."

The result was a turnaround in the division's fortunes. After cutting its personnel from 486 at the beginning of 1985 to 244 fourteen months later, AECL Medical was working overtime by early 1986. A year later, the division had shown six consecutive months of profits and was rehiring some of its former employees.

Today, both the Radiochemical Company and AECL Medical are slated for privatization. RCC is to be sold to outside interests, with the proceeds of the sale accruing to the federal government. AECL Medical will be first offered for sale to its own managers and employees. Failing this, it will also be sold to outside interests.

While the Committee applauds the initiative that both of these divisions have shown in achieving their profitable positions, it is concerned that selling profitable elements of AECL will erode the financial position of the remaining components of the Corporation. How will the basic and applied research that AECL performs in the national interest be sustained if federal funding is reduced at the same time that profitable parts of the company are being sold off? The Committee is also concerned that enterprises developed in part at taxpayer expense and involving world-leading technology might be bought up by foreign interests.

The Committee recommends that the federal government enable AECL to hold an interest in private companies. If AECL were to retain a minority interest in a privatized Radiochemical Company and in an employee-owned Medical Products Division, it could continue to receive some financial benefits from the radionuclide business that it had built up over 35 years. Customers would know that the parent company continues to have a direct interest in the success of the privatized RCC and AECL Medical. AECL's reputation in the international radionuclide business is held in high regard. At the same time, the RCC and AECL Medical could operate as private entities to joint venture, make acquisitions and move quickly on business opportunities which as part of a crown entity they cannot do. The Committee also recommends an explicit prohibition on foreign control of the RCC and AECL Medical, such as is embodied in frontier petroleum development. The Committee is not opposed to foreign interests holding a minority share in these privatized companies, but does not want to see the controlling interest leave Canada.

The radionuclide business is very much an international activity, one which AECL has carried on in more than 100 countries. From its base in Canada and five regional offices in the United States, the company is considering expanding its operations to a regional office in Europe, and thereafter into selected parts of the developing world. As such, AECL needs much more flexibility in its decision-making and financing than is currently the case. The Committee sees the virtue in privatizing these operations, but believes that these advantages can still be enjoyed while allowing AECL a residual role in the new entities.

Table 5 lists the principal radionuclides that have been applied by AECL to medical and industrial uses.

The medical applications of radioactivity have become very broad in recent years, and the use of industrial radioisotopes has also shown strong growth. In new albeit controversial areas of application, there are major opportunities open to AECL or its offspring. Food irradiation is an application of radioisotope technology which has generated recent debate, although it is clear that new approaches are needed to reduce food losses in storage, especially in the developing countries. Ionizing radiation passing through food leaves no residual radioactivity but does produce chemical changes. A 1986 report by the Advisory Committee on Irradiated and Novel Foods in the United Kingdom concluded that "there are no toxicologically significant qualitative differences between the radiolytic products in irradiated foods and the products in conventionally-processed foods, and that the chemical changes produced by irradiation of food are usually less than the changes found in foods processed by conventional methods whose safety is accepted" (Canada, Science Council, 1987, p. 9). Irradiation does alter the taste and texture of some foods and is not suitable for processing all food products. As is the case with other forms of food processing, irradiation does cause some nutritional loss.

Less well known is the application of radioactivity to the treatment of wastewater and sewage sludge, to counteract the pathogens which make them hazardous to humans. The Committee hopes that Canada will play an important role in these beneficial applications of radioactivity as it has in radiotherapy.

Table 5: Radionuclide Production and Use

Radionuclide	Half-Life	Type of Radiation	Principal Uses	Origin
Cobalt–60	5.3 years	Gamma	Sterilization Food irradiation Waste treatment Industrial radiography Gauging devices	Power and research reactors
Molybdenum–99	66 hours	Gamma	Raw material for the Technetium–99 (half-life 6 hours) generator; used in brain, bone, lung and kidney scans	Research reactors
Iridium–192	72 days	Gamma	Industrial radiography Pipeline weld inspection	Research reactors
Xenon–133	5 days	Gamma	Lung scanning	Research reactors
Iodine–131	8 days	Gamma	Thyroid imaging and therapy	Research reactors
Iodine–125	60 days	Gamma	Clinical laboratory test procedures Radioimmunoassay	Research reactors
Carbon–14	5,500 years	Beta	Synthesis of radioactive organic compounds for biochemical, biological and chemical research	Research reactors
Thallium–201	73 hours	Gamma	Cardiac imaging	Cyclotron
Gallium–67	78 hours	Gamma	Soft tissue tumor and abscess detection	Cyclotron
Iodine–123	13 hours	Gamma	Thyroid imaging Experimental nuclear medicine Brain and heart studies	Cyclotron

Source: Information sheet provided by AECL Radiochemical Company.

D. Spin-off Technologies

The Committee was not able to conduct a comprehensive review of new technologies which have been an outgrowth of Canada's nuclear power program. Members were able, however, to see selected examples of spin-off technologies and gain an appreciation of how the quality assurance standards developed by nuclear suppliers have benefitted Canadian manufacturing more generally. Several of these technologies and applications are briefly described in this section.

In its visits to Chalk River Nuclear Laboratories (CRNL), to AECL's Ottawa facilities, to CANDU Operations in Mississauga and to selected private sector companies in Ontario, the Committee was impressed with the less visible but nonetheless valuable offshoots of the domestic nuclear program. These activities, many of which are non-nuclear in character and application, are also at risk if the nuclear power program were to be phased out.

The SLOWPOKE Energy System is a heat generation and distribution system based on the SLOWPOKE thermal reactor. The original SLOWPOKE was developed in 1968-69 at Chalk River as a 20 thermal kilowatt pool-type reactor. The prototype began operation in 1970 and an additional eight units have subsequently been put into service. These SLOWPOKE research reactors are located at the University of Toronto, École polytechnique, Dalhousie University, the University of Alberta, the Saskatchewan Research Council, the University of the West Indies in Jamaica, the Royal Military College in Kingston, and the Radiochemical Company in Kanata. All of these reactors are licensed to operate unattended for periods up to 24 hours, although they are remotely monitored. Seven of the SLOWPOKEs operate on a highly enriched (93% U–235) fuel; the eighth and most recent uses a 20% U–235 fuel. All future SLOWPOKE research reactors will be fuelled with the less enriched uranium. (Lynch *et al*, 1986)

In temperate countries, more than 25% of primary energy consumption is in heating buildings. AECL has developed the SLOWPOKE Energy System for use in a district heating application, based on a 10 MWt heat source. The larger SLOWPOKE has the same main technical features as the smaller research reactor: it operates at atmospheric pressure without the need for a pressure vessel; heat transport occurs by natural convective cooling without the need for pumps; the reactor core is surrounded by a beryllium reflector to conserve neutrons; the reactor is remotely monitored and does not require an on-site operator; and the design is intended to be inherently safe. Inherent safety means that radiological protection is provided by the intrinsic characteristics of the reactor and does not depend upon engineered safety systems or operator intervention. The reactor has a negative reactivity coefficient, limiting power transients if reactor regulation is lost. A double containment system – made up of a steel liner and a surrounding concrete vault – prevents loss-of-coolant accidents. An air gap between the two containers is monitored for coolant leaks. The top of the reactor is enclosed by a steel cover plate to contain any radioactive gases escaping from the pool. The SLOWPOKE Energy System will run on a 4.9% U–235 enriched uranium, contained in 16 fuel bundles. Assuming a 50% annual load factor, the fuel will need to be replaced every six years. (Lynch *et al*, 1986)

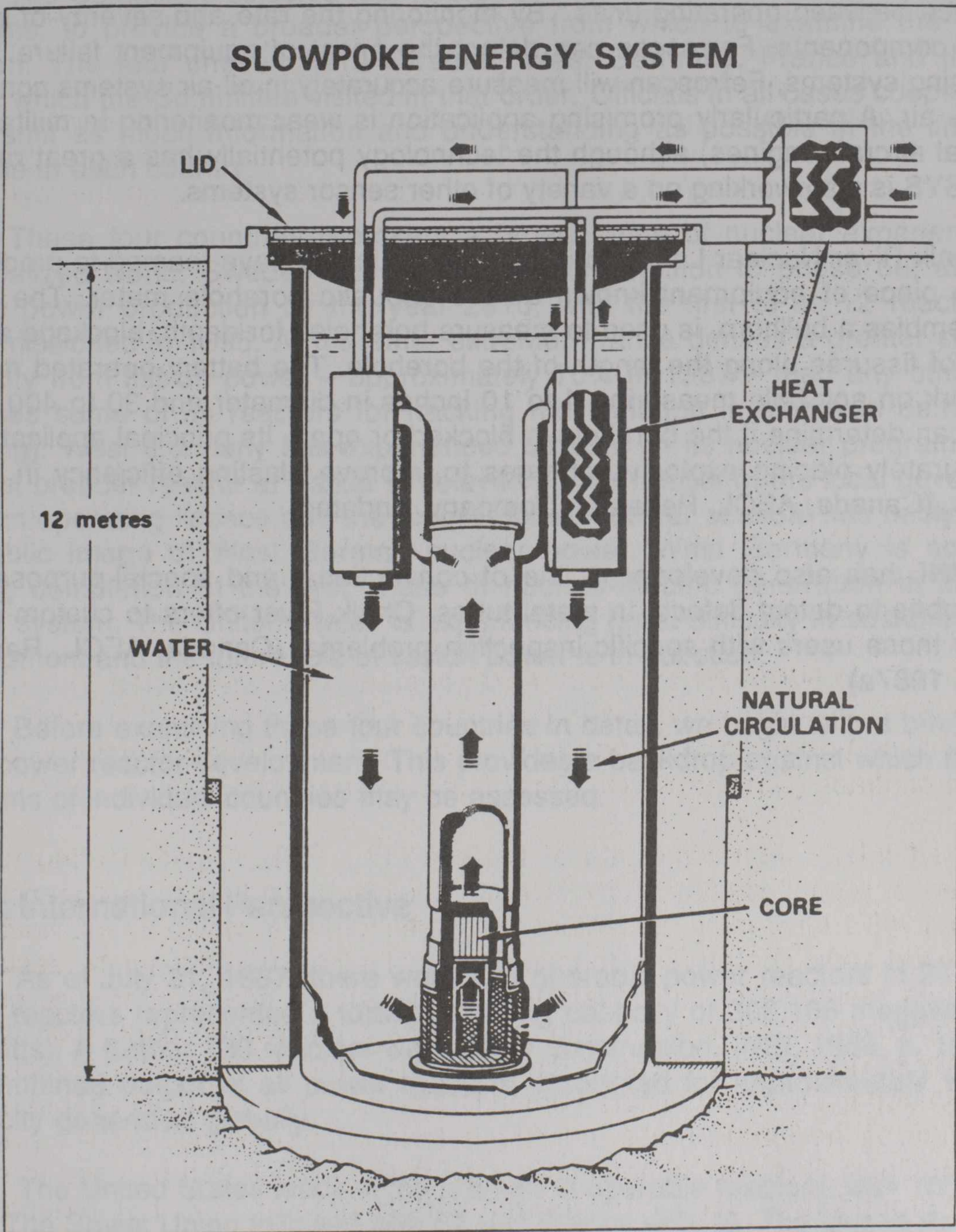
A 2 MWt demonstration unit has been constructed at Whiteshell Nuclear Research Establishment (WNRE) and will be operated to validate the design. The SLOWPOKE Energy System is claimed to be economically competitive with conventional heating in most regions of Canada. AECL calculates that heat can be supplied at a cost as low as 1.2 cents/kWh; a 10 MWt unit operating at a 40% load factor would supply heat at approximately 2 cents/kWh. This is said to be competitive with oil-fired systems with oil prices as low as $C 15 per barrel. The simplicity of the design with its elimination of pressurized systems and the short construction time (estimated at about one year) are the primary factors contributing to the low capital cost. (Lynch, 1987)

The SLOWPOKE Energy System is being developed in the Local Energy Systems Business Unit of AECL's Research Company at CRNL. Joint feasiblity studies between AECL and South Korea, China and Hungary have been started; Turkey, Romania and Yugoslavia have expressed interest in the concept.

The Research Company has developed high-performance and high-reliability pump seal technology which is now finding application in the U.S. space program. Failure of twin O-ring seals on the solid rocket boosters which lift the shuttle into space has been cited as the cause of the Challenger accident in 1986. The O-rings, made of synthetic rubber, are intended to prevent the escape of hot rocket gases through joints between the segments of the rocket boosters. Morton Thiokol Inc. of the United States, prime contractor to NASA for the solid rocket boosters, has contracted with AECL to draw upon the Company's expertise in fluid sealing technology. AECL's ability to field a multi-disciplinary team to work on the problem was an important factor in CRNL's winning the contract. (Canada, AECL, Research Company, 1987b)

A particularly interesting line of research at CRNL is investigating the link between cancer proneness and faulty DNA metabolism. Most human malignancies are believed to involve environmental factors in part, factors over which an individual may be able to exert some control. The concept of "equal exposure – equal risk" assumes a homogeneous response of individuals to cancer-causing agents. There is growing evidence, however, that there are subgroups within the human population with an abnormal sensitivity to specific carcinogenic agents. The varying ability of individuals to repair damage to DNA and restore normal DNA structure and function appears to be a determinant of the risk to those individuals from different cancer-causing agents. Scientists at Chalk River are attempting to devise tests which can be used to screen population groups and identify those who are at greater risk. For example, an individual abnormally sensitive to the effects of radiation should not be employed in an environment where he or she would be exposed to elevated levels of radioactivity. Similarly, an individual prone to develop cancer from overexposure to sunlight should avoid certain outdoor occupations. Such knowledge could be used to develop better strategies for the protection of human health, especially against occupational health hazards. (Gentner and Morrison, 1987)

Figure 8: The SLOWPOKE Energy System



Source: Lynch, G.F., *SLOWPOKE Energy System: Nuclear Technology in Local Energy Supply*, Local Energy Systems Business Unit, Whiteshell Nuclear Research Establishment, Atomic Energy of Canada Limited, Pinawa, Manitoba, February 1988, p. 5.

The SENSYS Business Unit of AECL, located in Nepean, Ontario, has developed an intelligent sensor system called Ferroscan. This real-time on-line sensor monitors the accumulation of iron wear debris in lubricating oil systems. Connected in groups and using appropriate software, Ferroscan sensors allow the user "to map equipment condition trends, plan for accurate maintenance schedules, and compare performance between operating units." By monitoring the rate and severity of wear in oil-wetted components, Ferroscan can detect the onset of equipment failure. Unlike other sensing systems, Ferroscan will measure accurately in oil-air systems containing up to 90% air. A particularly promising application is wear monitoring in military and commercial aircraft engines, although the technology potentially has a great range of use. SENSYS is also working on a variety of other sensor systems.

Chalk River Nuclear Laboratories and Inco Limited have teamed to produce an innovative piece of equipment known as the acoustic borehole meter. The meter, which resembles a bullhorn, is used to measure boreholes for depth, blockage and the presence of fissures along the length of the borehole. The battery-operated meter is said to work on any hole measuring 4 to 10 inches in diameter and 30 to 400 feet in length. It can determine if the borehole is blocked or open. Its principal application will be in accurately placing explosive charges to improve blasting efficiency in mining operations. (Canada, AECL, Research Company, undated)

CRNL has also developed a line of conventional and special-purpose eddy current probes to detect defects in metal tubes. Chalk River offers to custom design probes for those users with specific inspection problems. (Canada, AECL, Research Company, 1987a)

World Nuclear Power Development

The Committee selected four foreign countries for review of their nuclear power programs, to provide a broader perspective from which to examine the Canadian situation. The four chosen were Sweden, West Germany, France and the United States, which the Committee visited in that order. Officials in all cases cooperated fully to transmit as much information and understanding as possible in the limited time available in each country.

These four countries represent a broad range of nuclear experience in the industrialized world. Sweden has announced its intention to phase out all nuclear-electric power production by the year 2010, with the first of its 12 reactors to be decommissioned in 1995. At the other extreme, France derives a greater share of its electricity from fission power – approximately 70% in 1987 – than any other country and uses some of its reactors for tracking the variation in electrical demand (load following). West Germany has experienced difficulty in its nuclear program. The 300 MW fast breeder reactor at Kalkar is delayed by the refusal of the local government to issue an operating licence and the recent Hanau nuclear scandal has badly damaged the public image of West German nuclear power. West Germany is nonetheless nearing completion of the first phase of nuclear-electric generation in its national energy system. The United States is experiencing great difficulty in sustaining nuclear development and the future role of fission power is in question.

Before examining these four countries in detail, we begin with a brief review of world power reactor development. This provides a backdrop against which the nuclear programs of individual countries may be assessed.

A. An International Perspective

As of July 31, 1987, there were 418 operable power reactors in 26 countries. These reactors represented a total generating capacity of 308,166 megawatts (308.2 gigawatts). A further 130 reactors were under construction. (NEI, 1988, p. 10) In 1986, the combined output of all power reactors accounted for approximately 16% of the electricity generated globally.

The United States leads in the number of operable reactors, with 109 as of July 1987. The Soviet Union followed with 57 and France with 49. The United Kingdom was fourth with 38 operating reactors, Japan fifth with 37, West Germany sixth with 21, Canada seventh with 19 and Sweden eighth with 12. Table 6 lists the 26 countries with operable power reactors as of end-July 1987. The table also includes power reactors under construction, indicating that a further five countries will soon join the current group of nuclear-electric power producers.

Table 6: World Power Reactors in Operation or under Construction at July 31, 1987

Country	Operable Reactors Units	Operable Reactors MWe	Reactors under Construction Units	Reactors under Construction MWe
Argentina	2	1,005	1	745
Belgium	8	5,740	0	0
Brazil	1	657	2	2,618
Bulgaria	4	1,760	4	4,000
Canada	19	12,553	4	3,740
China	0	0	3	2,172
Cuba	0	0	2	880
Czechoslovakia	7	3,002	9	6,216
East Germany	5	1,835	6	2,640
Finland	4	2,400	0	0
France	49	46,693	14	18,477
Hungary	3	1,320	1	440
India	7	1,243	6	1,410
Italy	3	1,312	3	2,058
Japan	37	28,146	11	10,068
Mexico	0	0	2	1,350
Netherlands	2	540	0	0
Pakistan	1	137	0	0
Poland	0	0	2	930
Romania	0	0	5	3,395
South Africa	2	1,930	0	0
South Korea	7	5,816	2	1,900
Spain	8	5,810	2	2,022
Sweden	12	10,030	0	0
Switzerland	5	3,065	0	0
Taiwan	6	5,144	0	0
United Kingdom	38	12,796	5	3,822
United States	109	100,323	13	15,809
U.S.S.R.	57	34,334	29	29,620
West Germany	21	19,911	4	4,325
Yugoslavia	1	664	0	0
World Totals	**418**	**308,166**	**130**	**118,637**

Source: Nuclear Engineering International, "Reactor Statistics", *World Nuclear Industry Handbook 1988*, Reed Business Publishing, Sutton, England, 1988, p. 10.

Within the OECD, the proportion of nuclear-electric generation is higher than the 16% global average, amounting to almost 22% of all electricity produced during 1986. This average, however, conceals a wide range in nuclear-electric generating capacity: France produced 69.8% of its electricity at nuclear plants in 1986 while Turkey produced none. Belgium ranked second, generating 67.0% of its electricity from eight reactors; Sweden was third at 50.3%; and Switzerland was fourth at 39.2%. Canada, by comparison, produced 15.1% of its electricity in 1986 from nuclear stations and the United States 16.6%. Within Canada, nuclear power accounted for 46%, 43% and 3% of the electricity generated in 1986 in Ontario, New Brunswick and Quebec, respectively.

Japan is noteworthy for its long-term, highly-organized commitment to nuclear power. Given Japan's dependence on imported energy, this is not surprising from a strategic point of view: in 1985, Japan depended on imports for 80.5% of its total primary energy supply and 99.7% of its oil supply. At the time of the Arab oil embargo, 77.6% of the primary energy supply consisted of imported oil; only 0.6% was nuclear-electricity. In 1986, imported oil was down to 56.8% of primary energy supply and nuclear-electricity had increased to 9.5%. (Japan Industrial Location Center, 1988)

In July 1987, there were 37 operable Japanese power reactors representing 28,146 MW of installed capacity. Eleven units totalling 10,068 MW were under construction. In 1986, 24.7% of Japan's electricity came from nuclear units. (NEI, 1988) The nuclear development program calls for 53,000 MW of installed nuclear capacity in 2000 and 100,000 MW in 2030. The share which nuclear-electricity will claim of Japan's total electricity supply is projected to rise to 40% in 2000 and 60% in 2030. Fast breeder reactors will form the mainstream of Japanese nuclear development in the next century, allowing nuclear power to be established as a "quasi-domestic" energy source. (Japan, AEC, 1987)

Japan's rationale for exploiting atomic energy is evident in the following quotation from a report by the Japanese Atomic Energy Commission.

> Nuclear energy has huge potential, and its first practical use began in the field of power generation. Nuclear power generation has many outstanding advantages, such as the capability of generation of huge amounts of energy from a small amount of fuel, a low and stable generation cost, and a characteristic feature in the storage of the fuel, which allows the flexibility to cope with interruptions in the supply of fuel. Nowadays, nuclear power generation, together with oil and natural gas, is playing a principal role as an alternative energy to petroleum. The promotion of nuclear power generation in industrialized countries reduces the demand for petroleum, and contributes to easing the worldwide energy supply and demand situation.
>
> Such global scale environmental problems as acid rain, and the greenhouse effect accompanying the increasing concentration of carbon dioxide in the atmosphere, have caused serious concern in recent years, but on the other hand, nuclear power generation has less effect on the environment, and has the outstanding advantage of reducing the total release of pollutants into the atmosphere.

> Moreover, the promotion of nuclear power generation is also very important in releasing the limited and valuable fossil energy resources for use in other applications with higher added value. (Japan, AEC, 1987, p. 12)

Most Eastern European countries have also developed nuclear power programs. Bulgaria's four reactors in 1986 provided 30% of its electricity supply, Czechoslovakia's seven reactors produced 21%, Hungary's three reactors generated 18%, and East Germany's five reactors 12%. Soviet power reactors accounted for 11% of the electric power supply in the U.S.S.R. in 1986.

In the developing world, six countries were operating 24 commercial power reactors at the end of July, 1987. These were South Korea, Taiwan, Argentina, India, Pakistan and Brazil. Both Taiwan (with six reactors) and South Korea (seven reactors) derived approximately 44% of their 1986 electricity supply from fission power.

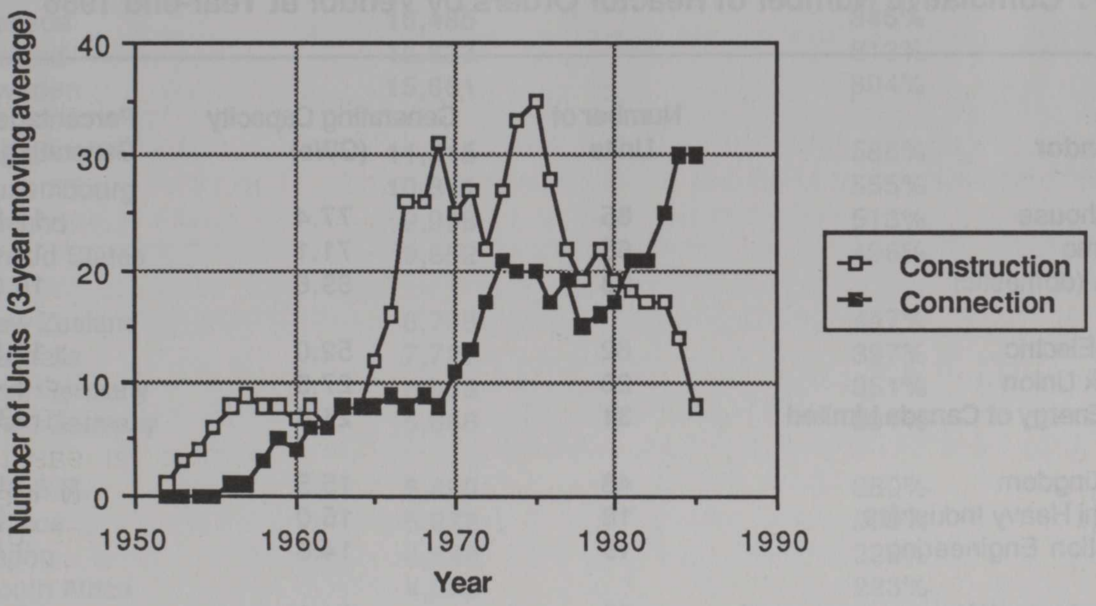
It is difficult to project world nuclear development beyond those reactor units already under construction. Forecasts of additions to generating capacity made in the 1960s and early 1970s were substantially reduced when it became apparent that the lower rate of growth in global energy demand following the 1973-74 and 1979-80 "oil crises" was not a passing phenomenon. What is apparent is that over at least the next 15 years the expansion in nuclear-electric power generation will slow markedly. Nuclear Engineering International provides the following projections of world nuclear-electric generating capacity in its most recent *Handbook* (1988, p. 11).

1985: 251.4 GWe (actual)	1990: 375.7 GWe
1995: 435.7 GWe	2000: 448.5 GWe

Slower growth in nuclear generating capacity over the remainder of the century reflects the downturn in the mid-1970s in reactor construction starts worldwide, given the time lag between start of construction and connection to the grid. Construction starts peaked in 1975, with work begun on 40 units that year. In 1986, construction was begun on only one unit. This is not an encouraging picture for those in the business of marketing power reactor systems. The reactor vendors with whom the Committee held discussions are rationalizing their operations and planning how they will survive the coming years of infrequent new orders. These vendors also expect that the early part of the next century will see a new surge in reactor construction, due to the declining availability of conventional light crude oil and growing environmental problems associated with the combustion of fossil fuels.

Figure 9 presents two sets of data: reactor construction starts and reactor connections to the grid. Both data sets are plotted as a three-year moving average because of the variability in the numbers on a year-to-year basis. Construction starts peaked in 1975; grid connections peaked in 1984-85, suggesting an average 10-year lag before units enter commercial service.

Figure 9: World Annual Reactor Construction Starts and Grid Connections, 1952-1985 (3-year moving average)



Note: Because of variability in the data, the graph has been plotted as a three-year moving average. The purpose of this illustration is to show the trends in reactor construction starts and grid connections, rather than the annual values.

Source: Modified from: Canada, AECL, *Nuclear Sector Focus*, Corporate Public Affairs, Ottawa, September 1987, p. D-17.

Another feature of global development is the swing in reactor construction away from the Western industrialized nations towards the Communist bloc and the Third World. Whereas the developing and Communist countries accounted for 15.9% of world nuclear generating capacity in 1985, they are projected to account for 27.9% in the year 2000 (Canada, AECL, 1987, p. D-10; NEI, 1988, p. 11). India, Brazil, Bulgaria, Czechoslovakia and the Soviet Union are forecast to have from two to five times as much nuclear capacity in their generating systems at the turn of the century as they had in 1987 (NEI, 1988, p. 11).

Through 1986, Westinghouse had been the most successful reactor vendor outside of the Communist bloc, with 85 orders for its PWR reactors, representing 15.2% of the world total of 558 reactor orders (net of any cancellations). Framatome was second with 65 orders (11.6%) and General Electric third with 62 orders (11.1%). AECL's 31 reactor orders (5.6%) exceeded Kraftwerk Union's 26 orders (4.7%), but the KWU units represented a larger total generating capacity. The U.S.S.R. had ordered

93 reactors domestically, for 16.7% of the global total, and had export orders for 29 units (5.2%). Table 7 provides more detail on the cumulative total of reactor orders by vendor, net of any cancellations. Vendors are ranked in Table 7 by the generating capacity represented by their orders, not by the number of units ordered.

Table 7: Cumulative Number of Reactor Orders by Vendor at Year-end 1986

Vendor	Number of Units	Generating Capacity (GWe)	Percentage of Total Generating Capacity
Westinghouse	85	77.4	17.8%
Framatome	65	71.1	16.4%
U.S.S.R. (domestic)	93	69.6	16.0%
General Electric	62	52.0	12.0%
Kraftwerk Union	26	27.8	6.4%
Atomic Energy of Canada Limited	**31**	**21.4**	**4.9%**
United Kingdom	43	15.5	3.6%
Mitsubishi Heavy Industries	18	15.0	3.5%
Combustion Engineering	15	14.8	3.4%
U.S.S.R. (export/Atomenergoexport)	29	14.6	3.4%
Babcock & Wilcox	11	10.5	2.4%
Toshiba	10	9.0	2.1%
Skoda	15	8.7	2.0%
ASEA-ATOM	11	8.7	2.0%
Hitachi	6	5.4	1.2%
Dept. of Atomic Energy, India	10	2.3	0.5%
Ansaldo	3	2.0	0.5%
Miscellaneous	25	8.6	2.0%
Totals	**558**	**434.4**	**100.0%**

Source: Nuclear Engineering International, "Reactor Statistics", *World Nuclear Industry Handbook 1988*, Reed Business Publishing, Sutton, England, 1988, p. 15.

The range in demand for electricity worldwide is revealed in statistics of per capita consumption. Table 8 presents per capita use of electricity in 23 selected countries in 1985. It is noteworthy that the top four nations are northern-latitude countries and that two of the four – Canada and Sweden – have well-developed nuclear power programs.

Table 8: The Per Capita Consumption of Electricity in Selected Nations in 1985

Country	kWh/Person	% of World Average Consumption
Norway	21,950	1,127%
Canada	16,485	846%
Iceland	15,833	813%
Sweden	15,661	804%
Qatar	11,415	586%
Luxembourg	10,811	555%
Finland	9,998	513%
United States	9,652	496%
New Zealand	8,708	447%
Australia	7,727	397%
East Germany	6,839	351%
West Germany	5,666	291%
U.S.S.R.	5,450	280%
France	5,072	260%
Japan	4,440	228%
South Africa	4,356	223%
United Kingdom	4,157	213%
World Average	1,950	100%
Brazil	1,316	68%
Mexico	1,177	60%
Egypt	474	24%
China	359	18%
India	165	8%
Nigeria	61	3%

Note: The world average has been calculated approximately using the values given for certain countries.

Source: Canada, AECL, *Nuclear Sector Focus*, Corporate Public Affairs, September 1987, p. C-12.

A startling feature of Table 8 is the broadness of the range in per capita electricity consumption. For example, on a per capita basis, Canadians use 270 times more electricity than Nigerians. This reveals the immense gap that exists between industrialized and developing countries in their consumption of electricity, and the enormous potential in the developing world for growth in demand for electricity, with all of its implications.

An average global value for per capita electricity consumption was not included in the source for Table 8 and has here been calculated using the percentage of world average consumption given for the various countries.

B. The Swedish Nuclear Power Program

1. History of Swedish Nuclear Development

With an area of 450,000 square kilometres (174,000 square miles), Sweden is the fourth largest country in Europe but has a population of less than 8.4 million. Over 85% of the population lives in the southern half of the country; Stockholm has almost 1.5 million inhabitants.

During World War II, the Atlantic blockade of Allied shipping by German submarines illustrated the peril of depending on imported fuels. When oil imports rose sharply in Sweden after the war, warnings were raised. The Swedish commitment to nuclear power in the 1950s was motivated in part by the desire to restrain these imports. Unlike most countries, nuclear power in Sweden was first viewed primarily for application in district heating systems. One reactor for this purpose (Ågesta, a 60 MWt reactor with 20 MWe later added to its output) was constructed underground in Stockholm and subsequently dismantled in the mid-1970s. Interest then shifted to using nuclear reactors for combined electricity and heat production (cogeneration). In a critical decision in the 1960s, a nuclear cogenerating station planned for the city of Västerås was cancelled and replaced by an oil-fired system. Since electricity production and distribution are separate functions in Sweden (in 1946, the State Power Board was granted the exclusive right to build and operate the bulk power grid), this was a serious setback to the producers who favoured the expansion of nuclear power. Development then shifted to the generation of nuclear-electricity at large, central stations, while some municipalities built their own oil-fired cogenerating plants. (Sweden, Secretariat for Future Studies, 1977) Prior to the 1970s, "good" energy policy was seen principally as policy which provided the general community with the cheapest energy possible.

At the time of the Arab oil embargo, Sweden depended on imported oil for about 73% of its primary energy needs. In 1975, the Swedish Parliament (Riksdag) instituted an energy policy which was intended to shape energy development until 1985. A major thrust of this policy was to maintain a range of energy options for the future. One goal of the policy was to reduce the annual rate of increase in energy demand from 4.5% to 2%. This reduction was seen not as an end in itself but as a means to curtail oil imports, to restrain the growth in nuclear-electric power production and to hold back hydro-electric development. The continued use of nuclear power had by then become the subject of vigorous debate, and the Riksdag decided in the 1975 policy to restrict nuclear power development through the year 1985 to existing sites and to 13 reactors in total. The new energy policy stressed freedom of action, which in practical terms meant developing energy alternatives (in both supply and demand) so that Swedes would not become "prisoners of the energy system" (Sweden, Secretariat for Future Studies, 1977, p. 15).

The March 1979 accident at unit 2 of the Three Mile Island nuclear generating station in Pennsylvania had a major impact on Swedish public opinion. An advisory referendum on the future of nuclear power in Sweden was conducted by the government in 1980, the fourth public referendum held in the country's history. This referendum contained three options, none of which provided for the retention of nuclear power. The text of the three options follows (as translated into English).

> ***Alternative 1:*** Nuclear power is to be phased out at the rate which is possible with due regard to the need for electric power to maintain employment and prosperity. In order among other things to reduce dependence on oil, and pending the availability of renewable energy sources, use will be made of not more than the twelve nuclear reactors which today are in operation, ready for commissioning or under construction. There is to be no further expansion of the nuclear power sector. Safety considerations will decide the order in which the reactors are to be taken out of service.
>
> ***Alternative 2:*** [Consisted of the text of Alternative 1 plus the following text printed on the reverse side of the ballot] Energy conservation is to be vigorously prosecuted and given further encouragement. The most disadvantaged groups in society are to be protected. Measures are to be taken to steer the consumption of electricity with the aim, among other things, of preventive direct-acting electrical heating in new permanent building development. Research and development activities concerning renewable energy sources are to be stepped up under public auspices. Measures to improve environmental standards are to be taken at nuclear power stations. A special safety study is to be carried out for each reactor. A safety committee including local representatives is to be appointed at every nuclear power station for purposes of public supervision. Electricity production in oil-based and coal-based condensation [thermal generation] is to be avoided. Principal responsibility for the production and distribution of electrical power is to be vested in society. Nuclear power stations and other future facilities of importance for the production of electricity are to be owned by national and local authorities. Excess profits accruing from hydro-electric power production are to be sequestered by means of taxation.
>
> ***Alternative 3:*** No further expansion of nuclear power. Closure within no more than ten years of the six reactors now in service. A conservation plan for the reduction of dependence on oil is to be based on: continued and intensified energy economization; greatly increased efforts to develop renewable energy sources. Stricter safety requirements are to be imposed on operational reactors. No unactivated reactors are to be commissioned. No uranium extraction is to be permitted in Sweden. If current or future safety analyses so require, this Alternative naturally implies an immediate shut-down. The campaign against nuclear weapons and their proliferation is to continue. No fuel reprocessing is to be allowed. Exports of reactors and reactor technology are to be discontinued. Employment to be boosted by means of alternative energy production, and more extensive upgrading of raw materials.

Of those Swedes entitled to vote, 75.6% cast a ballot, the highest level of participation in any of the four referenda. The results were:

Alternative 1: 18.9% Alternative 2: 39.1% Alternative 3: 38.7%

Only 3.3% of the ballots cast were blank.

Based on the results of the referendum, the Swedish Government announced that there would be no new nuclear power development, that the power reactors then under construction would be allowed to enter commercial service, and that all power reactors would be decommissioned by the year 2010. The Government decided that it was not possible at the time to specify when the phase-out of nuclear generation would begin but that the order of decommmissioning would be established on the basis of safety considerations. The construction of reactors for heating purposes alone was also prohibited, as was the construction of breeder reactors. The rate of phasing out nuclear generation was to be governed by the need for electric power to sustain employment and the national welfare.

In 1985, the previous 10-year energy policy having run its course, the Swedish Government issued a new statement of policy. This took the form of a Bill on Guidelines for Energy Policy, which was approved by the Riksdag without major alteration. This policy reaffirmed the Government's commitment to abandon nuclear power by 2010, to be achieved through energy conservation, the expanded use of district heating, the introduction of new energy sources and technologies, and continuing energy research and development. The policy also proposed to keep the level of Swedish energy use unchanged from about 1990 onwards. Efforts to reduce Sweden's dependence on oil were to continue. As the Government summarized its policy:

> During the rest of the 1980s the main aim of energy policy should be to *complete the reshaping of the energy system* from oil to renewable and indigenous energy sources, while gradually creating the conditions for a phasing out of nuclear power. An aspect of this reshaping process is the creation of an energy system that is less sensitive to international supply disruptions and which results in improved security of supply. (Sweden, Ministry of Industry, 1986, p. 7)

Sweden's *Act on Nuclear Activities* came into force in 1984. This Act clarified the responsibilities of the state and the electric power industry for nuclear safety. It required that all licencees of power reactors together prepare a comprehensive program of research and development in radioactive waste management, including final disposal, specifying all measures to be undertaken for at least six years in advance. The program is submitted to the Government every three years for evaluation, beginning in 1986. The Act also restated a requirement that had become law in 1976, that any power reactor being loaded with fuel for the first time must hold a special permit, granted only if the reactor operator:

> 1. has proved that there is a method for the handling and final disposal of spent nuclear fuel and radioactive waste deriving from it which is acceptable with regard to safety and radiation protection, and
>
> 2. has presented a programme for the research and development work necessary for ensuring that spent nuclear fuel from the reactor and radioactive waste deriving from it can be handled and finally disposed of in a safe manner. (Sweden, Ministry of Industry, 1984, p. 4)

The five reactors commissioned prior to 1976 were not affected by this stipulation, but the remaining seven have had to comply. The concept of deep geologic burial of high-level radioactive waste was advanced by the utilities and accepted by the Government as a safe disposal method.

The *Amended Act on the Financing of Future Measures for the Disposal of Spent Fuel* also came into force in 1984. This Act requires that reactor licencees shall defray the costs for:

> 1. the safe handling and final safe disposal of spent nuclear fuel from the reactor and radioactive waste deriving from it;
>
> 2. the safe decommissioning and dismantling of the reactor installation;
>
> 3. the performance of the research and development work necessary for the conditions referred to under subsections 1 and 2 to be met. (Sweden, Ministry of Industry, 1984, p. 11)

In addition to the above costs, reactor licencees are required by the legislation to defray costs incurred by the State in supplementing the R&D work of the licencees, certain administrative and other costs incurred in enforcing the Act, and costs incurred in the monitoring and inspection of final repositories. To accumulate the funds considered necessary to cover these costs, the licencee must pay an annual fee to the State for as long as the reactor is in operation. Those fees accumulate in accounts for each utility group. The rate is set by the State and is related to the amount of electricity delivered from the reactor. The fee is currently set at 0.019 Skr/kWh (approximately equivalent to 0.0037 $C/kWh or 3.7 mills/kWh). [The currency conversion rate used is 1 Swedish krona = 0.1923 Canadian dollar. The derived Canadian values are rounded.] These fees are bringing in 1,200 million Skr ($C 230 million) annually, of which about 600 million Skr ($C 115 million) is spent each year for the ongoing costs of the program. To the end of 1987, 3,900 million Skr ($C 750 million) had accumulated in the utility accounts. The total estimated future cost of the program is 38,000 million Skr ($C 7,310 million). The last year for collection of fees is 2010, but much of the spending comes later, with the largest expenditure being the final repository.

Some Swedes doubted that the Government would in fact end the use of nuclear power, given the difficulties in replacing this energy source. The Chernobyl accident of May 1986, with its radioactive fallout on Sweden, has stiffened government resolve and hardened public opinion. At the time of the Committee's visit to Sweden, legislation had been introduced in the Riksdag which would compel two reactors – one at Barsebäck and one at Ringhals – to be taken out of service in 1995 and 1996. The Committee understands that this legislation has now been passed. The Barsebäck reactor is privately owned by the Sydkraft power company and will not have reached the end of its useful life in 1995. Thus the Swedish Government will be faced with the question of financial compensation for the privately owned reactors that it will begin forcing out of service in 1995.

2. The Current Power Reactor Program

Sweden has 12 operating power reactors, with a net installed generating capacity of 9,663 MW. Nine are BWRs designed and installed by ASEA-ATOM (now part of ASEA/Brown Boveri), and three are Westinghouse PWRs. These 12 units are located at four stations. Three BWRs are situated at Oskarshamn on the Baltic coast about 300 km south of Stockholm. Three BWRs are located at Forsmark on the coast 150 km north of Stockholm. Two BWRs at Barsebäck lie across The Sound from the Danish capital of Copenhagen. The Ringhals station on the west coast about 60 km south of Göteborg has three PWRs and one BWR. Sweden's BWRs have the best average annual load factor – 82.5% in the 12-month period ending June 30, 1987 – of any country operating four or more reactors of this type (Howles, 1988, p. 22). No additional reactors are under construction or planned.

The 12 Swedish reactors are listed in Table 9. These units accounted for 15% of the country's total supply of primary energy in 1986.

Table 9: Sweden's Operating Power Reactors at 1 January 1988

Reactor Unit / Type	Commercial Operation	Net Electrical Output	Contractor
Oskarshamn 1 / BWR	1972	440 MW	ASEA–ATOM
Oskarshamn 2 / BWR	1975	595 MW	ASEA–ATOM
Oskarshamn 3 / BWR	1985	1,070 MW	ASEA–ATOM
Ringhals 1 / BWR	1976	750 MW	ASEA–ATOM
Ringhals 2 / PWR	1975	800 MW	Westinghouse
Ringhals 3 / PWR	1981	915 MW	Westinghouse
Ringhals 4 / PWR	1983	915 MW	Westinghouse
Barsebäck 1 / BWR	1975	595 MW	ASEA–ATOM
Barsebäck 2 / BWR	1977	580 MW	ASEA–ATOM
Forsmark 1 / BWR	1981	970 MW	ASEA–ATOM
Forsmark 2 / BWR	1981	970 MW	ASEA–ATOM
Forsmark 3 / BWR	1985	1,063 MW	ASEA–ATOM

Source: Sweden, Kärnkraftsäkerhet och Utbildning AB, *Summary of Operating Experience at Swedish Nuclear Power Plants 1987*, Stockholm, February 1988, p. 3.

In 1985, 42.4% of Sweden's domestic electricity production came from nuclear stations; in 1986 that share rose to 50.3%. This is the third largest share claimed by nuclear-electric generation in the OECD countries, with France leading in 1986 at

69.8% and Belgium second at 67.0%.

With all 12 reactors operational, the Swedish nuclear power program requires about 1,400 tonnes of uranium annually for fuelling. Approximately 90% of this amount is purchased under long-term contracts. For the period 1983-1992, about two-thirds of this uranium is being obtained from Canada, one-fifth from Australia, and the remainder from France and the United States. (Sweden, Ministry of Industry, 1986) In 1987, Canada exported 377 tonnes of uranium destined for Sweden after enrichment elsewhere, down from the 449 tonnes shipped in 1986 (Canada, AECB, 1988, p. 9). Although Sweden is known to possess deposits of uranium, potentially of commercial grade, no domestic mining of uranium has been undertaken, apparently on environmental grounds.

There are certain ironies in the Swedish nuclear situation. Sweden will shut down some of the world's most efficiently run BWRs, reactors which a Swedish commission has judged to be acceptably safe over their operating lifetime, while the Russians will continue to operate the RBMK reactor type that deposited the radioactive fallout on Sweden after the Chernobyl accident. To replace lost nuclear-electricity, the Swedes acknowledge that more fossil fuels will have to be consumed for some years to come, a curious exchange for a country that has been particularly affected by acidic precipitation. Sweden expects to import substantially larger quantities of natural gas as a substitute for nuclear-electricity. The Soviet Union may well supply much of this gas, the same country that Sweden has charged with frequent violations of its territorial waters by military submarines. Given the high priority that Sweden places on maintaining its neutral stance, such strategic dependence on the U.S.S.R. would be surprising.

3. Radioactive Waste Management

Sweden's radioactive waste management program is well organized and funded. The program is managed by a company created specifically in 1972 for this purpose: Svensk Kärnbränslehantering AB, or SKB (the Swedish Nuclear Fuel and Waste Management Company). SKB is owned by the four Swedish electric utilities which operate power reactors: Vattenfall (the Swedish State Power Board) (36%); Forsmarks Kraftgrupp AB (30%); OKG Aktiebolag (22%); and Sydsvenska Värmekraft AB (12%). The public service corporation Vattenfall is Sweden's largest electric utility, generating nearly half of the country's electricity and operating the four-unit Ringhals station. Forsmarks Kraftgrupp, which operates the three-unit Forsmark station, is jointly owned by Vattenfall and a private consortium. OKG Aktiebolag is an eight-company private consortium generating 40% of Sweden's electricity and operating the three-unit Oskarshamn station. The principal shareholder in OKG is Sydkraft AB, the largest private power company in Sweden and also the owner of Sydsvenska Värmekraft AB and the operator of the two-unit Barsebäck station. (Sweden, SKB, 1985) The Swedish nuclear power program is a mixed public and private enterprise.

SKB has the responsibility to develop, plan, construct and operate facilities for the management and disposal of spent nuclear fuel and other radioactive wastes produced at Swedish nuclear power stations. It is in charge of research and development activities within the field of radioactive waste management. SKB also handles matters of uranium prospecting, fuel enrichment, fuel reprocessing and uranium stockpiling for the Swedish nuclear power industry.

Three state agencies work closely with the SKB. The National Institute of Radiation Protection, SSI (Statens strålskyddinstitut), and the Swedish Nuclear Power Inspectorate, SKI (Statens kärnkraftinspektion), have regulatory functions. The National Board for Spent Nuclear Fuel, SKN (Statens kärnbränslenämnd), has a financial authority, collecting fees from reactor operators and holding program funds.

The Swedish National Institute of Radiation Protection, SSI, is contained within the Ministry of Environment and Energy, and administers the *Radiation Protection Act* and the Radiation Protection Ordinance. Since 1965, SSI has been the highest authority in Sweden on radiation protection. The Institute operates 25 measuring stations across the country, recording natural radiation levels. It also makes regular measurements of individual doses received by people working with ionizing radiation and today is monitoring about 14,000 people. In the field of nuclear power, SSI regulates the release of radioactivity at nuclear stations, reviews radiation protection requirements at these facilities, and prescribes dose limits for personnel. All transportation of radioactive material is supervised by SSI. The SSI and the National Rescue Administration are jointly responsible for emergency planning for nuclear power accidents. (Sweden, SSI, 1987)

The Swedish Nuclear Power Inspectorate, SKI, is the regulatory body established under the *Act on Nuclear Activities*. SKI's principal duties are to (Swedish Atomic Forum, undated, p. 33):

- evaluate the design of nuclear facilities from a safety point of view;
- formulate guidelines for safety and inspect nuclear facilities;
- survey and evaluate operational experience, and initiate safety precautions;
- inspect and account for nuclear materials according to international and Swedish regulations in order to prevent the non-peaceful use of such materials;
- inspect and prepare regulations for handling and storing nuclear waste;
- initiate and direct research and development in the field of nuclear safety; and
- inform the public about the work being done on nuclear safety.

Direct responsibility for the safety of nuclear facilities lies, however, with the owners, who must comply with any directives issued by SKI.

SKI is assisted in its work by three advisory committees: The Reactor Safety

Committee (which advises regarding reactor safety and licensing), The Safeguards Committee (which advises on the safeguarding of fissionable material and on protecting nuclear facilities and the transport of nuclear materials against theft and sabotage), and The Research Committee (which evaluates and proposes research projects). (Sweden, SKI, undated)

The SKI performs a function in Sweden similar to that of the Atomic Energy Control Board in Canada. The Committee notes that SKI has an Information Secretariat, whose "foremost function...is to inform the public of the work being done by SKI in the field of nuclear safety...Information on SKI's positions on various nuclear safety matters is aimed at the mass media, interest organizations and local safety committees as well as politicians, private persons and companies." (Sweden, SKI, undated, p. 7) This is a role that the Committee recommends be more fully developed by Canada's AECB.

According to a resolution of the Swedish Parliament, every power reactor must undergo at least three safety analyses during its planned lifetime, in addition to the safety analysis carried out before a reactor is commissioned. These recurring analyses incorporate the operating experience of the reactor, the results of test programs at the reactor, and the results of Swedish and international work on reactor safety.

The Swedish National Board for Spent Nuclear Fuel, SKN, was created in 1981 and is the central administrative authority under the *Amended Act on the Financing of Future Measures for the Disposal of Spent Fuel.* This legislation established three principles of nuclear waste management (Swedish Atomic Forum, undated, p. 34):

(1) The producer of the waste shall undertake the necessary actions for management and disposal of the waste.

(2) The state has the ultimate responsibility of ensuring that the waste is disposed of in a manner which is satisfactory to the Swedish public.

(3) The costs of waste management shall be paid by those who benefit from the nuclear-electric power. The capital needed for post-operational waste management activities shall therefore be raised during reactor operation and be held available for future needs.

With the *Act on Nuclear Activities* of 1984, SKN's financial authority was supplemented with authority over the R&D program which the nuclear power utilities implement for the management and disposal of spent nuclear fuel and nuclear plant decommissioning. SKN has thus been given the supervisory and economic authority to ensure that these three principles are followed. SKN recommends to the Government what fee needs to be charged per kilowatt-hour of nuclear-electricity produced to cover all future costs of nuclear waste managment and disposal and nuclear plant decommissioning. This fee is set annually and paid by the utilities into special accounts administered by SKN. Prior to 1981, the utilities developed internal reserves for these activities; SKN took over the accumulated funds when the fee system and the government accounts were established. Interest on these funds accrues at the prevailing rate. As the utilities spend money on waste management or decommissioning, SKN releases funds from the accounts to reimburse the utilities for these expenditures. (Swedish Atomic Forum, undated)

This policy presents an interesting challenge to SKN: expenditures on radioactive waste management and plant decommissioning are expected to be made until about 2050 or 2060, yet SKN can only collect the fees until the last reactor is shut down in 2010. How does the agency forecast what total expenditures will be in a program continuing some 70 years or more into the future? At this time, SKN does not know what the schedule of reactor shutdown will be beyond the two units to be taken out of service in 1995 and 1996.

The Swedish Government, by accepting the concept of deep geological disposal as embodied in what is termed the KBS–3 model, created a problem for itself. Accepting the concept meant that the nuclear utilities had satisfied the legal requirement for starting the remaining new power reactors. KBS–3 is the model which SKB (the Swedish Nuclear Fuel and Waste Management Company owned by the utilities) has subsequently built its R&D program around. The KBS–3 report was completed in 1983 and although subsequent research has not caused the Government to re-evaluate its conclusions about the safety of the KBS–3 concept, SKN would like SKB to broaden some of the R&D work, in order not to miss opportunities for improved technical solutions. This puts SKB in the position of being asked by the government agency which oversees its R&D program to spend more time and money investigating alternatives to the KBS–3 disposal system which the Swedish Government has already declared to be acceptable.

The Legal Requirement for Safe Disposal of Radioactive Wastes in Sweden

Under Swedish law dating back to 1976, nuclear power utilities have had to demonstrate that spent nuclear fuel can be safely handled and disposed of before being allowed to load fuel into new reactors and start operating them. The utilities submitted their first such research report, KBS–1, in November 1977 together with an application to fuel Ringhals 3 and Forsmark 1. Ringhals 4 and Forsmark 2 were subsequently added to this application. KBS–1 assumed that spent fuel would be reprocessed, which was then the preferred option in Sweden. In 1978, the KBS–2 report was submitted, based on the direct disposal of nuclear fuel without reprocessing. This report was accepted by the Government as the basis for approving fuel loading at the four reactors. In May of 1983, the KBS–3 report was appended to the fuelling applications for Forsmark 3 and Oskarshamn 3. KBS–3 developed and broadened the work of KBS–2; in June 1984, the Government granted fuelling permission for these last two Swedish reactors. The Government thereby acknowledged that the requirements of the law had been satisfied and that the utilities had demonstrated the existence of a method for disposing of spent nuclear fuel in an acceptably safe manner. (Sweden, SKB, 1985)

The KBS–3 approach has the spent reactor fuel emplaced in a 500-metre-deep repository in stable, crystalline bedrock. Copper canisters will be used to contain the spent fuel. When filled, the repository will be backfilled and sealed, and will not require further surveillance. Safety of the repository "is based on the fact that degradation of the canisters and subsequent transport of their contents with the groundwater to the surface of the ground will take such a long time that the radioactive substances will decay and be diluted to such a degree that they reach the biosphere only in harmless concentrations" (Sweden, SKB, 1985, p. 12). Site selection for the repository is set by SKB for 1990-92 and the choice of the engineered barrier system (that is, design of the repository, form of the emplaced radioactive waste, design of the canister containing the waste, and the nature of the buffer and backfill around the canisters) is to be made between 1994 and 1996. The siting application is to be made by 2000, the safety report submitted by 2006, construction of the repository started by 2010, and operation of the repository begun in 2020. Some critics of the program claim that this schedule does not allow for any unforeseen delays. (Sweden SKN, 1987b)

SKB works under the following guidelines for its waste management program (Sweden, SKN, 1987b, p. 31-32):

- The radioactive waste products generated by the Swedish nuclear power program shall be disposed of in Sweden.
- The spent nuclear fuel shall be finally disposed of without reprocessing.
- Technical systems and facilities shall fulfill high standards of safety and radiation protection and satisfy the requirements of Swedish authorities.
- In all essential respects, the radioactive waste problem shall be solved by the generation of Swedes utilizing electricity production from the nuclear power stations. That is, there will be no burden on future generations.
- A decision on the design of the final repository for spent nuclear fuel shall not be taken until around the year 2000, so that it can be based on a broad body of knowledge.
- The waste management systems shall be designed so that requirements for controlling fissionable materials can be fulfilled.
- The necessary technical solutions shall be arrived at within Sweden, although available foreign knowledge shall be gathered.
- The conduct of the work shall be subject to the continuing review of the regulatory authorities and the directives issued by them.
- The waste management activities shall be conducted openly and with broad public knowledge.

To advance its knowledge of the conditions for deep geological burial, SKB is operating an underground research facility for high-level waste disposal at the Stripa mine about 230 km west of Stockholm. At this facility, techniques are being developed to allow the design of a final repository in stable crystalline rock. Stripa is a former mine in an iron ore deposit. Work on the waste disposal program began here in 1976, when the ore body was mined out. Tunnels were excavated at the 360-metre-level in the mine in a granite bordering the ore body. Non-radioactive heating experiments were carried out at Stripa in a joint Swedish-U.S. project. Today the research centres on the detection and mapping of rock fracture zones, the measurement of groundwater flow and nuclide migration, and the use of bentonite clay for backfilling and sealing. (Sweden, SKB, undated(c))

Sweden's program of high-level radioactive waste disposal in stable, deep geological formations is similar to the programs of Canada and Switzerland, which the Swedes describe as "mature". Canada's R&D work in support of its disposal program was observed by the Swedes to be more advanced than their own in certain areas.

The disposal program for spent fuel is complemented in Sweden by a well-developed system for interim storage of all radioactive wastes and a disposal system for low-level and intermediate-level wastes.

All Swedish nuclear-electric generating stations are located along the coast and each has its own harbour facilities. SKB has established a complete transportation system for radioactive materials based on sea transport. Spent fuel is stored in water-filled bays at each reactor site for at least one year, following which it is loaded into casks and trucked onto a specially-designed, roll-on roll-off vessel, the *M/S Sigyn*, for shipment to a central storage facility for spent fuel. The spent nuclear fuel is placed in an 80-tonne shielded steel cask with a capacity of three tonnes of fuel. The transport cask sits on a frame and is hydraulically lifted by a vehicle which transports the frame and cask together. This cargo can be driven or lifted by crane onto the *Sigyn*, which can accommodate ten of these casks. The ship is also used to transport low- and intermediate-level wastes (reactor wastes) to a final repository at the Forsmark nuclear power station. *M/S Sigyn* makes approximately 30 trips per year between the four nuclear power stations, the central fuel storage facility and the repository for reactor wastes. (Sweden, SKB, undated(b))

M/S Sigyn is double-hulled, double-bottomed and fitted with several watertight bulkheads. This Swedish designed and French built ship is equipped with two independent propulsion systems; electric power is supplied from three generators, each of which can handle total ship demand. A sophisticated fire control system protects all parts of the vessel. A water-filled tank shields the crew quarters against radiation from the hold and concrete walls separate the engine rooms from the hold. Radiation monitoring equipment includes gamma and neutron detectors. (Sweden, SKB, undated(b))

The central storage facility for spent nuclear fuel at Oskarshamn is known as

CLAB. This pool storage system is designed to receive fuel from the four power stations for intermediate storage of about 40 years before final disposal. The fuel storage building has been excavated in bedrock and the roof of the 120-metre-long cavern is 25 to 30 metres below ground level. In its initial configuration, CLAB consists of four interconnected storage pools, each of which can hold 750 tonnes of spent fuel. The facility can be extended in the future with additional caverns constructed parallel to the first one. CLAB was commissioned in 1985 and built at a total cost of about Skr 1,700 million ($C 325 million). (Sweden, SKB, 1986)

A terminal vehicle transports the cask from the ship to CLAB and the the cask is unloaded in an air lock in the receiving building. The cask is lifted from the vehicle by crane, cooled to room temperature in a preparation cell, and then unloaded underwater by remotely-controlled handling machines. The spent fuel assemblies are transferred to storage containers and placed in predetermined locations in the storage pools. (Sweden, SKB, 1986)

Low- and intermediate-level radioactive wastes are sent to the SFR facility at Forsmark, a final repository for reactor wastes. Low-level wastes are defined as those wastes with such a low level of radiation that they can be handled without the need of shielding. The intermediate-level wastes must be shielded but do not require cooling. These wastes contain virtually no long-lived radionuclides and are considered harmless to human beings and to the environment after about 500 years. Under the most pessimistic assumptions used in the environmental impact assessment for SFR, these wastes would add a few per cent to natural background radiation in the area. SFR is located in bedrock 50 metres below the Baltic seabed. Water depth above the repository is five metres. This region of Sweden is still rebounding from the weight of the last ice sheet that covered the land until about 9,000 years ago. In 500 years, this area will be above sea level but the wastes will be essentially harmless by then. SFR is located beneath the Baltic because the groundwater regime is stagnant and no one will drill there in the future for fresh water. (Sweden, SKB, undated(a))

SFR consists of storage chambers and a silo in a series of rock caverns, reached by kilometre-long twin tunnels extending from land. The silo, the first of as many as four, will hold the most radioactive materials, primarily ion exchange resins solidified in concrete moulds or metal drums. The inside of the silo is divided into 2.5-metre-square cells running from top to bottom. Waste packages are placed in the cells and backfilled with concrete. The silo rests on a bed of sand and clay, and the space between the wall of the silo and the surrounding rock is filled with clay. Various types of packaging are being used for the wastes placed in the storage chambers, depending upon the radioactivity of the waste and the handling procedures at the nuclear power stations. SFR was completed in 1988 and the Committee visited this facility a few weeks before it began receiving reactor wastes. The first phase of SFR cost about Skr 740 million ($C 140 million). (Sweden, SKB, undated(a))

Studsvik Energiteknik AB is an energy research centre located about 100 km south of Stockholm on the Baltic coast. The Committee visited Studsvik because of its similarities with Chalk River Nuclear Laboratories and because of its work in managing reactor wastes in particular.

Studsvik began life in 1947 as AB Atomenergi, a joint state-private enterprise. The early development of a heavy water reactor system was carried out here, until Sweden opted for the LWR design in the 1960s. Studsvik designed and built the Ågesta reactor for the Stockholm district heating system. In 1969, Studsvik became wholly state-owned and ASEA-ATOM was formed as a separate company, half owned by ASEA and half by the Government. In 1978, the state-owned AB Atomenergi was transformed into the private commercial enterprise Studsvik Energiteknik AB. Today Studsvik competes for its work and because its income expectations were not realized in 1985 and 1986, the company has had to reduce staff and reorganize its operations. In 1987, Studsvik's $C 100+ million income broke down as follows: about $30 million from the Swedish nuclear industry; $33 million from its export business; $12 million from Swedish nuclear agencies in bidded contracts; $10 million in fees for university research performed at its facilities; $12 million in special government asignments; and $3 million in government subsidies for R&D performed jointly with industry.

Studsvik treats low- and intermediate-level wastes from power reactors, hospitals, research facilities and industry. It also incinerates reactor wastes received from West Germany, with the ash being encapsulated in concrete or bitumen and returned to Germany for disposal. Studsvik has recently completed Project AMOS, a comprehensive program to modernize all of its waste facilities. This modernization included a new building for processing solid and liquid wastes, an underground interim storage facility, and harbour facilities to accommodate the *M/S Sigyn*. The Studsvik Incineration System is a modern, multi-chamber electronically-controlled incinerator designed to burn low-level wastes. The resulting ash is encapsulated in concrete. Waste volume is reduced by a factor of approximately 100 through incineration. This unit began operation in 1977 and through 1988 had burned about 3,500 tonnes of waste, ranking it as one of the leading radioactive waste incinerators in the world. Studsvik is supplying an incinerator of double this capacity for Oak Ridge Nuclear Laboratories in the United States. Other sales are in prospect. (Sweden, Studsvik Energiteknik, 1987)

Studsvik has also developed an induction furnace to melt irradiated metals. This avoids the difficulty in trying to decontaminate complicated structures like steam generator piping. The metal is cut up and melted; the resulting ingot is scanned to ensure that it is safe for recycling. If the radiation level is too high, the ingot is simply stored until the radioactivity declines to an acceptable level.

The Committee is impressed with the thoroughness and design of the Swedish radioactive waste management program. The Committee favours the idea of maintaining separate government accounts funded by the users of nuclear-electricity and dedicated to radioactive waste management and reactor decommissioning.

C. The West German Nuclear Power Program

1. History of West German Nuclear Development

The Federal Republic of Germany, the FRG or West Germany, has an area of 249,000 square kilometres (96,000 square miles) and a population of 61 million. The country is made up of 11 federal states, including West Berlin. The most populous is North Rhine-Westphalia with 17 million inhabitants. The capital city of Bonn and the city of Essen, home of the largest German electrical utility Rheinisch-Westfälisches Elektrizitätswerk (RWE), are located in this state. Both cities were visited by the Committee.

Responsibility for nuclear energy at the federal level rests with four departments. Support for nuclear energy R&D is the responsibility of the Federal Minister for Research and Technology. The application of nuclear energy as one of Germany's important energy sources rests with the Federal Minister for Economic Affairs. Nuclear safety regulation is the responsibility of the Federal Minister for Environment, Nature Conservation and Nuclear Safety. West Germany's international commitments in the nuclear area are handled by the Foreign Office. (Breest, 1988)

Electric utilities, which hold the reactor licences and operate the power reactors, are organized as private companies, although municipalities and the states can own shares in them. State licensing and superintending authorities execute federal nuclear laws on behalf of the central government, supervised by the Federal Ministry for Environment, Nature Conservation and Nuclear Safety. There has in the past been close cooperation between the federal and state governments in nuclear development, especially in financing West Germany's nuclear research centres and university research. The Social Democratic Party, however, declared nuclear power to be unsafe after the Chernobyl accident and wants all German nuclear-electric generation to be phased out within 10 years. The Social Democrats control some state governments and, since the federal government has delegated the authority to license reactors to the state governments, this cooperation has evaporated in some cases. The stalled Kalkar breeder reactor is caught in this political situation.

Research and development of nuclear power in West Germany was only allowed beginning in 1955, with the Paris Souvereignty Treaty. The German Government thereafter established major nuclear research centres at Karlsruhe and Jülich; entered into bilateral cooperation agreements with such countries as France and the United States; and joined the IAEA, the Nuclear Energy Agency of the OECD, CERN (the European Organization for Nuclear Research) and EURATOM (the European Atomic Energy Community). German industrial concerns collaborated with U.S. companies to foster reactor development – Siemens with Westinghouse for the PWR design, and AEG with General Electric for the BWR design. By about 1970, West Germany had become technically independent in reactor design; Kraftwerk Union (KWU) was established by Siemens and AEG-Telefunken to develop a German nuclear power plant design and associated safety system. (Breest, 1988)

Not only had West Germany overtaken the lead of other industrial countries in power reactor development, it had begun to compete in the export market. In 1968, West Germany secured its first foreign order, the 320 MW Atucha reactor in Argentina. This was followed by the sale of a 450 MW reactor to the Netherlands in 1969, a 700 MW unit to Austria in 1971, and a 920 MW unit to Switzerland in 1972. (FRG, Federal Ministry for Research and Technology, 1974)

West Germany has based its commercial reactor program on the LWR, in both PWR and BWR designs. Looking to the future, it has also constructed a 15 MWe experimental high-temperature reactor (HTR) and recently completed a commercially-sized 300 MWe thorium high-temperature reactor (THTR). Because the HTR operates at a higher coolant temperature than the LWR, it can achieve a higher operating efficiency. Basing the HTR on the thorium cycle opens up another fuelling option. HTR reactors are also claimed to be inherently safer than LWRs.

An experimental 17 MWe sodium-cooled fast breeder reactor (FBR), which began operation at Karlsruhe in 1978, was the forerunner of the 300 MW Kalkar FBR. The Kalkar reactor is completed but the state government has refused to license its operation.

2. The Current Power Reactor Program

West Germany has 22 power reactors operating today, totalling 18,926 MWe of net installed generating capacity. A further three reactors are under construction and one completed reactor awaits licensing, the four units aggregating an additional 4,052 MWe. Six older units have been decommissioned. Nine reactor projects have been applied for but reduced energy demand in Germany makes their need questionable before the turn of the century. Information on the West German nuclear power program is contained in Table 10.

In 1986, 29.6% of West Germany's supply of electricity came from nuclear stations; in 2000, that share is projected to rise to 35%. However, opposition to continued nuclear power development has become stronger, especially with the political rise of the Green Party, and the German nuclear program is in difficulty. The most serious delay in the German program is the Kalkar 300 MW fast breeder reactor, a project which the West German Government initiated in 1972 in a cooperative program with the Netherlands and Belgium. Although the reactor has been ready for fuel loading since mid-1986, the state government of North Rhine-Westphalia refuses to issue an operating licence. RWE has a 68.85% interest in the West German holding company SBK (Schnell-Brüter-Kernkraftwerkgesellschaft mbH Gemeinsames Europäisches Unternehmen, Essen) which built and will operate Kalkar. The Dutch and Belgian electrical industries hold most of the remaining interest and a small share is held by British utilities. (RWE, 1988)

Table 10: West Germany's Operating Power Reactors at 1 January 1988

Reactor Unit / Type	In Operation	Net Electrical Output	Contractor
AVR Jülich / HTR	1969	13 MW	BB-Krupp
Obrigheim / PWR	1969	340 MW	Siemens
Stade / PWR	1972	630 MW	Siemens
Biblis A / PWR	1975	1,146 MW	Siemens-KWU
Biblis B / PWR	1977	1,240 MW	Siemens-KWU
Würgassen / BWR	1975	640 MW	AEG
Neckarwestheim-1 / PWR	1976	795 MW	Siemens-KWU
Brunsbüttel / BWR	1977	770 MW	AEG-KWU
Karlsruhe KNK-2 / Fast Breeder	1978	17 MW	Interatom
Isar-1 (Ohu) / BWR	1979	870 MW	AEG-KWU
Unterweser / PWR	1979	1,230 MW	Siemens-KWU
Philippsburg-1 / BWR	1980	864 MW	AEG-KWU
Philippsburg-2 / PWR	1985	1,268 MW	KWU
Grafenrheinfeld / PWR	1982	1,225 MW	KWU
Krümmel / BWR	1984	1,260 MW	AEG-KWU
Gundremmingen II-B / BWR	1984	1,249 MW	KWU
Gundremmingen II-C / BWR	1985	1,249 MW	KWU
Grohnde / PWR	1985	1,290 MW	KWU
Brokdorf / PWR	1986	1,307 MW	KWU
Mülheim Kärlich / PWR	1987	1,227 MW	RWE
Hamm-Uentrop / THTR	1987	296 MW	Konsortium THTR

Source: France, Commissariat à l'Énergie Atomique, *Les Centrales Nucléaires dans le Monde*, 1987 Edition, Paris, 1987, p. 16-17; Breest, H.-Ch., *Nuclear Energy in the Federal Republic of Germany*, Edition No. 101, Federal Ministry for Environment, Nature Conservation and Nuclear Safety, Federal Republic of Germany, March 1988, Figure 2.

Apart from the stalled Kalkar FBR, completion of the remaining three PWRs will end the current phase of West Germany's nuclear power program. Until growth in the demand for electricity picks up and until first generation power reactors are decommissioned and require replacement, the Committee was told that further reactor orders will not be placed.

SBK has a 16% interest in the French 1,200 MW Super-Phénix fast breeder reactor in Creys-Malville near Lyons. Shareholders in Super-Phénix are entitled to a share of the electricity generated proportional to their interest. The RWE holding is three-quarters of the SBK share, or 12% of the project. RWE also has a 7.5% interest in a proposal to construct a new nuclear power station in Switzerland and SBK holds a 51% share in a European consortium proposing to build a prototype breeder reactor in West Germany. (RWE, 1988) These examples demonstrate the international cooperation among Western European utilities in reactor construction, especially in breeder reactor technology, which also spreads the burden of the financial risk. The problems in licensing Kalkar, however, threaten to upset this cooperation.

The view expressed to the Committee by the West German Government was that nuclear energy is an essential component of the national energy system – nuclear and solar are the energy forms of the future. The principal challenge is to tailor these energy forms to the West German situation. Maintaining environmental quality is one of the main rationales for the West German nuclear program; the accumulation of carbon dioxide in the atmosphere is considered to be one of the most critical environmental issues of the future. According to Government representatives, the most important public issue in the German nuclear program today is resolving the radioactive waste management problem.

In the aftermath of Chernobyl, the German Reactor Safety Commission reexamined West Germany's reactors and concluded that no doubt had been cast on their safety. The German reactor program has never suffered a significant accident. As an RWE executive expressed it, "Chernobyl proved that it is possible to construct a reactor so badly and operate it so badly that an accident can occur. We already knew that."

RWE believes that no new nuclear generating capacity will be required in West Germany in the remainder of this century. Nonetheless, the utility will continue to work with KWU to plan for the reactor system of the year 2000. This is considered essential to preserve and expand the base of knowledge in German reactor development. Several billion dollars may have to be invested to preserve the nuclear option until it is once again required in West Germany. This is regarded as a necessary investment in the country's future.

Under current conditions, nuclear power is the most cost-effective generating option for West Germany. RWE quoted 10-12 pfennig/kWh as the projected average cost of nuclear-electricity in the early 1990s, compared with a 15-17 pfennig/kWh projected cost for coal-fired electricity using domestically mined coal and given the strict new environmental controls which coal-fired plants will have to meet. This cost differential is expected to widen with time. RWE told the Committee that it is spending six billion marks (about $C 4 billion at the current exchange rate) to control acid gas emissions at its 11,000 MW of lignite-fired generating capacity. If Germany's coal-fired plants were instead to burn imported coal, at today's depressed prices, they could just barely match nuclear power at its current cost.

Public liability in West Germany for nuclear accidents is split between the utilities and the state. The primary responsibility – up to one billion marks (approximately $C 675 million at the time of writing) – lies with the producer of the electricity. The Federal Government assumes an unlimited liability should claims exceed that amount.

The Germans have also been concerned with protecting their reactors against either sabotage or accident. Germany has tried to engineer its reactors so that an operator or a saboteur couldn't harm the outside environment even if successful in wrecking the reactor. Early German reactors were built with a concrete containment shell about 0.5 metres thick, designed to survive the impact of a light aircraft striking the shell. Newer reactors are protected by a 1.8 metre thick shell, designed to survive the impact of a fully loaded Tornado fighter aircraft weighing 17 to 18 tonnes. A jumbo jet represents less of a hazard because its mass would be distributed over a much larger section of the containment shell in an impact. As one official observed, the probability of an aircraft crashing into a stadium containing 50,000 people is higher and stadiums are not protected from such events, whereas Germany's reactors are.

Despite an admirable reactor safety record, one of the most advanced radioactive waste management programs in the world, a lack of indigenous energy resources apart from coal and serious air pollution problems, West Germany is still facing substantial public opposition to its nuclear power program.

3. Radioactive Waste Management

The West German nuclear program also includes uranium enrichment facilities, fuel fabrication plants for uranium oxide and mixed oxide fuel production, spent fuel and reactor waste interim storage, spent fuel reprocessing (to be done at a facility being developed at Wackersdorf in Bavaria) and the final disposal of radioactive wastes (with a final repository planned for the Gorleben salt dome). Until the Wackersdorf reprocessing plant is operational, spent fuel from the German reactors is being reprocessed under contract by the French company COGEMA and the British company BNFL (British Nuclear Fuels Limited).

West Germany has also seen its radioactive waste management program become the subject of strong public opposition, despite the Government's belief that it has put a strong, well-conceived program in place. Research has focussed on the use of salt as a disposal medium. In 1965, the disused Asse salt mine was purchased by the federal government to develop methods for storing radioactive wastes. From 1967 to 1978, approximately 124,500 drums of low-level wastes and 1,300 drums of intermediate-level waste were stored in the mine. An amendment to the *Atomic Energy Act* in 1976 resulted in the expiry of storage licences in 1978. Since then Asse has been used to continue R&D into salt as a disposal medium for radioactive wastes. Asse is judged unsuitable for high-level waste disposal but may be reopened as a repository for low- and intermediate-level wastes. (FRG, PTB, 1985)

In the 1970s, interest in using geologic formations other than salt led to investigation of the disused Konrad iron mine near Asse as a repository for wastes with low thermal impact. The Konrad mine is exceptionally dry, being overlain by clay-rich strata. The position of the mine workings at a depth of 800 to 1,300 metres is also a favourable feature. Licensing procedures have begun to establish the Konrad mine as a repository.

Also in the mid-1970s, the Gorleben salt dome north of Asse was selected as a provisional site for a repository to contain all categories of radioactive waste. If the site investigation confirms its suitability and the licensing procedure confirms the site, construction of a repository could start after 1995 with the emplacement of wastes at the turn of the century.

Work in the Asse salt mine and the subsequent studies in the Gorleben salt dome, both near the northeastern border with East Germany, triggered public opposition which has delayed the program. The intermediate storage facility for spent fuel elements at Gorleben is technically operational but has not entered service because of litigation. Construction of a second such facility in Ahaus is suspended by a court order. A storage facility for low-level radioactive waste at the Gorleben site is functional. Licensing is under way to construct a pilot plant at Gorleben for the conditioning of high-level wastes prior to final disposal in a facility also proposed for this salt dome. A 1987 accident in an exploratory shaft has set back the work schedule on the disposal facility by about a year. The disposal program is studying the emplacement of both reprocessing wastes and spent fuel at Gorleben. Approximately one billion marks (almost $C 700 million) has already been spent in this effort.

Under West German law, electric utilities must demonstrate in a six-year moving plan that they can manage spent reactor fuel. The Wackersdorf reprocessing plant and the program for disposing of reprocessing wastes at Gorleben are part of this demonstration. If the utilities instead decided to go to the direct disposal of spent fuel, they would no longer meet the requirements for their operation. Until direct disposal is sufficiently well studied to qualify as a safe disposal method, the utilities cannot abandon the Wackersdorf program for reprocessing irradiated fuel. The West German representatives observed that theirs was the only country to tentatively site a disposal facility, but this is no longer the case since the United States legislated the Yucca Mountain site in Nevada for its disposal facility (subject to site verification work).

Electricity consumers will pay for the waste management program entirely, since German electric utilities absorb the costs and in turn incorporate them into the rate base. The state governments are responsible for administering the program but not for funding it.

D. The French Nuclear Power Program

1. History of French Nuclear Development

France has a population of 56 million inhabiting a country of 549,000 square kilometres (212,000 square miles). The Committee's visit to France was limited to Paris and its immediate surroundings. Given the centralized nature of the French Government, however, this still afforded Committee members the opportunity to speak with officials from many of the relevant agencies in the nuclear field.

The French reactor program was initially based on a graphite-moderated and gas-cooled reactor fuelled with natural uranium. Nine reactors of this type were built, beginning with the 2 MW Marcoule G–1 reactor which was connected to the grid in 1956 and ending with the 540 MW Bugey–1 reactor connected in 1972. Four of these reactors are still in service. France began building PWR reactors in the 1960s, with the 310 MW Chooz A–1 unit being the first of this type to see service in 1967. In 1969, France decided to base its nuclear power program on the PWR, while recognizing that the breeder reactor was likely to play a key role in long-term nuclear development.

The problems caused by the 1973 oil embargo convinced France that energy independence was vital to the country's interests. In 1974, the French Government charged Electricité de France (EdF), the national electric utility, with the task of developing a nuclear power program capable of providing one-third of the nation's total energy needs by the year 1990. In 1987, France generated a greater share of its electricity – 70% – from nuclear units than any other country. France is second only to the United States in installed nuclear generating capacity. Almost one-sixth of nuclear reactor construction worldwide is taking place in France, whose nuclear building program is exceeded only by that of the Soviet Union. How France has managed this remarkable achievement is well expressed in the words of the Director-General of EdF's Engineering and Construction Division (EdF, 1986, p. 3):

> The essential ingredient in the success of France's nuclear power program is the high level of competence of each sector involved in the program. Success also rests on government's, EDF's, and industry's determination to reach defined goals. The coordinated implementation of skills and resources has endowed our nuclear power industry with a unique degree of coherence that explains its ability to get things done.

Perhaps one of the reasons that France has embraced nuclear power with so little public dissent is the central role that French scientists have played in the development of nuclear physics. Henri Becquerel, Pierre and Marie Curie, Frédéric Joliot and others brought distinction to French nuclear science. Even so, this distinguished history does not explain the French success. What also stands out is the organization that France has brought to the enterprise.

Key Components of the French Nuclear Power Program

Electricité de France is the world's largest electric utility, created in 1946 by the nationalization of more than 1,500 electricity producing and distributing companies. EdF generates 90% of France's electricity, owns all of the national transmission system and distributes 96% of the electricity. The utility designs, constructs, owns and operates its nuclear plants. EdF's electricity sales in 1986 amounted to 140 billion francs ($C 28 billion). It is France's largest investor, with 37 billion francs ($C 7.4 billion) invested in 1986.

The French nuclear industry is structured around two poles: the Commissariat à l'Énergie Atomique (French Atomic Energy Commission) and its subsidiaries on one hand and the major nuclear suppliers, led by Framatome and Alsthom, on the other.

The **Commissariat à l'Énergie Atomique** is a huge public company – with many subsidiaries and 40,000 employees – whose primary focus is nuclear research and development. CEA performs basic and applied research, develops military applications of atomic energy, is involved with all aspects of the nuclear fuel cycle including radioactive waste management, and provides assistance to the government in the fields of nuclear safety and security. COGEMA is CEA's largest subsidiary; its 14,000 employees supply the entire range of services associated with the nuclear fuel cycle. Also part of CEA is ANDRA – l'Agence Nationale pour la gestion des Déchets Radioactifs (National Radioactive Waste Management Agency). Since 1983, all of CEA's interests have been grouped in the holding company CEA-Industrie.

Framatome, established in 1958, designs and manufactures the main components of PWR reactors – pressure vessels, steam generators, pressurizers and in-core instrumentation. With its 5,000 employees, Framatome has performed the R&D and manufacturing of the nuclear steam supply systems for all three series of French PWRs. Framatome manufactures reactor fuel; carries out the supply, assembly, testing and commissioning of nuclear equipment; and performs reactor in-service inspections. Novatome, 70% owned by Framatome, built the Creys-Malville fast breeder reactor. Framatome also builds research reactors and nuclear propulsion reactors for submarines. In January of 1986, Framatome was reorganized and its new capital structure includes a 35% interest held by CEA-Industrie and a 10% interest held by EdF.

Alsthom is a group of companies employing 40,000 people and one of France's two largest heavy equipment manufacturers. One-third of Alsthom's activities are concentrated in the design and fabrication of electric power plant equipment; it is France's only manufacturer of turbo-generators.

Sources: EdF, 1986; Canada, External Affairs, Canadian Embassy, Paris, 1988; Framatome, 1987.

In 1946, the Commissariat à l'Énergie Atomique (CEA) assumed responsibility for promoting the use of nuclear energy in France. CEA's work resulted in three experimental power reactors being built at Marcoule. These reactors were the prototypes of the GGCR (natural uranium fuelled, graphite moderated, gas cooled) series. In 1956, the French Government asked EdF to build the first commercial

GGCRs, which took the form of the Chinon units A1, A2 and A3. The largest and last GGCR unit built in France was the 515 MWe (net) Bugey 1 reactor, which was connected to the grid in 1972. After development work on the enriched uranium, light water reactor design in the 1960s, France decided in 1969 to continue its nuclear program based on the PWR. (EdF, 1986)

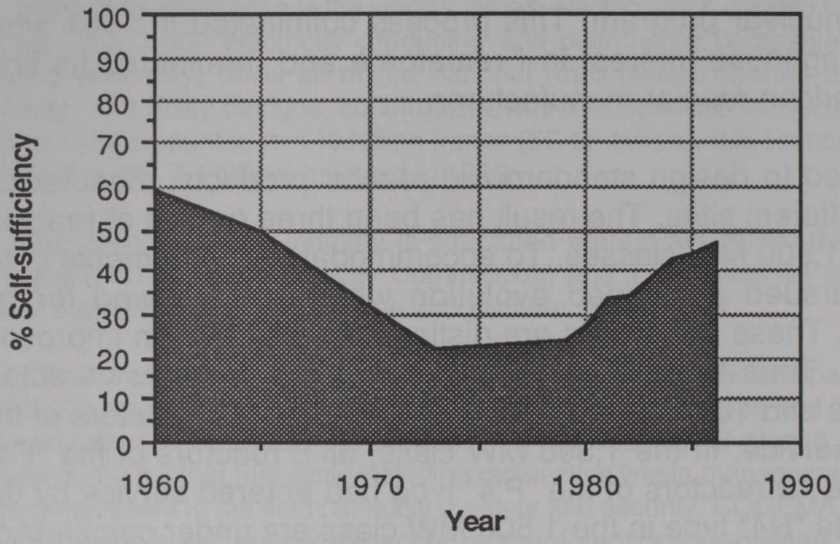
Having made this decision, the French Government undertook to establish a technically independent nuclear program. This process culminated in 1981 when the CEA acquired the Westinghouse interest in Framatome and terminated its licensing agreements with the American reactor manufacturer.

France also elected to design standardized reactor products, manufactured in series but adaptable to different sites. The result has been three groups of reactors: the 900 MW, 1,300 MW and 1,500 MW classes. To accommodate improvements in reactor technology, EdF has pursued a stepped evolution which has allowed for reactor sub-series within a class. These sub-series are distinguished by design improvements within the general class. Thus the 900 MW class has six "pre-series" reactors, 18 reactors of the "CP1" type and 10 reactors of the "CP2" type. All 34 reactors of the 900 MW class have entered service. In the 1,300 MW class, all 8 reactors of the "P4" type are in service and 4 of the 12 reactors of the "P'4" type had entered service by the end of 1987. Six reactors of the "N4" type in the 1,500 MW class are under construction. Six smaller reactors (four GGCRs, one PWR and one fast breeder) are also in service in France. During 1988, two 1,300 MW class reactors are expected to be connected to the national grid. (Framatome, 1988)

The first 900 MW reactor, Fessenheim 1, took 78 months to complete. Construction of the early CP1 units of the 900 MW class averaged about 70 months and later units were built in an average of 60 months. The 1,300 MW class reactors are taking from 72 to 80 months, from the start of civil works to grid connection, but the work schedule on some of these units is deliberately being stretched out because electricity demand has not grown as rapidly in recent years as had been forecast. (EdF, 1986)

In 1973, France obtained only 22.5% of its primary energy supply from domestic sources; in 1986, that share had risen to 46.2%, almost entirely due to the expansion of the nuclear power program. In the year 2000, France projects between 52% and 58% self-sufficiency in primary energy output. Figure 10 illustrates the change in France's energy self-sufficiency from 1960 to 1986. The decline in self-sufficiency from 1960 to 1973 reflects the substitution of imported oil for domestically produced coal in French energy use. Primary electricity represented 32.7% of France's consumption of primary energy in 1986 and nuclear-electricity accounted for 69.7% of the electricity used; therefore, nuclear-electricity comprised about 23% of French primary energy use. France projects that nuclear-electricity will satisfy 32% of its energy demand in 1990 (compared with 1.8% in 1973), oil 30% (66% in 1973), coal 15% (17.2% in 1973), natural gas 12% (8.4% in 1973), hydro-electricity 8% (5.5% in 1973) and renewable energy forms 3% (1.1% in 1973).

Figure 10: French Self-sufficiency in Primary Energy, 1960–1986



Source: Observatoire de l'Énergie, France.

2. The Current Power Reactor Program

France had 53 power reactors in service with a net installed generating capacity of 44,133 MWe as of 1 January 1988. An additional 10 units are under construction and will add a further 13,410 MWe to France's nuclear-electric generating capacity. Six older, smaller units have been shut down.

Table 11 presents information on France's operating power reactors.

In 1987, nuclear-electric generation accounted for 69.8% of France's total production of electricity. This share has grown rapidly in the 1980s, as the following statistics for nuclear-electricity as a percentage of total electricity output show: 1986 – 69.7%; 1985 – 64.9%; 1984 – 58.7%; 1983 – 48.3%; and 1982 – 38.7%. No other country in the world has this level of reliance on fission power in its domestic electricity system, and France projects that in 1990 three-quarters of its electricity (and almost one-third of the country's total requirement for primary energy) will be of nuclear origin.

Table 11: France's Operating Power Reactors at 1 January 1988

Reactor Unit / Type	In Operation	Net Electrical Output	Contractor
Chinon A-3 / GGCR	1967	480 MW	Industrie France
Chinon B-1 / PWR	1984	870 MW	Framatome
Chinon B-2 / PWR	1984	870 MW	Framatome
Chinon B-3 / PWR	1987	870 MW	Framatome
Chinon B-4 / PWR	1988	890 MW	Framatome
St-Laurent A-1 / GGCR	1969	480 MW	Industrie France
St-Laurent A-2 / GGCR	1971	515 MW	Industrie France
St-Laurent B-1 / PWR	1983	880 MW	Framatome
St-Laurent B-2 / PWR	1983	880 MW	Framatome
Chooz A-1 / PWR	1970	305 MW	A-F-W
Bugey-1 / GGCR	1972	540 MW	Industrie France
Bugey-2 / PWR	1979	920 MW	Framatome
Bugey-3 / PWR	1979	920 MW	Framatome
Bugey-4 / PWR	1979	900 MW	Framatome
Bugey-5 / PWR	1980	900 MW	Framatome
Phénix / FBR	1974	233 MW	Industrie France
Fessenheim-1 / PWR	1977	880 MW	Framatome
Fessenheim-2 / PWR	1978	880 MW	Framatome
Dampierre-1 / PWR	1980	890 MW	Framatome
Dampierre-2 / PWR	1981	890 MW	Framatome
Dampierre-3 / PWR	1981	890 MW	Framatome
Dampierre-4 / PWR	1981	890 MW	Framatome
Gravelines B-1 / PWR	1980	910 MW	Framatome
Gravelines B-2 / PWR	1980	910 MW	Framatome
Gravelines B-3 / PWR	1981	910 MW	Framatome
Gravelines B-4 / PWR	1981	910 MW	Framatome
Gravelines C-5 / PWR	1985	910 MW	Framatome
Gravelines C-6 / PWR	1985	910 MW	Framatome
Tricastin-1 / PWR	1980	915 MW	Framatome
Tricastin-2 / PWR	1980	915 MW	Framatome
Tricastin-3 / PWR	1981	915 MW	Framatome
Tricastin-4 / PWR	1981	915 MW	Framatome

Table 11 Continues...

Table 11 Continued (France's Operating Power Reactors at 1 January 1988)

Reactor Unit / Type	In Operation	Net Electrical Output	Contractor
Blayais-1 / PWR	1981	910 MW	Framatome
Blayais-2 / PWR	1983	910 MW	Framatome
Blayais-3 / PWR	1983	910 MW	Framatome
Blayais-4 / PWR	1983	910 MW	Framatome
Cruas Meysse-1 / PWR	1984	880 MW	Framatome
Cruas Meysse-3 / PWR	1984	880 MW	Framatome
Cruas Meysse-2 / PWR	1985	900 MW	Framatome
Cruas Meysse-4 / PWR	1985	880 MW	Framatome
Paluel-1 / PWR	1985	1,330 MW	Framatome
Paluel-2 / PWR	1985	1,330 MW	Framatome
Paluel-3 / PWR	1986	1,330 MW	Framatome
Paluel-4 / PWR	1986	1,330 MW	Framatome
Saint Alban-1 / PWR	1986	1,335 MW	Framatome
Saint Alban-2 / PWR	1987	1,335 MW	Framatome
Flamanville-1 / PWR	1986	1,330 MW	Framatome
Flamanville-2 / PWR	1987	1,330 MW	Framatome
Cattenom-1 / PWR	1987	1,300 MW	Framatome
Cattenom-2 / PWR	1987	1,300 MW	Framatome
Belleville-1 / PWR	1987	1,310 MW	Framatome
Nogent-1 / PWR	1987	1,310 MW	Framatome
Super-Phénix / FBR	1987	1,200 MW	Novatome

Source: France, Commissariat à l'Énergie Atomique, *Les Centrales Nucléaires dans le Monde*, 1987 Edition, Paris, 1987, p. 22-23; France, Commissariat à l'Énergie Atomique, *Dossier France au 1er janvier 1988*, CEA/DPg–E/88-53/JCLR, Paris, 1988.

Nuclear generating capacity already exceeds the base load and many of the 900 MW reactors are cycled to meet peaking power needs. Load following is most commonly required in May and June. In 1985, there were 935 daily cyclings by the 900 MW class reactors. During the peak month of June, there were more than 200 cyclings, with the 900 MW reactors running at less than 40% of capacity as a group during about 90 of those cyclings. (EdF, 1986) Some concern has been expressed about the stresses imposed on a reactor whose power level fluctuates on a frequent basis, but the French have no evidence to suggest that load following is prematurely aging these reactors.

Despite this less than optimal use of some of their reactors, the French claim a distinct cost advantage for nuclear-electricity. In 1985, 1 kilowatt-hour of nuclear-electricity cost 0.180 francs to produce while 1 kWh of coal-fired electricity cost 0.405 francs, more than twice as much. EdF asserts that "the French kWh is the cheapest in Europe." For a French power plant going into operation in 1992, EdF projects that the cost per kWh at a coal-fired station will be more than 150% of the cost at a nuclear station. (EdF, 1986)

Framatome has established an impressive record since the mid-1970s. Within France, the company built thirty-four 900-megawatt units from 1977 through 1987 and twelve 1,300-megawatt units from 1984 through 1987. Abroad, Framatome constructed five 900-megawatt units from 1975 through 1985. This totals 51 reactors in just 13 years, or an average of almost four units per year. Ten 1,300- and 1,500-megawatt units will be completed in France from 1988 through 1993, and four units will be completed abroad within the same period of time. The foreign sales have been to Belgium (three units operating and one under construction); South Africa (two units operating); South Korea (two units under construction); and China (two units under construction). (Framatome, 1988)

The remaining reactors under construction mark the end of France's intensive phase of reactor development. With reduced rates of load growth, reactor orders may fall to as few as one every 18 to 24 months. The French Government has committed itself, however, to providing whatever support is required to sustain domestic reactor manufacturing capability through this period of reduced activity. Continuing maintenance work on France's operating reactors, together with any reactor sales generated domestically or abroad, will be sufficient to sustain an essential level of activity. Framatome will intensify its work on improved unit performance, higher unit availability, safety enhancement and improved instrumentation and control systems. Framatome is also studying reactor life extension programs; officially, French reactors are designed for 40 years of operation but may be able to remain in service longer. Framatome observed that it builds reactor pressure vessels with about one-third as many welds as American-built pressure vessels. Therefore the French-made pressure vessels will suffer less embrittlement over time and should have a greater life expectancy.

Framatome will also diversify into non-nuclear fields, such as computer-based industrial systems, work on compressors and turbines, and special equipment and services in space and military applications of high technology. Another initiative is to fashion accords with foreign partners. For example, Framatome has an agreement with Babcock & Wilcox to market PWR fuel assemblies in North America; has entered into a joint study with KWU on the feasibility of introducing nuclear power in Indonesia; and, together with EdF and Westinghouse, is developing computer-aided training and systems services.

The French Government intends that Framatome will survive the temporary slump in reactor construction, whatever is required.

An objective of the CEA, arising from France's determination to be more independent in its energy system, has been complete control of the nuclear fuel cycle. This has been achieved. Uranium is produced by COGEMA, which controls two-thirds of France's reserves of this metal and produces 80% of the uranium mined in France. In the non-Communist world, COGEMA has access to more than 20% of uranium reserves. Through direct participation or acting through affiliates and subsidiaries, COGEMA has acquired uranium interests in such countries as Canada, the United States, Spain, Gabon, Niger, Zambia and Senegal. In Canada, COGEMA is the principal shareholder in Amok Ltd. (with a 38% direct interest and, through its 100% ownership of Compagnie de Mokta, a further 37% interest), mining at Cluff Lake in Saskatchewan, and holds a 36.4% interest in Cigar Lake Mining Corp., a joint venture with Saskatchewan Mining Development Corporation and Idemitsu. In 1986, COGEMA produced 7,700 tonnes of uranium concentrates, including 2,600 tonnes from its French mines. (Canada, External Affairs, Canadian Embassy, Paris, 1988; France, CEA, 1987)

Ore conversion into uranium metal and uranium hexafluoride is done by Comurhex, 49% owned by COGEMA. France's refining and conversion capacity is approximately 25,500 tonnes of uranium per year, or 25% of the non-Communist world's capacity. Its share of the market is roughly the same. France's uranium enrichment capacity is 11.4 million swu (isotope separative work units) (1) per year, out of a world capacity, including the Communist bloc, of 32.1 million swu/year. The great bulk of this capacity – 10.8 million swu/year – is represented by the Eurodif plant at Tricastin, the world's largest uranium enrichment complex. COGEMA holds a 51.5% interest in Eurodif, with Italy, Spain and Belgium being the other participants. Eurodif can supply the fuel for about ninety 1,000 MW reactors on a continuing basis. Eurodif currently holds about 43% of the global market for uranium enrichment. (NEI, 1988; Personal communication: CEA, 14 April 1988)

COGEMA is similarly involved in the business of fuel fabrication. Fuel for the GGCRs and fast breeder reactors is manufactured by SICN (Société Industrielle de Combustible Nucléaire), a wholly-owned subsidiary of COGEMA. Fragema, owned equally by COGEMA and Framatome, markets LWR fuel which is made by FBFC, owned 25% by COGEMA, 25% by Framatome and 50% by Uranium Péchiney. The fabrication of mixed-oxide (uranium-plutonium) fuels is done by Commox, owned 60% by COGEMA and 40% by Belgonucléaire. France has developed the capacity to manufacture about 1,550 tonnes of heavy metal (uranium and plutonium) fuel per year, and claims approximately 19% of the market. (Canada, External Affairs, Canadian Embassy, Paris, 1988; France, CEA, 1987; Personal communication: CEA, 14 April 1988)

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(1) The separative work unit is a measure of the effort expended in separating uranium into two streams, one enriched and the other depleted. The separative work unit is independent of the separation process applied. The kilogram is the unit of separative work, and enrichment charges and energy consumption are calculated per kilogram of separative work performed.

The reprocessing of spent fuel is carried out in COGEMA plants at Marcoule and La Hague. La Hague is undergoing a major expansion which will boost its reprocessing capability from 400 tonnes of heavy metal/year to 1,600 tonnes. Marcoule has a capacity of 600 tonnes/year. One of the new 800 tonnes/year reprocessing plants at La Hague is dedicating the first 10 years of its operation to 30 foreign customers of COGEMA who signed reprocessing contracts and financed its construction.

3. Radioactive Waste Management

ANDRA, the National Radioactive Waste Management Agency, is a non-profit government agency established in 1979 by ministerial decree within the CEA. It is responsible for the long-term management of all types of radioactive wastes from all sources. ANDRA reflects the decision by the French Government to separate radioactive waste management from regulatory and inspection activities.

ANDRA has two responsibilities: (1) to manage existing disposal sites of which there is one at Centre de la Manche on the Cotentin Peninsula; and (2) to design, site and construct new long-term facilities. Funding to cover the costs of these activities including transportation of radioactive wastes to the facilties comes directly from the waste producers, particularly EdF but also research laboratories, hospitals, universities and industry. No public funds are used for waste management. ANDRA notes that, in 1982, radioactive wastes were being created in France at the rate of 1 kg per capita annually, while all other domestic and industrial wastes were being generated at the rate of 2,500 kg per capita annually (France, CEA, ANDRA, undated).

Radioactive wastes are divided into two categories for disposal. Short-lived wastes are those radioactive materials having a half-life of up to 30 years. After 300 years (ten times the longest half-life of any radionuclide in this group), the residual radiological risk at the disposal facility will be so low that the site can be put to unrestricted use. Short-lived wastes are therefore adequately cared for in the French view by near-surface disposal. Long-lived wastes, whether low-, intermediate- or high-level, must be kept from the population for thousands of years and are therefore to be disposed of through deep burial (several hundred metres) in stable geological formations.

Near-surface disposal of short-term wastes is based on three levels of protection: site selection, facility design and waste packaging. The objective is to prevent the radioactive materials from being transported away from the site by water. At Centre de la Manche, much of the waste is enclosed in drums. These drums stand freely if their contents are low-level wastes; they are encased in concrete monoliths if their contents are higher-level wastes. There is a system for monitoring the level of radioactivity within the facility and inspection galleries are part of its design. Begun in 1969, Centre de la Manche was taken over by ANDRA in 1979. This facility has a capacity of 485,000 cubic metres; to mid-1986, 350,000 cubic metres of wastes had been emplaced. With wastes being added at the rate of approximately 30,000 cubic metres annually, Centre de la Manche will be filled in 1991. The site for a new facility has been selected about 250 km from Paris and permission to construct a repository was granted in 1987. This facility, known as Centre de l'Aubé, will have a capacity of one million cubic metres and be adequate for about 30 years. It is scheduled to begin commercial operation in late 1990 or early 1991. To stabilize the generation of lower-level, short-lived wastes at roughly 30,000 cubic metres per year, France's nuclear power stations have begun a major program to decrease waste production.

The second element of ANDRA's activities is long-lived radioactive waste disposal. When the second reprocessing unit at La Hague becomes operational, about 4,000 to 5,000 cubic metres of long-lived wastes will be generated yearly. By the year 2000, accumulated wastes will amount to approximately 60,000 cubic metres. ANDRA is currently engaged in a site research program to select an appropriate location for a disposal facility. Granite, salt, clay and shale are all considered suitable geological formations for disposal and France has a research site in each of these four types. A program was begun in 1987 to confirm a single site; that process is expected to be finished in 1990. The next step will be to construct a full-fledged laboratory to qualify the site, with site validation anticipated around 1995. Facility construction could be completed by very early in the next century, although ANDRA suspects that this schedule may not be met.

The French regard radioactive waste management as a *technical* problem; it is not an issue whose solution is to be determined by a referendum or by protest. Unlike the situation in Sweden and West Germany, local governments in France have no right to refuse a site selected by ANDRA for a disposal facility. To date there has not been any significant problem with public acceptance of the waste management program, in part because ANDRA undertakes a major public information program to explain its activities. The public is said to be strongly opposed, however, to the notion of accepting radioactive wastes from other countries.

E. The U.S. Nuclear Power Program

1. History of American Nuclear Development

The first demonstration of a sustained fission chain reaction was accomplished by Enrico Fermi, under the stands of Stagg Field at the University of Chicago. Fermi built a graphite-moderated natural uranium "pile" operating at very low power so that it could be cooled in the open air. This pile went critical on December 2, 1942, and was immediately followed by the construction of larger piles at Hanford in Washington State, with the intention of producing plutonium for an atomic bomb.

Congress subsequently passed the *Atomic Energy Act* of 1946, which dealt with the continued military development of nuclear energy while establishing a legal framework for industrial applications. This Act created the Atomic Energy Commission (AEC) and provided it with oversight authority for U.S. nuclear activities. In 1954, Congress approved a program to build five industrial prototype reactors. These included an experimental boiling water reactor at the Argonne National Laboratory near Chicago; a graphite-moderated sodium-cooled reactor at Santa Susanna in California; a heavy water reactor at Oak Ridge, Tennessee; an experimental breeder reactor at Idaho Falls; and the 60 MW Shippingport prototype PWR reactor which began operation in 1957. Shippingport became the first civilian power reactor in the United States, and was built by Westinghouse under contract for the AEC. It remained in service as a power reactor until 1974, ending its life as a test reactor before being decommissioned in 1982.

With the assistance of the AEC, private companies took up civilian reactor construction. After Shippingport, Westinghouse constructed the 185 MW Yankee Rowe PWR in Massachusetts, which entered service in 1961. Babcock & Wilcox built the 265 MW Indian Point 1 reactor near New York City, continuing the evolution of the PWR design. General Electric opted for the BWR design path, building the 200 MW Dresden 1 reactor in Illinois for Commonwealth Edison. From this auspicious beginning, the U.S. nuclear industry was to grow rapidly through the 1960s and 1970s.

The accident at unit 2 of the Three Mile Island nuclear power station near Harrisburg, Pennsylvania on March 28, 1979 was a major setback to the U.S. nuclear program. The plant was extensively damaged and radioactivity was released to the environment. The average radiation dose delivered to an individual living within a five-mile radius of the plant was calculated to be about 10% of the annual background radiation, and the maximum exposure to an off-site individual in the general population was estimated at 70 millirems. [This level of exposure is roughly half of what an average person would be exposed to over the course of a year from natural sources, medical sources, etc.] Exposure of the general public to radioactivity was so small that it was concluded that there would be no detectable increase in the cancer rate, developmental abnormalities or genetic effects. Nonetheless, the accident had a profound impact. As the 1979 *Report of The President's Commission on the Accident at Three Mile Island* observed (page 2):

> ...The accident was initiated by mechanical malfunctions in the plant and made much worse by a combination of human errors in responding to it...During the next 4 days, the extent and gravity of the accident was unclear to the managers of the plant, to federal and state officials, and to the general public. What is quite clear is that its impact, nationally and internationally, has raised serious concerns about the safety of nuclear power...

The Commission stated that its findings did not require drawing the conclusion that nuclear power is inherently too dangerous to be exploited, but did observe that "fundamental changes are necessary if those risks [associated with nuclear power] are to be kept within tolerable limits". The Commission concluded that people-related problems were the fundamental issue, not equipment problems.

> When we say that the basic problems are people-related, we do not mean to limit this term to shortcomings of individual human beings – although those do exist. We mean more generally that our investigation has revealed problems with the "system" that manufactures, operates, and regulates nuclear power plants. There are structural problems in the various organizations, there are deficiencies in various processes, and there is a lack of communication among key individuals and groups...
>
> We note a preoccupation with regulations. It is, of course, the responsibility of the Nuclear Regulatory Commission to issue regulations to assure the safety of nuclear power plants. However, we are convinced that regulations alone cannot assure safety. Indeed, once regulations become as voluminous and complex as those regulations now in place, they can serve as a negative factor in nuclear safety. The regulations are so complex that immense efforts are required by the utility, by its suppliers, and by the NRC to assure that regulations are complied with...
>
> The most serious "mindset" is the preoccupation of everyone with the safety of equipment, resulting in the down-playing of the importance of the human element in nuclear power generation. We are tempted to say that while an enormous effort was expended to assure that safety-related equipment functioned as well as possible, and that there was backup equipment in depth, what the NRC and the industry have failed to recognize sufficiently is that the human beings who manage and operate the plants constitute an important safety system. (United States, The President's Commission on the Accident at Three Mile Island,1979, p. 8-10)

It is the Committee's impression that many of these systemic problems persist in the U.S. nuclear power program.

The United States terminated its main work on breeder reactors when Congress voted to end support of the 350 MW Clinch River, Tennessee breeder project. Begun in 1973, Clinch River had absorbed nearly $US 2 billion when the project was stopped.

The expansion of U.S. nuclear generating capacity since the 1973 oil embargo is calculated to have displaced more than 3.5 billion barrels of imported oil at a saving estimated to approach $US 100 billion. The corresponding capital investment in this expanded nuclear-electric generating capacity amounted to $US 130 billion. In 1973, nuclear-electricity stood fifth in the United States among the various sources of electric power production. Nuclear power overtook oil-fired generation in 1980, gas-fired generation in 1983 and hydro-electric generation in 1984. Today, nuclear power stands second only to coal-fired generation.

Although total energy consumption in the United States in 1986 was up by only about 2% from the level of 1973, the demand for electricity had increased by more than 40% while the demand for non-electric energy had fallen by approximately 11%.

To the end of 1987, 13 state referenda had been held to shut down operating power reactors or to prevent the operation of reactors under construction. All 13 referenda had been defeated. Seven votes were held in 1976; two have been conducted since the Chernobyl accident. Three attempts to shut down Maine's one operating power reactor, Maine Yankee, failed by margins of 60-40 (1980), 55-45 (1982) and 59-41 (1987). Maine Yankee has produced electricity for 15 years at an average operating cost of 2.5 cents/kWh, one of the lowest unit costs in the world. (USCEA, 1988b) At least three attempts will be made to shut down operating power reactors during 1988 (in California, Oregon and Massachusetts).

2. The Current Power Reactor Program

The United States has the world's largest nuclear-electric power program. At January 1, 1988, there were 109 operable reactors totalling 97.2 GW of generating capacity, 14% of the nation's total electrical generating capacity. These units supplied approximately 18% of the electricity generated in the United States during 1987. Thirty-three of the 50 states have licensed power reactors, led by Illinois with 13 units. Fourteen reactors with an aggregate capacity of 16.6 GW are under construction and two reactors with a capacity of 2.2 GW are on order. Four states (Vermont, Connecticut, New Jersey and South Carolina) derive more than 50% of their electricity from nuclear generation, with Vermont leading at 76% in 1987. An additional 12 states obtain more than 25% of their electricity from nuclear stations. (USCEA, 1988a) Table 12 lists operable power reactors by state, as of January 1, 1988.

The PWR design has dominated the U.S. program, with twice the installed capacity of the BWR type (65,299 MW of PWR capacity compared with 33,802 MW of BWR capacity, as of July 1987). With the exception of two BWR units, all of the reactor capacity under construction in the United States today is of PWR design. (NEI, 1988, p. 13)

Although this world-leading program is an impressive accomplishment in the country that originated the LWR technology, the statistics obscure the fact that the U.S. nuclear power program is in disarray today. Not a single new unit is planned in the United States, and the most recently-placed reactor order, after reactor cancellations are excluded, dates back to October of 1973. Thus every remaining reactor under construction in the United States is 15 years or more old. It was made clear to the Committee in its U.S. discussions that no new reactor orders will be placed as long as the current conditions prevail.

The average U.S. electrical generating station is now 19 years old. Although life-extension programs are underway at many of these stations, both fossil-fuelled and nuclear, the growing age of American electric capacity is causing some erosion in generating efficiency. Coupled with the lack of new generating capacity, problems in electric power reliability will soon emerge and, in fact, are already becoming apparent in New England. The New England Power Pool had to institute voltage reductions on three occasions in 1987 while two completed nuclear plants in or adjoining the region – Shoreham on Long Island, New York and Seabrook in Vermont – sit idle. [Seabrook is authorized to load fuel but not permitted to operate, and remains in the construction permit category although 100% complete.]

Table 12: Operating Power Reactors in the United States as of 1 January 1988

State	Reactor Unit / Type	Commercial Operation	Net Electrical Output (MW)	Manufacturer
Alabama	Joseph M. Farley 1-2 / PWR	77/81	829/829	Westinghouse
	Browns Ferry 1-3 / BWR	74/75/77	1065/1065/1065	General Electric
Arizona	Palo Verde 1-3 / PWR	86/86/88	1270/1270/1270	Combustion Engineering
Arkansas	Arkansas Nuclear 1-2 / PWR	74/80	850/912	Babcock & Wilcox
California	Diablo Canyon 1-2 / PWR	85/86	1084/1106	Westinghouse
	Rancho Seco 1 / PWR	75	918	Babcock & Wilcox
	San Onofre 1 / PWR	68	436	Westinghouse
	San Onofre 2-3 / PWR	83/84	1070/1080	Combustion Engineering
Colorado	Fort St. Vrain / HTGR	79	330	General Atomic
Connecticut	Haddam Neck / PWR	68	582	Westinghouse
	Millstone 1 / BWR	70	660	General Electric
	Millstone 2 / PWR	75	870	Combustion Engineering
	Millstone 3 / PWR	86	1153	Westinghouse
Florida	Crystal River 3 / PWR	77	850	Babcock & Wilcox
	Turkey Point 3-4 / PWR	72/73	666/666	Westinghouse
	St. Lucie 1-2 / PWR	76/83	839/839	Combustion Engineering
Georgia	Edwin I. Hatch 1-2 / BWR	75/79	775/781	General Electric
	Alvin W. Vogtle 1 / PWR	87	1122	Westinghouse
Illinois	Dresden 2-3 / BWR	70/71	794/794	General Electric
	Zion 1-2 / PWR	73/74	1040/1040	Westinghouse
	Quad Cities 1-2 / BWR	72/72	789/789	General Electric
	LaSalle 1-2 / BWR	84/84	1078/1078	General Electric
	Braidwood 1-2 / PWR	88/88	1120/1120	Westinghouse
	Byron 1-2 / PWR	85/87	1120/1120	Westinghouse
	Clinton 1 / BWR	87	933	General Electric
Iowa	Duane Arnold / BWR	75	565	General Electric
Kansas	Wolf Creek / PWR	85	1150	Westinghouse
Louisiana	River Bend 1 / BWR	86	940	General Electric
	Waterford 3 / PWR	85	1104	Combustion Engineering
Maine	Maine Yankee / PWR	72	825	Combustion Engineering
Maryland	Calvert Cliffs 1-2 / PWR	75/77	825/825	Combustion Engineering
Massachusetts	Pilgrim 1 / BWR	72	670	General Electric
	Yankee / PWR	61	175	Westinghouse

Table 12 continues...

Table 12 Continued **(Operating Power Reactors in the United States as of 1 January 1988)**

State	Reactor Unit / Type	Commercial Operation	Net Electrical Output (MW)	Manufacturer
Michigan	Big Rock Point / BWR	65	69	General Electric
	Palisades / PWR	71	777	Combustion Engineering
	Fermi 2 / BWR	88	1100	General Electric
	Donald C. Cook 1-2 / PWR	75/78	1030/1100	Westinghouse
Minnesota	Monticello / BWR	71	545	General Electric
	Prairie Island 1-2 / PWR	73/74	530/530	Westinghouse
Mississippi	Grand Gulf 1 / BWR	85	1250	General Electric
Missouri	Callaway / PWR	84	1120	Westinghouse
Nebraska	Cooper / BWR	74	760	General Electric
	Fort Calhoun 1 / PWR	73	492	Combustion Engineering
New Jersey	Oyster Creek / BWR	69	650	General Electric
	Salem 1-2 / PWR	77/81	1106/1106	Westinghouse
	Hope Creek 1 / BWR	86	1067	General Electric
New York	Indian Point 2-3 / PWR	73/76	873/965	Westinghouse
	James A. FitzPatrick / BWR	75	816	General Electric
	Shoreham / BWR	(a)	809	General Electric
	Nine Mile Point 1-2 / BWR	69/88	610/1080	General Electric
	Robert E. Ginna / PWR	70	470	Westinghouse
North Carolina	Brunswick 1-2 / BWR	77/75	821/821	General Electric
	Shearon Harris 1 / PWR	87	900	Westinghouse
	William McGuire 1-2 / PWR	81/84	1129/1129	Westinghouse
Ohio	Perry 1 / BWR	87	1205	General Electric
	Davis-Besse 1 / PWR	77	860	Babcock & Wilcox
Oregon	Trojan / PWR	76	1130	Westinghouse
Pennsylvania	Beaver Valley 1-2 / PWR	76/87	833/836	Westinghouse
	Three Mile Island 1-2 / PWR	74/78 (b)	819/900	Babcock & Wilcox
	Susquehanna 1-2 / BWR	83/85	1050/1050	General Electric
	Peach Bottom 2-3 / BWR	74/86	1065/1065	General Electric
	Limerick 1 / BWR	86	1055	General Electric
South Carolina	H.B. Robinson 2 / PWR	71	700	Westinghouse
	Oconee 1-3 / PWR	73/74/74	846/846/846	Babcock & Wilcox
	Catawba 1-2 / PWR	85/86	1129/1129	Westinghouse
	Summer 1 / PWR	84	885	Westinghouse
Tennessee	Sequoyah 1-2 / PWR	81/82	1148/1148	Westinghouse

Table 12 continues...

Table 12 Continued **(Operating Power Reactors in the United States as of 1 January 1988)**

State	Reactor Unit / Type	Commercial Operation	Net Electrical Output (MW)	Manufacturer
Texas	South Texas Project 1 / PWR	88	1250	Westinghouse
Vermont	Vermont Yankee / BWR	72	528	General Electric
Virginia	Surry 1-2 / PWR	72/73	781/781	Westinghouse
	North Anna 1-2 / PWR	78/80	926/926	Westinghouse
Washington	WPPSS 2 / BWR	84	1100	General Electric
Wisconsin	Point Beach 1-2 / PWR	70/72	485/485	Westinghouse
	Kewaunee / PWR	74	535	Westinghouse

Notes: Reactors shown as beginning commercial operation in 1988 hold low power or full power licences issued before the end of 1987.

(a) The Shoreham reactor received a nonrestricted low power operating licence on July 3, 1985, but has not been allowed to enter commercial service.

(b) Three Mile Island 2 has been shut down since the accident of March 28, 1979, and is not included as a licensed reactor. Three Mile Island 1 was shut down on March 28, 1979, and allowed to resume commercial operation on November 8, 1985.

Source: U.S. Council for Energy Awareness, *Electricity from Nuclear Energy*, 1988 Edition, Washington, D.C., 1988a, p. 9-19.

State Public Utility Commissions are increasingly unwilling to allow the full cost of completed nuclear stations (and some coal-fired stations) be included in the rate base. Over the period 1980-1986, state regulators made the following disallowances for new power reactors coming into service (values are given in U.S. funds and the year of commercial operation is shown in brackets) ("Disallowances by State Regulators for Nuclear Units (1980-1986)", *Nuclear Industry*, March/April 1988, p. 64):

Wolf Creek 1 (Kansas/1985) – $1,641.0 million
Waterford 3 (Louisiana/1985) – $284.0 million
Summer 1 (South Carolina/1984) – $123.0 million
Susquehanna 1 (Pennsylvania/1983) – $287.0 million
Susquehanna 2 (Pennsylvania/1985) – $560.0 million
Shoreham 1 (New York/no commercial service) – $1,395.0 million

San Onofre 2 & 3 (California/1983 and 1984) –	$328.0 million
Millstone 3 (Connecticut/1986) –	$353.0 million
Limerick 1 (Pennsylvania/1986) –	$368.9 million
Grand Gulf 1 (Mississippi/1985) –	$49.0 million
Fermi 2 (Michigan/1988/1985 full power operating licence) –	$680.0 million
Callaway 1 (Missouri/1984) –	$421.7 million
Byron 1 (Illinois/1985) –	$101.5 million

These disallowances may change in amount as regulatory decisions are appealed and court settlements occur. Most U.S. utilities are privately owned and it is the stockholders who ultimately shoulder this penalty; they are understandably reluctant to underwrite new investments in nuclear power.

The cost of nuclear-electricity is a subject of debate in the United States. Earlier nuclear stations have a clear cost advantage over oil-fired plants. Science Concepts of Washington, in research funded by the U.S. Council for Energy Awareness, calculates that the life-cycle cost of nuclear-electricity averaged over all nuclear units completed through 1987 amounts to 4.7¢/kWh compared with oil-fired electricity at 8.2¢/kWh (low oil price scenario), 9.7¢/kWh (base case for future oil prices), or 11.4¢/kWh (high oil price scenario). If the subgroup of the most expensive nuclear stations – those completed from 1984 through 1987 – is considered, Science Concepts finds their life-cycle cost to be marginally below the low oil price scenario, at 7.6¢/kWh. Given the large "front loading" effect caused by absorbing the capital cost of a reactor into the rate base, the first-year cost of nuclear-electricity from the high-cost recent reactors is calculated to be 60% higher than the first-year cost of oil-fired electricity but to be 20% below the life-cycle cost of the oil-fired electricity in the U.S. Department of Energy (DOE) oil price base case. The life-cycle of a nuclear or oil-fired generating unit is taken to be 30 years. The oil price projections used were those of the DOE. The low price scenario has oil costing $US 27.83 per barrel in constant 1987 dollars in the year 2000; the base case has oil costing $US 34.18 in 2000; and the high price scenario has oil at $US 43 at the end of the century. In the high price case, the cost of oil is projected to fall to $US 30 (in constant 1987 dollars) in 2010, as substitutes for oil reduce demand. (Lennox and Mills, 1988a)

DOE's Energy Information Administration (EIA) has released a study of nuclear power plant operating costs in the United States. Its findings are not comforting for the U.S. nuclear industry. The question that the EIA attempted to answer was: What factors caused the escalation in nonfuel operating costs of power reactors over the period 1975-1984? The analysis considered operating and maintenance (O&M) costs and the cost of post-operational capital additions. The study did not identify all of the factors contributing to the escalation in the cost of nuclear-electricity nor did it disaggregate all of the costs, but did reach a number of conclusions. (United States, DOE, EIA, 1988)

The principal factors contributing to increased O&M costs were determined to be: (a) real effects of rising O&M wage rates, the price of O&M materials, lagged O&M costs and simple inflation; (b) increased regulatory requirements by the Nuclear Regulatory Commission (NRC); and (c) increases in the cost of replacement power. Increasing age and reactor operating experience reduced O&M costs, and O&M costs tended to fall as the price of reactor capital additions rose. Some states have introduced incentive rate-of-return programs (rewarding utilities with a higher rate of return if their nuclear plants perform well and penalizing them if the units do not) which were found to increase O&M costs. The rising costs of post-operational capital additions were primarily a function of: (a) increased regulatory requirements by the NRC; (b) unexplained costs; (c) increasing age; and (d) the replacement of steam generators and pipe cracking repairs. Past maintenance practices, as measured by average real O&M costs in previous years, reduce capital additions costs as maintenance expenditures rise. The effect of state regulatory factors on capital additions costs could not be determined. (United States, DOE, EIA, 1988)

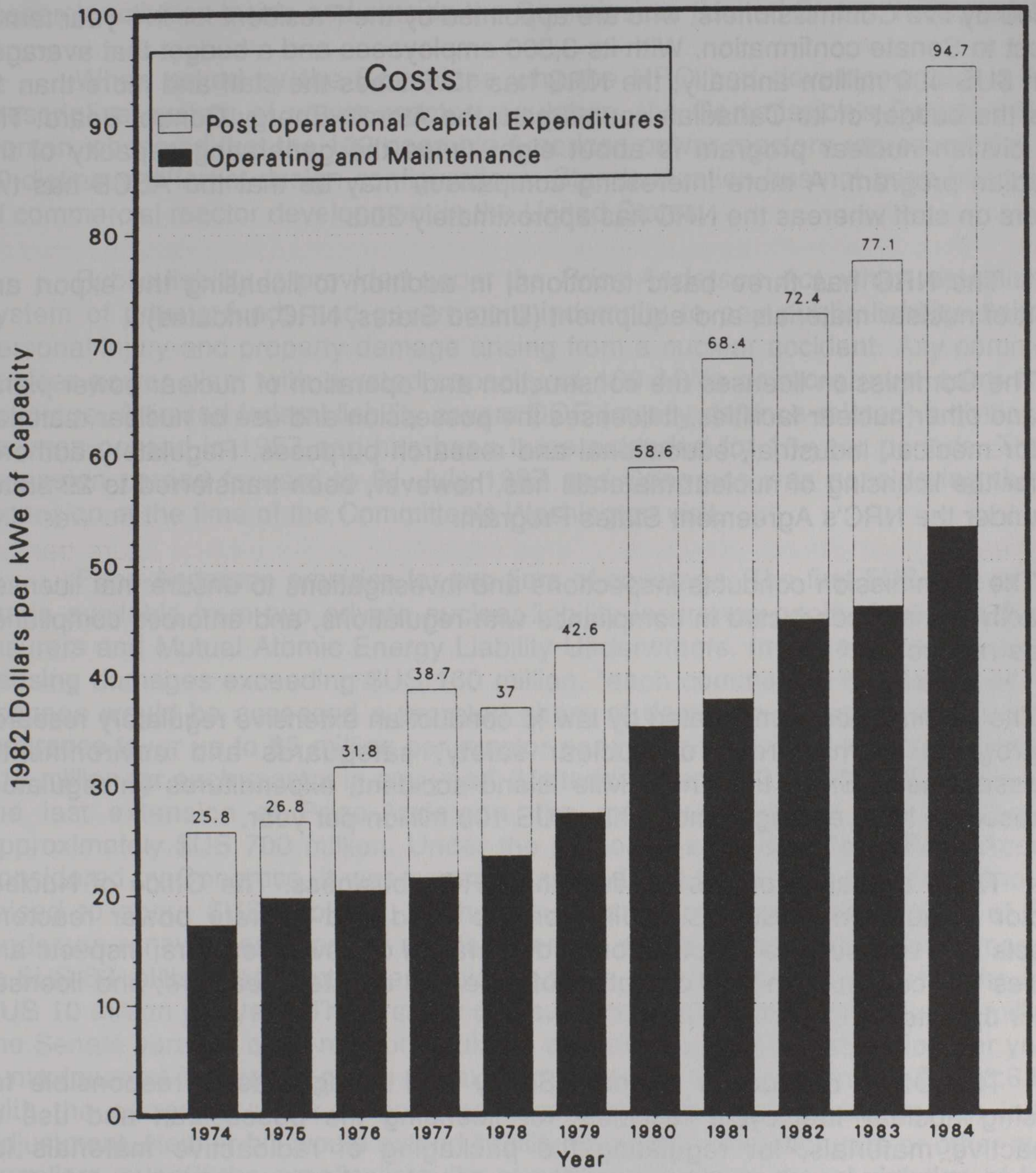
Plant aging has a dual effect: operating experience tends to reduce costs while plant deterioration tends to increase costs. For O&M costs, the learning effect was found to outweigh the aging effect. For post-operational costs of capital additions, however, the aging effect outweighs the learning effect. Since the study was restricted to nuclear reactors of 400 MW capacity or greater, the average plant age was only eight years; DOE cautions against drawing firm conclusions about the future trend in O&M costs as a function of plant aging based on this limited experience. (United States, DOE, EIA, 1988)

Figure 11 displays the escalation in annual, real, nonfuel operating costs of U.S. power reactors over the 11-year period 1974-1984. Costs are subdivided into post-operational capital expenditures and operating and maintenance expenditures, and are expressed in constant 1982 dollars.

The EIA estimates that routine operating and maintenance expenses, measured in 1982 dollars, rose from $US 17 per kilowatt of installed electrical generating capacity in 1974 to $US 53 per kilowatt in 1984. This translates into an average annual increase of 12%. Post-operational capital investments rose from $US 9 per kilowatt of capacity to $US 42, an average annual increase of 17%. In contrast, the EIA reports that the real O&M costs at coal-fired plants increased at a rate of only 2% annually over the same period. This led the EIA to draw two conclusions.

> ...First, the continued escalation in operating costs may reduce or possibly even negate any cost advantage that nuclear power might have. Many analysts believe that the nuclear power plants that entered commercial operation in the 1960's and 1970's were economical relative to coal-fired power plants. This may not be the case if operating costs continue to escalate. Second, many proponents of nuclear power are currently assuming an expected licensed operating lifetime of nuclear power plants of more than 40 years. If operating costs continue to escalate, at some point in time it may be economical to shut down older plants, and thus the assumption of a 40-year operating life may be optimistic... (United States, DOE, EIA, 1988, p. 1)

Figure 11: Escalation in Annual, Real, Nonfuel Operating Costs for U.S. Reactors of 400 MW Capacity or Greater, 1974-1984



Source: United States, DOE, EIA, Office of Coal, Nuclear, Electric and Alternate Fuels, *An Analysis of Nuclear Power Plant Operating Costs*, DOE/EIA–0511, Washington, D.C., 16 March 1988, p. viii.

The Nuclear Regulatory Commission regulates the civilian use of nuclear materials in the United States. Created by the *Energy Reorganization Act* of 1974, the NRC took over the regulatory functions of the former Atomic Energy Commission. The Energy Research and Development Administration (which was in turn to become part of the Department of Energy) assumed the other functions of the AEC. The NRC is headed by five Commissioners, who are appointed by the President for five-year terms, subject to Senate confirmation. With its 3,300 employeees and a budget that averages about $US 400 million annually, the NRC has 12.5 times the staff and more than 19 times the budget of its Canadian counterpart, the Atomic Energy Control Board. The U.S. civilian nuclear program is about eight times the generating capacity of the Canadian program. A more interesting comparison may be that the AECB has two lawyers on staff whereas the NRC has approximately 200.

The NRC has three basic functions, in addition to licensing the export and import of nuclear materials and equipment (United States, NRC, undated):

(1) The Commission licenses the construction and operation of nuclear power plants and other nuclear facilities. It licenses the possession and use of nuclear materials for medical, industrial, educational and research purposes. Regulatory authority for the licensing of nuclear materals has, however, been transferred to 29 states under the NRC's Agreement States Program.

(2) The Commission conducts inspections and investigations to ensure that licensed activities are conducted in compliance with regulations, and enforces compliance as required.

(3) The Commission is mandated by law to conduct an extensive regulatory research program in the areas of nuclear safety, safeguards and environmental assessment. Since the Three Mile Island accident, expenditures on regulatory research have averaged more than $US 100 million per year.

Three operating offices conduct the NRC's business. The Office of Nuclear Reactor Regulation evaluates applications to build and operate power reactors; inspects and licenses the construction and operation of power reactors; inspects and licenses the construction and operation of research and test reactors; and licenses reactor operators.

The Office of Nuclear Material Safety and Safeguards is responsible for licensing nuclear fuel cycle facilities; for licensing the possession and use of radioactive materials; for regulating the packaging of radioactive materials for transport; for developing policies to safeguard nuclear facilities and materials from theft, sabotage or diversion; and for reviewing the application of IAEA safeguards on U.S.-sourced nuclear materials used in foreign countries. This Office also directs the implementation of the Commission's responsibilities under the *Nuclear Waste Policy Act* of 1982; the *Low-Level Radioactive Waste Policy Act* of 1980 and the *Low-Level Radioactive Waste Policy Amendments Act* of 1985, which govern the disposal of low-level wastes; and the *Uranium Mill Tailings Radiation Control Act* of 1978.

The Office of Nuclear Regulatory Research plans and implements programs of nuclear regulatory research; develops standards and resolves safety issues at regulated facilities; develops and promulgates technical regulations; and coordinates research activities inside and outside the Commission. (United States, NRC, 1987b)

When asked by the Committee why the NRC had developed such a highly prescriptive system of power reactor regulation, the Commission's Director, Harold Denton, observed that the 109 operable American power reactors represented at least 60 distinctly different design configurations. Standardization has not been been a goal of commercial reactor development in the United States.

Public liability is provided under the *Price-Anderson Act*, which established a system of private funds and government indemnity to pay public liability claims for personal injury and property damage arising from a nuclear accident. Any commercial nuclear power plant with a rated capacity of 100 MWe or more must carry liability coverage. A limited federal liability covers DOE (mostly defence-related) activities. The Act was passed in 1957 and has been twice extended for 10-year periods. The last extension carried forward to 31 July 1987 and Congress was considering the next extension at the time of the Committee's Washington visit.

Price-Anderson provides for two tiers of coverage. The first $US 160 million is made available from two private nuclear-liability insurance pools, American Nuclear Insurers and Mutual Atomic Energy Liability Underwriters. In the event of an accident causing damages exceeding $US 160 million, "each commercial nuclear power plant licensee would be assessed a prorated share of damages in excess of the primary insurance layer up to $5 million per reactor per year per incident but not in excess of $10 million for each reactor in any year" (United States, NRC, 1983, p. 1). Thus, under the last extension of Price-Anderson, the maximum liability per accident was approximately $US 700 million. Under the proposed amendments to Price-Anderson considered by Congress, it was generally agreed that the liability coverage should be raised to about $US 7 billion. In the House of Representatives version of Price-Anderson renewal, each power reactor licensee would become liable for damages up to $US 63 million per reactor per accident, to be paid into a claims fund at the rate of $US 10 million per year. The first tier of insurance would remain at $US 160 million. In the Senate version, each reactor would be assessed up to $US 12 million per year for a maximum of five years, giving a maximum coverage of approximately $US 6.6 billion with the current number of licensed reactors. Both bills provide for an inflation adjustment. Neither bill would extend liability to reactor manufacturers or other nuclear suppliers, even if the supplier is guilty of negligence or intentional violation of federal safety regulations. Part of the debate centred on whether the *Price-Anderson Act* should be renewed for 10 years (House version) or for 20 years (Senate version). (Price-Anderson Campaign, "Floor Vote Briefing Packet")

In August 1988, the House and Senate reached a compromise on Price-

Anderson renewal. The Act was extended for 15 years to 1 August 2002. The ceiling on liability was raised to approximately $US 7 billion and now applies both to NRC reactor licensees and to the facilities of DOE contractors. In the case of NRC licensees, damages would be paid from the insurance pool described above. In the case of an accident occurring at the nuclear facility of a DOE contractor, the federal government would pay the damages. If damages from a nuclear accident are expected to exceed $US 7 billion, the President must submit to Congress a compensation plan that includes an estimate of damages and recommendations for sources of funding to pay for damages exceeding the liability limit. In a new departure, the Act allows the Secretary of Energy to impose fines of up to $US 100,000 per day on contractors who violate DOE safety regulations. Contractors' employees become subject to criminal penalties for willful violation of safety rules. These civil penalties do not apply to DOE nuclear research laboratories (such as Los Alamos, Lawrence Livermore, Sandia and Brookhaven).

Critics of Price-Anderson note that the NRC proposed to Congress in 1983 that utility liability be unlimited, with a reactor licensee responsible for annual assessments of $US 10 million per year per reactor until all public damages arising from an accident are settled. Figure 11 indicates that non-fuel operating costs had already risen to $US 95 per kilowatt of installed capacity (measured in constant 1982 dollars) by 1984; a surcharge of $US 10 million per reactor per year in 1988 dollars added to today's operating costs would not represent a large increment in those costs and could be accommodated in the rate base if passed through to consumers. Critics also want nuclear suppliers and contractors subject to some degree of liability. A utility can sue a supplier for damages – as GPU Nuclear Corp. (a consortium of Metropolitan Edison, Jersey Central Power & Light and Pennsylvania Electric) did to reactor manufacturer Babcock & Wilcox for on-site damages at Three Mile Island – but the supplier need not purchase liability insurance nor compensate members of the public for damages.

Some U.S. utilities have failed to bring an acceptable degree of commitment to nuclear plant operation. In the aftermath of the Three Mile Island accident, the U.S. nuclear industry created its own Institute of Nuclear Power Operations (INPO), to monitor the operation of utility nuclear stations. Some of INPO's findings are very disturbing. For example, at the Peach Bottom nuclear power station in Pennsylvania, INPO reports that reactor operators were sleeping, playing video games and otherwise being inattentive while on duty in the control room. On March 31, 1987, Peach Bottom was ordered shut down by the Nuclear Regulatory Commission as a result of reports of operators sleeping on shift. In correspondence with utility management, INPO used the following language to describe its dissatisfaction with the situation:

> ...The grossly unprofessional behavior by a wide range of shift personnel, involving all shifts, and condoned by the shift superintendents reflects a major breakdown in the management of a nuclear facility. It is an embarrassment to the industry and to the nation.

Other utilities, like Duke Power headquartered in North Carolina, have brought extensive resources to the nuclear endeavour and are running successful programs.

Even so, American utilities have not generally attained the lifetime load factors that many European and Japanese utilities – and Ontario Hydro – have achieved.

The U.S. nuclear industry is at a watershed. Without rejuvenation, the industry may languish for the foreseeable future.

3. Radioactive Waste Management

The U.S. nuclear fuel cycle is presented in Figure 12. Solid arrows indicate the fuel cycle as it operates today, without commercial reprocessing and without a disposal facility in place. Broken arrows show how the cycle would be closed if the United States moved to spent fuel reprocessing and waste disposal.

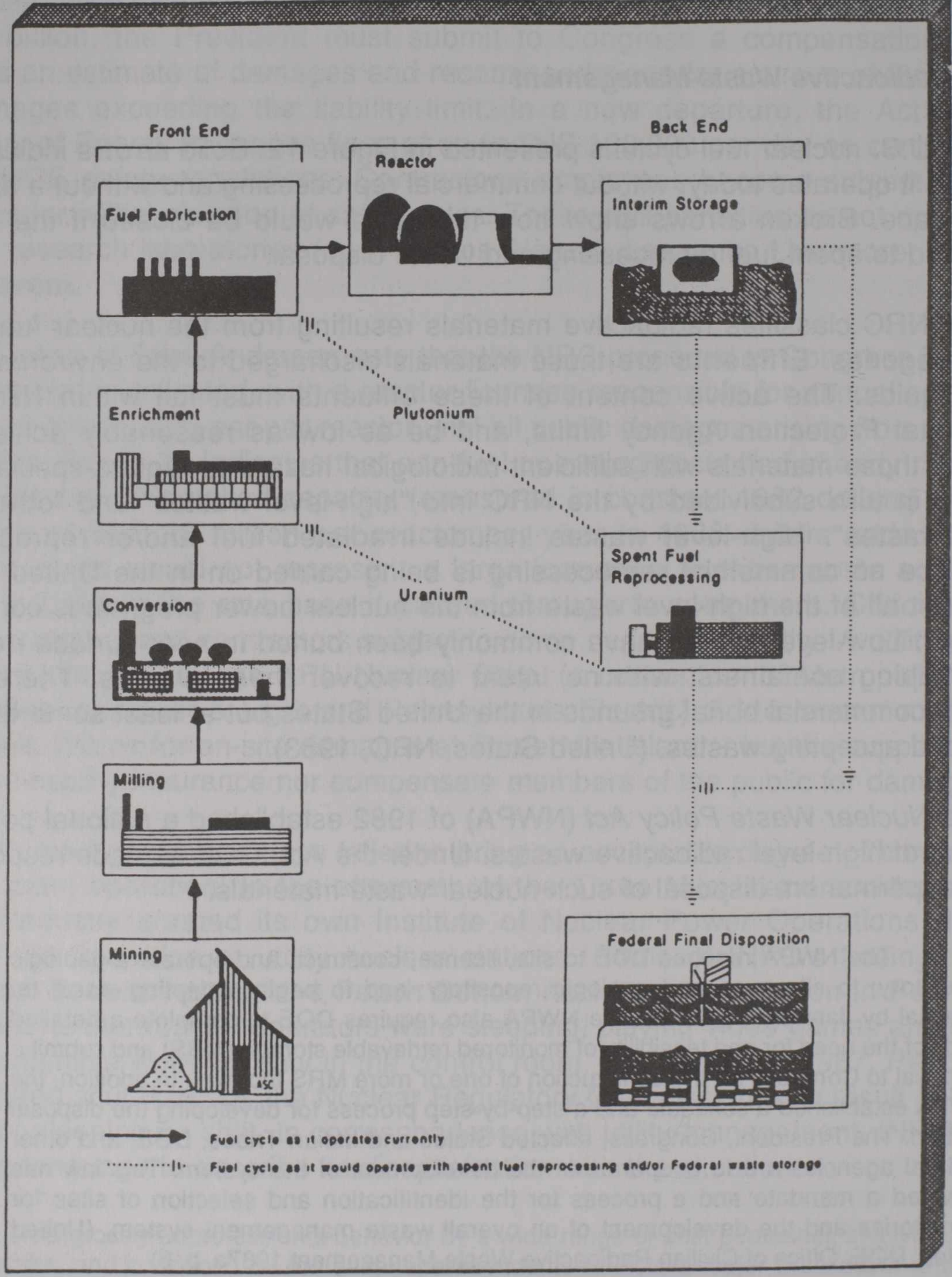
The NRC classifies radioactive materials resulting from the nuclear fuel cycle into two categories. **Effluents** are those materials discharged to the environment as gases or liquids. The active content of these effluents must fall within NRC and Environmental Protection Agency limits, and be as low as reasonably achievable. **Wastes** are those materials with sufficient radiological hazard to require special care. Wastes are in turn subdivided by the NRC into "high-level wastes" and "other than high-level wastes". High-level wastes include irradiated fuel and/or reprocessing wastes. Since no commercial reprocessing is being carried on in the United States today, almost all of the high-level waste from the nuclear power program is contained in spent fuel. Low-level wastes have commonly been buried in near-surface trenches in their shipping containers, with no intent to recover these wastes. There were formerly six commercial burial grounds in the United States but at least some of these have stopped accepting wastes. (United States, NRC, 1983)

The *Nuclear Waste Policy Act* (NWPA) of 1982 established a national policy for the disposal of high-level radioactive wastes. Under the Act, DOE is made responsible for the safe, permanent disposal of such nuclear waste materials.

> The NWPA requires DOE to site, license, construct, and operate a geologic repository; to site a second geologic repository; and to begin accepting waste for disposal by January 31, 1998. The NWPA also requires DOE to complete a detailed study of the need for and feasibility of monitored retrievable storage (MRS) and submit a proposal to Congress for the construction of one or more MRS facilities. In addition, the NWPA established a schedule and a step-by-step process for developing the disposal system. The President, Congress, affected States and Indian Tribes, DOE, and other Federal agencies are to cooperate in the development of the system. This law has provided a mandate and a process for the identification and selection of sites for repositories and the development of an overall waste management system. (United States, DOE, Office of Civilian Radioactive Waste Management,1987a, p. 6)

The Act established the Office of Civilian Radioactive Waste Management within DOE and made it responsible for implementing the Act, executing its policy and managing the national program.

Figure 12: The U.S. Nuclear Fuel Cycle



Source: United States, DOE, EIA, Office of Coal, Nuclear, Electric and Alternate Fuels, *World Nuclear Fuel Cycle Requirements 1987*, DOE/EIA–0436(87), Washington, D.C., 27 August 1987, p. 2.

Two federal agencies are assigned the task of developing regulatory requirements for the disposal of high-level radioactive wastes. The Nuclear Regulatory Commission is the primary regulatory agency for repository siting, construction, operation and decommissioning. NRC will license the repository and define its technical criteria. The Environmental Protection Agency, EPA, is responsible for developing standards for repositories to protect the health and safety of the public.

NWPA requires that the users of nuclear-electricity pay for the cost of disposing of spent nuclear fuel. The federal government collects a fee of 1 mill per kilowatt-hour (0.1¢/kWh) from utilities operating nuclear power plants. This money accumulates in the Nuclear Waste Fund and is used to pay for all elements of the waste disposal program: the repository, any MRS facility constructed, waste transportation and federal support for state and Indian tribe participation. The status of the fund is reviewed annually to ensure that sufficient money is accumulating to cover the full cost of the disposal system. As of 31 January 1988, the fund had a balance of $US 1,967.6 million. The federal government will pay for defence wastes which are placed in the repository.

NWPA required DOE to build and operate one repository and to conduct siting activities for a second repository. Until recently, site studies for the first repository were being conducted in three different rock types; salt domes and bedded salt deposits in Deaf Smith County in Texas, basalt at the Hanford site in Washington State, and volcanic tuff (solidified volcanic ash) at Yucca Mountain in Nevada. In recent amendments made by Congress to the NWPA, the siting process was restricted to the Yucca Mountain site, over the objections of Nevada representatives, subject to site confirmation studies. The NWPA amendments direct that site-specific activities at the Hanford and Deaf Smith sites be phased out within 90 days, except for reclamation work. The requirement in the NWPA to locate a second geologic repository was repealed and replaced by the requirement that DOE report to the President and Congress between 2007 and 2010 on the need for a second repository. Authorization to site, construct and operate one monitored retrievable storage, MRS, facility was given in the amendments. At the same time, the amendments annulled the Secretary of Energy's proposal to locate an MRS on the former Clinch River reactor site at Oak Ridge, Tennessee. The amendments direct that in siting an MRS, "the Secretary shall make no presumption or preference to such sites by reason of their previous selection."

The current schedule for developing the first geological repository has the following objectives (Kay, 1988, p. 8).

• Start of exploratory shaft construction	2nd quarter 1989
• Start of *in situ* testing	4th quarter 1990
• Submission of site selection report and environmental impact statement to the President	1994
• Submission of licence application to the NRC	1995

• Receipt of construction authorization from the NRC	1998
• Start of construction	1998
• Start of phase 1 operations	2003
• Start of phase 2 operations	2006

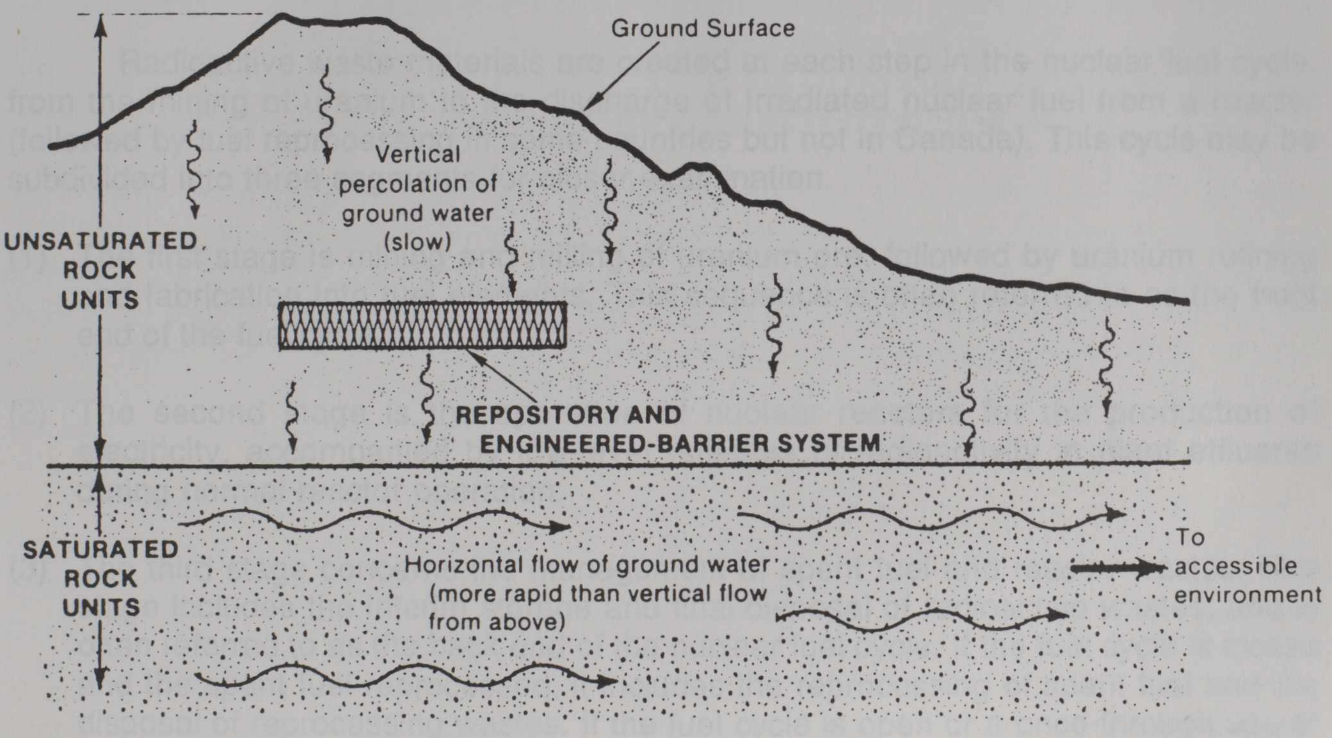
In licensing the repository, the NRC divides the approval process into four steps. These are site characterization, construction authorization, repository licensing and repository decommissioning. Reports must be submitted to the NRC and to the appropriate federal and state agencies at each stage; these documents are subject to public review. The site must meet a 10,000-year waste isolation requirement established by the EPA. Yucca Mountain is located in an arid region of the southwestern United States. The repository would be constructed above the water table in a rock zone experiencing a very slow downward flow of groundwater, as shown schematically in Figure 13.

Yucca Mountain lies in southern Nevada on the western boundary of the Nevada Test Site, about 100 miles from Las Vegas. The site straddles the junction of three blocks of federal land. Most of the repository and its associated surface facilities would lie within the Nellis Air Force Range, with smaller portions of the site lying within the Nevada Test Site and on land managed by the Bureau of Land Management.

The host rock for the repository would be a welded tuff, the solidified remains of a hot volcanic ash flow that occurred during a period of volcanism lasting from about 16 to 8 million years ago. The resulting sequence of volcanic rocks is about 6,500 feet thick at the site. The principal design criteria for a mined geologic repository are given in the following list (Personal communication: Jerome Saltzman, Office of Civilian Radioactive Waste Management, DOE, Washington, D.C., 1 May 1988).

Major Parameters	**Requirement/Criterion**
Waste types accepted	Spent fuel, vitrified reprocessing wastes and defence high-level wastes
Capacity	70,000 tonnes of waste
Receiving rate	Phase 1 (2003): 400 tonnes/year Phase 2 (2008): 3,000 tonnes/year
Isolation of radioactivity	10,000 years
Waste package containment	Substantially complete for 300-1,000 years
Groundwater travel time	1,000 years to the accessible environment
Radionuclide release rate (after 1,000 years)	1 part in 100,000 per year

Figure 13: Schematic Cross Section through the Proposed Yucca Mountain Site



Source: United States, DOE, Office of Civilian Radioactive Waste Management, *Site Characterization Plan – Overview: Yucca Mountain Site, Nevada Research and Development Area, Nevada. Consultation Draft*, DOE/RW–0161, Washington, D.C., January 1988, p. 41.

Waste emplacement at Yucca Mountain is scheduled to last for 26 years, at which time the repository is projected to be filled. Following emplacement, a "caretaker" period of 24 years begins. Over this 50-year span of time, during which various tests will be conducted to make sure the repository is functioning as expected, the waste will be retrievable. At the end of the caretaker period, the repository will be permanently sealed. The surface facilities will be decontaminated and decommissioned, and the site returned to its natural state to the extent practicable. Site markers will be erected to warn future generations of the presence of a repository. (United States, DOE, Office of Civilian Radioactive Waste Management, 1988, p. 33)

If the site characterization studies reveal that Yucca Mountain is unsuitable for locating a high-level waste repository, the exploratory facilities will be decommissioned and a new site determined.

- Receipt of construction authorization from the NRC 1998
- [illegible]
- Start of phase 1 operations 2003
- Start of phase 2 operations 2008

In licensing the repository, the NRC divides the approval process into four steps. These are site characterization, construction authorization, repository licensing and repository decommissioning. Reports must be submitted to the NRC and to the appropriate federal and state agencies at each stage, and these documents are subject to public review. The site must meet a 10,000-year waste isolation requirement established by the EPA. Yucca Mountain is located in an arid region of the southwestern United States. The repository would be [illegible] above the water table in a rock zone [illegible] a very [illegible] groundwater, as shown schematically in Figure 13.

Yucca Mountain is located [illegible] boundary of the Nevada Test Site, about [illegible] from Las Vegas. The site straddles the junction of three blocks of [illegible] the repository and its associated surface facilities would be [illegible] the Nevada Test [illegible] managed by the Bureau of Land Management.

The host rock for the repository would be a welded tuff, the solidified remains of a hot volcanic ash flow [illegible] during a period of volcanism lasting from about 16 to 8 million years ago. The resulting sequence of volcanic rocks is about 6,500 feet thick at the site. The principal design criteria for a mined geologic repository are given [illegible]

Major Parameters	Requirement/Criterion
[illegible]	[illegible]
[illegible]	Phase 1 (2003): 400 tonnes/year Phase 2 (2008): 3,000 tonnes/year
Waste package containment	Substantially complete for 300-1,000 years
Radionuclide release rate (after 1,000 years)	1 part in 100,000 per year

Radioactive Waste Management in Canada

A. The Nuclear Fuel Cycle in Canada

Radioactive waste materials are created at each step in the nuclear fuel cycle, from the mining of uranium to the discharge of irradiated nuclear fuel from a reactor (followed by fue! reprocessing in some countries but not in Canada). This cycle may be subdivided into three segments for closer examination.

(1) The first stage is mining and milling of uranium ore, followed by uranium refining and fabrication into fuel elements. This sequence is often referred to as the front end of the fuel cycle.

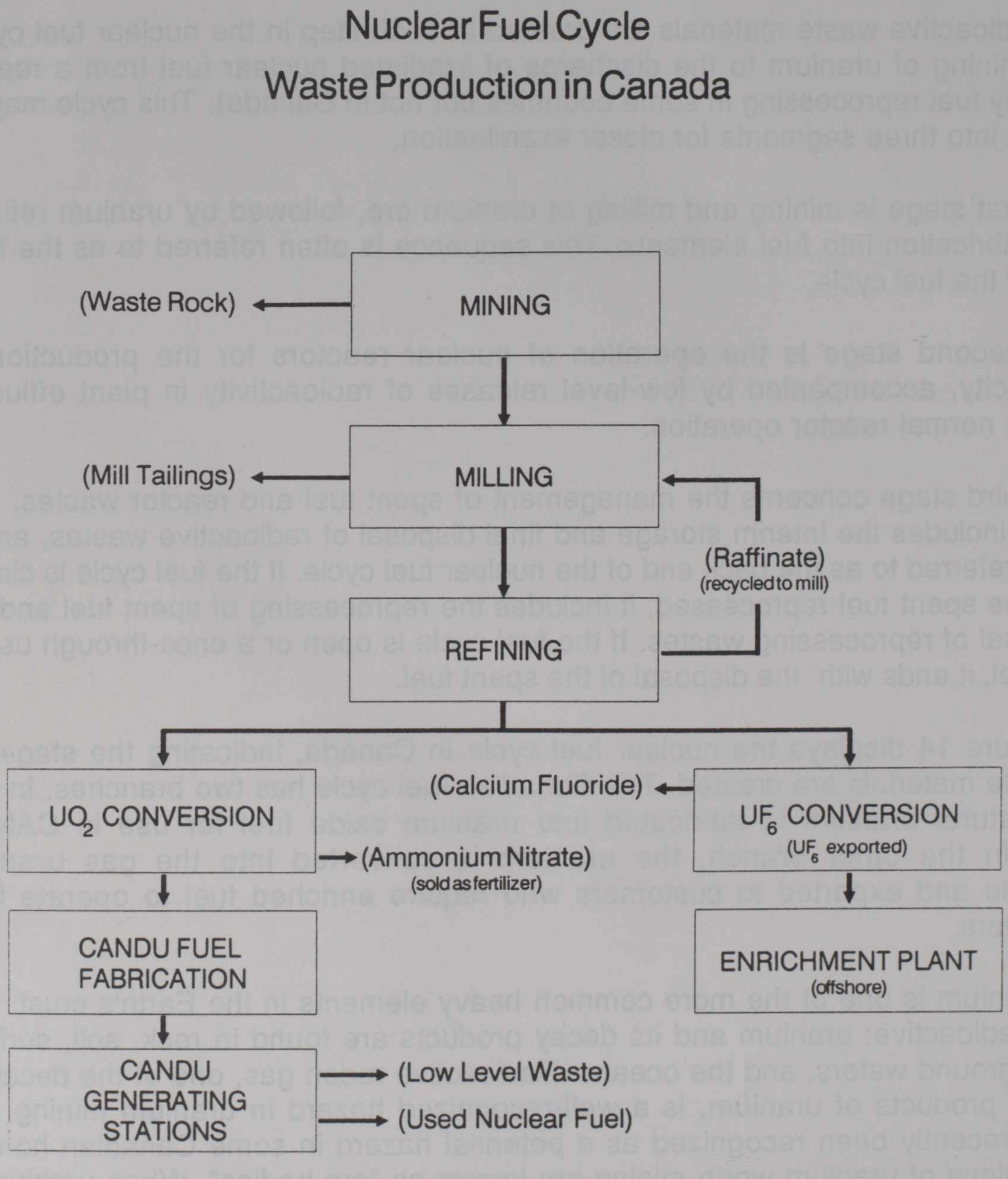
(2) The second stage is the operation of nuclear reactors for the production of electricity, accompanied by low-level releases of radioactivity in plant effluents during normal reactor operation.

(3) The third stage concerns the management of spent fuel and reactor wastes. This stage includes the interim storage and final disposal of radioactive wastes, and is often referred to as the back end of the nuclear fuel cycle. If the fuel cycle is closed and the spent fuel reprocessed, it includes the reprocessing of spent fuel and the disposal of reprocessing wastes. If the fuel cycle is open or a once-through use of the fuel, it ends with the disposal of the spent fuel.

Figure 14 displays the nuclear fuel cycle in Canada, indicating the stages at which waste materials are created. The Canadian fuel cycle has two branches. In one branch, natural uranium is fabricated into uranium oxide fuel for use in CANDU reactors. In the other branch, the uranium is converted into the gas uranium hexafluoride and exported to customers who require enriched fuel to operate light water reactors.

Uranium is one of the more common heavy elements in the Earth's crust. It is naturally radioactive; uranium and its decay products are found in rock, soil, surface and underground waters, and the oceans. Radioactive radon gas, one of the decay or "daughter" products of uranium, is a well-recognized hazard in uranium mining and has more recently been recognized as a potential hazard in some Canadian homes. Concentrations of uranium worth mining are known as "ore bodies". When uranium is mined, substantial quantities of waste rock are excavated along with the uranium ore. The waste rock contains some radioactive material but is too low in uranium content to warrant processing. Mine wastes are stored at the surface in the vicinity of the mine, and the common practice is to cover the waste rock with earth and vegetation. (Lyon and Tutiah, 1984)

Figure 14: The Nuclear Fuel Cycle in Canada and Its Associated Wastes



Nuclear Fuel Cycle
Waste Production in Canada

Source: Personal communication: Eva Rossinger, Whiteshell Nuclear Research Establishment, AECL, Pinawa, Manitoba, 4 July 1988.

The uranium ore is transported to a mill, usually located near the mine, where the uranium is separated from the remaining waste rock. The ore is crushed and ground into a fine sand to which chemicals are added to dissolve the uranium. The liquid with its dissolved uranium is then chemically treated to extract the uranium; the resulting concentrate is filtered and dried in a form known as "yellowcake". Milling wastes, or mill "tailings", include the finely ground waste rock and radioactive materials other than uranium. These wastes are discharged from the mill as a slurry and typically stored in tailings ponds. (Lyon and Tutiah, 1984) Mill tailings from some Saskatchewan mines are more radioactive, however, and are stored in concrete bunkers.

Proper management of mill tailings is important. The tailings not only contain radioactive materials arising from the uranium decay chain but also toxic elements such as arsenic and selenium which are present in the ore body. Tailings ponds should be engineered to prevent contaminated liquids from entering the groundwater system and surface waterways, and the amount of radon gas escaping to the atmosphere should be controlled. Unfortunately, uranium mine and mill tailings have not always been well managed in Canada.

Table 13 lists uranium mine/mill facilities licensed by the AECB as of 31 March 1988. All uranium mining and milling in Canada at the present time is carried out in Ontario and Saskatchewan. Table 13 does not include licences which the AECB has issued for "ore removal" or "underground exploration", where companies are extracting limited quantities of uranium ore for testing, assay or other noncommercial purposes.

Yellowcake is transported from the various mills to Canada's one uranium refinery, operated by Eldorado Resources Ltd. at Blind River, Ontario. This refinery has the capacity to produce 18,000 tonnes of uranium annually in the form of uranium trioxide (UO_3). Refinery waste is called raffinate and contains unwanted radioactive materials together with some useful uranium. The raffinate is recycled through one of two uranium mills at Elliot Lake (see Table 13) to extract more of the uranium. The remaining constituents of the raffinate are disposed of as part of the mill tailings. (Lyon and Tutiah, 1984; Canada, AECB, 1988)

The uranium trioxide produced at Blind River takes one of two conversion routes, depending on whether the uranium is destined to become CANDU fuel or whether it will be sold abroad for enrichment and use in light water reactors. Both conversion steps are carried out by Eldorado Resources at conversion plants located in Port Hope, Ontario. Most of the uranium produced in Canada is destined for export. This uranium is converted into uranium hexafluoride (UF_6) as a preparatory step to enrichment and is exported in this form. Calcium fluoride is the principal waste from this conversion process. At the present time, there is no use for the calcium fluoride and it is buried at a waste management site, but its potential as a fluxing agent in steel production is being studied. No other waste materials accrue to Canada from this branch of the nuclear fuel cycle since the enrichment plants are located in foreign countries. (Lyon and Tutiah, 1984)

Table 13: Canadian Uranium Mine/Mill Facilities Licensed by the AECB

Facility and Location	Licensee	Capacity
Cluff Lake, Phase II, Saskatchewan	Amok Ltd.	1,000 tonnes/year of uranium
Collins Bay B-Zone, Eldor Mines, Saskatchewan	Eldorado Resources Ltd.	3,200 tonnes/year of uranium
Denison Mines, Elliot Lake, Ontario	Denison Mines Ltd.	10,900 tonnes/day of mill feed 4,000 tonnes/year of acid raffinate 900 tonnes/year of limed raffinate
Key Lake, Saskatchewan	Key Lake Mining Corp.	5,700 tonnes/year of uranium
Panel Mine, Elliot Lake, Ontario	Rio Algom Ltd.	3,000 tonnes/day of mill feed
Quirke Mine, Elliot Lake, Ontario	Rio Algom Ltd.	6,350 tonnes/day of mill feed 5,000 tonnes/year of acid raffinate
Stanleigh Mine, Elliot Lake, Ontario	Rio Algom Ltd.	6,000 tonnes/day of mill feed
Stanrock Mine, Elliot Lake, Ontario	Denison Mines Ltd.	3,800 tonnes/day of ore

Source: Canada, AECB, *Annual Report 1987-88*, Ottawa, 1988, p. 18.

Uranium for use in CANDU reactors, about 20% of our uranium production, is converted into uranium dioxide (UO_2), a process which produces ammonium nitrate as waste. The ammonium nitrate has very low levels of radioactivity and is marketed as a commercial liquid fertilizer to local farmers. (Lyon and Tutiah, 1984)

Eldorado Resources also has the capability at its Port Hope operations to produce depleted uranium metal and alloys, and ammonium di-uranate.

The uranium dioxide to be used in CANDU reactors is sintered into pellets and then fabricated into fuel bundles. Negligible amounts of waste are created in the fuel fabrication step. The companies licensed by the AECB as of 31 March 1988 for fuel fabrication in Canada, the location of their facilities, and their fuel fabrication capacities are (Canada, AECB, 1988, p. 20):

- Canadian General Electric Canada Inc.:
  Toronto, Ontario– 1,050 tonnes/year of uranium as fuel pellets
  Peterborough, Ontario– 1,000 tonnes/year of uranium as fuel bundles

- Zircatec Precision Industries Inc.:
  Port Hope, Ontario– 900 tonnes/year of uranium as fuel pellets and bundles

- Earth Sciences Extraction Co.:
  Calgary, Alberta– 70 tonnes/year as uranium oxide compounds

Reactor operation results in the release of small quantities of radioactivity to the environment in liquid and airborne effluents. These releases are monitored and controlled in accordance with AECB regulations. In normal reactor operation, these releases are a very small fraction of the natural radiation to which all Canadians are exposed.

Reactor operation and maintenance also create other types of radioactive wastes. More than 99% of all the radioactivity associated with the back end of the nuclear fuel cycle is contained in the irradiated fuel discharged from Canada's power reactors. These intensely active spent fuel bundles contain an array of newly-created radionuclides. Their safe management is an essential component of the nuclear power program in Canada.

Table 14, provided by AECL's Whiteshell Nuclear Research Establishment, summarizes the generation of waste materials from the full CANDU fuel cycle. Waste quantities are those associated with the production and use of one CANDU fuel bundle, with an assumed fuel burnup of 7,500 megawatt-days per tonne of uranium. Radioactivity levels for irradiated fuel are specified one year after discharge from the reactor. At the mining and milling stages, values are given both for Ontario uranium ore and the richer Saskatchewan ore. The volume of waste generated is greatest in uranium mining and milling. Waste management practices at this stage have depended on the level of radioactivity per unit of waste volume. Mill tailings from Ontario mines are stored in the open, whereas those from some Saskatchewan operations are stored in concrete bunkers.

Low-level radioactive wastes from the nuclear power stations are placed in earth trenches, tile holes or concrete bunkers. By far the greatest amount of the radioactivity is contained in the irradiated fuel. Spent fuel is stored either in water-filled concrete-lined pools or in air-cooled, dry concrete canisters. The concrete canisters are used to store spent fuel from the decommissioning Douglas Point, Gentilly 1 and NPD reactors. Canada has not yet determined the means of finally disposing of high-level wastes but is concentrating its research program on deep burial in a stable rock formation. The philosophy here is to isolate high-level wastes until their radiological hazard has declined to an acceptable level and to manage this in such a fashion that future generations are not burdened with waste management or surveillance.

An additional aspect of the waste management issue is the decommissioning of nuclear reactors and other nuclear facilities.

Table 14: Wastes Produced in the CANDU Fuel Cycle per Fuel Bundle

Wastes from the CANDU Fuel Cycle

Amount of waste produced from one CANDU fuel bundle, which produces 33.6 million KWh of electricity, enough to supply the average Canadian home with energy for cooking, heating, etc. for more than 100 years.

		Amount		Total Activity (1)	
		Ont. ore	*Sask. ore*	*Ont. ore*	*Sask. ore*
Mining (Waste Rock)		20 Tonnes	10 Tonnes	0.0008 Curie	0.008 Curie
Milling (Mill Tailings)		20 Tonnes	1 Tonne	0.0713 Curie	0.0648 Curie
Refining (Raffinate - recycled to mill)		(8 Kilograms) (2)		0.00004 Curie	
Conversion (Ammonium Nitrate -sold as fertilizer)		(20 Kilograms) (2)		Background	
Generating Stations	Low Level Waste (3)	0.43 Cubic Metre		1.7 Curies	
	Used Fuel (4)	20 Kilograms (0.005 cu. m)		16,000 Curies	

(1) One Curie (Ci) is very nearly equal to the amount of radioactivity in one gram of Radium -226.

(2) Refinery wastes and conversion wastes are completely recycled.

(3) Average for Ontario Hydro, 1986 and 1987, as received. After processing, volume was reduced to an average of .29 cubic metres.

(4) Assuming a burnup of 7,500 MW-days per tonne. Activity specified is one year after discharge.

Source: Personal communication: Eva Rossinger, Whiteshell Nuclear Research Establishment, AECL, Pinawa, Manitoba, 4 July 1988.

B. High-Level Radioactive Waste Management

The Committee concentrated on the back end of the nuclear fuel cycle in its study of radioactive waste management. This examination extended to the countries visited by the Committee and most particularly to Sweden, where the waste management program has numerous parallels with the Canadian program.

The management of radioactive wastes at the back end of the fuel cycle is essentially a question of managing spent nuclear fuel, in the absence of reprocessing. Comparatively minor amounts of radioactivity are generated in other ways and are referred to as reactor wastes. As examples, some of the deuterium in the heavy water absorbs neutrons and is converted to radioactive tritium; water filters screen out small quantities of radioactive corrosion products; and disposable clothing may carry tiny amounts of radioactivity.

Irradiated fuel is highly radioactive and the spent fuel elements contain more than 100 radionuclides created during reactor operation. These fall within two groups. The first category includes the **fission products**, created when a heavy atom splits to form two lighter atoms. This fissioning does not always occur in the same manner and consequently an array of fission products is created within the fuel. Some of these new elements are stable; the remainder decay with their own characteristic half-lives, forming new radionuclides in some cases. The fission products are strong beta and gamma emitters and most have relatively short half-lives.

The second group of radionuclides in the spent fuel includes the **actinides**. Actinides are a series of elements with atomic number equal to or greater than 89 and similar chemical properties. Uranium and plutonium are the best known members of this group. In a CANDU reactor, one neutron per fission is absorbed by uranium–235 to perpetuate the chain reaction. The remaining 1.5 neutrons generated on average per fission are absorbed by other materials, principally uranium–238. The actinides form through a series of neutron absorption reactions and radioactive decays. They tend to be alpha emitters and many have long half-lives.

Table 15 indicates the change in composition of a CANDU fuel bundle before and after irradiation in a reactor and allowing for a cooling period of six months. Quantities are expressed in grams and the constituents total 19 kilograms. The calculation assumes a fuel burnup of 6,500 gigajoules per kilogram of uranium. Table 16 lists some of the important fission products in spent CANDU fuel. The more important actinides present in CANDU spent fuel are listed in Table 17. Both tables show activity levels at discharge, at one year, and at 10 years. Among the fission products, technetium–99, iodine–129 and cesium–135 represent the greatest long-term hazard. Among the actinides, plutonium–239 and plutonium–240 are particular long-term hazards.

Table 15: CANDU Fuel Bundle Composition Before and After Irradiation

Constituent	New Fuel (grams)	Irradiated Fuel (grams)
Actinides		
Uranium–238	18,865	18,725
Uranium–235	134	44
Other Uranium Isotopes	1	15
Plutonium	-	71
Other Actinides	-	1
Fission Products		
Iodine	-	1
Cesium	-	11
Technetium	-	4
Other Fission Products	-	128
Total Constituents	**19,000**	**19,000**

Source: Personal communication: William T. Hancox, AECL, Research Company, Ottawa, 9 February 1988.

Most of the newly-created fission products are inactive. The discharged fuel consists of 98.85% uranium oxide by weight; the remaining 1.15% – essentially made up of fission products and various plutonium isotopes – consists of 0.65% inactive fission products, 0.11% active fission products and 0.38% plutonium.

When irradiated fuel is first discharged from the reactor, the fission products dominate the radioactivity, as is apparent in comparing the activity levels in Tables 16 and 17. With time, the activity of the spent fuel declines, dropping by about a factor of 10 over the first decade as the short half-life radionuclides dwindle. At approximately 200 years, the activity of the fission products drops below the activity of the actinides, which thereafter are the principal determinant of the level of radioactivity. Fission product activity continues to fall sharply until, at 500 years, this activity has declined to roughly 1/100,000 of its initial level. Actinide activity drops slowly and, at 500 years, is down to about 1/15 of its initial level. Short-term storage under water at the reactor sites allows the fission products to become less of a hazard, while the disposal of spent fuel is predicated on preventing the actinides from escaping from a repository.

Table 16: Selected Fission Products in Irradiated CANDU Fuel

Radionuclide	Half-Life (years)	Activity (curies/kilogram of uranium) at discharge	at 1 year	at 10 years	Significant Radiation
Tritium (H–3)	12.3	0.17	0.16	0.10	beta
Krypton–85	10.7	2.22	2.19	1.23	beta, gamma
Strontium–89	0.14	443	3.95	9.8×10^{-20}	beta, gamma
Strontium–90	29	17.5	16.0	12.9	beta
Yttrium–91	0.16	578	77	1.1×10^{-16}	beta, gamma
Zirconium–95	0.18	825	17.3	1.3×10^{-14}	beta, gamma
Niobium–95	0.10	802	36.6	2.9×10^{-14}	beta, gamma
Technetium–99	2.1×10^{5}	3.4×10^{-3}	3.4×10^{-3}	3.4×10^{-3}	beta, gamma
Ruthenium–106	1.0	182	101	0.21	beta
Iodine–129	1.6×10^{7}	7.9×10^{-6}	7.9×10^{-6}	7.9×10^{-6}	beta, gamma
Iodine–131	0.02	525	1.2×10^{-11}	0	beta, gamma
Cesium–134	2.17	16.9	11.3	0.55	beta, gamma
Cesium–135	2.3×10^{6}	4.5×10^{-5}	3.8×10^{-5}	3.8×10^{-5}	beta
Cesium–137	30.2	25.3	24.8	20.2	beta, gamma
Cerium–144	0.78	424	181	0.06	beta, gamma
Promethium–147	2.6	58.9	50.7	4.7	beta, gamma

Source: Boulton, J. (ed.), *Management of Radioactive Fuel Wastes: The Canadian Disposal Program*, AECL–6314, Whiteshell Nuclear Research Establishment, Research Company, AECL, Pinawa, Manitoba, October 1978, p. 19.

Total heat output from a bundle of irradiated CANDU fuel is displayed with time after discharge from the reactor in the upper half of Figure 15, and the activity levels of the fission products and the actinides are plotted against time after discharge in the lower half of Figure 15. These values are characteristic of CANDU fuel which has undergone an average burnup of 7,500 megawatt-days/tonne of uranium. The time scale is logarithmic and extends from one second to 10 million years. The vertical scale representing heat output in the upper illustration and radioactivity in the lower one is also logarithmic and covers 11 orders of magnitude.

Table 17: Selected Actinides in Irradiated CANDU Fuel

	Half-Life	Activity (curies/kilogram of uranium)			Significant
Radionuclide	(years)	at discharge	at 1 year	at 10 years	Radiation
Neptunium–237	2.1×10^{6}	2.1×10^{-5}	2.1×10^{-5}	2.2×10^{-5}	alpha, gamma
Plutonium–238	87.7	7.2×10^{-2}	8.3×10^{-3}	8.0×10^{-2}	alpha, gamma
Plutonium–239•	2.4×10^{4}	0.15	0.15	0.15	alpha, gamma
Plutonium–240	6.8×10^{3}	0.24	0.24	0.24	alpha, gamma
Plutonium–241•	14.7	22.9	21.8	14.2	beta, gamma
Americium–241	432	11.5×10^{-3}	4.7×10^{-2}	0.3	alpha, gamma
Americium–243	7.4×10^{3}	5.3×10^{-4}	5.3×10^{-4}	5.3×10^{-4}	alpha, gamma
Curium–242	0.45	2.58	0.44	8.9×10^{-6}	alpha, gamma
Curium–244	18.1	1.6×10^{-2}	1.5×10^{-2}	1.1×10^{-2}	alpha, gamma

• denotes a fissionable actinide.

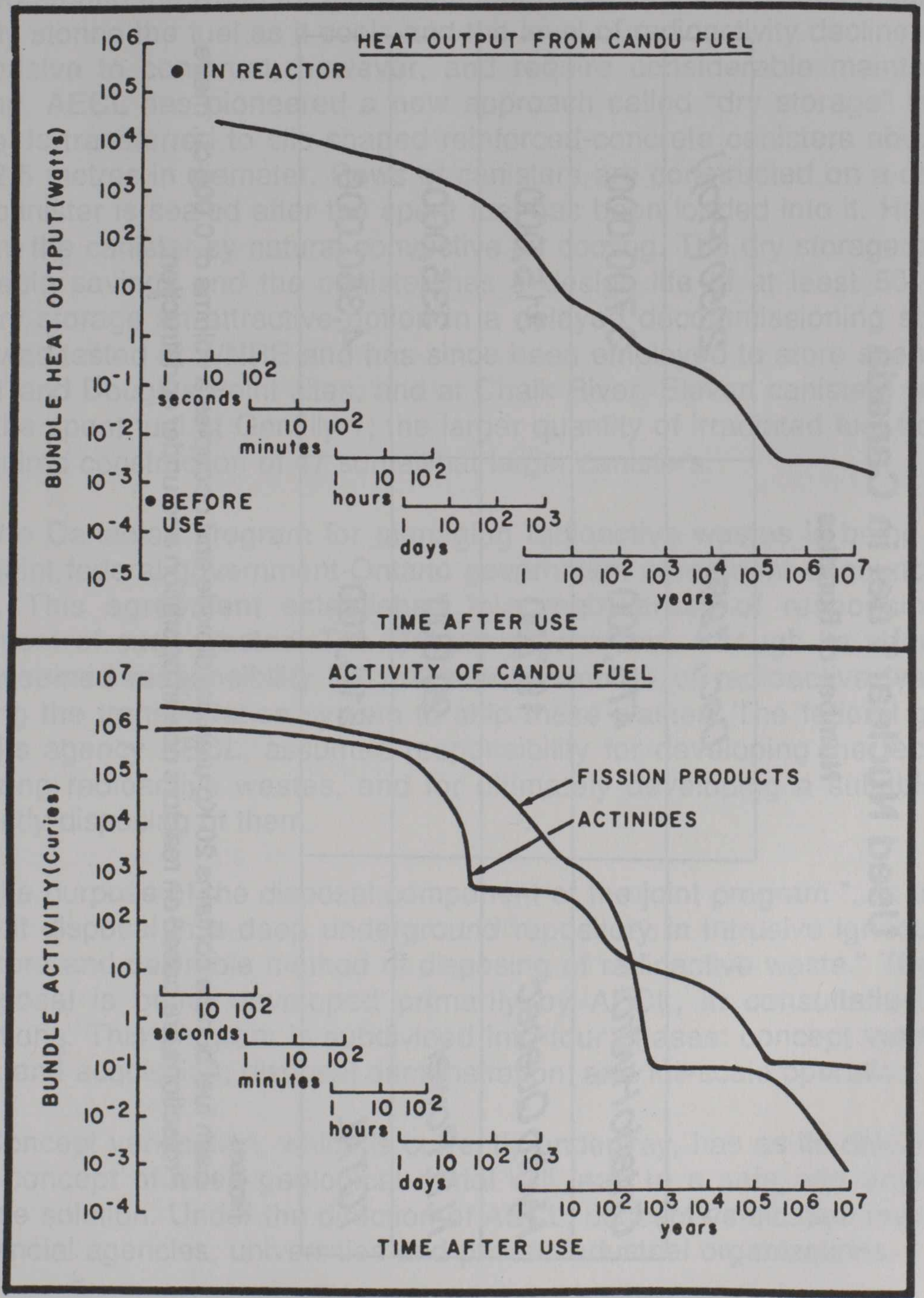
Source: Boulton, J. (ed.), *Management of Radioactive Fuel Wastes: The Canadian Disposal Program*, AECL–6314, Whiteshell Nuclear Research Establishment, Research Company, AECL, Pinawa, Manitoba, October 1978, p. 19.

Figure 15 reveals that the heat output of an irradiated CANDU fuel bundle has dropped to less than one-thousandth of its initial value within approximately three years of discharge from the reactor. Radioactivity is down to 1/10,000 of its initial value after about 100 years.

Table 18, supplied by AECL's Whiteshell Nuclear Research Establishment, provides data on the amount of irradiated fuel to be disposed of in Canada. The first column in the table gives the quantity of spent fuel generated to year-end 1987, by utility, and projects to the year 2050 what that amount will grow to, based upon the Canadian power reactors now in operation and under construction.

Although 4.35 million spent fuel bundles may seem to be a large quantity, at 20 kilograms of uranium oxide per bundle this amounts to 87,000 tonnes. For purposes of comparison, the Syncrude plant in the Alberta oil sands, operating at full production, can mine and process over 100,000 tonnes of oil sand in one 8-hour shift. [At full output, Syncrude can handle 300,000 tonnes of oil sand and produce 175,000 barrels of bitumen in a 24-hour period.] Thus the quantity of spent fuel to be managed is substantial but in no sense is it an overwhelming amount.

Figure 15: Heat Output and Radioactivity Levels of Irradiated CANDU Fuel



Source: Boulton, J. (ed.), *Management of Radioactive Fuel Wastes: The Canadian Disposal Program*, AECL–6314, Whiteshell Nuclear Research Establishment, Research Company, AECL, Pinawa, Manitoba, October 1978, p. 20.

Table 18: The Accumulation of Irradiated Nuclear Fuel in Canada

Used Nuclear Fuel in Canada

Number of Bundles

	Dec., 1987	*2050 (Proj.)*
Ontario Hydro	475,000	3,700,000
Hydro Quebec	19,700	315,000
N.B. Power	20,000	335,000
TOTAL	514,700	4,350,000

Notes:

Each fuel bundle contains 20 Kg uranium dioxide and occupies a volume of 0.005 cu. metre. Projections are based on reactors now in operation and under construction.

Source: Personal communication: Eva Rossinger, Whiteshell Nuclear Research Establishment, AECL, Pinawa, Manitoba, 4 July 1988.

Irradiated fuel is removed from the reactor core by remotely-controlled equipment and transferred to a water-filled pool for storage. Protection against radiation is provided by about four metres of water covering the fuel stacks and the thick concrete walls of the pool. This method, commonly termed "wet storage", has been used around the world for more than four decades and provides a safe means of retrievably storing the fuel as it cools and the level of radioactivity declines. The pools are expensive to construct, however, and require considerable maintenance and monitoring. AECL has pioneered a new approach called "dry storage" in which the spent fuel is transferred to silo-shaped reinforced-concrete canisters about 6 metres tall and 2.5 metres in diameter. Rows of canisters are constructed on a concrete pad and the canister is sealed after the spent fuel has been loaded into it. Heat is carried away from the canister by natural convective air cooling. The dry storage option offers considerable savings and the canister has a design life of at least 50 years. This makes dry storage an attractive option in a delayed decommissioning strategy. The concept was tested at WNRE and has since been employed to store spent fuel at the Gentilly-1 and Douglas Point sites, and at Chalk River. Eleven canisters were needed to store the spent fuel at Gentilly-1; the larger quantity of irradiated fuel from Douglas Point required construction of 47 somewhat larger canisters.

The Canadian program for managing radioactive wastes is being carried out under a joint federal government-Ontario government agreement announced on June 5, 1978. This agreement established four main areas of responsibility in the management of such wastes. The Ontario government, through its agency Ontario Hydro, assumed responsibility for the interim storage of radioactive waste and for developing the transportation system to ship these wastes. The federal government, through its agency AECL, assumed responsibility for developing the technology for immobilizing radioactive wastes, and for ultimately developing a suitable means of permanently disposing of them.

The purpose of the disposal component of the joint program "...is to verify that permanent disposal in a deep underground repository in intrusive igneous rock is a safe, secure and desirable method of disposing of radioactive waste." The method of final disposal is being developed primarily by AECL, in consultation with other organizations. This program is subdivided into four phases: concept verification; site selection and acquisition; disposal demonstration; and full-scale operation.

Concept verification, which is currently underway, has as its objective to verify that the concept of deep geological burial will lead to a safe and environmentally acceptable solution. Under the direction of AECL, concept verification involves federal and provincial agencies, universities and private industrial organizations.

Phase two consists of site selection and acquisition. On the basis of what is learned from the concept verification phase, a variety of possible sites will be selected for further testing, in consultation with the involved communities. The mechanism by which this will be achieved has yet to be put into place, but will presumably involve a lengthy public hearings process. A single site will ultimately be selected and acquired.

Phase three is a disposal demonstration at the selected site. It is intended that the underground disposal facility would be extensively tested over a period of years, both to verify the scientific assumptions developed during concept verification and to verify the suitability of the selected site. This phase would also include the construction of a pilot plant for immobilizing the wastes before being placed in the repository.

The final phase is the full-scale or commercial operation of a disposal facility. This will only occur after the disposal technology has been established as suitable for that site. It seems likely that only one facility will be built to handle spent fuel from power reactors in Ontario, Quebec and New Brunswick.

A tentative schedule was established for the disposal component of the program. The specific targets were (Boulton, 1978, p. 59 and 61)

(a) to have verified the basic concepts of disposal of irradiated fuel or fuel wastes in deep hard rock, at least to the stage where there is general acceptance, by 1981;

(b) to have recommended technically-suitable sites for selection by governments and to have constructed a demonstration disposal repository by 1985;

(c) to have the demonstration completed to a stage where the construction of a full-scale repository could be considered by 2000.

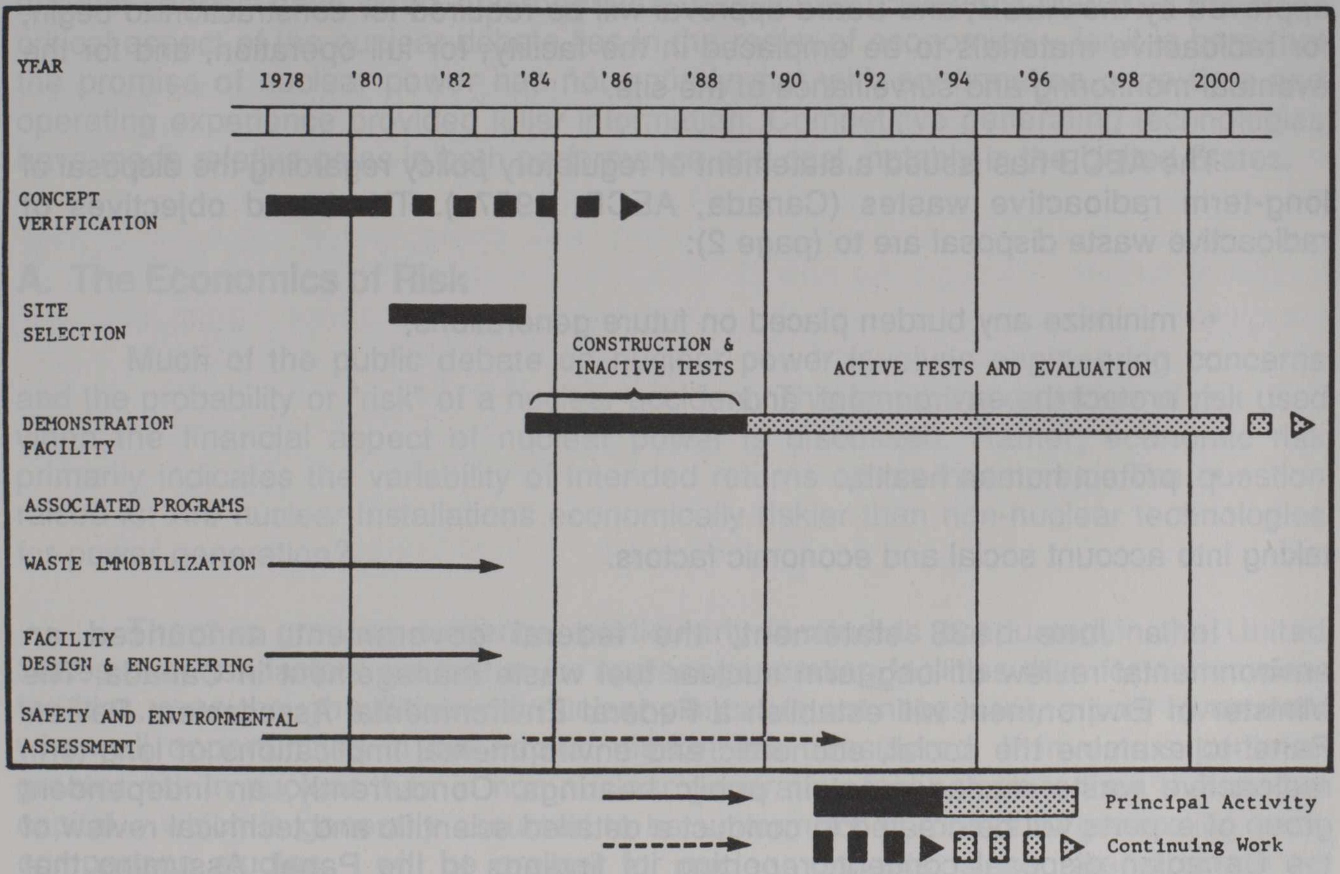
Figure 16 shows the schedule released in 1978 for the complete waste disposal demonstration program. At the time, this schedule was criticized as being unreasonably optimistic, particularly by the scientific community which understood the nature of the R&D required for the first phase, known as concept verification. Time has shown the critics to be correct.

The delays in the disposal program do not constitute a problem of public safety. Interim storage methods for spent fuel have proven to be quite satisfactory and could be used for an indefinite period of time. What does result from continuing delay is an erosion in public confidence in the waste management program, an increase in public confusion about the progress of the program, and an increase in the overall cost of R&D for the program.

By far the largest burden of R&D in support of the program falls on AECL. Unlike the past, when AECL conducted research almost entirely within its own establishment, it has reached out in this case to a wider research community. A substantial number of private companies and universities are making major technical contributions to the program.

Formerly each year, and now every six months, AECL issues a report on the progress of its waste management program; each year, an independent Technical Advisory Committee (TAC) publicly reports its views on the adequacy of the Canadian program.

Figure 16: 1978 Schedule for the Spent Fuel Disposal Program



Source: Boulton, J. (ed.), *Management of Radioactive Fuel Wastes: The Canadian Disposal Program*, AECL–6314, Whiteshell Nuclear Research Establishment, Research Company, Atomic Energy of Canada Limited, Pinawa, Manitoba, October 1978, p. 60.

The Technical Advisory Committee is comprised of ten members, selected from a list of nominees submitted by the major scientific and engineering societies in Canada. Four features of its operation guarantee its autonomy. First, TAC membership is only open to persons nominated by Canada's learned societies. Second, TAC reports annually and on a public basis. Third, TAC members are assured full and free access to all aspects of the research program. Fourth, TAC has resources made available to it for obtaining further specialist advice through consultants, as and when it judges it necessary to do so. The Committee's Swedish hosts noted that TAC had been invited to comment on Sweden's radioactive waste management program and had done so to the benefit of that program.

The Atomic Energy Control Board plays a fundamental role in the process of developing appropriate waste management technology. When the concept verification phase is pronounced complete, AECB will state its views on the acceptibility of the concept. The Board has also decided that it will apply the same licensing procedure to a disposal facility as it does to any other nuclear facility. Thus there will be a requirement for public information before site selection; the proposed site must be approved by the AECB; and Board approval will be required for construction to begin, for radioactive materials to be emplaced in the facility, for full operation, and for the eventual monitoring and surveillance of the site.

The AECB has issued a statement of regulatory policy regarding the disposal of long-term radioactive wastes (Canada, AECB, 1987a). The broad objectives of radioactive waste disposal are to (page 2):

- minimize any burden placed on future generations,
- protect the environment, and
- protect human health,

taking into account social and economic factors.

In a June 1988 statement, the federal government announced an environmental review of long-term nuclear fuel waste management in Canada. The Minister of Environment will establish a Federal Environmental Assessment Review Panel to examine the social, economic and environmental implications of long-term radioactive waste management in public hearings. Concurrently, an independent group of experts will be created to conduct a detailed scientific and technical review of the Canadian disposal concept, reporting its findings to the Panel. Assuming that guidelines are available from the Panel in 1989, AECL expects to submit its Concept Assessment Documentation to the Panel and to the Atomic Energy Control Board in 1991. Public hearings would then be convened by the Panel to review AECL's assessment. Site specific investigations would not begin until the assessment had successfully completed this government and public review process.

As its report was being completed, the Committee was advised that the Swiss Government has officially recognized the feasibility in principle of safely disposing of radioactive wastes. Sweden and Switzerland are the only two nations operating power reactors to require a formal demonstration of safe disposal, and that requirement has now been acknowledged by government to have been met in both countries. Sweden and Switzerland intend to isolate their long-lived radioactive wastes in stable, deep geological formations, as does Canada.

The Economics of Nuclear Power

As Western countries have gained experience in operating nuclear plants, there has been growing controversy about pursuing the nuclear option. While various interest groups have aired environmental and safety concerns, perhaps the most critical aspect of the nuclear debate lies in the realm of economics – for it is here that the promise of nuclear power has not entirely met with confirmation once time and operating experience provided fuller information. Competitive generating technologies have made relative gains in both performance and cost, notably in the United States.

A. The Economics of Risk

Much of the public debate on nuclear power involves engineering concerns and the probability or "risk" of a nuclear accident. This is not the definition of risk used when the financial aspect of nuclear power is discussed. Rather, economic risk primarily indicates the variability of intended returns on an investment. The question raised is: Are nuclear installations economically riskier than non-nuclear technologies for power generation?

There is growing evidence, particularly in studies conducted in the United States, that risk factors are higher for nuclear generating facilities than for non-nuclear facilities, even though utilities with nuclear plants are not necessarily a poor investment when all opportunities in the capital market are considered. If investors perceive greater risk in nuclear than in non-nuclear generating technologies, then the cost of capital – which is generally assumed to be uniform for purposes of generating cost-comparison studies – will be greater for nuclear projects, since rate of return on investment is a large component of the cost of capital.

Several major American investment houses suggest that economic risk is indeed higher with nuclear plants. Merrill Lynch, after the Three Mile Island accident, determined that institutional investors consider a utility's use of nuclear power to be a risk factor. Other brokers, such as Salomon Brothers, advise clients to be wary of companies with nuclear facilities.

Several years ago, the U.S. Federal Energy Regulatory Commission (FERC) allowed the Connecticut Yankee Atomic Energy Corporation a return on equity of 17%, which was at the time the highest rate of return ever granted to an American electric utility. In its ruling, FERC cited the risk associated with nuclear power in the aftermath of the Three Mile Island accident; investors perceive that they have little security if a utility company's sole asset is a nuclear reactor. (United States, DOE, EIA, 1984)

Three events contributing to the existence of a risk premium for nuclear power are cited in a 1984 U.S. Department of Energy study, *Investor Perceptions of Nuclear*

Power. They are: (1) the March 1979 accident at Three Mile Island; (2) the subsequent realization that the the cleanup costs of an accident of the magnitude of Three Mile Island could be over $US 1 billion, which is not fully insurable and could therefore result in substantial losses; and (3) decisions by the Tennessee Valley Authority in 1982 to cancel some of its nuclear plant construction projects and by the Nuclear Regulatory Commission to stop work on the Zimmer reactor while warning of the possible closing of the Indian Point 2 and 3 reactors. (United States, DOE, EIA, 1984)

This study suggests that as a result of the Three Mile Island accident, the value of an investment in a nuclear utility would have dropped 10% relative to an investment in a non-nuclear utility. Such a decrease could be prompted by as little as a one or two percentage point premium in the the rate of return required by investors to actually purchase such securities. Investor concern was compounded because of two additional factors. Through the end of 1982, there had been over $US 15 billion in abandonment costs resulting from the cancellation of nuclear power plants; investors were estimated to have absorbed 30% of those costs. Secondly, U.S. nuclear power plants on average have operated at only a little more than 55% of their design capacity [the average, cumulative load factor for all U.S. reactors of 150 MWe and larger was 56.6% at end-June 1987], whereas comparative cost studies had often assumed a load factor of 70%. Shareholders are also having to bear some of the costs arising from this lower-than-expected operating efficiency. (United States, DOE, EIA, 1984)

What do these U.S. findings imply for investment in Canadian nuclear facilities? The structure of the Canadian electrical power industry differs from that of the United States in several respects. The fact that most Canadian electrical utilities are publicly owned means that their shares do not trade in the stock market. Unlike American utilities, most of which are privately owned and must attract equity investment, Canadian utilities rely on provincial governments for ultimate decisions on expansion strategy, and for equity capital.

A major source of funds for Canadian utilities is indirect investment, where investors purchase long-term bonds issued by the provincial utilities. A high proportion of these bonds are floated abroad. The reliance on indirect investment accounts for the higher debt-to-equity ratios of Canadian utilities.

To the extent that provincial governments guarantee loans taken out by their utilities, Canadian utilities are in a much stonger investment position than their American counterparts. The credit rating of a Canadian public utility is directly connected to the credit rating of its parent province. Another difference is that, as a proportion of company assets, Canadian utilities do not have as high a concentration in nuclear assets as do some American utilties, although Ontario Hydro's 38% of fixed assets in nuclear generating stations is a substantial value.

Another major difference is the superior operating record of Canadian power reactors. To the end of June 1987, Canadian reactors had achieved an average, cumulative load factor of 78.7%, exceeded only by Switzerland (79.7%) and Finland

(79.3%) among those non-Communist countries operating four or more power reactors. Even considering the annual average load factor for the 12 months ending June 30, 1987 (to reflect the full impact of the shutdown of Pickering units 1 and 2 for retubing), the result was 71.4%.

Nonetheless, when cost comparisons are made between nuclear and non-nuclear technologies, the cost of capital for nuclear facilities should be risk adjusted. With the strong evidence that such risk premiums are required by private investors, utility decisions in Canada should reflect real costs in the marketplace, even though they may not show themselves as explicity as in privately owned U.S. utilities.

B. Nuclear versus Coal

The primary choice for expanding electrical generating capacity in the Western industrialized world over the next several decades is between coal-fired and nuclear plants. Regional considerations may colour the issue, but the IAEA study of new additions to electrical generating capacity referred to earlier confirms this basic choice, at least in the near-term.

Large hydro-electric stations are no longer an option in many countries because the most promising sites have already been dammed, or environmental considerations preclude development. A notable exception to this generalization is the James Bay II hydro-electric development in Quebec.

Most countries are unwilling today to accept the price risk and the security of supply risk associated with using imported oil for new base load generating capacity. Some countries with reliable access to natural gas supplies are using gas for peaking generation and even for new base load capacity. In general, however, natural gas is neither as widely available nor as inexpensive as coal for use in power generation.

This leaves coal or nuclear as the basic options open to many countries. Nuclear power is economically preferred for continuous base load electricity production, while coal firing is more readily adapted to interruptible or peaking purposes. Nonetheless, the French have demonstrated the use of power reactors in load following.

The strong embrace given nuclear power by some nations is due to a lack of alternatives, in contrast to the Canadian situation where indigenous coal is plentiful, and where technologies to transport it and burn it more cleanly are becoming viable and competitive. According to officials with whom the Committee spoke in Sweden, West Germany and France, nuclear power is clearly the cheapest large-scale generating capacity now in use and (with the exception of Sweden) is considered a necessary element of any strategy to meet electricity demand into the next century. On more emotional issues, some nuclear programs abroad have run into trouble.

In Canada, the economic question of coal versus nuclear is very much a regional consideration. Nuclear power offers a long-run cost advantage in the Ontario Hydro and New Brunswick Electric Power Commission systems, according to the best calculations of those with the actual experience of running the nuclear installations. High marks can be given to the CANDU system for performance, reliability and safety – all of which are key factors in any investment decision. In other regions, however, coal is the obvious choice, especially where generating stations can be built adjacent to or near open-pit coal mines. As coal preparation, transportation and combustion technology improves and as electricity markets continue their adjustment, indigenous coal may become a viable option for central Canada. And Canada, unlike most other industrialized nations, still has a sizeable hydro-electric potential remaining in certain regions of the country, including the north.

A commitment to nuclear power or coal-fired generation or hydro-electricity is not just a commitment to the flow of expenditures that will occur over the construction and operating life of the plant or station; it is effectively also a voluntary withdrawal from a different technology which may turn out to be preferable, as costs become known and as technology develops.

C. Indicators of Nuclear Cost in Canada

The economic track record of nuclear reactors in Canada in terms of a standardized unit energy cost has been good. AECL and Ontario Hydro have conducted studies comparing the cost experience of actual nuclear and coal installations in Ontario, showing that the nuclear plants are more economically efficient today than comparable thermal units. Through the 1990s and into the first 25 years of the next century, the gap is projected by Ontario Hydro to widen, positioning Ontario nuclear stations such as Pickering B and Bruce B at less than half of the cost per kilowatt-hour of comparable thermal stations equipped with wet scrubbers.

Even so, the economic track record for Canadian nuclear development has been less auspicious than expected. Cost overruns of huge proportions have been characteristic of nuclear installations. Pickering B, estimated to cost $1,585 million, actually cost $3,862 million (five times more than Pickering A); Bruce B, estimated to cost $3,869 million, actually cost $6,036 million and came on line two years later than originally targetted; Point Lepreau, estimated to cost $466 million, cost $1,448 million, and was four years late. Nonetheless, studies by AECL and Ontario Hydro indicate that Canadian nuclear reactors are more cost efficient than their coal-fired counterparts.

Canadian utilities generally use two approaches to express generating costs. The **annual** cost approach evaluates actual generating costs at existing or future stations, using current dollars together with assumptions on future inflation and interest rates. The result is a projection of annual generating costs varying over the life of a station. This approach is referred to as the **Total Unit Energy Cost** or **TUEC**. As applied by Ontario Hydro, TUEC is defined as the total annual cost of producing energy (measured in current dollars) divided by the total annual energy produced (measured in megawatt-hours of electrical equivalent, including both electricity and the electrical equivalent of useful steam energy produced at Bruce A).

The **lifetime** cost approach is typically used to compare different types of future stations. The result is an average annual cost expressed in constant dollars and referred to as the **Levelized Unit Energy Cost** or **LUEC**. The LUEC for a CANDU unit in the Ontario Hydro system in 1984 was calculated to be 21 mills/kWh compared to a LUEC of 33 mills/kWh for a coal-fired plant. (This could be interpreted as an "average" score of nuclear plants compared to thermal plants in Ontario.) The average lifetime energy cost is expressed in constant dollars per megawatt-hour in some reports.

Cost estimates involving discount rates and cost of capital are subject to revision as economic conditions, and particularly interest rates, change. Labour costs escalated significantly in the late 1970s, and unforeseen delays and problems with faulty steam generators were among the unexpected events causing increased cost and delay in completing CANDU installations.

As well, the cost-comparison figures being advanced are not in fact completely comparable. Inflation is not the only reason. A power plant coming on line at a later date than scheduled is not simply costing the sum of all installation expenditures. The cost of alternate power to cover the late commissioning must also be considered, as must the significance of a service life shifted several years into the future. Construction delays generate additional carrying costs that add to the final price tag. Finally, and in the limited Canadian experience, costs are so project-specific that a generic average cost for a standardized nuclear installation does not really exist.

A characteristic of megaprojects in general, and of Canadian nuclear power plants in particular, is the impossibility of saying in advance with any confidence what these projects are likely to have cost by the time they become operational, let alone throughout their operating lifetime. If the favourable cost-efficiency reports of agencies such as AECL and Ontario Hydro are true, this must either indicate good fortune or that nuclear power is an economically superior product to the extent that billion-dollar overruns don't offset a nuclear project's economic efficiency rating compared with competing generating technologies.

The Total Unit Energy Cost (TUEC) of nuclear generation is compared to that of fossil-fuelled generation (comprising coal, oil and gas) in the Ontario Hydro system in Table 19, for the five-year period 1982-1986. The average cost calculated in Table 19 includes operations, maintenance and administration; fuel; depreciation; and financing charges. It excludes costs related to transmission, distribution and corporate administration. Also excluded on the nuclear side are costs arising from reactor decommissioning and spent fuel disposal.

Table 19: **Cost Performance of Ontario Hydro Nuclear and Fossil-fuelled Stations, 1982-1986**

Year	Average Cost (cents/kWh) Nuclear	Fossil	% Cost Advantage (Nuclear over Coal)
1982	1.754	3.413	49 %
1983	1.874	3.371	44 %
1984	2.197	3.445	36 %
1985	2.794	4.043	31 %
1986	3.004	4.733	37 %

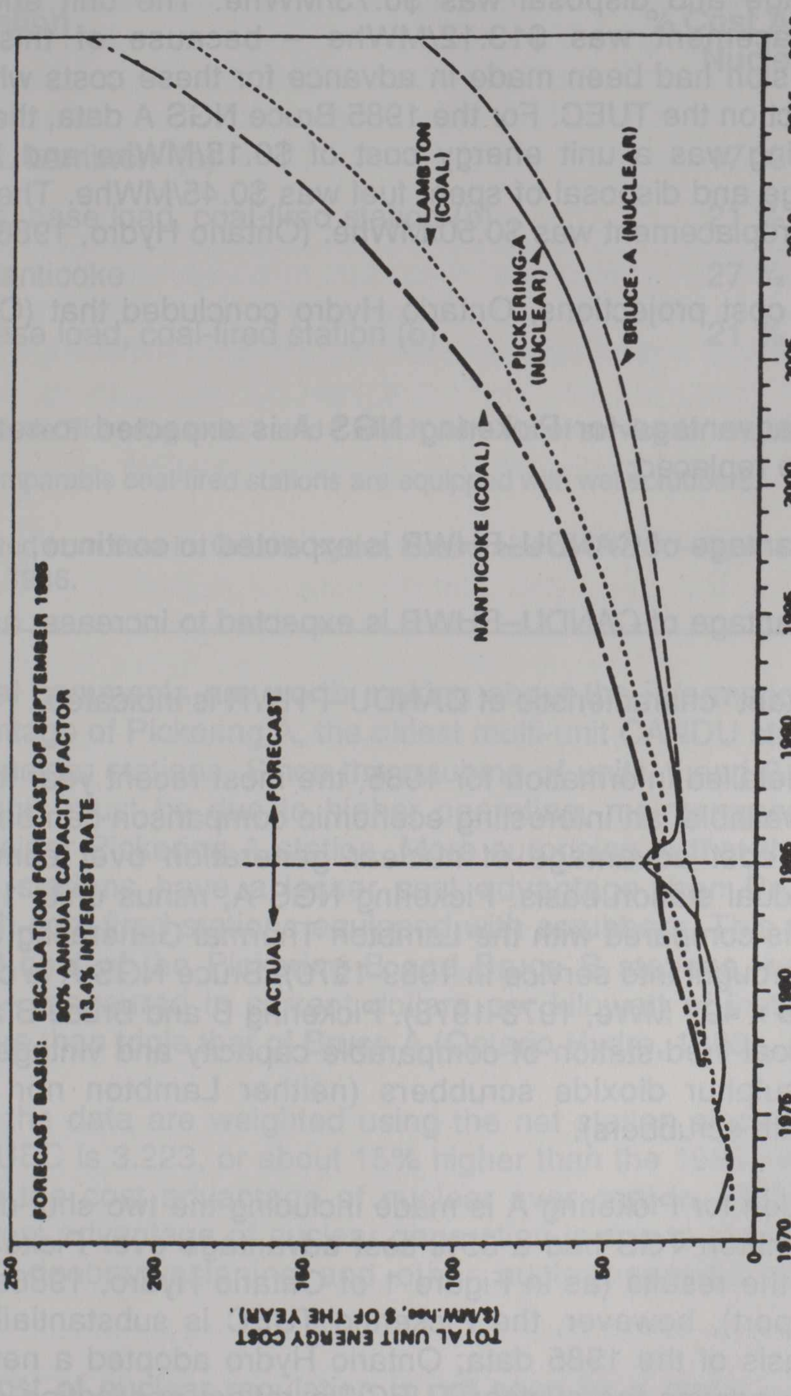
Note: Average cost per kilowatt-hour represents the costs attributable to generation but excludes costs related to transmission, distribution and corporate administrative activities. These values reflect the historical accounting costs of operating facilities and the actual energy generated by these facilities during the year. Fossil fuel costs include all use of coal, oil and natural gas.

Source: Ontario Hydro, *Inside Hydro*, Corporate Relations Branch, Toronto, December 1987, p. 109.

According to this information, nuclear generation retains a cost advantage over fossil fuel (largely coal-fired) generation. It is interesting to note, however, that nuclear's cost advantage declined over the first four of the five years covered by Table 19, recovering a little in 1986 as the remaining units under construction at Pickering B and Bruce B came into service. Over the full five-year period, the average cost of generating a kilowatt-hour of nuclear-electricity rose by 71.3% while the cost of fossil-fuelled generation rose by 38.7%. It seems reasonable then to question long-term predictions by Ontario Hydro of the growing cost advantage of nuclear over coal generation. Such a projection is displayed in Figure 17, which forecasts total unit energy costs in current dollars per megawatt-hour of electrical equivalent for the Nanticoke and Lambton coal-fired generating stations and the Pickering A and Bruce A nuclear generating stations to the year 2018.

The projections in Figure 17 "exclude the probable retrofit of SO_2 scrubbers at coal-fired stations but include provisions for pressure tube replacement at nuclear stations" (Ontario Hydro, 1986a, page 23). At the time that this forecast was made, however, Hydro had not anticipated the early retubing of Pickering NGS A units 3 and 4. The rise in the TUEC for Pickering A due to the retubing of units 1 and 2 is evident in Figure 17; it would be useful to see this projection recalculated to incorporate the early retubing of units 3 and 4.

Figure 17: Total Unit Energy Cost for Major Operating Nuclear and Thermal Stations in the Ontario Hydro System, 1970-2018



Source: Ontario Hydro, *Economics of CANDU–PHW – 1985*, NGD–10, Toronto, August 1986, page 24.

Provision for the future cost of decommissioning the nuclear stations and for the disposal of spent fuel are incorporated in the projections. Ontario Hydro introduced decommissioning and irradiated fuel transportation, storage and disposal charges into its nuclear cost accounting in 1982. Provision for future pressure tube removal costs was introduced in 1984. For the 1985 Pickering A data, the provision for future decommissioning was a unit energy cost of $0.64/MWhe and for future irradiated fuel transportation, storage and disposal was $0.73/MWhe. The unit energy cost for pressure tube replacement was $13.12/MWhe – because of this unforeseen occurrence, no provision had been made in advance for these costs which therefore had a very large effect on the TUEC. For the 1985 Bruce NGS A data, the provision for future decommisioning was a unit energy cost of $0.15/MWhe and for the future transportation, storage and disposal of spent fuel was $0.45/MWhe. The provision for future pressure tube replacement was $0.50/MWhe. (Ontario Hydro, 1986a)

From these cost projections, Ontario Hydro concluded that (Ontario Hydro, 1986a, page 23):

- the nuclear cost advantage for Pickering NGS A is expected to return once the pressure tubes are replaced;
- the base load advantage of CANDU–PHWR is expected to continue;
- the base load advantage of CANDU–PHWR is expected to increase; and
- the "inflation-resistant" characteristic of CANDU–PHWR is indicated.

Using more detailed information for 1985, the most recent year for which such data are generally available, an interesting economic comparison can be made. Table 20 summarizes the cost advantage of nuclear generation over comparable coal stations on an individual station basis. Pickering NGS A, minus units 1 and 2 out of service for retubing, is compared with the Lambton Thermal Generating Station (TGS) (4 x 495 MWe units brought into service in 1969-1970). Bruce NGS A is compared with the Nanticoke TGS (8 x 497 MWe, 1973-1978). Pickering B and Bruce B are compared with a hypothetical coal-fired station of comparable capacity and vintage, assumed to be equipped with sulphur dioxide scrubbers (neither Lambton nor Nanticoke is currently equipped with scrubbers).

If the calculation for Pickering A is made including the two shut-down reactors, then in 1985 the Lambton TGS had a 35% cost advantage over Pickering A. When Ontario Hydro plots the results (as in Figure 1 of Ontario Hydro, 1986a, p. 11, or in Figure 17 of this report), however, the Pickering TUEC is substantially lower than calculated on the basis of the 1985 data; Ontario Hydro adopted a new accounting policy in 1985 which adjusts the nuclear TUEC "to reflect application of the sinking fund for Fuel Channel Removal since the start of operation" (Ontario Hydro 1986a, p. 10 and 12). This "smoothing" of the nuclear data tends to obscure the financial impact of the retubing.

Table 20: The 1985 Cost Advantage of Nuclear Generation over Coal-fired Generation at Ontario Hydro Stations

Station	% Cost Advantage (1985) Nuclear over Coal	
Pickering A vs. Lambton (a)	17 %	(1983: 29%)
Pickering B vs. base load, coal-fired station (b)	21 %	
Bruce A vs. Nanticoke	27 %	(1983: 40%)
Bruce B vs. base load, coal-fired station (b)	21 %	

(a) Does not include Pickering units 1 and 2 which were out of service for retubing.

(b) Assumes comparable coal-fired stations are equipped with wet scrubbers.

Source: Calculated from data in: Ontario Hydro, *Economics of CANDU–PHW – 1985*, NGD–10, Toronto, August 1986.

Several comments are worth making about the information in Table 20. First, the cost advantage of Pickering A, the oldest multi-unit CANDU station, is less than that of the other nuclear stations. Since the retubing of units 1 and 2 is excluded from the comparison, this must be due to higher operating, maintenance and administrative costs for the older Pickering A station. More surprising is that the newer Pickering B and Bruce B stations have a lesser cost advantage than Bruce A, even though compared with coal-fired stations equipped with scrubbers. This reflects the relatively higher capital cost of the Pickering B and Bruce B stations, both of which have a specific cost – measured in current dollars per kilowatt of installed, net generating capacity – more than triple that of Bruce A (Ontario Hydro, 1986a, page 27).

When the data are weighted using the net station electrical outputs for 1985, the nuclear TUEC is 3.223, or about 15% higher than the 1985 value in Table 19. This would reduce the cost advantage of nuclear over coal in 1985 to about 20%. The decrease in cost advantage of nuclear generation is due to the inclusion of spent fuel management, decommissioning and other nuclear-specific costs in the detailed comparison.

The cost of nuclear regulation is not seen as a major issue in Canada. In a 1985 report (Harvie, 1985), the AECB assessed the costs of nuclear regulation, drawing principally on the findings of a contracted study by SECOR Inc. (Canada, AECB, 1981) The SECOR study identified costs associated with radiation health, safety and environmental measures in each part of the nuclear fuel cycle. These costs were then subdivided into two components: (1) those costs which would have been incurred by a prudent operator in the absence of regulation; and (2) those costs incurred only to satisfy regulatory requirements, the so-called marginal cost of regulation.

To assess the impact of regulation on the capital cost of nuclear power generation, the Pickering B station was examined. Out of a total capital cost of the Pickering B station given as $3,097 million, $309.5 million or 10% was attributed to radiation health, safety and environmental considerations. Of this amount, $196.9 million (6.4%) was estimated to be the cost which would have been incurred by a prudent but unregulated operator; $112.6 million (3.6%) was estimated to be the marginal cost of regulation.

To assess the costs of safety and regulation in an operating reactor, the Bruce A station was selected for the 1980 operating year. The total cost of radiation health, safety and environmental measures was estimated at $30.7 million, or 8.9% of the Bruce A total cost of producing electricity that year. Of this amount, $15.55 million (4.5%) was deemed to be costs which would have been incurred by a prudent but unregulated operator; $15.15 million (4.4%) was deemed to be the marginal cost of regulation.

The AECB drew the conclusion that the cost of regulating power reactors in Canada was a relatively small proportion of the total cost of producing nuclear-electricity. The Board cautioned, however, that these findings were only approximate because they were based on the study of two specific stations and because there was uncertainty in subdividing costs to the prudent operator and to the marginal regulatory cost. In any case, "The existence of a competent regulatory authority appears to be a necessary prerequisite for public acceptance of the CANDU nuclear power program" (Harvie, 1985, p. 2).

D. The Economic Cons of Nuclear Power

1. Pattern of Expenditure

Risk and uncertainty are two undesirable, and hence expensive, components of investment projects. Safety considerations aside, nuclear power plants are perceived by many utilities to carry a greater economic risk than comparable coal-fired stations. This perception is reinforced by the testimony of the NBEPC before the Committee, regarding a second unit at Point Lepreau. Although government-owned utilities in Canada are not in the same position as are privately-owned utilities in the United States (where costs of capital are sensitive even to such factors as delay suffered due of blockages in the regulatory process arising from public pressure), carrying costs – that is, the interest rate times the capital borrowed – are just as much affected by delay.

Because the greatest share of nuclear plant costs is borne up front (given the relatively higher construction cost and lower operating and fuel costs), utilities end up with high carrying charges in any case, and the consequences of construction delay are much more costly than they might be for a thermal plant, the construction (or "capital") costs of which are a relatively lower proportion of total lifetime cost. Moreover, the time period required to bring a nuclear plant into commercial service is generally longer than for a thermal plant of equivalent capacity. This means that not only are carrying charges less with coal units, but a more flexible and responsive strategy to power planning is possible. The trend in the capital cost of Ontario Hydro's CANDU reactors, measured in current dollars per unit of installed, net generating capacity (including the electrical equivalent of useful Bruce A steam), is presented in Table 21.

Table 21: Trend in Ontario Hydro Nuclear Station Costs, Measured in Current Dollars per Kilowatt of Installed Net Electrical Equivalent Capacity

Station	Specific Cost ($ per kWe)	Year in Service
Actual Cost		
Pickering A	362.4	1971-1973
Bruce A	606.0	1977-1979
Estimated Cost		
Pickering B	1871.1	1983-1986
Bruce B	1821.8	1984-1987
Darlington	3095.3	1988-1992

Source: Ontario Hydro, *Economics of CANDU–PWH – 1985*, NGD–10, Toronto, August 1986, page 27.

It is apparent from Table 21 that the capital cost of the three more modern stations, even allowing for inflation, is significantly higher than the cost of the original Pickering A and Bruce A stations.

Among nuclear power reactors themselves, CANDU also represents a higher-cost option. The CANDU reactor system has a higher capital cost than an LWR of comparable generating capacity. To this must be added the one-time cost of the heavy water charge for the CANDU. [The estimated cost of the initial inventory of heavy water for the four new Darlington reactors is $1,539 million, almost 14% of the projected total capital cost of the station.] Although the CANDU will cost significantly less to operate than the LWR, the up-front cost is nonetheless a very important factor in a utility's decision on the type of generating capacity that it will install.

Table 22 summarizes Ontario Hydro data comparing a four-unit CANDU station based on Bruce A costs with a comparable four-unit PWR station. All unit energy costs are expressed in 1985 dollars per megawatt-hour of electrical equivalent. Decommissioning, spent fuel disposal and retubing costs are not included in Table 22. The CANDU units are assumed to operate with an average net capacity factor of 78%; the PWR is analyzed both for a "high" capacity factor of 68% and for an "average" capacity factor of 61%.

Table 22: Ontario Hydro CANDU Costs Versus Estimated PWR Costs in 1985

		PWR	
	CANDU	**High Capacity Factor**	**Average Capacity Factor**
Station Size (MWe net)	4 x 809	4 x 809	4 x 809
Net Capacity Factor	78%	68%	61%
Interest & Depreciation Unit Energy Cost			
Dry capital	10.44	11.98	13.35
Commissioning	0.42	0.48	0.54
Fuel	0.14	0.69	0.77
Heavy water	2.75	–	–
Total Interest & Depreciation Unit Energy Cost	**13.75**	**13.15**	**14.66**
Operation, Maintenance & Administration Unit Energy Cost	4.18	4.79	5.34
Fueling Unit Energy Cost	4.65	8.90	8.90
D_2O Upkeep Unit Energy Cost	0.37	–	–
TOTAL UNIT ENERGY COST	**22.95**	**26.84**	**28.90**

Source: Ontario Hydro, *Economics of CANDU–PHW – 1985*, NGD–10, Toronto, August 1986, page 37.

The CANDU displays a lower Total Unit Energy Cost than the PWR, but some of the assumptions underlying the calculation can be questioned. The average capacity factor assumed for the PWR was 61%, based upon international operating experience through 1985. [The world capacity-weighted, average lifetime load factor for PWRs to mid-year 1987 was 62.7%.] The average cumulative load factors achieved by several industrialized countries operating (four or more) reactors has been considerably better than the "high" value of 68% assumed in Table 22. Switzerland, operating three PWRs and two BWRs, had a 79.7% cumulative load factor through June 30, 1987. Finland's record for two PWRs and two BWRs stood at 79.3%, and Belgium's eight PWRs at 78.0%. (NEI, 1988, p. 13 and 19) Thus significantly better operating records have been achieved in a few countries, for both the PWR and BWR types.

The decision to exclude pressure tube removal costs, on the grounds that "...these exclusions do not have a significant effect on the relative costs of alternative types of nuclear generation for a major program" (Ontario Hydro, 1986a, p. 36), also appears questionable. Although Ontario Hydro now includes provision for future costs of decommissioning, fuel disposal and pressure tube replacement, these provisions are said by the authors of the study to "...have too much uncertainty to be meaningful in comparisons of alternative generation types" (Ontario Hydro, 1986a, p. 36).

It is evident from Table 22 that heavy water is a significant component of cost in the Canadian program. In this calculation, the initial heavy water charge and heavy water upkeep together account for 13.6% of the CANDU TUEC of 22.95. According to Ontario Hydro, the cost of producing heavy water at Bruce is a strong function of the production rate. The 1987 heavy water cost of production is quoted by Ontario Hydro as $364 per kilogram (dividing the total 1987 heavy water production cost of $256.6 million by the output of 705 tonnes). In 1988, with a substantially lower rate of production, the unit cost is estimated to be $563 per kilogram (dividing the projected 1988 production cost of $243.1 million by the projected output of 432 tonnes). [Note that these are unit production costs, not sales values – the amount that Hydro receives for external sales of heavy water may not be directly linked to the production cost.] The utility estimates for its internal bookkeeping purposes that the cost of the initial heavy water inventory for the four new Darlington reactors will be $1,539 million, including transportation and storage charges, out of a final capital cost now projected to total $11,171 million. (Personal communication: Cameron Campbell, Government Relations, Ontario Hydro, 8 August 1988) If one assumes that an initial heavy water inventory of 0.8 tonne is required per megawatt of installed generating capacity at Darlington, then the unit cost of the heavy water is approximately $545 per kilogram (ignoring transportation and storage charges).

2. CANDU Pressure Tube Problems

The pressure tube deterioration in the Pickering A reactors is a good example of what can go wrong, even under the best conditions of planning and development. According to Ontario Hydro, the November 1987 estimate of the direct cost of materials, labour and equipment needed to remove and replace the pressure tubes, including recommissioning, of Pickering units 1 and 2 was $402 million. Added to this is the cost of providing replacement energy: approximately $200,000-$250,000 per day for each unit. Thus the cost of replacement energy has more than doubled the direct financial impact of the retubing.

The retubing of units 1 and 2 has not only affected Ontario Hydro. Although ownership of these two units is vested in Ontario Hydro, the utility, the Province of Ontario and AECL are parties to an agreement covering their construction and operation. Under this Nuclear Payback Agreement, payments totalling about two-thirds of the financial benefit from the two reactors (based on the net operational advantage of the power generated by Pickering units 1 and 2 compared with the coal-fired Lambton units 1 and 2) have been made each year by the utility to the other two parties. Conversely, the Agreement has also committed AECL and the Province to share the costs of the retubing and the replacement energy. Since late 1983, the value of the payback has been negative and has remained so during the retubing. Ontario Hydro has not been collecting these costs from the other two parties; under an amendment to the Payback Agreement, the utility will recover this accumulated "negative payback", including interest, over the remaining life of the Agreement (to 2003). Consequently, only about one-third of the cost of the retubing will accrue to Ontario Hydro ratepayers; the remainder will in effect be deducted from revenues that AECL and the Province of Ontario would otherwise have received from the operation of units 1 and 2.

As of 31 December 1987, the negative payback amount totalled $205 million (Ontario Hydro, 1988a, p. 38), with AECL and the Province sharing this obligation about equally. Under the amended Agreement, Ontario Hydro commences recovery of this amount with the return to service of both units.

It is only fair to mention, however, that the learning experience of this problem has provided preventive measures for future installations and has engendered sophisticated and efficient technological advances in detecting and correcting pressure tube problems.

3. Nuclear Waste Management and Plant Decommissioning

The question of nuclear waste management is a contentious issue in Canada, as it is in most countries with nuclear power programs. The estimated costs of dealing with that waste remain substantially unproven, until a definitive policy on waste disposal is worked out by government and the nuclear industry. While the Committee has every confidence that nuclear waste is being dealt with conscientiously and safely in Canada, it acknowledges that this issue, and the potentially large expenditures involved in settling it, does not arise with non-nuclear power stations.

Another factor in the calculations is the cost of decommissioning nuclear facilities. It remains unclear what the service life of a CANDU reactor may be, but a further expenditure will be incurred when the facility is taken out of service. While Canada has several facilities which are being decommissioned, the most recent being the NPD reactor, we have not yet had the experience of terminating the operational life of a large, multi-unit station. The costs of doing so in another twenty or thirty years are merely educated guesses as funds are allocated for this purpose now.

Fossil-fuelled stations, in contrast, have more potential for modernizing, as new parts and technologies can be incorporated into the station, and are also more likely to be used in a limited capacity for peaking power later in their life cycle. This allows the postponement of full-plant replacement costs, and offers the possibility of on-going refurbishment to avoid the difficulties of committing to and raising a large sum for a new plant.

A 1986 study by the Nuclear Energy Agency of the OECD, to which Canada contributed information, evaluated the cost of decommissioning nuclear facilities (OECD, NEA, 1986a). Decommissioning was divided into three stages. Stage 1 decommissioning involves blocking and sealing mechanical systems while maintaining the first contamination barrier as it was during operation. Some fuel handling systems may be kept operational for later decontamination work. Access to the containment building is controlled and the plant is kept under surveillance. Stage 2 decommissioning has the easily dismantled reactor parts removed and a long-term contamination barrier put in place. If the containment building no longer plays a role in radiological safety, it may be removed. Nonradioactive parts of the plant may be converted to new uses. Surveillance continues at a reduced level. Stage 3 decommissioning involves the removal of all contaminated equipment and structures. Unless the site is re-used, it is released without restrictions due to residual radioactivity and no further surveillance is required.

Based on these decommissioning stages and converting the national data received into 1984 U.S. dollars, the NEA calculated the decommissioning cost for a standard-sized 1,300 MWe reactor, including a contingency fund of 25%. For a 1,300 MWe PHWR of the CANDU type, the undiscounted cost of proceeding immediately to a stage 3 decommissioning was assessed at $US(1984) 145 million. If the strategy was to proceed with a stage 1 decommissioning, followed by 30 years storage and then stage 3 decommissioning, the undiscounted cost was calculated to be $US(1984) 117 million. Using a discount rate of 5% to the year of shutdown, the costs became $US(1984) 129 million for the immediate decommissioning and $US(1984) 29 million for the delayed decommissioning. (OECD, NEA, 1986a, p. 9) Assuming (1) a reactor service life of 20, 25 or 30 years; (2) either a prompt or delayed decommissioning strategy; and (3) using discount rates of 0%, 5% or 10%, the decommissioning cost for a 1,300 MWe PHWR per unit of electricity produced over the reactor lifetime was in all cases calculated to be less than one 1984 U.S. mill per kilowatt-hour. Higher discount rates and longer reactor service life lower the calculated unit cost. (OECD, NEA, 1986a, p. 62-63)

Ontario Hydro makes accounting provisions for decommissioning and fuel disposal costs within the category of "accrued fixed asset removal and irradiated fuel disposal costs" (Ontario Hydro, 1988a, p. 43). Fixed asset removal costs include the costs of decommissioning nuclear generating stations and heavy water production facilities after their service lives, and the costs of fuel channel replacements. To the end of 1987, Ontario Hydro had accrued fixed asset removal costs of $311 million ($162 million for accrued decommissioning costs and $149 million for accrued fuel channel removal costs). Hydro plans a delayed decommissioning, with a 30-year surveillance period between shutdown and dismantling. For estimating future costs of irradiated fuel disposal, Hydro assumes that a commercial disposal facility will begin receiving spent fuel in 2010. To the end of 1987, Ontario Hydro had accrued irradiated fuel disposal costs of $306 million. Hydro's annual report provides the set of assumptions used in calculating retubing, decommissioning and fuel disposal costs.

4. Government Support

Critics of nuclear development in Canada often refer to the massive amount of government funding of nuclear research and development – a subsidy unavailable to other industries in the economy. To the end of fiscal year 1978/79, a total federal investment of approximately $3.4 billion in as-spent or current dollars had been made in the development and use of nuclear power in Canada, as determined in a 1980 study prepared by the Department of Finance (Canada, EMR, 1981, p. 301-330).

This study summarized federal support in four general categories. Of the $3.4 billion invested since World War II, 56% went into nuclear power development, 22% into heavy water production, 22% into financing nuclear sales and 2% into uranium industry support.

The study also subdivided expenditures under the headings of (1) research and development – $2,137.1 million; (2) prototype reactors (Douglas Point and Gentilly 1) – $157.5 million; (3) commercial reactors – $385.5 million; (4) export reactor sales – $305.4 million; (5) heavy water plants – $540.2 million; (6) regulation and insurance – $41.8 million; (7) Eldorado Nuclear Ltd. – $64.7 million; (8) Uranium Canada Ltd. – $42.7 million; and (9) miscellaneous financial flows – $16.0 million. Some of these expenditures were in the form of loans to be repaid, for example, when an export reactor entered service or when heavy water sales were made.

The Committee has collected more recent information that suggests a further $3.3 billion has been invested by the federal government since the 1978/79 fiscal year. Most of this support – $3,085.6 million through fiscal year 1987/88 – has gone to AECL to fund nuclear R&D, the federal heavy water program, and the decommissioning and safeguarding of prototype reactors. Of this total, $816.9 million represents the forgiveness of heavy water plant loans and interest charges. From fiscal year 1979/80 through 1988/89, federal appropriations for the Atomic Energy Control Board have totalled $187.8 million. Federal funding of the nuclear fusion program, principally on the jointly funded Varennes, Quebec Tokamak, amounts to approximately $33 million. Thus there has been a total federal investment in nuclear power approaching $7 billion over 40 years of development. Heavy water costs have been prominent in Canadian nuclear development, accounting for almost one-quarter of all federal support.

Regarding the costs of regulation, there is at present no shifting of the burden of funding the AECB – the industry regulator – onto licence holders. This is in contrast to the United States, where Congress has directed the Nuclear Regulatory Commission to collect user fees so as to offset 45% of its budget. In 1988, the NRC budget amounts to $US 392.8 million. For reference, total Canadian AECB regulatory expenditures during the period 1946-1979 were $42 million (not including AECB research expenditures of $79.2 million over that period). Annual AECB expenditures are today about $24.4 million.

Finally, there is a continuing debate between nuclear critics and the industry regarding nuclear liability insurance. At present, under the *Nuclear Liability Act*, owners of nuclear facilities must carry a total of $75 million in insurance (public liability) for each individual facility. This coverage is provided through two mechanisms.

(a) A basic level of coverage is prescribed by the AECB. Such coverage is obtained through an approved private carrier, which in Canada's case is the insurance industry pool operating the Nuclear Insurance Association of Canada (NIAC).

(b) Supplementary insurance is required to bring the total coverage to $75 million for some facilities. Such insurance may, if required, be provided through a reinsurance agreement with the federal government, subject to Treasury Board approval.

In 1987, the cost of this insurance for Ontario Hydro's Pickering A and B stations and the Bruce A and B stations was $1.667 million. For 1986, the cost of these premiums represented approximately 0.1% of the cost of nuclear generation. Insurance costs, if full liability were to be borne by the nuclear industry, would alter the economics of nuclear power. It has been argued by some nuclear opponents that the nuclear option would then become prohibitively expensive, although the U.S. NRC has advanced a proposal for full liability that it maintained could be accommodated by American nuclear utilities. The Committee does not believe that higher public liability coverage in Canada will impose an undue burden on the nuclear industry.

E. Summary Remarks

The Committee concludes on the basis of the economic data that it has reviewed that nuclear power is less expensive on a unit cost basis than fossil-fuelled generation in the Ontario Hydro and New Brunswick Electric Power Commission systems. This does not mean that nuclear costs are invariably lower. The retubing of units 1 and 2 forced the unit energy cost for the Pickering A station temporarily above that of an equivalent Ontario Hydro coal-fired station. The impact on the unit energy cost of retubing units 3 and 4 will be less dramatic now that Hydro has established a sinking fund to cover such expenditures. NBEPC observes that the energy cost at Point Lepreau, at 5.5 cents per kilowatt-hour, exceeded the cost of oil-fired generation at Coleson Cove in 1986. However, Point Lepreau was a much cheaper source of electricity prior to the oil price collapse and nuclear-electricity will regain its cost advantage as the price of oil recovers. Adding to Point Lepreau's strength is the exceptional record that this reactor has established in its first five years of operation.

Of more concern is a general tendency for nuclear power to lose some of its economic advantage over coal with time, as indicated by the Ontario Hydro data. Even with the impact of the Pickering retubing removed, the nuclear cost advantage has been diminished. The principal culprit here is the escalation in capital cost of the Pickering B, Bruce B and Darlington stations beyond what can be readily explained by the higher inflation rates of that period. More detailed and up-to-date cost analyses are needed in these cases to track this evolution in detail and to see what it implies for the future.

On the international scene, the Committee sees a mixed picture. In France and Sweden, nuclear-electricity has a clear cost advantage over other large-scale generating alternatives, notwithstanding Sweden's decision to phase out its nuclear generating capacity. In West Germany, nuclear-electricity is less expensive than power produced from domestically mined coal and that cost advantage is expected to increase. Imported thermal coal, at its currently depressed price, can just about match German nuclear-electric costs, but West German utilities are having to install scrubbers and this major investment will force the cost of coal-fired generation to rise significantly. Both France and West Germany regard nuclear power as an essential and expanding component of their energy systems.

The U.S. nuclear program is in trouble on several fronts. Regulatory complexity and delay, litigation initiated by various groups, the proliferation of reactor configurations, and the inadequate resources and training brought by some utilities to their nuclear programs are acting to force costs up sharply. It is not clear to the Committee how these varying problems will be resolved. The U.S. Government has acted to move the radioactive waste management program ahead, which may allay some public concern, but there is little indication that government and the nuclear industry have yet discovered how to overcome the general industry malaise.

What Future for the Canadian Nuclear Industry?

As a reactor vendor, AECL's prospects in the near term are not particularly promising. Ontario Hydro will need to bring new generating capacity into its system in the 1990s but there is no guarantee that the next increment in capacity will be nuclear. Hydro-Québec is looking to an expansion of its James Bay hydro-electric complex and is unlikely to consider additional nuclear units until well into the next century. New Brunswick Electric Power Commission could be in the market for a CANDU 300, but is wary of the financial commitment. A risk-sharing agreement with the federal government seems necessary to make this project go. A CANDU 300 sale is key to AECL's international marketing strategy and the federal government should look closely at some arrangement with NBEPC.

It is clear that reactor sales alone will not carry AECL through the coming low period without financial assistance. To minimize the need the federal funding, AECL must look to other business opportunities.

One such opportunity is the Canadian Submarine Acquisition Program. In his White Paper, the Minister of Defence announced the government's intention of acquiring a fleet of 10 to 12 nuclear-powered submarines. AECL was subsequently asked to assist in the evaluation of the potential vendors of the nuclear propulsion reactor, and responded by establishing a Marine Propulsion Unit in Ottawa. A task force of senior AECL Research and CANDU Operations staff has recently been acting in an advisory capacity for the submarine program.

As the primary Canadian reservoir of knowledge and expertise in nuclear technology, one can expect that this advisory role will expand as program requirements become clearer. Because of concerns expressed by the potential foreign reactor suppliers about the confidentiality of the technology transfer, it seems likely that AECL's participation as a crown corporation would be favoured over private sector nuclear companies. It has been suggested that AECL may be named the prime contractor for all nuclear elements of the submarine program.

Given the requirements for Canadian content in the submarine program, proceeding with this acquisition would generate substantial employment in both AECL and the private sector of the nuclear industry.

Another opportunity lies in the proposed "kaon factory". The operators of TRIUMF, Canada's National Meson Facility located in Vancouver, have proposed the construction of a $400 million accelerator complex which would provide more energetic and more intense particle beams for a wide range of frontier studies in fundamental and applied science. Many of the skills required in the construction of this so-called kaon factory are common to those needed in the nuclear power industry and include robotics, remote handling, radiation monitoring and radiation shielding.

This project offers the possibility of maintaining this base of skills through expanding the operations of many participants in the industry. AECL, with its history of association with TRIUMF and its demonstrated skills in these areas of technology, seems a likely contender for significant design and engineering work.

The TRIUMF proposal is currently awaiting a funding decision by the federal government.

Within AECL itself, a number of Business Units are taking spin-off technologies from the nuclear business and attempting to establish them as commercial enterprises. The SENSYS Business Unit in Nepean, Ontario is developing an engine wear monitor for military and industrial markets. Morton-Thiokol in the United States has awarded AECL a technical studies contract for improving the engine O-ring seals on the shuttle launch vehicle, failure of which destroyed the Challenger spacecraft. A Chalk River spin-off company was established to market radiation detectors using the bubble detection method developed at AECL. These are examples of important initiatives in expanding and diversifying AECL's scope of operations.

A disturbing trend is the shortage of skilled scientific and engineering personnel which is beginning to emerge in all segments of the nuclear industry, despite the turndown in activity. Many Canadian organizations, public and private sector, are reporting difficulties in locating experienced staff to fill vacancies. Although these shortages are currently limited to intermediate and senior level positions, the reduction in undergraduates entering nuclear-related university and college programs poses a serious long-term manpower problem.

Factors contributing to the short-term shortage include normal attrition and loss of intermediate-level staff due to poor career advancement opportunities in a contracting field. The lack of interest in nuclear-related training by new students reflects the poor opinion of nuclear power held by part of the public and the apprehended lack of promotional opportunities.

Given the average age of nuclear engineering staff at the specialist level, the 30 to 40 years (and perhaps more) of operational support required for power reactors and the lack of new staff, special attention will need to be given to maintaining an adequate reservoir of technical expertise in the 1990s and beyond.

In response to the general industry downturn, certain companies have reduced or ended their nuclear-related activities. DSMA-Atcon, a private sector consulting firm formerly active in the nuclear field, apparently ceased its Canadian operations in 1986/87. The Groupe d'Analyse Nucléaire which operated at the Ecole polytechnique in Montreal no longer offers support services to Hydro-Québec. CAE's nuclear power plant simulator unit has been unsuccessful in recent contract bidding, has lost part of its nuclear staff, and its continued operation in the reactor simulator business is reportedly in question. Many of the skilled workers who have left these organizations are permanently lost to the nuclear industry. This erosion in manpower in the industrial base supporting the nuclear power program is also disturbing.

A strong institutional framework will help sustain the nuclear industry in the years ahead. The federal government should make a clear policy statement of the part that it expects nuclear power to play in Canada's future energy development, and the degree to which it will support the nuclear option. The public needs a better explanation of the federal position on radioactive waste management, and on nuclear safety and liability. The forthcoming study by Ontario of the economics of Ontario Hydro's nuclear-electric power production will further clarify that aspect of the situation.

Appendix A

Two Dissenting Statements

Statement by the Member for Cape Breton–The Sydneys

I agree with the Committee's endorsement of nuclear power as a necessary and environmentally acceptable energy source of the future – although my reservations about its shortcomings are stronger than those portrayed in the report – and I agree with the wording of the 14 recommendations presented. My disagreement is with the Committee's acceptance of a role for private enterprise in some important aspects of nuclear development.

The Committee accepts the privatization of the Radiochemical Company and the Medical Products Division, subject to AECL being able to retain a minority interest in the new companies and to control of these entities remaining in Canada. I recommend against these elements of AECL being spun off as private companies at all, because I do not believe that it is in Canada's interest to have the marketing of a host of radioactive substances carried out as a private business, and because AECL will lose a major source of income. The manufacture and sale of radioisotopes for medical purposes, for food and wastewater irradiation, and for industrial applications will be subject to less abuse and will be better monitored if carried out as a government enterprise. I do not object in general to AECL Business Units, many of which are developing non-nuclear applications of technology, being converted into private companies.

For similar reasons I do not approve of the commercial deployment of the SLOWPOKE Energy System. Although SLOWPOKE is a comparatively safe form of thermal reactor, the prospect of having these low-power reactors dispersed across Canada in private hands for district heating purposes or as a source of process energy for industry is disturbing.

Given the innate biological hazard of radioactive materials, I prefer to see control of the applications of atomic energy kept within government.

Statement by the Member for Yorkton–Melville

New Democrats recognize and respect the public's genuine concern about Canada's active involvement in the nuclear age. As such, New Democrats were prepared to participate in this economic review of nuclear power – although it fell far short of previous Conservative promises of a Parliamentary inquiry into all aspects of the nuclear fuel cycle – in the hope that the Committee would at least approach the question of economics in an objective manner. Unfortunately, the Committee's analysis is so simplistic and so uncritically pro-nuclear that it cannot be supported by New Democrats.

The Committee fails to determine the true costs of nuclear power and fails to consider seriously the economic and energy potential of conservation and alternate energy sources such as hydrogen. The Committee's report is such a collection of selective facts, subjective assumptions and pure speculation that one is almost tempted to conclude that it was prepared by the nuclear industry itself and not by an impartial Standing Committee of the House of Commons.

Appendix B

List of Witnesses

Witness	Date	Issue
From the Department of Energy, Mines and Resources:	03/11/87	29
Arthur Kroeger, Deputy Minister		
Robert W. Morrison, Director General, Uranium and Nuclear Energy Branch		
Ted Thexton, Adviser, Nuclear		
From Atomic Energy of Canada Limited:	04/11/87	30
James Donnelly, President		
Stan Hatcher, President, Research Company		
Ronald Veilleux, Corporate Secretary and Vice-President, Corporate Relations		
Michel Therrien, Corporate Executive Vice-President		
From the National Energy Board:	18/11/87	31
Roland Priddle, Chairman		
Mark Segal, Director, Economics Branch		
Alex Karas, Director, Electric Power Branch		
From the Atomic Energy Control Board:	18/11/87	32
René J.A. Lévesque, President		
Zigmund Domaratzki, Director General, Directorate of Reactor Regulation		
David Smythe, Director General, Directorate of Fuel Cycle and Materials Regulation		
John Beare, Director, Regulatory Research Branch		
R.W. Blackburn, Director, Planning and Administration Branch		
From Energy Probe:	19/11/87	33
Norman Rubin, Director, Nuclear Research		

Witness	Date	Issue
From the Canadian Nuclear Association:	01/12/87	34
Noel O'Brien, Chairman		
Michael Harrison, President		
Ian Wilson, Vice-President		
Rita Dionne-Marsolais, Vice-President, Information		
Nick Ediger, Director and Past Chairman		
From the Canadian Electrical Association:	15/12/87	37
Wallace Read, President		
Hans Konow, Director, Public Affairs		
From Ontario Hydro:	16/12/87	38
Lorne McConnell, Vice-President, Power System Program		
Mitch Rothman, Chief Economist and Director, Economics and Forecast Division		
Ken Snelson, Manager, Bulk Electricity System Resources Planning Department		
Ted Bazeley, Manager, Nuclear Fuel Supply Department		
Richard Furness, Government Relations Officer		
From Passmore Associates International:	02/03/88	39
Jeff Passmore, President		
David Argue, Senior Associate		
From the New Brunswick Electric Power Commission:	04/03/88	40
Terry Thompson, Director, Public Affairs		
A.R. Mackenzie, Plant Manager		
From Marbek Resource Consulting:	10/03/88	41
Brian Kelly, President		
From Torrie, Smith and Associates:		
Ralph Torrie, President		

Witness	Date	Issue
From TransAlta Utilities Limited:	10/05/88	42
Walter Saponja, Senior Vice-President, Generation		
Edward J. Barry, Vice-President, Research		
From the Ontario Nuclear Safety Review:	14/06/88	43
F. Kenneth Hare, Commissioner		

From the Canadian Nuclear Association:

Noel O'Brien, Chairman

Michael [illegible]

Ian Wilson, [illegible]

[illegible], Vice-President, Information

Nick [illegible], Director and Past Chairman

From the Canadian Electrical Association: 15/12/87 37

[illegible], President

[illegible], Director, Public Affairs

From Ontario Hydro: 16/12/87 38

Lorne McConnell, Vice-President, Power System Program

[illegible], Chief Economist and Director, Economics and Forecast Division

[illegible], Manager, Bulk Electricity System Resources Planning Department

[illegible], Manager, Nuclear Fuel Supply Department

Richard [illegible], Government Relations Officer

From Passmore Associates International: 02/02/88 39

Jeff Passmore, President

David [illegible], Senior Associate

From the New Brunswick Electric Power Commission: 04/03/88 40

Terry Thompson, Director, Public Affairs

A.R. [illegible], Plant Manager

From Marbek Resource Consulting: 10/03/88 41

Brian Kelly, President

From Torrie, Smith and Associates:

Ralph Torrie, President

Appendix C

Committee Travel

The Standing Committee on Energy, Mines and Resources made three trips within Ontario and two trips internationally to broaden its knowledge and understanding of nuclear power development in Canada and in selected foreign countries. The organizations and individuals with whom the Committee consulted during this travel are listed below.

Committee Travel to Chalk River Nuclear Laboratories, March 1,1988

Chalk River Nuclear Laboratories, Chalk River

Peter J. Harvey, General Manager, Chalk River Nuclear Laboratories

Ralph E. Green, Vice-President, Reactor Development

Howard K. Rae, Vice-President, Radiation Applications and Isotopes

J.C. Douglas Milton, Vice-President, Physics and Health Sciences

Donald H. Charlesworth, Director, Waste Management Technology Division

Bernard DeAbreu, Manager, Reactor Operations Branch

Rudy M. Lepp, Manager, Components and Instrumentation Division

Gerald F. Lynch, General Manager, Local Energy Systems Business Unit

Norman E. Gentner, Radiation Biology Branch

William R. Taylor, Technical Specialist, Mechanical Systems Design Branch

Lorna E. Evans, Manager, Public Affairs

Committee Travel in Southern and Eastern Ontario, March 20-23,1988

Canadian General Electric, Peterborough

Paul Schofield, Vice-President, Power Systems and Services

Sil Dragan, Manager – Marketing, Nuclear Fuel Handling Operations, Power Systems and Services

Dean A. Wasson, Manager – Nuclear Products, Power Systems and Services

Dave Irwin, Manager – Nuclear Fuel Handling Operations, Power Systems and Services

Harvey R. Lee, Manager – Nuclear Fuel Operations, Power Systems and Services

Invar Manufacturing Ltd., Batawa

Brian Riden, Vice-President and General Manager
Maurice Mainville, General Sales Manager
James A. Steenburg, Material Control Manager

CANDU Operations, Atomic Energy of Canada Limited, Mississauga

Don S. Lawson, President
H.M. VanAlstyne, Vice-President, Technical
Dennis R. Shiflett, Vice-President, Engineering Services Business Unit
L. John Ingolsfrud, Vice-President, Ontario Hydro Business Unit
David N. Harrington, Executive Assistant to the President

Masoneilan/Dresser Canada, Inc., Mississauga

Brian E. Minns, Vice-President and General Manager
Ray Briggs, Sales and Marketing Manager

Babcock & Wilcox Canada, Cambridge

Paul Koenderman, President
James Smith, Manager, Nuclear Products Marketing
Malcolm Cox, Manager, Projects
Dennis Dueck, Manager, Facilities Engineering

Bruce Nuclear Power Development, Ontario Hydro, Tiverton

Terry D. Squire, Corporate Relations
Brian Wood, Operation Manager
Darrell Davidson, Manager
Les Broad, Station Manager, Douglas Point Generating Station
Cameron D. Campbell, Analyst, Government Relations, Corporate Relations Branch (Toronto)

RESOLUTE Development Corp., Kincardine

Sam MacGregor, President

Committee Travel in Sweden, West Germany and France, April 8-16,1988

Sweden

Canadian Embassy, Stockholm

His Excellency Dennis B. Browne

Gregory J. Kozicz, Third Secretary and Vice-Consul

Miljö- och Energidepartementet / Ministry of Environment and Energy, Stockholm

Rolf Annerberg, Under-Secretary of State

Lars Ekecrantz, Expert

Kärnkraftsäkerhet och Utbildning AB / Nuclear Training and Safety Centre, Nyköping

Rolf I. Odin, Senior Engineer and Project Manager

Statens strålskyddsinstitut / National Institute of Radiation Protection, Stockholm

Gunnar Johansson, Radiation Protection Officer

Statens kärnbränslenämnd / National Board for Spent Nuclear Fuel, Stockholm

Olof Söderberg, Director

Nils Rydell, Chief Engineer

Margaretha Stålfors, Director of Finance

Statens kärnkraftinspektion / Swedish Nuclear Power Inspectorate, Stockholm

Sören Norrby, Director, Division of Nuclear Waste

Studsvik Energiteknik AB, Nyköping

Walter Hübner, Vice President, Research and Development, Energy Technology Division

Claes Harfors, Vice President, Power Plant Services, Nuclear Division

Eric Hellstrand, Vice President, Safety and System Analysis, Nuclear Division

Lennart Devell, Deputy Head, Safety and System Analysis, Nuclear Division

Per Linder, Project Manager, Nuclear Division

Svensk Kärnbränslehantering AB / Swedish Nuclear Fuel and Waste Management Company, Stockholm

Sten Bjurström, President

Vattenfall / Swedish State Power Board, Östhammar

Arthur Monsen, Service Department Manager

Federal Republic of Germany

Canadian Embassy, Bonn

His Excellency W.T. Delworth

Maureen Lofthouse, Counsellor, Science and Technology

Richard Têtu, Counsellor, Political

Christian Luckner, Science and Technology

Dennis Baker, Canadian Consul General (Düsseldorf)

Government of the Federal Republic of Germany, Bonn

Albert Probst, Parliamentary Secretary of State, Federal Ministry for Research and Technology

Martin Grüener, Parliamentary Secretary of State, Federal Ministry for Environment, Nature Conservation and Reactor Safety

Rheinisch–Westfälisches Elektrizitätswerk AG, Essen

Klaus P. Messer, Director

France

Canadian Embassy, Paris

Alain Dudoit, Political Counsellor

Robert Hage, Counsellor, Political Affairs

Jean-Pierre Juneau, Minister-Counsellor, Political Affairs

Ian MacLean, Economic Counsellor

Commissariat à l'Énergie Atomique / Atomic Energy Commission, Paris

Pierre Cachera, Director, Technology and Equipment

Philippe Hammer, Assistant to the Technology Director

Philippe Raimbault, Liaison – International Relations

Framatome, Paris

Pierre-Yves Gatineau, President, International Relations

Association France–Canada , Paris

Senator Adolphe Chauvin, President

Agence Nationale pour la gestion des Déchets Radioactifs / National Agency for Nuclear Waste Management, Paris

Armand Faussat, Assistant Director

Institut National des Sciences et Techniques Nucléaires / National Institute of Nuclear Science and Technology, Saclay

Yves Chelet, Director

Georges Le Guelte, Assistant Director

Committee Travel to Washington, D.C., May 1-4,1988

Canadian Embassy

Leonard H. Legault, Deputy Head of Mission and Minister (Economic)

T. D'Arcy McGee, Counsellor (Energy)

Henry C. Armstrong, Counsellor (Commercial)

Jonathan Fried, First Secretary

Ross Glasgow, First Secretary

Department of Energy

Theodore J. Garrish, Assistant Secretary

Del Bunch, Principal Deputy Assistant Secretary for Nuclear Energy

Richard H. Williamson, Deputy Assistant Secretary for International Affairs

Jerome Saltzman, Deputy Director, Office of Facilities Siting and Development, Office of Civilian Radioactive Waste Management

Mary Ann Novak, Special Assistant to the Assistant Secretary for Nuclear Energy

Betsy O'Brien, Data Analysis and Forecasting Branch, Energy Information Administration

Dan Nikodem, Office of Nuclear and Alternate Fuels, Energy Information Administration

Wanda M. Klimkiewicz, International Program Assistant, Office of International affairs and Energy Emergencies

Senate Committee on Energy and Natural Resources

Benjamin S. Cooper, Professional Staff

Mary Louise Wagner, Professional Staff

Marilyn Meigs, Professional Staff Member, Office of Senator James A. McClure

Nuclear Regulatory Commission

Harold Denton, Director, Government and Public Affairs

Stuart A. Treby, Assistant General Counsel for Rule Making and Fuel Cycle

Joseph F. Sento, Acting Assistant General Counsel for Hearings

Hans B. Schechter, Senior International Relations Specialist, Office of International Programs

Congressional Research Service

Warren H. Donnelly, Senior Specialist

Robert L. Civiak, Head, Advanced Technology Section, Science Policy Research Division

Carl E. Behrens, Head, Fuels and Mineral Section, Energy and Natural Resources Division

Francis T. Miko, Specialist in International Relations, Foreign Affairs & National Defense Division

Mark Holt, Energy Policy Analyst

U.S. Council for Energy Awareness

Harold B. Finger, President and Chief Executive Officer

Bill Harris, Senior Vice President

Paul Turner, Vice President, Industry Communications and Publications

John R. Siegel, Vice President, Technical Programs

Carl A. Goldstein, Vice President, Media and Public Relations

U.S. Public Interest Research Group

Kathleen Welch, Energy Policy Coordinator

Ken Bossong, Critical Mass Energy Project

House of Representatives Subcommittee on Energy and Power

Sue Sheridan, Counsel

Tom S. Runge, Counsel

Pat Davis, Counsel, Nuclear Regulatory Commission

American Nuclear Energy Council

Edward M. Davis, President

John T. Conway, Chairman and Executive Vice President, Corporate Affairs, Consolidated Edison Company of New York, Inc.

Andrea Dravo, Vice President, Strategic Planning

Kevin Billings, Vice President, Government Affairs

Diane Holmes, Director, Development

Duke Power Company

K.P. Lau, Congressional Affairs Specialist, Design Engineering Department

Committee Travel in Ottawa Area, May 26, 1988

AECL Radiochemical Company, Kanata

Paul O'Neill, President

David Drummond, Manager, Isotope Quality Control

John Worswick, Manager, Cobalt Operations

Jeff Norton, Manager, Cobalt Operations

AECL Medical Products Division, Kanata

Frank H. Warland, Vice-President

Peter E. Habgood, General Manager, Manufacturing

Robert L. Wolff, General Manager, Service, Technology, Human Resources and Administration

Steve R. Lee, Director, Sales

SENSYS, Nepean

Philip Campbell, General Manager

Appendix D

Abbreviations and Acronyms Used in the Report

AEC	Atomic Energy Commission (United States and Japan)
AECB	Atomic Energy Control Board
AECL	Atomic Energy of Canada Limited
AGR	advanced gas-cooled reactor
ANDRA	Agence Nationale pour la gestion des Déchets Radioactifs (National Radioactive Waste Management Agency, France)
ANEC	American Nuclear Energy Council
Bq	becquerel (unit for measuring radioactivity)
BWR	boiling water reactor
CANDU	CANada–Deuterium–Uranium
CANDU–BLW	CANDU boiling light water reactor
CANDU–OCR	CANDU organically-cooled reactor
CANDU–PHWR	CANDU pressurized heavy water reactor
CEA	Canadian Electrical Association
CEA	Commissariat à l'Énergie Atomique (France)
CERN	European Organization for Nuclear Research
CGE	Canadian General Electric Company
CLAB	central interim storage facility for spent nuclear fuel (Sweden)
CNA	Canadian Nuclear Association
CRNL	Chalk River Nuclear Laboratories
DOE	Department of Energy (United States)
ECCS	emergency core cooling system
EdF	Électricité de France (France)
EIA	Energy Information Administration (United States)
EMR	Energy, Mines and Resources, Department of
EPA	Environmental Protection Agency (United States)
EURATOM	European Atomic Energy Community
FBR	fast breeder reactor
FRG	Federal Republic of Germany
GCR	gas-cooled reactor
GGCR	graphite-moderated gas-cooled reactor (French GCR)
HTR	high-temperature reactor
HWP	heavy water plant
HWR	heavy water reactor
IAEA	International Atomic Energy Agency (Austria)
INPO	Institute of Nuclear Power Operations (United States)
KSU	Kärnkraftsäkerhet och Utbildning AB (Swedish Nuclear Training and Safety Centre)

KWU	Kraftwerk Union (West Germany)
LMFBR	liquid-metal-cooled fast breeder reactor
LWGR	light water graphite-moderated reactor
LWR	light water reactor
MWe or MW	megawatts (electrical)
MWt	megawatts (thermal)
NBEPC	New Brunswick Electric Power Commission
NEA	Nuclear Energy Agency (of the OECD, France)
NEB	National Energy Board
NEI	Nuclear Engineering International (United Kingdom)
NGS	Nuclear Generating Station
NIAC	Nuclear Insurance Association of Canada
NPD	Nuclear Power Demonstration
NRC	Nuclear Regulatory Commission (United States)
NRU	National Research Universal
NRX	Nuclear Research Experimental
NWPA	Nuclear Waste Policy Act (United States)
O&M	operating and maintenance
OECD	Organisation for Economic Co-operation and Development
PHWR	pressurized heavy water reactor
PTB	Physikalisch-Technische Bundensanstalt (Physical-Technical Agency, West Germany)
PWR	pressurized (light) water reactor
R&D	research and development
RBMK	Reactor Bolche Molchnastie Kipiache (Soviet LWGR of Chernobyl type)
R,D&D	research, development and demonstration
RCC	Radiochemical Company
RWE	Rheinisch–Westfälisches Elektrizitätswerk (West Germany)
SFR	final repository for reactor waste (Sweden)
SKB	Svensk Kärnbränslehantering AB (Swedish Nuclear Fuel and Waste Management Company)
SKI	Statens kärnkraftinspektion (Swedish Nuclear Power Inspectorate)
SKN	Statens kärnbränslenämnd (Swedish National Board for Spent Nuclear Fuel)
Skr	the Swedish unit of currency, the krona
SSI	Statens strålskyddsintitut (Swedish National Institute of Radiation Protection)
THTR	thorium high-temperature reactor
USCEA	U.S. Council on Energy Awareness
WNRE	Whiteshell Nuclear Research Establishment
ZEEP	Zero Energy Experimental Pile

Appendix E

Terminology

The definitions in this and the following section on terminology are taken, with minor modifications, from the NEB report *Electric Power: A Compendium of Terms*, Information Bulletin 8, May 1985; from the Ontario Hydro report *Meeting Future Energy Needs: Draft Demand/Supply Planning Strategy*, Report 666 SP, December 1987; and from the World Energy Conference report *Energy Terminology*, 2nd Edition, Pergamon Press, 1986.

Terminology: Electric Power Systems

Acid rain: A general term describing precipitation in any form that has been acidified by the presence of atmospheric pollutants, primarily the oxides of sulphur and nitrogen.

Alternating current: An electric current that flows alternately in one direction and then in the reverse direction. In North America, the standard for alternating current is 60 complete cycles per second; such electricity is said to have a frequency of 60 hertz. Alternating current is used in almost all aspects of power systems because it can be transmitted and distributed much more economically than direct current.

Alternative energy/technology: Energy sources or technologies which are not yet widely used, as opposed to "conventional" energy/technology. The term usually refers to renewable energy sources and small, decentralized installations. Examples are photovoltaics, solar heating, wind power and waste-fueled electrical generation.

Assured system capacity: The dependable power-generating capacity of system facilities available for serving system load after making provision for required reserve generation, including the effects of agreements with other systems.

Asynchronous tie: A direct-current interconnection between two alternating-current systems, so-called because the two systems need not be in synchronism with each other.

Average energy: The energy which would be generated by the hydro-electric stations in a river system under average streamflow conditions.

Average streamflow: The arithmetic average of all recorded flows in a river over a specified period of time, usually measured on an annual basis.

Avoided cost: The cost which would be incurred by an electric utility in providing new generating capacity if the utility were to provide the power itself instead of purchasing it from an independent generator.

Base load: The minimum continuous load over a given period of time.

Base-load generating station: A generating station which is normally operated to supply all or part of the base load of a system and which consequently operates at full output whenever available. Base-load generating units tend to be large units with low operating costs.

Bulk electricity system: The generation and high voltage transmission facilities (generally 115 kilovolts and up) considered as a whole.

Bus: A set of electrical conductors that serves as a common connection for two or more circuits. A bus may be in the form of rigid bars ("busbars") or in the form of cables.

Capability: The maximum load that a station or equipment is capable of carrying under specified conditions.

Capacity: The rate of delivery of energy (for example, a utility might sell 50 megawatts of capacity or electric power); or

The maximum quantity of power that a piece of equipment or a system is capable of carrying or supplying (for example, a generating unit might have a rated capacity of 50 megawatts).

Capacity factor: For any equipment, the ratio of the average load during some period of time to the rated capacity of the equipment. Capacity is usually expressed as a percentage.

Circuit: Any conductor or set of conductors intended to carry electricity.

Circuit breaker: A switching device to open or close an electric power circuit during either normal system operation or fault conditions.

Cogeneration: The combined production of electricity and useful heat (usually steam).

Control centre: The control room from which instructions are issued for switching of power system equipment, stations or lines, and for changing the amount of power generated in power stations. Typically such a centre is equipped with remote controls, telemetering and computer facilities. Automated system maps indicate the operating status of generating units, transmission lines and main substation equipment. Metering devices show the loads being carried by units and lines, and the voltage levels at selected locations. Thus the system supervisor is provided with a complete picture of the main features of the power system and can coordinate its operations.

Converter station: An installation for converting direct current into alternating current, or for changing one frequency of alternating current to another.

Current: The flow of electricity in a conductor. Current is measured in amperes.

Demand: The desire of purchasers for electricity. "Demand" is often used synonymously with "power" which is the rate at which electrical energy is being delivered.

Demand charge: The component of a two-part price for electricity which is based on a customer's highest power demand reached in a specified period, usually a month, regardless of the quantity of energy used. The other component of the two-part price is the energy charge.

Demand management: Actions taken by a utility or other agency intended to influence the amount or timing of customers' use of electricity. These actions can be divided into three groups: load growth, load shifting and load reduction.

Dependable capacity: The load-carrying ability of a station or system under adverse conditions, as for example, the capacity of a hydro-electric station under defined low-flow conditions.

Direct current: Current that flows continuously in one direction (as opposed to an alternating current). The current supplied from a battery is direct current.

Direct current transmission: Transmission of electricity by direct current instead of the usual alternating current. Direct current has certain advantages for long-distance point-to-point transmission and for interconnecting power systems that would otherwise be unstable if an attempt were made to tie them together by alternating current transmission. There are four high-voltage dc installations in service in Canada: (1) the Vancouver Island underwater transmission link; (2) the Nelson River (Manitoba) overhead transmission line; (3) the Eel River (New Brunswick) asynchronous tie; and (4) the Chateauguay (Quebec) asynchronous tie.

Distribution system: The lines, transformers, switches, etc. used to distribute electricity over short distances from the transmission system to customers. Distribution generally takes place at relatively low voltages (44 kilovolts and less).

Economy energy: Energy sold by one power system to another to effect a saving in the cost of generation when the receiving utility has adequate capability to supply the loads on its own system.

Electrical utility: An organization that has as its prime purpose the generation, transmission and/or distribution of electric energy for sale.

Electro-technology: A technology that uses electricity in its processes, especially new technologies used to displace other energy sources. An example is the use of electrically-driven heat pumps for kiln drying wood, in place of air heated by on-site fuel combustion.

Energy charge: The component of a two-part price for electricity that is based on the amount of energy taken. The other component of price is the demand charge.

Extra high voltage (EHV): Any transmission voltage higher than those commonly used. The utility industry has generally considered EHV to be 345 kilovolts (kV) or higher, although such voltages are becoming increasingly common.

Firm power: Electric power intended to be available at all times during the period of the agreement for its sale.

Forced outage rate: The probability that a particular generating unit or other system component will be unavailable for service because of breakdown.

Fuel replacement energy: Energy sold by one utility to another to enable the purchaser to avoid burning fuel in its own thermal generating facilities. Fuel replacement energy is typically priced at a percentage of the fuel cost avoided by the purchasing utility.

Generating station: A station comprising one or more generating units for the production of electricity. The main types of generating stations are hydro-electric, nuclear-electric and fossil-fueled (by coal, oil or natural gas). In some parts of the world, such as The Geysers region of California, geothermal-electric power is becoming an important element in generating capacity.

Generating unit: An electric generator, the prime mover that drives the generator, and all the associated equipment that must be operated together as a group to generate electricity. A generating unit can usually operate independently of other units at a multi-unit station.

Generation rejection: Disconnecting selected generating units from a power system to preserve the continuing safe operation of the rest of the system. This action is sometimes taken if a large block of load has suddenly been cut off by some emergency, leaving generators feeding into the system without enough connected load to absorb their output. The units would otherwise overspeed, raising the frequency and voltage on the system to unacceptable levels.

Grid: A network of electric power lines and connections.

Head (hydraulic): The difference in elevation between the water level immediately above a hydro-electric generating station and the water level immediately below it. The power output of the station is proportional to the hydraulic head.

Heat rate: A measure of generating station thermal efficiency, generally expressed as British thermal units per net kilowatt-hour. It is computed by dividing the total heat (Btu) content of the fuel burned by the resulting net kilowatt-hours of electricity generated. In metric units, the heat rate is expressed as kilojoules per kilowatt-hour.

Hertz: The unit of frequency for alternating current, formerly given in cycles per second. The standard frequency for power supply in North America is 60 hertz.

High tension: Any voltage in excess of 750 volts.

Hydro-electric station: An electric generating station in which the prime movers are hydraulic turbines.

Incremental generating cost: The cost of generating one additional unit of electric energy above some previously determined base quantity.

Independent (private) generation: Generation owned or operated by producers other than a utility. These producers usually have generating plants for the purpose of supplying electric power required in their own industrial and commercial operations. The term also covers private plants whose sole purpose is the sale of electricity to a utility.

Installed (generating) capacity: The capacity measured at the output terminals of all the generating units in a station, before deduction of station service requirements.

Integrated planning: Joint planning by different power systems in order to minimize total costs. Integrated planning is one characteristic of a true power pool.

Interconnection agreement: An agreement made between two power utilities to govern the operation of interconnections between their systems. Typically such an agreement defines different classes of inter-utility electricity transfers and specifies how they shall be priced between the two companies.

Interconnected system: A system consisting of two or more individual power systems connected together by tie lines.

Interruptible energy: Energy made available under an agreement that permits curtailment or interruption of delivery at the option of the supplier.

Inter-utility transfer: A transfer of electric power between two or more electrical utilities. The NEB Part VI Regulations define five classes of inter-utility transfer. These are:

(1) Adjustment transfer: A transfer of electric power or energy made: (a) to adjust an energy account balance; (b) to compensate for electrical losses; (c) to compensate for services rendered; (d) to deliver output entitlements; or (e) to provide upstream or downstream benefits.

(2) Carrier transfer: A transfer of electric power or energy by one utility over the circuits of another, for delivery either to a third party or back to the originating utility.

(3) Equichange transfer: An interchange of equal quantities of electric power or energy within a stated period.

(4) Sale transfer: A transfer of electric power or energy under a contract of sale.

(5) Storage transfer: An electric energy transfer "banked" for the time being in the form of water in the reservoir space of another electrical utility, in the expectation that equivalent electric energy will be returned at a later time.

Isolated system: An electric power system not interconnected with any other system (such as the Northern Canada Power Commission). Isolated systems are usually of relatively small capacity.

Licence: A licence to export electricity from Canada, issued under Part VI of the National Energy Board Act, following a public hearing. A licence is subject to the approval of the Governor in Council.

Load: A curve for a specified period (such as a day, month or year) showing the amount of time during that period that the power load exceeded different values or different percentages of the maximum value.

Load curve (shape): The pattern of electricity use or production when demand is plotted against time.

Load factor: The ratio of the average load during a designated period to the peak or maximum load in that same period, usually expressed as a percentage of the peak load. The annual load factor for the entire Ontario Hydro system is about 68%.

Load rejection (load shedding): Interrupting the supply of electricity to a selected region or group of customers as a means of preserving the continuing safe operation of the remainder of a power system. This action is sometimes taken in an emergency when the total system load exceeds the the capacity of the generation available to supply it.

Load shifting: Shifting electrical demand from one period to another, usually from high-load to low-load periods.

Locked-in energy: Energy production capability at a generating station which cannot be used because of inadequate transmission capability connecting the generating station to the load. For example, part of the generating capacity of the Bruce Nuclear Generating Station is locked in.

Losses: Energy or power lost in circuits or equipment, mainly in the form of heat, when current flows through the circuit.

Marginal cost: The cost of supplying an additional unit of output. When the extra unit of output can be supplied simply by increasing production from the existing plant, it is usually specified as the "short-run marginal cost" or "incremental cost"; when new plant is required to supply the additional production, it is usually termed the "long-run marginal cost".

Marginal cost pricing: A rate structure in which prices are set at the cost of the last (marginal) unit of production, rather than at cost of production averaged over all output.

Mothball: To take equipment that is surplus to current needs or that has reached the end of its normal life and retain it in a preserved state. Mothballed equipment is not available for immediate use but can, with preparation, be resurrected for future use.

Name-plate rating: The full-load continuous rating of a generator or other electrical equipment under the conditions designated by the manufacturer, as indicated on the name plate attached to the device.

Outage: The state of any circuit component when it is not available to perform its intended function because of some event associated with that component. An outage may or may not cause an interruption of service to customers, depending on the layout of the system.

Parallel power: Independent generation which is linked to and synchronized with the bulk electricity system.

Peak demand: The maximum load consumed by a customer, group of customers or by the entire system in a stated period of time, such as a year.

Peak period: Periods during which relatively high demands are placed on an electrical system, as opposed to off-peak periods.

Peaking unit: A generating unit intended to be operated intermittently to supply peak loads.

Power pool: A grouping of two or more interconnected electric systems planned and operated to supply power in the most reliable and economical manner for their combined load requirements.

Power system: All the interconnected facilities of an electrical utility. A power system includes the generating stations, transformers, switching stations, transmission lines, substations, distribution lines, and circuits to the customers' premises; that is, all the facilities required to provide electrical services to the customers.

Primary energy source: The source of primary energy from which electricity is generated, including falling water, uranium (by nuclear fission), coal, oil, natural gas, wind, biomass, direct solar radiation, geothermal energy and tidal energy.

Prime mover: The turbine or engine that drives an electrical generator.

Pumped storage: An arrangement in which water is pumped from a lower to a higher reservoir, during off-peak hours. During peak hours, the water is allowed to return to the lower reservoir through hydro-electric turbines, thus generating power. Usually the turbines are reversible so that they can also serve as the pumps in the system.

Renewable energy source: A source of energy which is inherently self-renewing, such as the various manifestations of solar energy (water power, biomass, wind energy, direct solar radiation, wave energy and ocean currents), tidal energy and geothermal energy.

Reserve (generating) capacity: The extra generating capacity required on any power system over and above the expected peak load. Such a reserve is required for two main reasons: in case of the unexpected breakdown of generating equipment; and in case the actual peak load is higher than forecast.

Right-of-way: The strip of land on which a power line is located, and on which the power company has acquired the legal right to perform construction and maintenance, to restrict the growth of vegetation, and sometimes to restrict construction by other parties. The width of the right-of-way varies with line voltage.

Run-of-the-river plant: A hydro-electric generating station having negligible capacity for the storage of water, so that the plant has to run on the natural flow of the river. The output of the plant may therefore be subject to considerable variation.

Scheduled maintenance: Maintenance of equipment performed in accordance with a prearranged schedule.

Seasonal diversity: The diversity between loads that reach their maximum values at different seasons of the year. For example, most Canadian power systems experience their annual peak loads in the winter, whereas many U.S. systems have their annual peaks in the summer because of air conditioning. Systems that differ in this way can effect economies of scale by exchanging energy on a seasonal basis.

Service area: The area within which a utility is required, or has the right, to serve consumers.

Short-term power: Power and associated energy which one utility purchases from another for the purpose of obtaining a supply of power intended to be available at all times during the period covered by the commitment.

Social benefits: Benefits, whether tangible or intangible, resulting from a project. Social benefits are distinguishable from private benefits in that they include all the benefits of a project, whether or not they accrue to project sponsors.

Social costs: Costs or damages, whether tangible or intangible, which a project causes to be imposed. Social costs are distnguishable from private costs in that they include all the costs of a project incurred by all citizens rather than those only incurred by the project sponsors.

Spinning reserve: That portion of the reserve generating capacity which is actually in service, connected to the system, spinning (but not generating full power), and which is ready to pick up load automatically at a moment's notice.

Split savings: A widely-used formula for the pricing of energy, especially economy energy sold by one utility to another, in which the total saving resulting from a sale is split equally between buyer and seller.

Stability: The ability of power systems to remain in synchronism.

Station service: The electricity required at a generating station to run the auxiliary plant plus the capacity represented by the losses in the generator transformers.

Storage: The water held in a reservoir. Storage is used to even out the natural variations of flow in a river, so that the ouput of hydro-electric generation can be made as independent as possible of such natural variations.

Strategic conservation: Efficiency improvements which would not be undertaken by customers based only on the value of the savings available to them. Additional financial or other incentives, or the removal of barriers by the utility or by government, are required to promote the conservation initiative.

Substation: A station at which the voltage of the bulk power system is stepped down to a level suitable for distribution, and at which the feeders at this lower voltage originate and may be switched on or off.

Sulphur dioxide: A heavy, odourless, suphocating gas with the chemical formula SO_2. It occurs in the flue gases emitted from furnaces where fuel is burned, including thermal generating stations. Combining with water vapour in the atmosphere, and in the presence of sunlight, it produces sulphuric acid and together with other acids leads to the phenomenon of acidic precipitation.

Summer peak: The highest load on a power system during the summer, usually caused by air conditioning in hot weather.

Superconductor: An electrical conductor offering negligible resistance to the flow of electricity.

Surplus energy: Energy that is surplus to the needs of its owner, including both load and reserve. Surplus energy can be produced whenever the total generating capacity exceeds the total load, and is often sold on an interruptible basis.

Switching station: A station at which the transmission lines of a power system can be selectively connected or disconnected by means of switchgear.

Synchronism: The condition of alternating current generators being "in phase"; that is, timed so that their voltage waves reach the maximum and minimum values at exactly the same instant. This is an essential condition in order for alternating current generators to operate on the same system.

Synchronous tie: Any alternating current tie line. All generating units interconnected by the tie must be in synchronism.

Thermal generating station: An electric generating station where the prime movers are driven by gases or steam produced by burning fuels (such as coal, oil, gas, wood or refuse) or by nuclear processes.

Time-of-use (time-differentiated) rates: Rates which vary based on the time of day, day of the week, or season of the year.

Transformer: An electromagnetic device for raising or lowering the voltage of alternating current electricity.

Transmission line: A line used for the transmission of electric power at high voltage. Transmission lines may be constructed overhead, underwater or underground. Lines of voltage less than 115 kilovolts are usually considered to be subtransmission or distribution.

Transmission system: Lines, transformers, switches, etc. used to transport electricity in bulk from sources of supply to other principal parts of the system. Transmission is generally at voltages of 115 kilovolts and above.

Turbine (hydraulic): A rotary type of prime mover in which mechanical energy is produced by the force of water, steam or gas directed against blades fastened to a rotating shaft.

Ultra high voltage (UHV): Any voltage in excess of approximately 1,000 kilovolts.

Voltage: The electrical force, measured in volts or multiples of volts (e.g. kilovolts) that causes a current to flow in a circuit. In North America, the standard voltage for residential use is 115 volts, with 230 volts used for heavy appliances such as ranges, dryers and hot water heaters. Voltages used for urban and rural distribution range from about 4 kV to 44 kV. The most common transmission voltages are 115, 132, 230, 345, 500 and 735 kV. The higher the voltage, the more power a transmission line can carry.

Wheeling: The transmission of power belonging to one utility through the circuits of another utility, for delivery either to a third party or back to the originating system.

Winter peak: The highest load on a power system during the six-month period October to March. In Canada, the winter peak almost always occurs in December or January.

Terminology: Nuclear Power

Actinides: A series of elements with atomic numbers of 89 or above and with similar chemical properties. The series includes such naturally occurring elements as thorium and uranium, together with the induced "transuranic" elements such as plutonium and americium. Among their isotopes are long-lived alpha emitters which must be taken into account in radioactive waste disposal.

Boiling water reactor: A reactor in which water is used as coolant and moderator and allowed to boil in the core.

Breeder reactor: A reactor which produces a fissile substance from a fertile substance, in greater quantity than the fissile substance being consumed in reactor operation (that is, with a conversion or "breeding" ratio greater than one).

CANDU: A family of nuclear fission reactors developed in Canada that uses natural uranium as the fuel and heavy water as the moderator and coolant.

Coolant: A liquid or gas circulated through or around the core of a reactor to remove heat.

Critical: A reactor is said to be "critical" when the rate of neutron production is exactly equal to the rate of neutron disappearance; that is, when the neutron multiplication factor equals one. If the multiplication factor exceeds one, the reactor is "supercritical"; if the factor is less than one, the reactor is "subcritical".

Critical mass: The minimum mass of fissile material with a specified configuration, material composition and environment that can sustain a critical chain reaction.

Emergency shutdown (scram): The act of shutting down a reactor suddenly to prevent or minimize a dangerous condition.

Enriched uranium: Uranium in which the percentage of the fissionable isotope uranium-235 has been increased beyond the 0.71% share that it comprises of naturally occurring uranium.

Fast reactor: A reactor in which nuclear fission is induced predominantly by fast neutrons.

Fertile material: Isotopes capable of being readily transformed, directly or indirectly, into fissionable material by the absorption of neutrons (particularly uranium-238 and thorium-232).

Fissile material: Nuclides readily fissioned by slow neutrons (for example, uranium-235, uranium-233, plutonium-239 and plutonium-241).

Fission energy: The energy released when an atom is split.

Fission products: Nuclides produced either by fission or by the subsequent radioactive decay of the nuclides thus formed.

Fuel cycle: The sequence of steps – such as fuel fabrication, utilization, reprocessing, refabrication and reutilization – through which nuclear fuel may pass.

Fuel inventory: The total amount of nuclear fuel invested in a reactor, a group of reactors or an entire fuel cycle.

Fuel reprocessing: The processing of nuclear fuel after its use in a reactor, to remove fission products and recover fissile and fertile material.

Gas-cooled reactor: A reactor in which a gas is used as coolant and graphite as moderator. The gas-cooled reactor, sometimes referred to as the "Magnox" type, uses natural uranium; the "advanced gas-cooled reactor" (AGR) and the "high-temperature gas-cooled reactor" (HTGR) require enriched fuel.

Half-life: The time taken for half of the atoms in a radioactive substance to spontaneously disintegrate, and hence for the activity to decay to half of its original value.

Heavy water: Deuterium oxide or D_2O. Heavy water is water in which the hydrogen atom is represented by the hydrogen isotope deuterium. It is used in an essentially pure state as both moderator and coolant in the CANDU reactor system.

Heavy water reactor: A reactor that uses heavy water as the moderator. The coolant may be gas, light water or heavy water (as in the CANDU system). Depending on the type, the fuel may be either natural or enriched uranium.

Isotope: Nuclides having the same atomic number but different masses (mass being proportional to the total number of protons and neutrons in the nucleus). For example, the element hydrogen, atomic number 1, can occur in three isotopes: common hydrogen or protium (with one proton in the nucleus); deuterium (with one proton and one neutron); and tritium (with one proton and two neutrons), which is unstable.

Light water reactor: A reactor in which ordinary (light) water serves as coolant and moderator. The BWR and PWR are examples of light water reactor systems.

Moderator: A material used to reduce neutron energy (that is, to produce "slow" or thermal neutrons) by scattering and slowing without excessive neutron capture.

Natural uranium: Uranium with the naturally occurring mixture of isotopes (99.28% fertile uranium-238, 0.71% fissile uranium-235 and 0.006% uranium-234).

Nuclear fission: The division of a heavy nucleus into two (or, rarely, more) parts, usually accompanied by the emission of neutrons, gamma radiation and energy release.

Nuclear fuel: A substance containing one or more fissile nuclides capable of maintaining a chain reaction in a reactor. The term may also be used to include a substance containing one or more fertile nuclides that can be transmuted into such fissile nuclides.

Nuclear power: Power generated at a station where the steam to drive the turbines is produced by the process of atomic fission, rather than by burning a combustible fuel.

Nuclear (fission) reactor: A device in which a self-sustaining nuclear fission chain reaction can be maintained and controlled. The term "nuclear reactor" is sometimes applied to a device in which a nuclear fusion reaction can be produced and controlled (fusion reactor).

Nuclide: An individual atomic species. Deuterium and tritium, although they are both isotopes of hydrogen, are two different nuclides.

Power reactor: A nuclear reactor whose primary purpose is to produce energy. Reactors in this class include electric power reactors, heat-producing reactors (producing heat for industrial processing, to supply district heating systems, etc.), and propulsion reactors in nuclear-powered surface vessels and submarines.

Radioactive waste: Unwanted radioactive materials obtained in the processing, handling or utilization of radioactive substances. Such wastes may be classified according to their degree of activity or to their half-lives, as follows.

A. According to the radionuclide content:

high-level waste: the highly radioactive liquid separated during the chemical reprocessing of irradiated fuel; or irradiated reactor fuel if it is not foreseen that the spent fuel will be reprocessed; or any other waste with a comparable radioactivity level.

intermediate-level waste: waste of a lower radioactivity level than high-level waste, but which still requires shielding during handling.

low-level waste: waste which does not require shielding during normal handling because of its low radionuclide content.

B. According to the half-life of the radioactive waste:

long-lived waste: waste that will not decay to an acceptable activity level in a period of time during which administrative controls can be expected to last.

short-lived waste: waste which will decay to a level considered to be insignificant from a radiological viewpoint, in a time period during which administrative controls can be expected to last. In some jurisdictions, radionuclides with a half-life of less than 30 years are considered to fall into this category.

Radioactive waste management: All activities, administrative and operational, that are involved in the handling, treatment, conditioning, transportation, storage and disposal of radioactive waste.

Radioactivity: The property of certain nuclides of spontaneously emitting particles or gamma radiation from their nucleus, of undergoing spontaneous fission, or of emitting X-radiation.

Thermal reactor: A reactor in which fission is induced predominantly by thermal or "slow" neutrons.

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Pursuant to Standing Order 99(2), the Committee requests that the Government table a comprehensive response to its report.

A copy of the relevant Minutes of Proceedings and Evidence of the Standing Committee on Energy, Mines and Resources (*Issues Nos. 29, 30, 31, 32, 33, 34, 37, 38, 39, 40, 41, 42, 47 and 48, which includes this report*), is tabled.

Respectfully submitted,

Paul

for

BARBARA SPARROW
Chairman

MINUTES OF PROCEEDINGS

TUESDAY, June 21, 1988
(76)

The Standing Committee on Energy, Mines and Resources met in camera at 8:20 o'clock a.m., in Room 306 West Block, this day, the Chairman, Barbara Sparrow, presiding.

Members of the Committee present: Paul Gagnon, Len Gustafson, Russell MacLellan and Barbara Sparrow.

In attendance: Dean Clay, Consultant; Lawrence Harris, Researcher.

The Committee resumed consideration of its draft report.

Agreed, - That the draft report be adopted as the Committee's Tenth Report to the House and that 3,500 extra copies be printed with a special cover.

Agreed, - That the Committee engage the services of an editor for the French version of the report.

Agreed, - That the Committee seek an Order of the House empowering it to table its Tenth Report with the Clerk of the House if the House is adjourned for the summer.

At 9:40 o'clock a.m., the Committee adjourned to the call of the Chair.

Eugene Morawski
Clerk of the Committee